



Revised recommendations of the Polish Medical Society of Radiology and the Polish Neurological Society for a protocol concerning routinely used magnetic resonance imaging in patients with multiple sclerosis

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ABSTRACT

Multiple sclerosis (MS) is a chronic immune-mediated inflammatory demyelinating disease of the central nervous system (CNS), the exact etiology of which remains unknown. The pathological hallmark of MS involves CNS tissue damage characterized by dissemination in space (DIS) and dissemination in time (DIT). Magnetic resonance imaging (MRI) represents the most sensitive paraclinical tool for detection, diagnosis, and longitudinal monitoring of MS, playing a crucial role in treatment decision-making.

The recently published 2024 McDonald criteria, incorporating advances in MR acquisition and post-processing techniques, necessitate revision of current MRI protocols used in routine clinical practice. These updated criteria expand the definition of typical MS lesion locations to include the optic nerves and introduce novel MRI biomarkers — the central vein sign (CVS) and paramagnetic rim lesions (PRLs) — which enhance diagnostic specificity and differential diagnosis.

This manuscript presents the third version of recommendations developed by the Polish Medical Society of Radiology and the Polish Neurological Society for standardized MRI examination protocols in patients with MS. These evidence-based recommendations incorporate contemporary technical advances, provide practical guidance for radiographers and radiologists, and aim to standardize imaging procedures across all MRI departments in Poland. Implementation of this protocol is essential for establishing reliable diagnoses, ensuring adequate disease monitoring, and supporting critical clinical decisions regarding treatment initiation and modification.

Keywords: multiple sclerosis, magnetic resonance imaging, imaging protocol, guidelines, central vein sign, paramagnetic rim lesions

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Introduction

Multiple sclerosis (MS) is a chronic inflammatory demyelinating disease of the central nervous system (CNS) characterized by remarkable heterogeneity in its clinical, pathological, and radiographic manifestations [1]. Since 2001, the diagnosis of MS has relied on the McDonald criteria, which establish diagnostic certainty through demonstration of dissemination in space (DIS) and dissemination in time (DIT), combined with careful exclusion of alternative diagnoses [2–6].

The diagnostic paradigm has evolved considerably through successive revisions of the McDonald criteria, with each iteration increasingly emphasizing the role of magnetic resonance imaging (MRI) [3–6]. The most recent 2024 revision, published in 2025, represents a landmark advancement by establishing MRI as a central diagnostic modality in MS; however, a pragmatic approach may be appropriate only in exceptional circumstances [2]. This contrasts with earlier versions where, theoretically MS could be diagnosed based solely on clinical evidence of DIT and DIS in the absence of neuroimaging.

The 2024 McDonald criteria introduce several critical modifications that directly impact MRI protocol design and interpretation. First, the optic nerves are now recognized as the fifth typical CNS location for MS lesions, joining periventricular, juxtacortical/cortical, infratentorial, and spinal cord regions in defining DIS criteria (Tab. 1) [2]. This expansion acknowledges the frequent involvement of the anterior visual pathway in MS pathology and necessitates consideration of optic nerve imaging in the diagnostic work-up.

Second, the updated criteria incorporate specific imaging features of demyelinating plaques as diagnostic biomarkers: the central vein sign (CVS) and paramagnetic rim lesions (PRLs) [2]. These MRI biomarkers enable more nuanced differential diagnosis, particularly in clinically ambiguous cases where traditional DIS criteria are not fully met. The inclusion of these biomarkers as supportive criteria for confirming DIT represents a paradigm shift toward more pathologically specific diagnostic imaging.

These developments necessitate adaptation of MRI examination protocols to accommodate both the expanded anatomical scope (including optic nerves) and the technical

Table 1. Dissemination in space (DIS) and dissemination in time (DIT) based on magnetic resonance imaging (MRI) according to the 2024 McDonald criteria [2]

DIS	DIT
Presence of at least one T2-weighted lesion in at least two of the following typical locations: 1) juxtacortical/cortical; 2) periventricular; 3) infratentorial; 4) spinal cord; 5) optic nerve	The presence of one or more new T2 lesions or one or more gadolinium-enhancing lesions on a follow-up MRI examination compared with a reference examination, irrespective of the interval since the baseline examination, OR concomitant occurrence of contrast-enhancing and non-enhancing lesions, irrespective of the time of the examination in relation to the onset of neurological signs and symptoms

OR — odds ratio

requirements for visualizing novel biomarkers [through optimized susceptibility-weighted imaging (SWI) sequences]. Consequently, we present updated recommendations for performing MRI examinations in patients with MS in routine clinical practice, building upon our previous guidelines published in 2020 [7, 8] and incorporating current international consensus recommendations [9].

Material and methods

The development of these recommendations followed a structured consensus process involving expert representatives from the Polish Medical Radiological Society (MH, AM, JW, JB, EJ, BS, EK, ZS, ES, KKK) and the Polish Neurological Society (MS, AK, MAS, MSt, WB, SW, BK, DMG, MN, AK, HBP).

The consensus process comprised four online meetings conducted in 2025. An initial draft was prepared by the lead authors (MS, MH). This draft underwent detailed review by a core writing group (MS, MH, AK, MAS, KKK, AM), followed by iterative revisions incorporating feedback from all advisory committee members. The final version was approved unanimously by all co-authors.

Key considerations in formulating these recommendations included: 1) practical applicability across diverse clinical settings in Poland; 2) technical feasibility on both 1.5T and 3.0T MRI scanners; 3) alignment with current international standards [9]; 4) integration of novel MRI biomarkers (CVS and PRLs); and 5) optimization of diagnostic accuracy while maintaining examination efficiency.

Results

General comments

Patients with MS should undergo MRI examinations using scanners with a magnetic field strength of at least 1.5T, with 3.0T being preferred due to superior signal-to-noise ratio (SNR), enhanced spatial resolution, and improved detection of cortical lesions and novel MRI biomarkers [9].

The administration of macrocyclic gadolinium-based contrast agents (GBCAs) is recommended in the following clinical scenarios: a) for differential diagnosis, particularly when distinguishing MS from other inflammatory or demyelinating conditions; b) in the presence of clinical disease activity, including relapses and/or progression independent of relapse activity (PIRA); and c) in other clinically justified situations determined by the referring neurologist. In pediatric populations, the dose of macrocyclic contrast agents should be reduced to 0.05 mmol/kg body weight (half the standard adult dose). The retention characteristics of each GBCA should be carefully considered in all patients. Linear contrast agents are not recommended due to potential long-term adverse effects associated with gadolinium accumulation in body tissues, including the CNS [10].

Although gadolinium retention is more pronounced with linear agents, current evidence does not support a clear association with adverse clinical outcomes. As indicated in the cited reference [10], no neurotoxicity has been demonstrated in clinical studies, including in patients with MS, nor in animal models exposed to supradiagnostic doses.

Imaging of the cervical and/or thoracic spinal cord (including the conus medullaris) and/or optic nerves for diagnostic purposes and disease monitoring should be considered on an individual basis according to clinical presentation and neurologist referral. The MRI protocol for brain, spinal cord, and optic nerve examinations in patients under 18 years of age should follow the same technical specifications as used in the adult population.

Recommendations for MRI in the diagnostic work-up of MS

General comments

A comprehensive baseline MRI examination with contrast agent administration is recommended for diagnosis, differential diagnosis, and as a reference for monitoring disease course and evaluating treatment effectiveness. The examination should be performed according to the protocols detailed in Tables 2–4.

Brain MRI

The brain MRI protocol incorporates several technical specifications designed to optimize lesion detection and characterization:

1. Scan orientation: axial plane imaging should proceed in an upward direction (inferior to superior), while sagittal plane acquisitions should progress from right to left. This applies to both brain and spinal cord examinations.
2. Slice gap: Inter-slice gaps should be minimized or eliminated entirely (zero gap) to ensure complete tissue coverage and prevent missed lesions.
3. 3D T1-weighted imaging: this sequence should be acquired first to minimize motion-related artifacts. Three-dimensional T1-weighted imaging enables precise volumetric evaluation of the brain, facilitating assessment of brain atrophy.
4. Susceptibility-weighted imaging: modern SWI sequences capable of generating phase maps (filtered phase images) are essential for assessing both CVS and PRLs [11, 12]. High SNR and reproducible acquisition parameters are critical for reliable biomarker evaluation.
5. Fluid-attenuated inversion recovery (FLAIR) sequence timing: FLAIR sequences should be performed after contrast agent administration to allow appropriate delay (5–10 minutes) before T1-weighted post-contrast imaging, optimizing contrast enhancement detection. Contrast agents do not compromise FLAIR image quality. Post-contrast FLAIR imaging may demonstrate leptomeningeal or cortical enhancement, though contrast-enhancing lesions are assessed exclusively on T1-weighted sequences.

Table 2. Brain magnetic resonance imaging (MRI) protocol

Parameter	Description
Electromagnetic field	Images should be of good quality with an appropriate SNR value and resolution Minimum 1.5T; 3.0T preferred
Reference setting	When setting the scanning plane, the angulation of the planned slices should be identical to that used in the previous examination
Scanning range	Whole brain
Slice thickness and gaps	≤ 3 mm, with no gaps (for 2D and 3D acquisitions)
Basic sequences	3D T1 isotropic imaging (preferably ≤ 1 mm, with subsequent reconstructions in the sagittal and coronal planes²) in the axial plane aligned with the lower edge of the corpus callosum; the direction of axial slices must be upwards 3D T2 imaging with subsequent reconstruction in the axial plane aligned with the lower edge of the corpus callosum; the direction of axial slices must be upwards (if not possible, 2D T2 axial imaging is acceptable) Administration of contrast agent¹ (3DT1 imaging 5–10 minutes after administration!) - SWI (preferably in 3D mode) 3D FLAIR+C sagittal plane (fat saturation recommended), with subsequent axial reconstructions aligned with the lower edge of the corpus callosum; the direction of axial slices must be upwards (if not possible, 2D FLAIR axial imaging is acceptable) 3D T1+C isotropic imaging in axial plane with subsequent reconstructions in the sagittal and coronal planes²; mandatory at baseline examination and optional during follow-up
Optional sequences	- DIR — highly recommended when using 3.0T - DWI - PD/T2

¹The recommended dose of a contrast agent is 0.1 mmol/kg body weight (0.05 mmol/kg in pediatric populations; see General comments); ²Reconstructed images must be archived in the picture archiving and communication system (PACS) system/patient's CD, as an integral part of the examination; DIR — double inversion recovery; DWI — diffusion-weighted imaging; FLAIR — fluid-attenuated inversion recovery; PD — proton density; SNR — signal-to-noise ratio; SWI — susceptibility-weighted imaging; 2D — two-dimensional; 3D — three-dimensional; +C — post-contrast

Table 3. Spinal cord magnetic resonance imaging (MRI) protocol

Parameter	Description
Electromagnetic field	Images should be of good quality with an appropriate SNR value and resolution Minimum 1.5T; 3.0T preferred
Scanning range	Spinal cord segment under examination
Slice thickness and gaps	Sagittal: ≤ 3 mm, no gaps; axial: 3 mm, no gaps
Basic sequences ²	- T2-weighted sagittal - T1-weighted sagittal Administration of contrast agent¹ (T1 imaging 5–10 minutes after administration!) - STIR+C sagittal - T2+C axial at the level of the lesions identified in the sagittal plane - T1+C sagittal - T1+C axial
Optional sequences	- T2-weighted in coronal plane at the level of the lesions identified in other sequences 3D T1 imaging

¹The recommended dose of a contrast agent is 0.1 mmol/kg body weight (0.05 mmol/kg in pediatric populations; see General comments); ²Recommended parameter modifications for spinal cord imaging: Sag T2: TE 60–80 ms, refocusing/flip angle 90°; Sag STIR: TE 40–50 ms. To reduce pulsatile artifacts: flow compensation option: ON. Use PROPELLER/BLADE/MultiVane sequences; SNR — signal-to-noise ratio; STIR — short tau inversion recovery; +C — post-contrast

Table 4. Magnetic resonance imaging (MRI) protocol for optic nerves

Parameter	Description
Electromagnetic field	Images should be of good quality with an appropriate SNR value and resolution Minimum 1.5T; 3.0T preferred
Scanning range	Optic nerve and chiasm area
Slice thickness and gaps	Axial/coronal: ≤ 2–3 mm, no gaps (for 2D or 3D)
Basic sequences	- T1 FAT-SAT axial and coronal Administration of contrast agent¹ (T1 imaging 5–10 minutes after administration!) - T2 FAT-SAT or STIR axial and coronal - T1 FAT-SAT+C axial and coronal
Highly recommended sequence	T2-weighted sagittal; DIR (from the brain protocol when using a 3.0T scanner)
Optional sequences	Contrast-enhanced 3D FLAIR fat-suppressed from the brain protocol

¹The recommended dose of a contrast agent is 0.1 mmol/kg body weight (0.05 mmol/kg in pediatric populations; see General comments); DIR, double inversion recovery; FAT-SAT — fat saturation; FLAIR — fluid-attenuated inversion recovery; SNR — signal-to-noise ratio; STIR — short tau inversion recovery; +C — post-contrast

6. 3D FLAIR and T2 imaging: when available, 3D T2 and 3D FLAIR sequences should be acquired in the sagittal plane with subsequent axial reconstructions aligned parallel to the inferior edge of the corpus callosum. In such protocols, consideration should be given to performing 3D T2 sequences after contrast administration to ensure adequate delay before T1-weighted post-contrast acquisition.
7. Cortical lesion detection: double inversion recovery (DIR) or phase-sensitive inversion recovery sequences are recommended for enhanced detection of cortical and juxtacortical lesions, particularly at 3.0T [13, 14].

Brain imaging should be performed according to the technical parameters specified in Table 2.

Spinal cord MRI

Comprehensive examination of the entire spinal cord is recommended for MS diagnosis, particularly in patients who meet clinical criteria for primary progressive MS, where spinal cord involvement is common [9]. Spinal cord MRI has particular value in excluding alternative diagnoses, especially in patients aged 50 years and older or with significant vascular risk factors, in whom its use is strongly recommended according to the updated diagnostic criteria [2]. In addition, spinal cord demyelinating lesions carry important prognostic implications. Spinal cord MRI also plays an essential role when alternative causes of CNS demyelination are suspected, as it helps distinguish MS from other myelopathies [9]. Imaging must include the conus medullaris to ensure complete evaluation of the spinal cord. Spinal cord imaging should be performed according to the parameters detailed in Table 3.

MRI of the optic nerves

Recognition of the optic nerves as one of five typical anatomical locations for MS lesions in the 2024 McDonald criteria mandates consideration of optic nerve imaging in the diagnostic evaluation [2]. Demyelinating lesions in the optic nerves satisfy DIS criteria (Tab. 1), potentially enabling earlier diagnosis in appropriate clinical contexts.

The DIR sequence is particularly valuable for assessing optic nerve lesions [9]. However, high-quality contrast-enhanced 3D FLAIR sequences with fat suppression from standard brain MRI protocols may adequately visualize hyperintense optic nerve lesions [15, 16]. Therefore, the need for dedicated optic nerve MRI should be determined through consultation with the referring neurologist, considering clinical presentation and findings on brain MRI.

Imaging of the optic nerves, when clinically indicated, should follow the parameters outlined in Table 4.

Novel MRI biomarkers: CVS and PRLs

General technical considerations

Proper visualization of novel MRI biomarkers requires implementation of specific imaging techniques, primarily modern SWI protocols. Given the substantial variability in

SWI parameters across different scanner platforms and manufacturers, emphasis must be placed on achieving reproducible 3D SWI acquisitions with high SNR.

Central vein sign

The central vein sign represents a relatively novel diagnostic MRI marker with particular importance in the differential diagnosis of MS [2, 9]. CVS-positive lesions are highly characteristic of MS, constituting more than 85% of white matter lesions in MS patients [17, 18], while occurring far less frequently in conditions that may mimic MS. For instance, CVS is observed in approximately 8% of small vessel disease lesions and 14% of lesions in other inflammatory autoimmune disorders [19–22].

According to the 2024 McDonald criteria, CVS-positive lesions serve as an additional diagnostic criterion in patients with suspected MS who do not fulfill standard DIS criteria [2] (Suppl. Tab. 1). An MRI examination is classified as CVS-positive when at least 6 CVS-positive lesions are identified (the “Select 6” rule) [2, 9, 23]. When fewer than 10 hyperintense lesions are visible on T2-weighted images, the examination is considered positive if the majority of lesions demonstrate CVS (the “majority” rule). In pediatric MS populations, CVS presence in more than 50% of lesions is considered diagnostically significant [2, 9]. CVS-positive lesions are characterized by specific features that have been well described and published [11] (Tab. 5).

Paramagnetic rim lesions

Paramagnetic rim lesions may be utilized as an additional diagnostic criterion when DIS is not met and focal lesions are present in only one typical MS location [2] (Suppl. Tab. 1). PRLs demonstrate high specificity for MS; consequently, even a single PRL is considered indicative of MS-related demyelination [23]. In a prospective study, all patients with clinically isolated syndrome and at least one PRL developed clinically definite MS during follow-up [24]. PRLs also represent an important prognostic parameter, correlating with an increased risk of disease progression and disability accumulation [23, 25].

The presence of PRLs can be confirmed when specific imaging criteria are satisfied [12] (Tab. 5).

Recommendations for MRI-based monitoring of disease course

Serial MRI examinations are essential for assessing disease activity, treatment efficacy, and long-term prognosis in MS patients. The following principles should guide monitoring protocols:

1. Scanner consistency: MRI examinations performed for disease course assessment and treatment effectiveness evaluation should ideally be conducted on the same scanner. At minimum, consistent magnetic field strength and adherence to the standardized protocol are mandatory to ensure reproducibility and reliable detection of changes over time.

Table 5. Characteristic features of the central vein sign (CVS) and paramagnetic rim lesions (PRLs) [11, 12]

CVS	PRLs
Inclusion criteria	Inclusion criteria
1. Appears as a single thin (< 2 mm) hypointense line or a small hypointense dot	1. A discrete rim with paramagnetic properties continuous around at least two-thirds of the outer edge of the white matter portion of the lesion (excluding any cortical or ependymal border), on the slice of maximum visibility
2. Visualized in at least two perpendicular MRI planes, appearing as a thin line or dot in at least one plane	2. The rim colocalizes with the edge of all or part of a lesion core that is hyperintense on T2-weighted images; in large T2-lesions, detection of the paramagnetic rim lesion core can be facilitated by also looking at a more discernible hypointense core on T1-weighted images
3. Runs partially or entirely through the lesion	3. The rim, or part of it, is visible on at least two consecutive slices (2D acquisition) or in two orthogonal planes (3D acquisition)
4. Positioned centrally in the lesion (approximately equidistant from lesion edges, passing through the edge at no more than two places), irrespective of lesion shape	4. The core of the lesion colocalizes with all or part of a T2-hyperintense lesion that does not enhance on post-gadolinium T1-weighted images*
Exclusion criteria	Exclusion criteria
1. Lesion diameter < 3 mm in all planes	1. Veins running alongside the rim that might resemble a rim
2. Confluent lesions merging with another lesion	Red flags and cautions:
3. Lesion containing multiple distinct veins or poorly visualized due to motion or other MRI-related artifacts	2. Small paramagnetic or diamagnetic structures (e.g., iron-laden ferritin or hemosiderin deposits, veins, and myelin debris)
	3. Lesions showing magnetic dipole artifacts (often best seen in coronal or sagittal reformations)
	4. Anatomical regions with susceptibility artifacts (including the anterior temporal lobes, orbitofrontal cortices, and infratentorial brain regions)

*If post-gadolinium MRI is not available, a lesion should be classified as a paramagnetic rim lesion only if the corresponding lesion was present on a T2-weighted scan acquired at least 3 months earlier. If neither post-gadolinium MRI nor a previous scan is available, the lesion should be classified as a possible PRL, and its chronicity should be confirmed on a follow-up scan obtained at least 3 months later

2. Examination frequency: Brain MRI with contrast agent administration to detect gadolinium-enhancing lesions and/or new or enlarging T2-hyperintense lesions should be performed at least annually during the initial years of treatment. In patients demonstrating complete clinical and radiological stability, less frequent imaging intervals may be appropriate. The frequency of follow-up imaging should be individualized based on clinical context.
3. Contrast administration in long-term follow-up: For established patients on stable long-term treatment with sustained disease control, MRI with contrast agent administration may be optional and should be performed based on neurologist referral and clinical indication. This approach balances diagnostic yield with minimizing cumulative gadolinium exposure.

Radiological reporting

Standardized radiological reporting is critical for ensuring consistent communication between radiologists and neurologists, facilitating accurate diagnosis, and enabling reliable longitudinal comparison. Radiological reports for MS patients should employ standardized terminology and include the following components:

Description of focal lesions

1. Lesion location: Specify anatomical distribution using standard categories:
 - Supratentorial: cortical, juxtacortical, periventricular (including corpus callosum), deep white matter;
 - Infratentorial: brainstem, cerebellum;

- Spinal cord: cervical, thoracic, conus medullaris;
 - Optic nerves.
2. Lesion count: report the number of demyelinating lesions in each anatomical location using the following scheme: 1, 2, 3–8, ≥ 9. This semi-quantitative approach balances precision with practical reporting efficiency.
 3. Lesion size: the maximum diameter of the largest lesion should be reported in millimeters. According to current consensus definitions, demyelinating lesions are characterized as focal hyperintensities with a diameter ≥ 3 mm [9].
 4. Central vein sign: report the number of CVS-positive lesions and specify whether the examination meets diagnostic criteria: “Select 6” rule (≥ 6 CVS-positive lesions), “majority” rule (more than 50% of lesions CVS-positive when < 10 total lesions), or pediatric criteria (> 50% of lesions CVS-positive) [2, 9].
 5. Paramagnetic rim lesions: document the number of PRLs identified, as even a single PRL carries diagnostic significance [2, 9].
 6. Lesion characterization: describe whether lesion appearance is typical of MS-related demyelination or whether features suggest alternative diagnoses requiring further investigation (e.g., ischemic lesions, tumefactive demyelination, neoplasm, infectious or other inflammatory processes).

Assessment of DIS and DIT criteria

Explicitly state whether imaging findings fulfill McDonald criteria for DIS and DIT as defined in Table 1. This direct assessment facilitates clinical application of diagnostic criteria.

Assessment of disease activity

Document the number of contrast-enhancing lesions on the current examination and the number of new or enlarging T2-hyperintense lesions compared with baseline and/or previous examinations (when available). Comparison with prior imaging is essential for assessing disease activity, determining treatment eligibility, and evaluating treatment response. In patients already receiving disease-modifying therapy, comparisons should be made with both the previous examination and the baseline pre-treatment examination.

Assessment of brain atrophy (optional)

When technically feasible, quantitative volumetric measurements should be reported, including: total brain volume, gray matter volume, white matter volume, corpus callosum volume, and bilateral thalamic volumes. The potential role of volumetric assessment in treatment decision-making is increasingly recognized. However, volumetric analysis remains relatively uncommon in routine clinical practice due to multiple confounding factors, including acquisition parameter variations, intra-scanner variability, pseudoatrophy (related to resolution of inflammation following treatment initiation), patient hydration status, and motion-related artifacts [26]. Nevertheless, appropriately acquired 3D T1-weighted images enable utilization of various software tools for longitudinal CNS atrophy assessment [26]. Volumetric brain analysis should be performed using validated, certified software applications (several of which are available in Poland).

Clinical application and future directions

The updated 2024 McDonald criteria enable substantially earlier MS diagnosis compared with previous iterations, with MRI assuming central diagnostic importance. Consequently, achieving optimal MRI image quality combined with rigorous image interpretation is essential for establishing accurate diagnoses and monitoring disease evolution. However, implementation of novel imaging parameters necessitates protocol optimization and additional training for radiologists and radiographers.

Future directions include further refinement of CVS and PRL detection protocols, development of automated image analysis tools to facilitate biomarker identification, expansion of quantitative volumetric analysis in clinical practice, and investigation of emerging imaging biomarkers including cortical pathology assessment and myelin water imaging. Continued collaboration between radiologists and neurologists will be essential for translating technical advances into improved patient care.

Conclusions

This third version of Polish recommendations for MRI in MS reflects substantial advances in MS diagnosis, particularly the integration of novel MRI biomarkers and

expansion of typical lesion locations to include the optic nerves. Standardized implementation of these protocols across Poland will enhance diagnostic accuracy, facilitate earlier diagnosis, improve disease monitoring, and ultimately contribute to better patient outcomes. Successful implementation requires commitment to protocol standardization, investment in radiologist education, and ongoing collaboration between radiology and neurology communities. As MRI technology and our understanding of MS pathology continue to advance, these recommendations will require periodic revision to maintain alignment with evolving best practices.

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