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NEURORADIOLOGY

ORIGINAL ARTICLE

Added diagnostic value of postcontrast susceptibility-weighted imaging with 1.5-Tesla magnetic resonance imaging for central vein sign assessment in multiple sclerosis

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PURPOSE

This study aimed to assess whether post-contrast susceptibility-weighted imaging (SWI) at 1.5-T improves visualization of the central vein sign (CVS) in multiple sclerosis (MS) lesions.

METHODS

In this prospective observational study, 30 patients with MS underwent 1.5-T brain magnetic resonance imaging (MRI), including pre-contrast SWI (SWI–C) and post-contrast SWI (SWI+C) sequences. Lesions were evaluated for location, contrast enhancement, and the presence of CVS and paramagnetic rim lesions (PRLs). Counts of CVS- and PRL-positive lesions were compared between SWI–C and SWI+C using the Wilcoxon signed-rank test, and the proportion of patients meeting the select-6 criterion was assessed with McNemar's test. Additional analyses using alternative thresholds (select-3 and > 50%) were performed to evaluate CVS positivity across different criteria. Correlations with Expanded Disability Status Scale (EDSS) scores were assessed using Spearman's rank correlation.

RESULTS

The cohort included 24 women (80%) with a mean age of 39.6 ± 12.5 years. There was a significant increase in CVS counts on SWI+C compared with SWI–C ($P < 0.01$). Across patients, the mean number of CVS was 5 (range: 0–14) on SWI–C and 6 (range: 0–19) on SWI+C. SWI+C demonstrated increased CVS in 20/30 patients (66.7%), with Wilcoxon signed-rank testing confirming a significant difference between pre- and post-contrast counts ($P < 0.01$). According to the select-6 criterion, CVS positivity increased from 14/30 (46.7%) pre-contrast to 20/30 (66.7%) post-contrast ($P = 0.031$), corresponding to 6 additional patients classified as CVS-positive, indicating improved detection with contrast-enhanced imaging. Using alternative thresholds, CVS positivity remained unchanged with the select-3 criterion (76.7% in both), whereas a > 50% threshold showed an increase from 13.3% to 30.0%, although fewer patients were identified compared with the select-6 method. The mean PRL count did not significantly change following contrast administration ($P = 0.18$). No significant correlations were observed between EDSS, CVS, or PRL counts on either SWI–C or SWI+C.

CONCLUSION

SWI+C at 1.5-T significantly enhances the detection of the CVS in MS lesions without substantially affecting PRL visualization, suggesting its practical value for routine clinical assessment of CVS.

CLINICAL SIGNIFICANCE

SWI+C at 1.5-T, a widely accessible MRI field strength, enhances detection of the CVS in MS lesions, potentially improving diagnostic specificity in routine practice.

KEYWORDS

Multiple sclerosis, magnetic resonance imaging, susceptibility-weighted imaging, central vein sign, paramagnetic rim lesions

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Multiple sclerosis (MS) is the most common inflammatory demyelinating condition of the central nervous system (CNS) in young and middle-aged adults, although it may affect older people. The diagnosis requires the demonstration of dissemination in space and dissemination in time (DIT) of demyelinating lesions in addition to excluding alternative diagnoses that may clinically or radiologically mimic MS.[1-3] Since early initiation of disease-modifying therapies has been associated with improved clinical outcomes, accurate early diagnosis is paramount.[4] However, sensitivity and specificity are still limited with current diagnostic criteria, and their inappropriate use in daily clinical practice—especially in patients with atypical presentations, such as nonspecific symptoms, headache, or encephalopathic features—may result in a misdiagnosis of MS. These challenges stress the need for imaging biomarkers that would increase diagnostic specificity and help distinguish MS from its many mimics.[4,5]

One of the most characteristic pathological hallmarks of MS, identified in histologic studies for decades, is the perivenular distribution of demyelinating plaques. This pattern is considered to reflect the migration of activated immune cells across the blood–brain barrier (BBB) into the CNS and the resulting inflammatory damage centered around small veins and venules.[6,7] In this context, the visualization of a small intralesional vein—the central vein sign (CVS)—has emerged as a promising magnetic resonance imaging (MRI) correlate of this underlying perivenular pathology. On susceptibility-weighted imaging (SWI), depiction of small parenchymal vessels within white matter lesions provides radiologic evidence of inflammatory demyelination.[8,9] The CVS has thus been proposed as a powerful imaging biomarker for MS, and several studies have reported its potential to distinguish MS from other white matter diseases.[4,6]

Main points

- Post-contrast susceptibility-weighted imaging (SWI) at 1.5-T increases detection of the central vein sign in multiple sclerosis lesions.
- The proportion of patients meeting the select-6 criterion rises with post-contrast imaging.
- Paramagnetic rim lesion counts are not significantly affected by contrast.
- Post-contrast SWI at widely available 1.5-T scanners may improve diagnostic specificity in routine clinical practice.

Acute white matter lesions, reflecting BBB breakdown and active inflammation, appear as contrast-enhancing lesions and are associated with clinical relapses and short-term disease prognosis. Over time, these acute lesions may evolve into chronic active lesions, chronic inactive plaques, or partially remyelinated lesions. Chronic active lesions—also termed mixed active/inactive or smoldering lesions—are considered important markers of ongoing chronic inflammation behind a relatively intact BBB and represent persistent areas of tissue injury in MS.[10] In addition to the CVS, paramagnetic rim lesions (PRLs)—visible on susceptibility-based sequences—represent another increasingly recognized imaging marker of chronic inflammatory activity.[10,11]

According to the 2024 revisions of the McDonald criteria, CVS and PRL signs are not essential for the diagnosis of MS; however, they may be highly useful in specific clinical situations. In patients with lesions limited to a single typical MS region, the presence of at least six CVS positive lesions together with DIT or positive cerebrospinal fluid (CSF) findings is considered sufficient for the diagnosis of MS. Likewise, in patients with involvement of only one typical lesion region, the presence of one or more PRL-positive lesions in combination with DIT or positive CSF findings is sufficient to establish the diagnosis of MS.[11]

For optimal visualization, CVS and PRLs are typically evaluated on 3-T MRI, with enhanced fluid-attenuated inversion recovery (FLAIR*) post-processed images recommended for CVS detection.[12-14] However, CVS detection remains influenced by factors such as magnetic field strength, technical parameters, and reader experience, and standardization is still needed. Post-contrast SWI (SWI+C) sequences have been shown to improve the visibility of vascular structures, suggesting that post-contrast imaging could enhance CVS detection even at 1.5-T.[8,12-15] However, studies evaluating the CVS using SWI+C are scarce and are mostly limited to small cohorts or technical feasibility reports. In this study, we compare pre-contrast SWI (SWI–C) and SWI+C sequences at 1.5-T to assess whether contrast administration improves CVS detection and visualization, given the widespread use of 1.5-T MRI in routine clinical practice. Furthermore, we investigate the relationship between CVS and PRLs on both SWI–C and SWI+C sequences and clinical disability assessed by the Expanded Disability Status Scale (EDSS).

Methods

The study was approved by the Local Ethics Committee of İstanbul Medeniyet University Non-Interventional Clinical Research Ethics Committee (approval number: 2025-GOSEK-0475, date: June 25, 2025). All clinical and imaging procedures were conducted in accordance with the Declaration of Helsinki (1975) and its later amendments. Written informed consent was obtained from all participants prior to inclusion in the study.

Study design and population

This prospective observational study included patients with a confirmed diagnosis of MS who were referred to the radiology department for routine brain MRI. In addition to the standard imaging protocol, SWI+C was acquired. All participants were adults with a clinically established diagnosis of MS according to the 2017 McDonald diagnostic criteria.[3] Demographic variables, including age, sex, and EDSS scores, were recorded at the time of imaging.

Inclusion and exclusion criteria

Patients were eligible if they met the following criteria: a confirmed diagnosis of MS established by a neurologist; availability of a complete brain MRI protocol, including both SWI–C and SWI+C sequences acquired within the same imaging session; and the presence of white matter lesions. Exclusion criteria included the following: severe motion artifacts compromising SWI image quality; absence of either SWI–C or SWI+C sequences; coexisting intracranial pathology that could interfere with SWI interpretation; or white matter lesions < 3 mm, due to reduced reliability for detecting the CVS and PRLs on SWI (Figure 1).

Magnetic resonance imaging acquisition

All MRI examinations were performed on a 1.5-T system using a standardized MS imaging protocol. The protocol included axial T1-weighted, axial T2-weighted, sagittal T2-weighted, and axial diffusion-weighted imaging, SWI–C, contrast-enhanced T1-weighted imaging, and sagittal three-dimensional (3D) Cube FLAIR (multiplanar reconstructions of the 3D FLAIR images were generated in the axial, coronal, and sagittal planes). Following intravenous administration of a gadolinium-based contrast agent at a standard dose of 0.1 mmol/kg, contrast-enhanced SWI was subsequently acquired. SWI+C was obtained within approximately 5 minutes after contrast injection, using the

following imaging parameters: TR minimum, TE 50 ms, flip angle 15°, slice thickness 2 mm, voxel size 0.8 mm, acquisition matrix 288 × 192, bandwidth 31.25 kHz, and acceleration factor 2.0.

Definition of imaging biomarkers

Central vein sign

A lesion was considered CVS-positive when a thin, linear intralesional venous structure was visualized traversing the center of the lesion on SWI. Lesions were evaluated according to the North American Imaging in Multiple Sclerosis (NAIMS) Cooperative recommendations for CVS assessment.[12] However, due to anisotropic 1.5-T acquisitions, evaluation was performed on axial SWI images only.

Overall CVS positivity was defined using the "select-6" method, whereby CVS positivity was assigned in the presence of ≥ 6 CVS-positive white matter lesions or, when < 10 lesions were present, if the majority of lesions demonstrated the CVS.

In addition to the primary select-6 definition, exploratory analyses using alternative thresholds (select-3 and > 50%) were performed to evaluate CVS positivity across different criteria.[16]

Paramagnetic rim lesions

PRLs were evaluated using both filtered phase and SWI images. Lesions showing a distinct hypointense peripheral rim with relative central hyperintensity were classified as PRL-positive, consistent with chronic low-grade inflammation. Assessment was performed in accordance with the NAIMS Cooperative consensus recommendations for PRL evaluation.[12]

Lesion selection and analysis

White matter lesions measuring < 3 mm were excluded because of reduced reliability for detecting the CVS and PRLs on SWI. For each patient, lesion evaluation was performed by identifying corresponding slices on 3D Cube FLAIR and SWI sequences to allow synchronous assessment of the same lesion across modalities. Image evaluation for CVS and PRLs was primarily performed on axial SWI images. For each patient, the following parameters were recorded: lesion location (periventricular, juxtacortical, deep white matter, and infratentorial), number of contrast-enhancing lesions on post-contrast T1-weighted images, number of lesions demonstrating a CVS on SWI–C and SWI+C, and number of PRLs identified on SWI–C and SWI+C. Following initial CVS counting, patients meeting the select-6 criterion were further evaluated on both SWI–C and SWI+C. In addition to the select-6 approach, CVS assessment was performed using alternative thresholds, including select-3 and a > 50% cut-off, for comparative analysis.

All imaging sequences were reviewed in consensus by a 4th year radiology resident and an attending neuroradiologist with 15 years of experience. Image assessment was performed blinded to EDSS scores and demographic data. Although images were anonymized, complete blinding to pre- or post-contrast status may not have been feasible due to increased vascular conspicuity following contrast administration.

Statistical analysis

Continuous variables were summarized as mean ± standard deviation or median [interquartile range (IQR)] and categorical variables as counts and percentages. The number of CVS-positive and PRL lesions per patient on SWI–C and SWI+C were compared using the Wilcoxon signed-rank test. The proportion of patients fulfilling the CVS positivity criteria, including the select-6 definition and alternative thresholds (select-3 and > 50%), was compared using McNemar's exact test. Correlations between lesion counts and EDSS were assessed using Spearman's rank correlation coefficient. A P value of < 0.05 was considered statistically significant.

Results

A total of 30 patients (24 women; 80%) with a mean age of 39.6 ± 12.5 years were included. The median EDSS score was 2 (IQR: 1–3). Gadolinium-enhancing lesions were uncommon; 25 patients (83.3%) showed no contrast-enhancing lesions on MRI.

Central vein sign

Across patients, the mean number of CVS was 5 (range: 0–14) on SWI–C and 6 (range: 0–19) on SWI+C. SWI+C demonstrated a significant

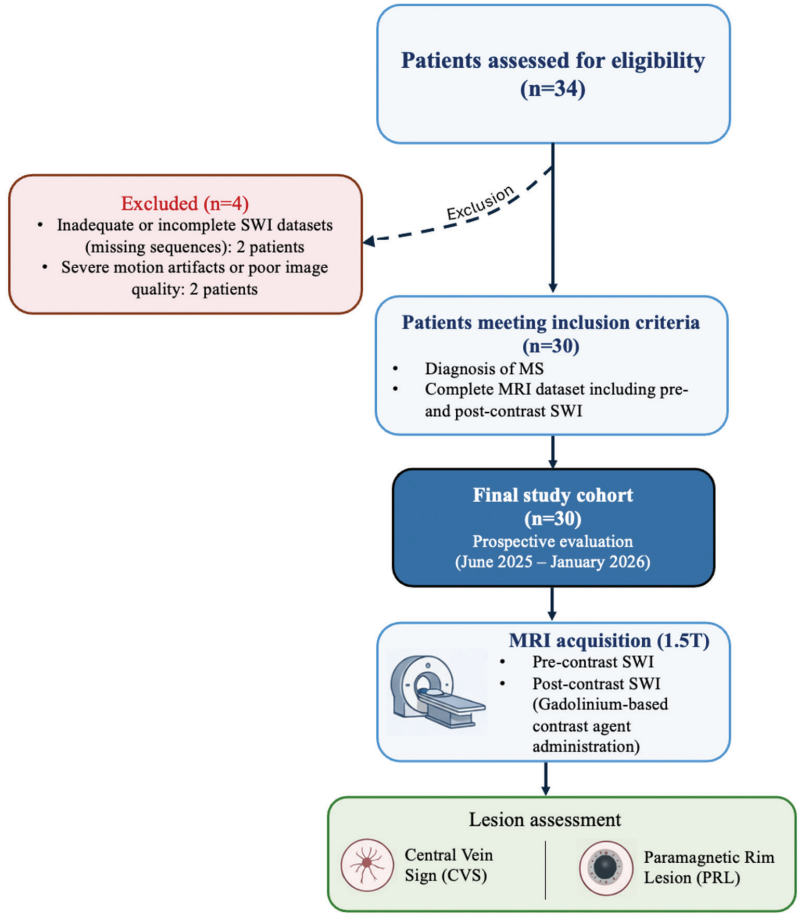

Figure 1. Study flowchart illustrating patient selection, exclusions, and the final cohort included for analysis of pre- and post-contrast susceptibility-weighted imaging for central vein sign and paramagnetic rim lesion assessment. SWI, susceptibility-weighted imaging; MRI, magnetic resonance imaging.

increase in CVS count, with 20/30 patients (66.7%) showing an increase (Figures 2-4) and 10 patients (33.3%) showing no change. The Wilcoxon signed-rank test indicated a significant difference between SWI–C and SWI+C ($P < 0.01$).

According to the select-6 criterion, CVS positivity increased from 14/30 (46.7%) on SWI–C to 20/30 (66.7%) on SWI+C. This increase was statistically significant ($P = 0.031$) and corresponded to 6 additional patients being classified as CVS-positive on SWI+C, indicating improved detection of the CVS with contrast-enhanced imaging (Table 1).

Exploratory analyses using alternative thresholds demonstrated distinct patterns in CVS positivity. When applying the select-3 criterion, CVS positivity remained unchanged between SWI–C and SWI+C (23/30, 76.7% in both), indicating a ceiling effect, as most patients were already classified as CVS-positive on pre-contrast imaging. In contrast, using a > 50% threshold, CVS positivity increased from 4/30 (13.3%) on SWI–C to 9/30 (30.0%) on SWI+C, corresponding to 5 additional patients. However, the number of patients identified as CVS-positive with this threshold remained lower than that obtained using the select-6 method.

Lesion counts differed significantly among the four anatomical locations (periventricular, juxtacortical, deep white matter, and infratentorial) ($P < 0.01$). Periventricular lesions were more frequent than in the other locations. Region-based analysis showed that the increase in CVS detection with SWI+C was significant in periventricular lesions ($P < 0.01$), whereas no significant differences were observed in other regions.

Paramagnetic rim lesions

The mean PRL count increased slightly from 0.87 (range: 0–6) to 0.97 (range: 0–6) following contrast, although this change was not statistically significant ($P = 0.18$). Parametric rim lesion positivity (≥ 1 PRL) was detected in 12 patients (40%) on SWI–C and 14 patients (46.7%) on SWI+C, with 2 additional patients becoming positive after contrast; however, this difference was not significant ($P = 0.50$) (Figure 5).

Correlation with disability

No significant associations were found between EDSS and the number of CVS on either SWI–C ($P = 0.21$, $P = 0.26$) or SWI+C ($P = 0.17$, $P = 0.37$). Similarly, PRL counts showed no significant correlation with EDSS on SWI–C ($P = –0.05$, $P = 0.79$) or SWI+C ($P = 0.06$, $P = 0.75$).

Table 1. Effect of contrast administration on CVS and PRL detection

Variable	Pre-contrast SWI	Post-contrast SWI	*P* value
Mean CVS count (range)	5 (0–14)	6 (0–19)	< 0.01**
CVS-positive patients, n (%)*	14 (46.7%)	20 (66.7%)	0.031**
Mean PRL count (range)	0.87 (0–6)	0.97 (0–6)	0.18
PRL-positive patients (≥1), n (%)	12 (40%)	14 (46.7%)	0.50

*CVS positivity was defined using the "select-6" method (≥ 6 CVS-positive lesions or, when < 10 lesions were present, > 50% CVS-positive lesions). **P value < 0.05 was considered statistically significant. CVS, central vein sign; PRL, paramagnetic rim lesion; SWI, susceptibility-weighted imaging.

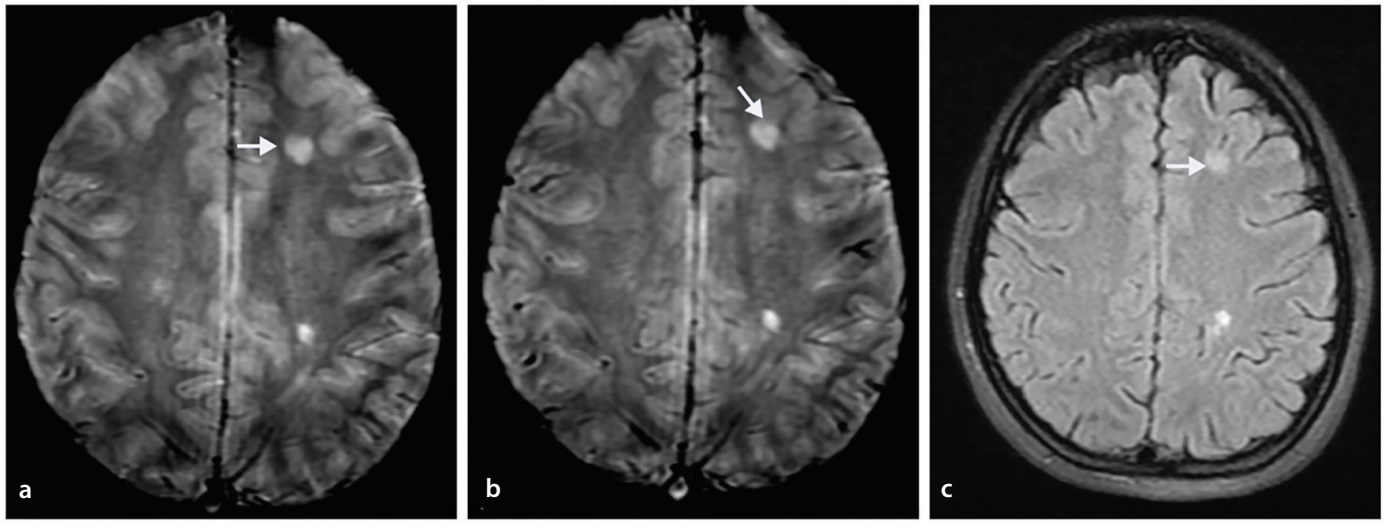

Figure 2. Axial susceptibility-weighted imaging (SWI) demonstrating pre-contrast (**a**) and post-contrast (**b**) images, along with fluid-attenuated inversion recovery (**c**). The intralesional central vein (arrows) is not appreciable on the pre-contrast image but becomes clearly visible on post-contrast SWI.

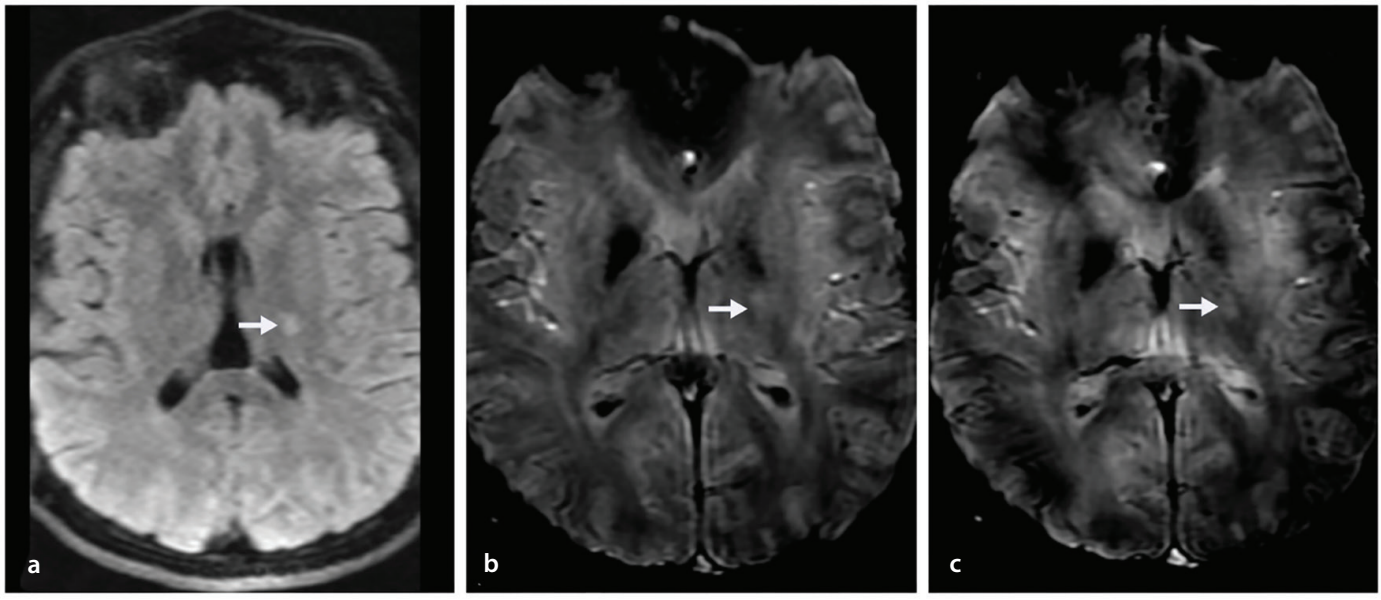

Figure 3. Axial fluid-attenuated inversion recovery image (**a**) demonstrating a multiple sclerosis lesion (arrow), and susceptibility-weighted imaging (SWI) images obtained without contrast (**b**) and with contrast enhancement (**c**). The central vein sign (arrows) is not visible on pre-contrast SWI but becomes clearly visible on post-contrast SWI.

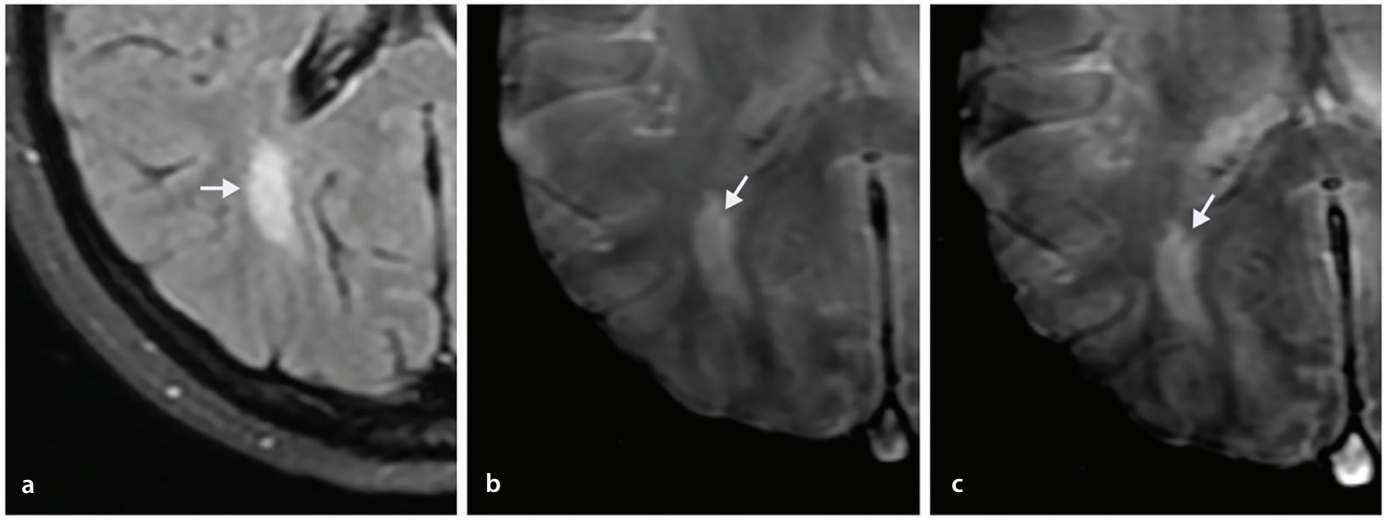

Figure 4. (**a**) Axial fluid-attenuated inversion recovery image showing a multiple sclerosis plaque in the right posterior periventricular white matter. (**b**) Pre-contrast susceptibility-weighted imaging (SWI) and (**c**) post-contrast SWI images demonstrating the central vein sign (arrows), which is more clearly visualized on the contrast-enhanced SWI sequence.

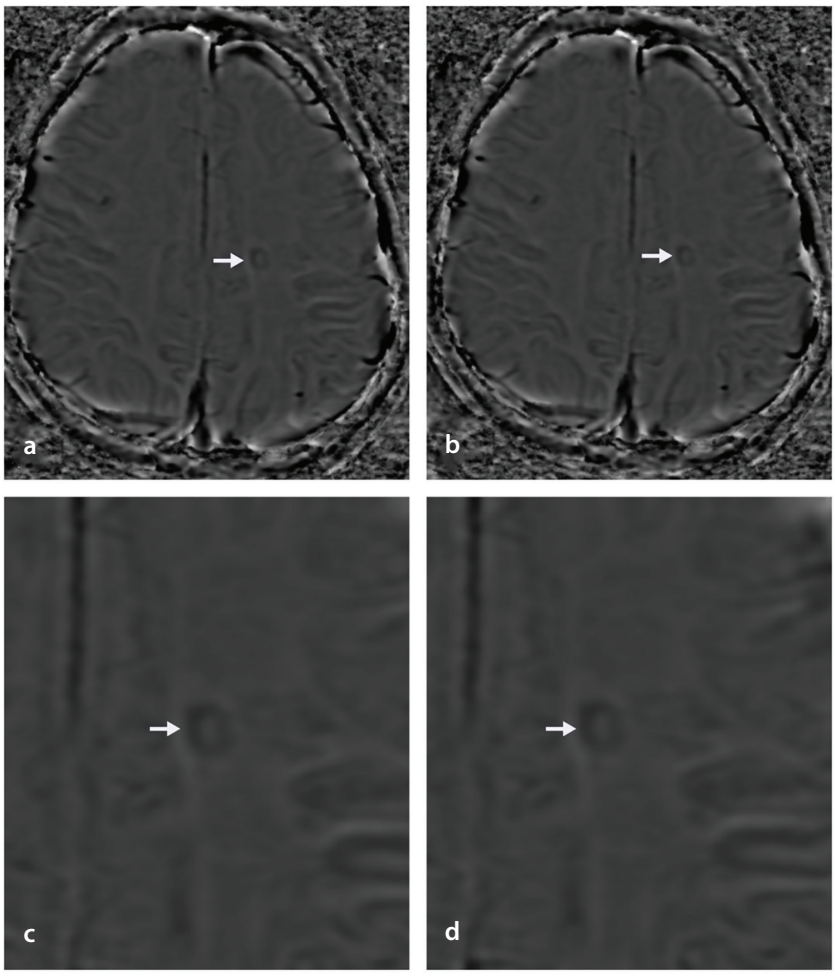

Figure 5. Susceptibility-weighted imaging images acquired before (**a, c**) and after (**b, d**) contrast administration demonstrate a paramagnetic rim lesion (arrows), with similar visualization on both pre- and post-contrast images and no obvious effect of contrast enhancement.

Discussion

In this prospective study, in patients with MS, SWI+C demonstrated a modest but consistent increase in the detection of CVS lesions compared with SWI–C. These results suggest that SWI+C may enhance lesion visualization and serve as a valuable tool for improving diagnostic confidence in routine 1.5-T MRI practice. Neither CVS nor PRL counts correlated with disability, as measured by EDSS, in this cohort.

Perivenular inflammation is well recognized in the pathophysiology of MS, and the visualization of the CVS has emerged as a promising MRI correlate of this underlying pathology.[4,7] Although CVS demonstrates high specificity for differentiating MS from other white matter disorders, the 2024 diagnostic criteria emphasize that it is not mandatory for establishing a diagnosis. The 2024 McDonald criteria propose that, in patients with clinically isolated syndrome or radiologically isolated syndrome (RIS) affecting at least two typical regions, the presence of ≥ 6 CVS-positive lesions are sufficient to support an MS diagnosis. When < 10 white matter lesions are present, a positive result is defined by the majority of lesions exhibiting the CVS. These criteria highlight the potential diagnostic value of CVS, particularly in early or RIS cases.[11] Nonetheless, evaluating CVS in clinical practice presents potential limitations. Its inclusion as an MRI biomarker in the 2024 MS diagnostic criteria has further highlighted the need for standardization of CVS assessment.

Although the CVS can be detected on 1.5-T MRI, the proportion of identifiable lesions is lower than on 3-T or 7-T scanners. The 2024 revised McDonald criteria specifically indicate that, when using 1.5-T MRI, optimized imaging protocols or the administration of paramagnetic contrast may be necessary to enhance visualization of the CVS.[11] In this context, SWI+C may offer an advantage by enhancing the conspicuity of intralesional veins, providing a practical approach for achieving reliable CVS detection on widely available 1.5-T scanners, even in centers without access to high-field or specialized sequences.

The prevalence of the CVS is highest in periventricular lesions (up to 94%) and deep white matter lesions (up to 84%).[17] Its frequency in cortical or juxtacortical, infratentorial, and spinal cord regions remains to be fully investigated. In our cohort, periventricular lesions were the most common location for the CVS. Although identification of the CVS is not mandatory for diagnosing MS, it can aid in distinguishing MS lesions from those caused by vascular disease or migraine, thereby increasing diagnostic specificity. In addition, CVS has been shown to correctly identify up to 87% of patients who were previously misdiagnosed with MS.[18]

CVS detection should be performed according to the NAIMS consensus recommendations, and a susceptibility-sensitive sequence should be included in the imaging protocol for this purpose. As a post-processed sequence, combinations of FLAIR with SWI or T2*-weighted sequences (FLAIR*), are recommended for reliable detection of the CVS.[12] Furthermore, higher field strengths and the administration of intravenous gadolinium-based contrast have been reported to further enhance CVS detection rates.[8,12-15] Although prior studies have reported improved visualization of the CVS using post-contrast T2* imaging, these studies were mostly based on small sample sizes and were often designed as case reports or technical feasibility studies. In addition, many of these studies were conducted prior to the revised McDonald criteria and, therefore, were not interpreted within the context of current diagnostic frameworks. Our study is prospective in design and focuses on 1.5-T MRI, reflecting routine clinical practice. Importantly, we evaluated both CVS and PRLs, providing a more comprehensive assessment of MS-related imaging biomarkers. Furthermore, our findings are interpreted within the framework of the "select-6" concept and the updated McDonald criteria, thereby increasing their current clinical relevance.

A prior case-based study by Maggi et al.[15] demonstrated that gadolinium-enhanced SWI can improve the conspicuity of venous structures in MS, supporting the feasibility of SWI+C for central vein visualization. However, this early work was limited to a small, exploratory cohort without systematic diag-

nostic evaluation or application of current CVS criteria.[15]

Sparacia et al.[8] demonstrated with 1.5-T MRI that SWI+C may improve the visibility of the CVS by enhancing venous conspicuity after gadolinium administration. In this study, which included 19 patients, the detection rate of the CVS was higher on gadolinium-enhanced SWI (86%) than on unenhanced SWI (54%), indicating improved CVS visibility following contrast administration.[8] Our findings are consistent with prior reports demonstrating improved CVS visualization on SWI+C. In comparison with this previous study, our lesion cohort is larger (n = 30), which increases the robustness of CVS assessment. We also included an evaluation of PRLs, providing a more comprehensive assessment of MS-related imaging biomarkers. Furthermore, we specifically investigated the added value of SWI+C in the context of the "select-6" framework.

In a 3-T study, SWI+C was used primarily for differentiating active and inactive MS lesions rather than for a systematic evaluation of the CVS. However, they reported that SWI+C and magnification facilitated the visualization of penetrating veins while having no impact on the total number of detectable veins.[19]

A 3-T field strength MRI study showed that both T2*-weighted and phase-contrast images from a 3D segmented echo-planar imaging sequence were sensitive to MS lesions, parenchymal veins, and tissue iron, with venous conspicuity further increased during gadolinium-based contrast.[20]

Recent studies have demonstrated that CVS assessment is feasible at 1.5-T, including contrast-enhanced isotropic FLAIR*, which has been shown to improve CVS visibility, particularly in smaller or less conspicuous lesions. Although the detection performance was lower than that reported for 3-T MRI systems, their findings confirmed the feasibility of CVS assessment at 1.5-T.[13,14] In our study, CVS was evaluated using SWI+C, which provided improved visualization of the central vein within MS lesions. Furthermore, as contrast-enhanced imaging is already routinely performed for the assessment of MS disease activity, the acquisition of SWI+C can be readily incorporated into standard imaging protocols. Unlike FLAIR*, which requires additional post-processing, SWI can be acquired directly, making it a more practical option for routine imaging. Considering the widespread global use of 1.5-T scanners, the use of SWI+C may facilitate visualization of the CVS and potentially improve diagnostic confidence as well as the broader clinical implementation of CVS assessment in patients with suspected MS.

A recent study investigated the feasibility of assessing the CVS on conventional FLAIR images by identifying central hypointensity within lesions and comparing these findings with those obtained from FLAIR* and post-contrast FLAIR* images. However, the authors concluded that the presence of central hypointensity on FLAIR alone is insufficient for reliable assessment of the CVS.[21]

A recent systematic review and meta-analysis supported the clinical feasibility and reliability of simplified CVS evaluation strategies and highlighted that combining CVS and PRL assessment may further improve diagnostic specificity for MS. In this meta-analysis, the select-6 and count-1 PRL approaches were reported to be highly specific for MS, whereas the select-3 method demonstrated higher sensitivity.[22] In our cohort, we further evaluated the effect of contrast administration on select-3, > 50%, and select-6 criteria. We found that the select-3 threshold resulted in a ceiling effect with no additional diagnostic yield, whereas the > 50% criterion increased CVS positivity after contrast administration but still identified fewer CVS-positive patients than the select-6 method. Overall, these findings indicate that the effect of SWI+C on CVS detection becomes more apparent when more stringent thresholds are applied, whereas lower thresholds may be less sensitive to incremental improvements due to saturation effects. As CVS has recently been introduced as a biomarker in the diagnostic criteria for MS, wider availability of appropriate imaging sequences, increased radiologist familiarity with this marker, and the standardization of imaging protocols will be crucial for improving diagnostic reliability and minimizing potential misinterpretation of imaging findings.

Although many studies on PRLs have been conducted using 7-T MRI, their routine clinical applicability is limited. An increasing number of investigations at 3-T and 1.5-T have reported high inter-observer agreement; however, it remains unclear whether these results can be reliably reproduced in less experienced centers. Evidence supporting the specificity of PRLs for the diagnosis of MS is still emerging and is rapidly accumulating. Importantly, PRLs are rarely observed in other radiological mimics of MS, further highlighting their potential value as a highly specific diagnostic marker.[23-25] In addition to focusing on CVS assessment, we examined the presence of PRLs and potential differences in SWI+C. The mean PRL count showed no statistically significant change. The improved visualization of the CVS on SWI+C is likely attributable to enhanced depiction of vascular structures following gadolinium administration (Figure 6). In contrast, PRLs reflect iron accumulation associated with chronic inflammation, and SWI+C is not expected to alter their visibility. This explains why PRL detection showed no significant change after contrast administration, highlighting the differential mechanisms underlying CVS and PRL appearance on susceptibility-sensitive sequences.

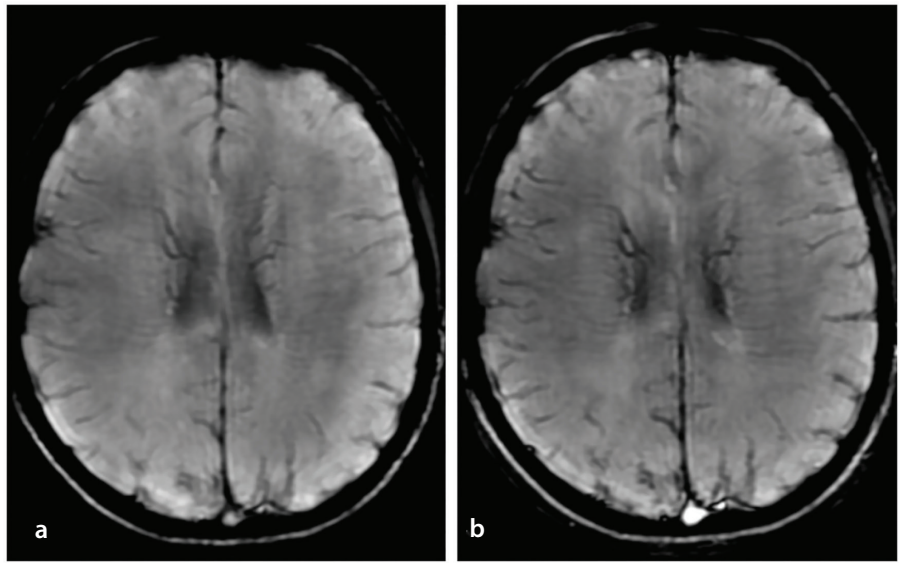

Figure 6. Axial susceptibility-weighted imaging (SWI) obtained without contrast (**a**) and after contrast administration (**b**). Contrast-enhanced SWI demonstrates improved conspicuity and delineation of vascular structures compared with the non-contrast image, highlighting the added value of contrast in visualizing venous anatomy.

No significant associations were observed between EDSS and the number of CVS lesions on either SWI–C or SWI+C. Similarly, PRL counts did not demonstrate a significant correlation with EDSS on either sequence. Although previous studies have reported an association between PRLs and disease progression, we did not observe a significant correlation between PRL counts and EDSS in our cohort. This may be partly explained by the limited number of PRLs and the low median EDSS score, which could reduce variability and limit statistical power. Additional factors, such as the relatively small sample size, the use of 1.5-T MRI, which may be less sensitive for subtle rim lesions, and the predominance of patients with early or mild disease, may also have contributed to the lack of significant association.

This study has some limitations, including a relatively small sample size and single-center design; additionally, the number of PRLs was limited, and the cohort had a low median EDSS score of 2, which may affect generalizability. A limitation of our study is the use of routine 1.5-T SWI, which may limit multiplanar visualization and CVS detection sensitivity. Another limitation of this study is the absence of a higher-field-strength MRI system as a reference standard, which may limit the assessment of the absolute accuracy of CVS and PRL detection at 1.5-T MRI. In addition, our cohort included patients with established MS and a relatively high lesion burden; therefore, the observed increase in CVS detection likely reflects improved lesion visualization rather than true diagnostic performance. These factors should be considered important limitations.

SWI+C on 1.5-T MRI enhances the visualization of the CVS in MS lesions compared with SWI–C. This improvement may increase the number of patients meeting diagnostic CVS thresholds, providing a practical and readily implementable tool for routine clinical assessment of MS.

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Footnotes

Conflict of interest disclosure

The authors declared no conflicts of interest.

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