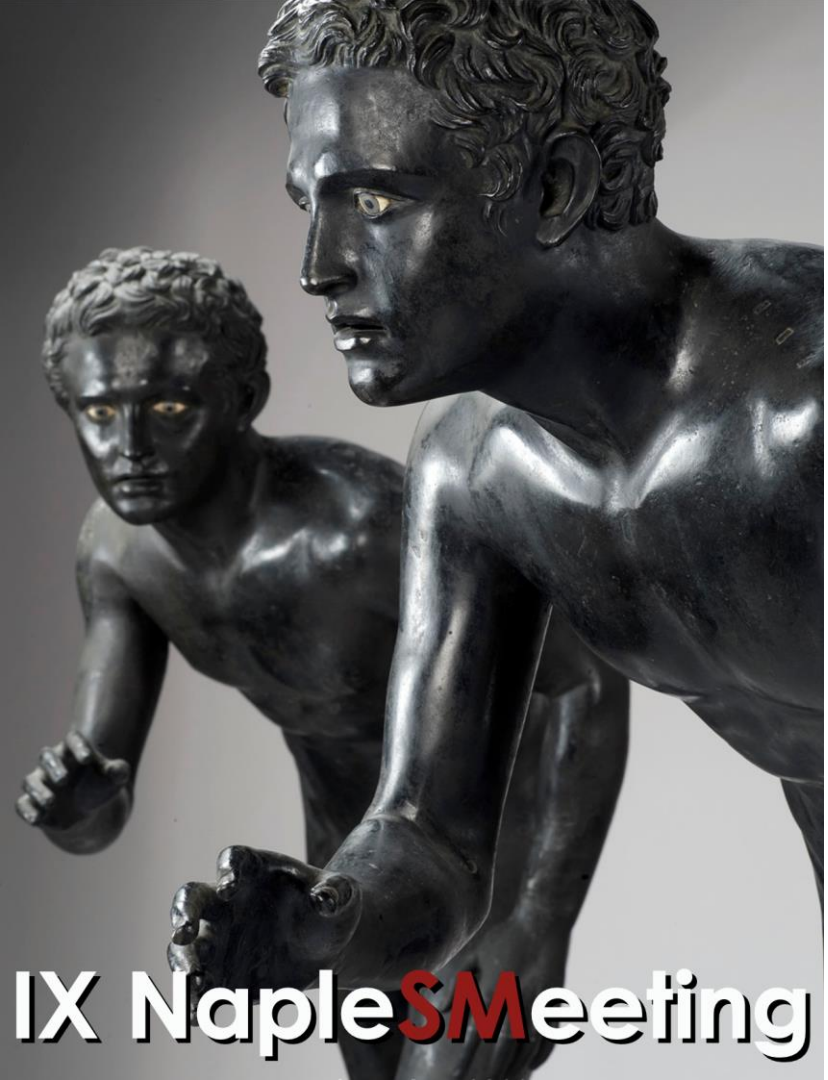

MRI protocol and sequences for optimal brain and spinal cord imaging

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Centro di Ricerca in Neuroimmagini

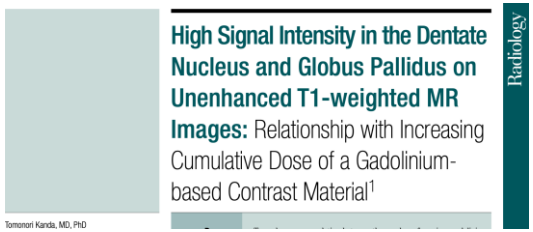
MRI and MS

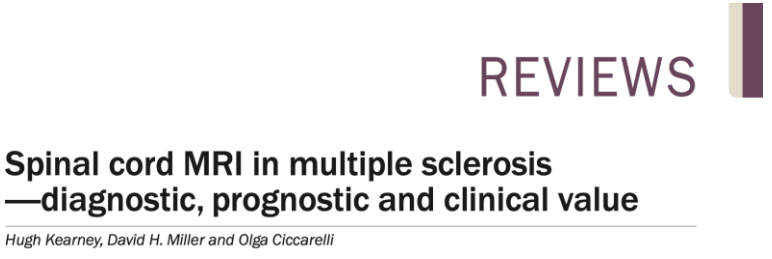
- ✓ The value of **MRI** in patients with MS for ***diagnostic***, ***prognostic***, and ***monitoring*** purposes is well established.

- ✓ The 2015 MAGNIMS and 2016 CMSC **consensus guidelines** on the use of MRI in patients with MS guided neuroradiologists and neurologists to **standardise** their image ***acquisition protocols*** and the indications for when and how to use MRI.

Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

MRI and MS





- ✓ AIR recon – Compressed SENSE
- ✓ High-field scanner; coil; hardware
- ✓ Synthetic imaging

Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

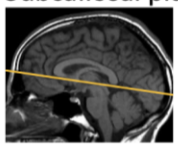
MRI and MS

- ✓ The **2017 revisions** emphasised the strong need for **strict standardisation** of MRI acquisition and interpretation to avoid misdiagnosis.

- ✓ The crucial need for a **standardised brain and spinal cord MRI acquisition** and **reporting** at the time of the first clinical presentation and during the early course of multiple sclerosis **goes beyond diagnostic purposes** since it provides important **prognostic information**.

Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

MRI and MS: *brain*

MRI PROTOCOLS	Brain	Spinal Cord	Optic Nerve
Field Strength	≥1.5 T (preferably 3T)	≥1.5 T (3T no added value)	≥1.5 T
Acquisition	3D (preferred) or 2D	2D or 3D	2D or 3D
Slice Thickness	3D: 1mm isotropic [1] 2D: ≤3mm, no gap [2]	Sagittal ≤3mm, no gap Axial ≤5mm, no gap	≤2-3mm, no gap
In-Plane Resolution	≤1mm x 1mm	≤1mm x 1mm	≤1mm x 1mm
Coverage	Whole Brain (include as much of cervical cord as possible)	Whole cord (cervical, thoracolumbar including conus)	Optic nerve & chiasm
Axial slice orientation	Subcallosal plane 	Perpendicular to sagittal axis of cord	Align to optic nerve/chiasm orientation

T = Tesla; **3D** = three dimensional; **2D** = 2 dimensional
[1] Isotropic preferred, if over-contiguous (through-plane and in-plane), not > 1.5 mm with 0.75 mm overlap
[2] Diffusion-weighted imaging, slice thickness should be ≤ 5mm with a 10-30% slice gap

Magnims Magnetic Resonance Imaging in Multiple Sclerosis

CMSC The Consortium of Multiple Sclerosis Centers

NAIMS North American Imaging in MS Cooperative

Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

MRI and MS: *brain*

- ✓ **3D acquisition** techniques (particularly for FLAIR and T1-w) are preferred to 2D acquisitions, as 3D techniques have become more routinely available on clinical scanners than before and they **improve** both **lesion detection** and the **realignment of anatomic orientation** that is necessary to detect new lesions when comparing serial MRI scans.

Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

MRI and MS: *brain*

Brain Sequences	Diagnostic workup	Follow Up	Safety Monitoring
Axial T_2	Recommended	Recommended (Optional if 3D Flair acquired)	Recommended (Optional if 3D Flair acquired)
Sagittal & Axial FLAIR	Recommended	Recommended	Recommended
Post-Gd axial (or 3D sagittal) T_1	Recommended	Optional	Optional
Diffusion-weighted imaging	Optional	Optional (useful for differential Dx)	Recommended (for PML detection)
DIR or PSIR	Optional (for cortical lesions)	Optional	Optional
High-resolution 3D T_1	Optional (for brain atrophy monitoring)	Optional	Not Required
Susceptibility-weighted imaging	Optional (for central vein sign)	Not Required	Not Required

T_2 (TSE/FSE, turbo/fast spin echo)
Gd macrocyclic agent, 0.1mm/kg body weight, minimum delay 5-10 minutes
T_1 (TSE/FSE)
FLAIR (fluid-attenuated inversion recovery)
DIR (double inversion recovery) and **PSIR** (phase-sensitive inversion recovery)
High resolution 3D T_1
(e.g.MP-RAGE, MP2RAGE magnetization-prepared rapid acquisition of gradient echoes; IR-SPGR, inversion-prepared spoiled gradient; TFE, turbo field-echo)

Magnims — Magnetic Resonance Imaging in Multiple Sclerosis
CMSC — The Consortium of Multiple Sclerosis Centers
NAIMS — North American Imaging in MS Cooperative

Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

MRI and MS: *brain*

- ✓ On the basis of its high sensitivity, sagittal **3D FLAIR** acquisition is considered to be the **core sequence for MS** diagnosis and monitoring.
- ✓ In centres that are unable to acquire sufficiently high quality 3D FLAIR images, **high quality 2D** pulse-sequences (ie, ≤3 mm slice thickness and no gap between slices) can provide an **acceptable alternative**.
- ✓ Precontrast **T1-w sequences** are **not routinely needed**

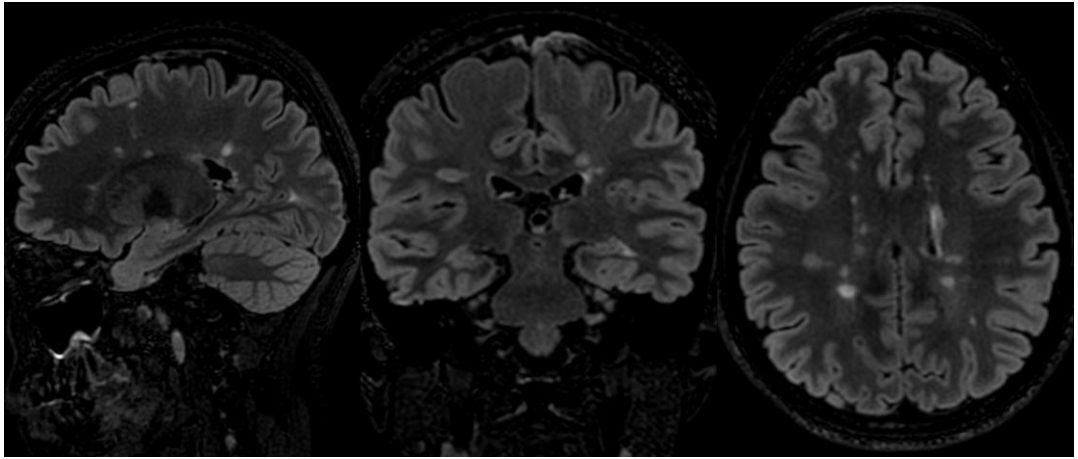
Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

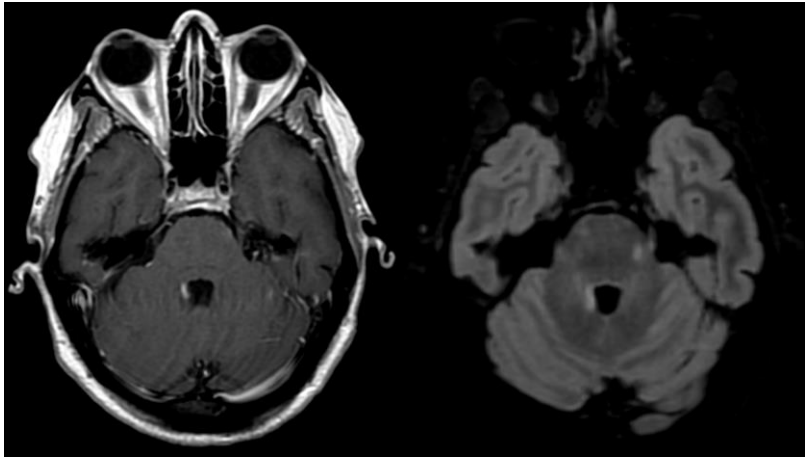
MRI and MS: *brain*

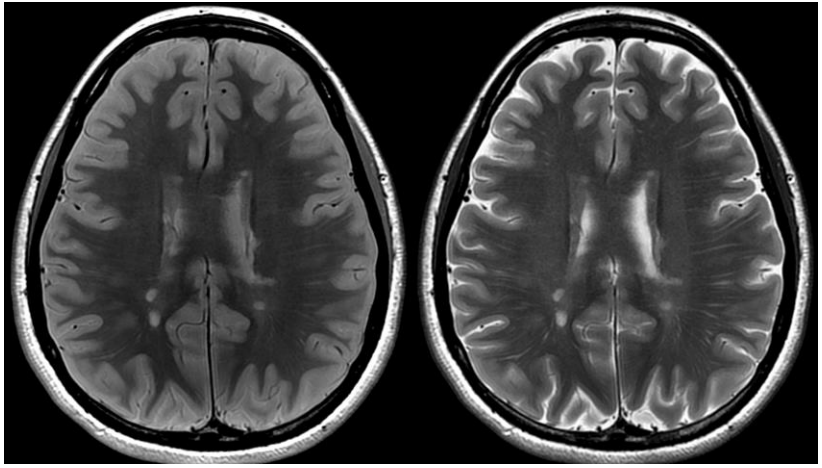
- ✓ The use of scanners with field strengths that are **less than 1.5 T** is **not recommended**
- ✓ The use of **1.5 T** scanners continues to be **sufficient for detection of brain lesions** at the time of diagnosis, as long as scans are of good quality with adequate signal-to-noise ratio and spatial resolution
- ✓ **3T** scanners provide a **higher detection rate** for multiple sclerosis lesions and offer potentially **shorter acquisition times**

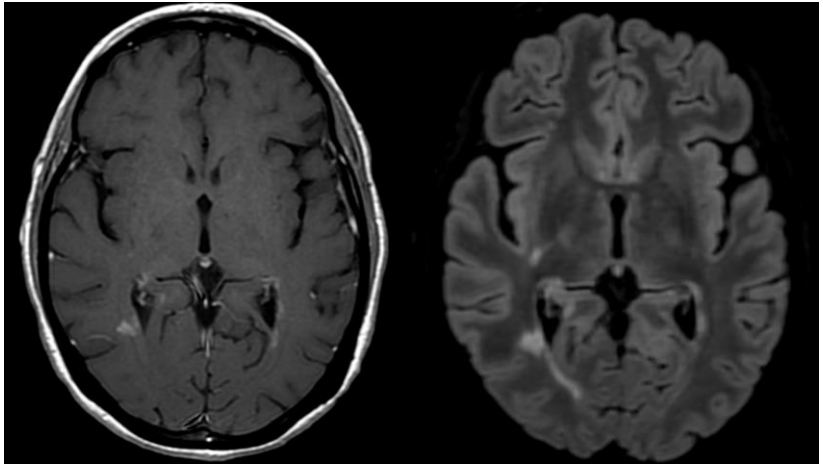
Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

MRI and MS: *brain*





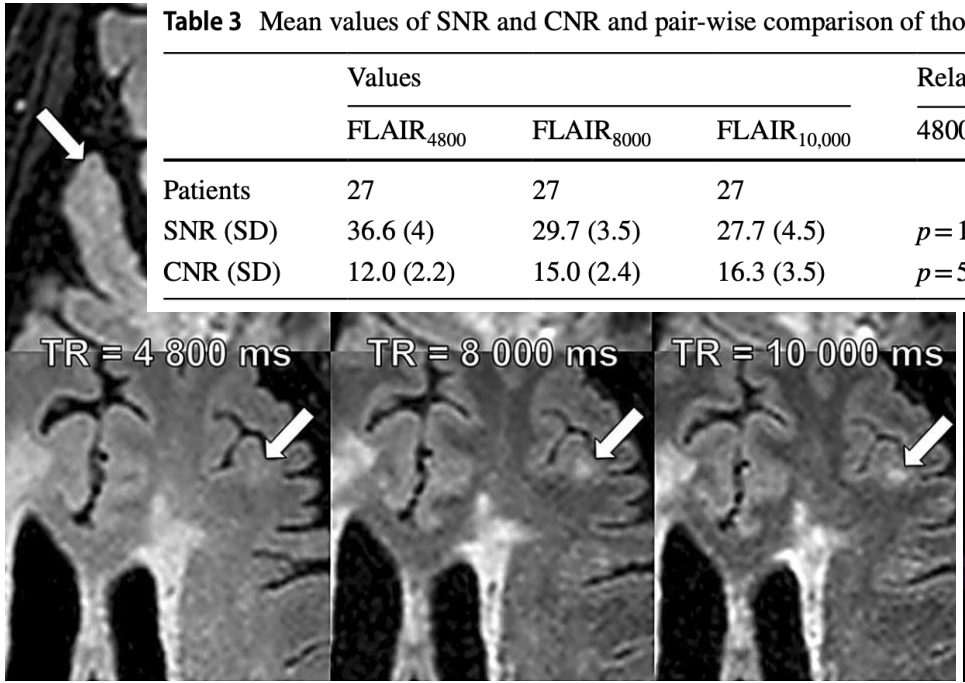


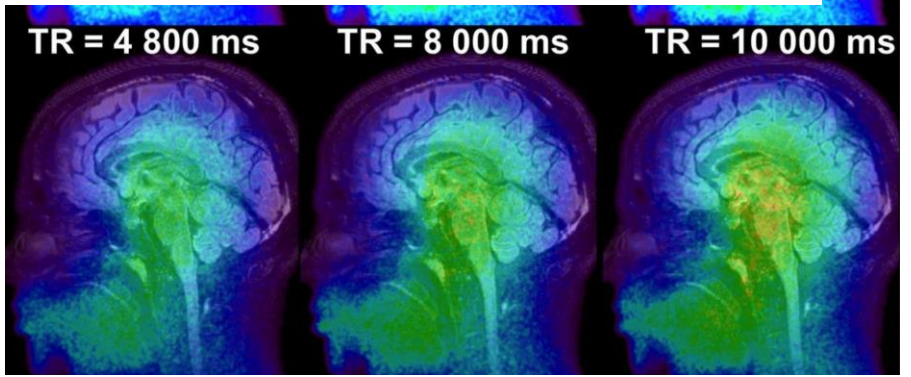


MRI and MS: *brain*

Table 3 Mean values of SNR and CNR and pair-wise comparison of those values

	Values			Relative comparison[§]			
	$FLAIR_{4800}$	$FLAIR_{8000}$	$FLAIR_{10,000}$	4800 VS 8000		4800 VS 10,000	8000 VS 10,000
Patients	27	27	27				
SNR (SD)	36.6 (4)	29.7 (3.5)	27.7 (4.5)	$p=1\times10^{-8}$*	$p=1\times10^{-7}$*		$p=0.001$*
CNR (SD)	12.0 (2.2)	15.0 (2.4)	16.3 (3.5)	$p=5\times10^{-7}$*	$p=2\times10^{-6}$*		$p=0.01$*

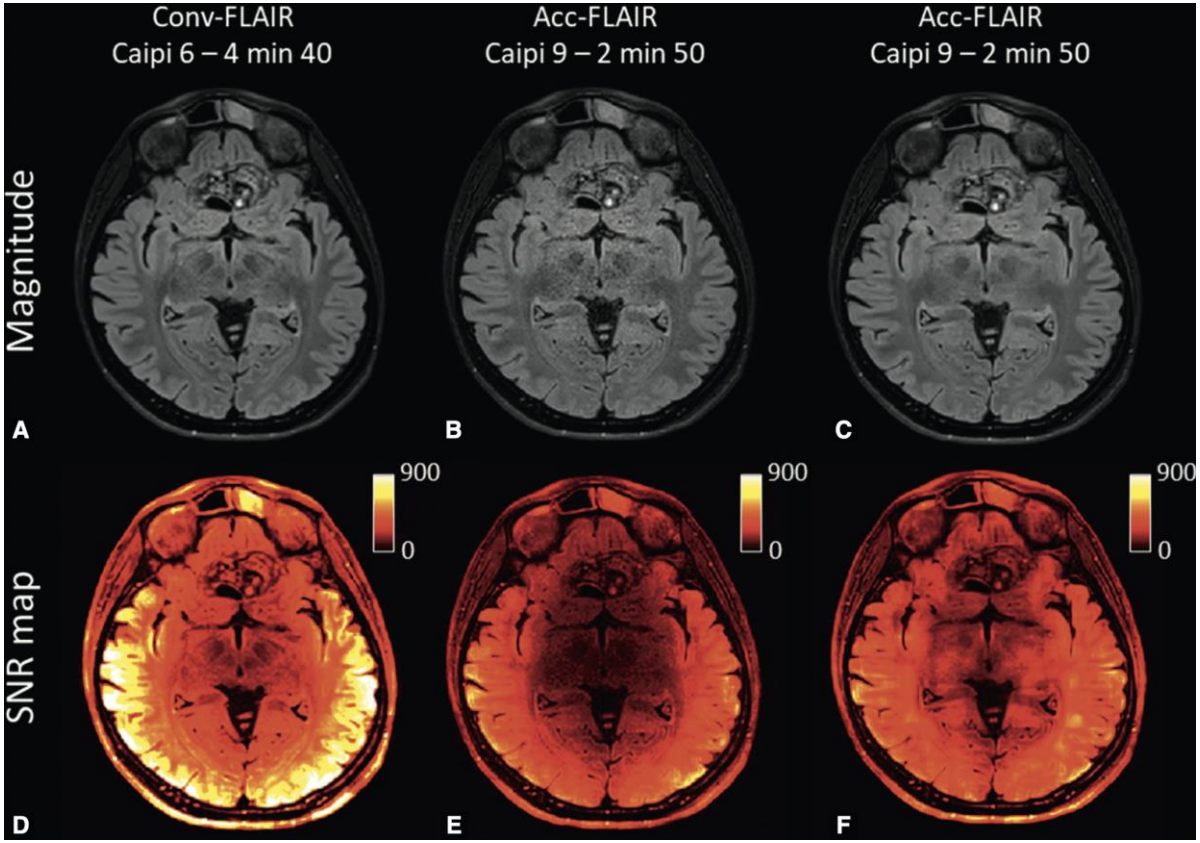




✓ We need to go **beyond the standardization of protocols** and **standardize sequences** themselves to improve results' reproducibility and therefore patients' care.

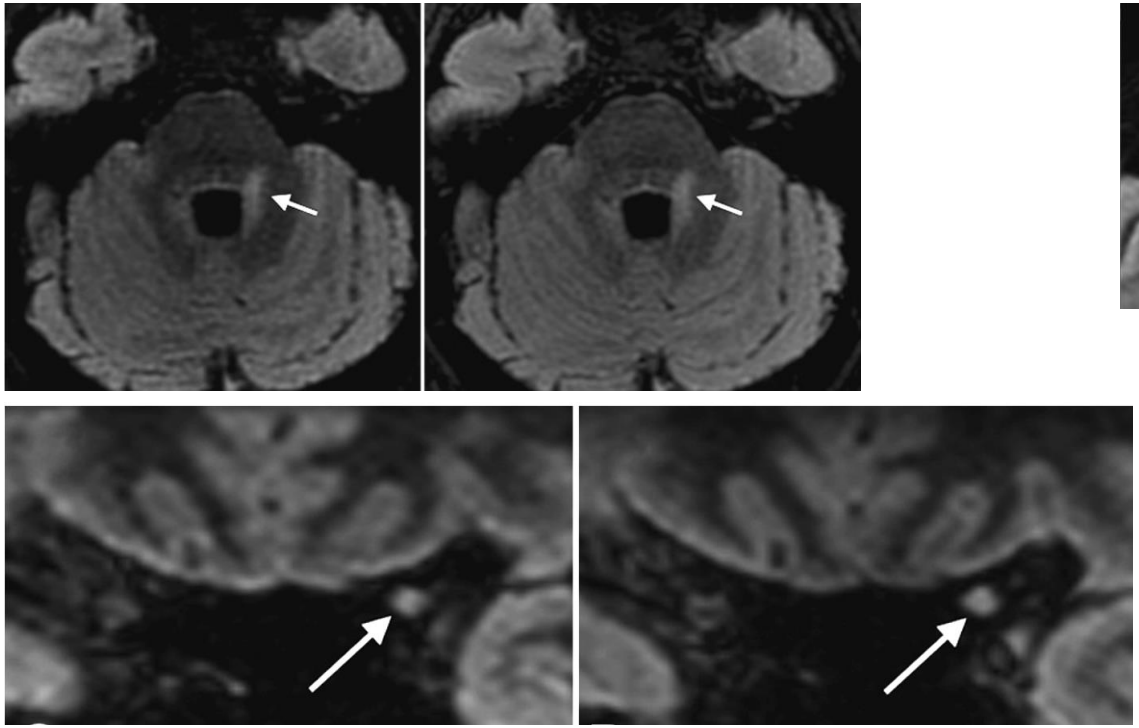
Lecler A., et Al.: *Optimizing 3D FLAIR to detect MS lesions: pushing past factory settings for precise results* . J of Neurol 2019

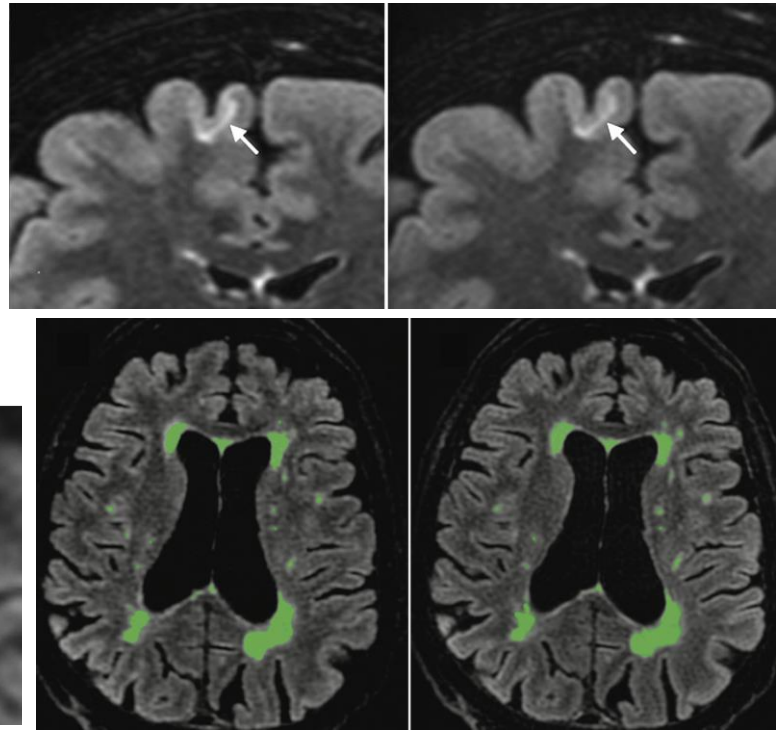
MRI and MS: *brain*



Elizer M., et Al.: *Iterative denoising accelerated 3D SPACE FLAIR sequence for brain MR imaging at 3T.* Diag Interv Imaging 2022

MRI and MS: *brain*

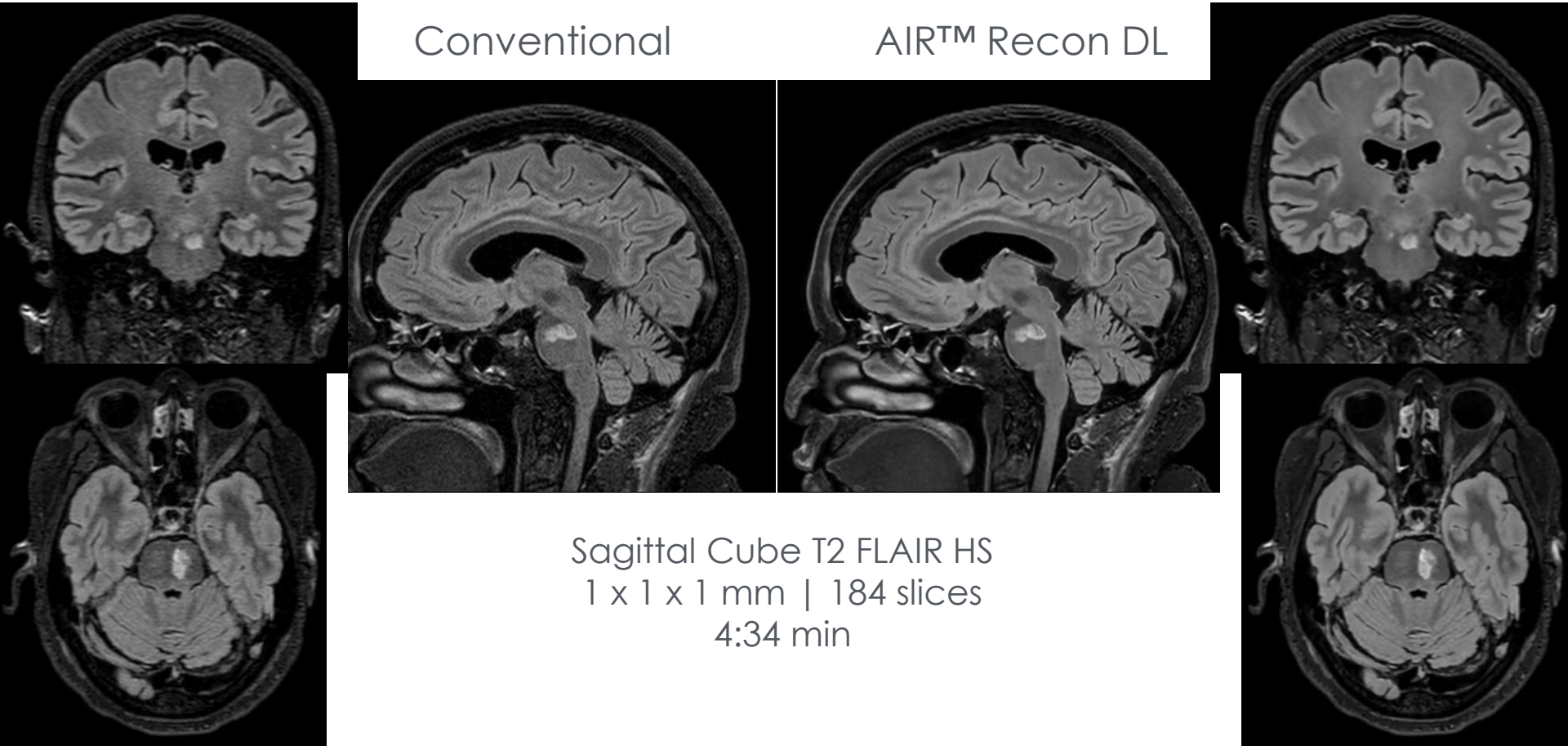




- ✓ With a **compressed sensing** factor (1.3), **3D-FLAIR is 27% faster** and preserves diagnostic performance for the MS plaques at 3T.

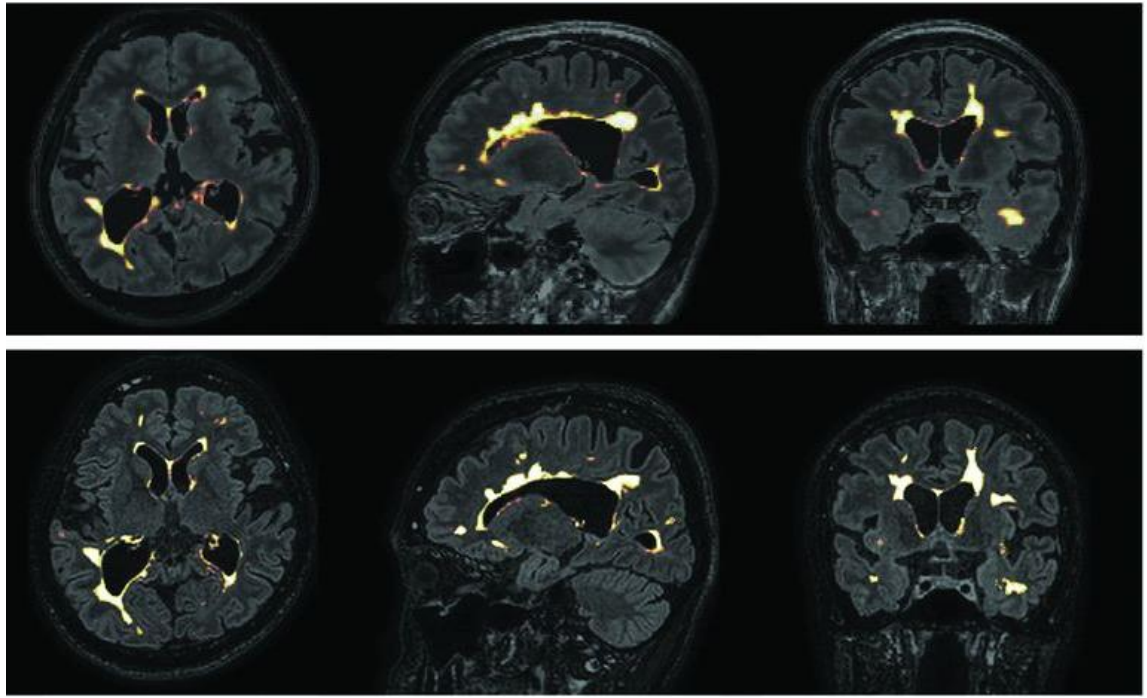
Toledano-Massiah S., et Al.: *Accuracy of the Compressed Sensing Accelerated 3D-FLAIR for the Detection of MS Plaques at 3T..AJNR 2018*

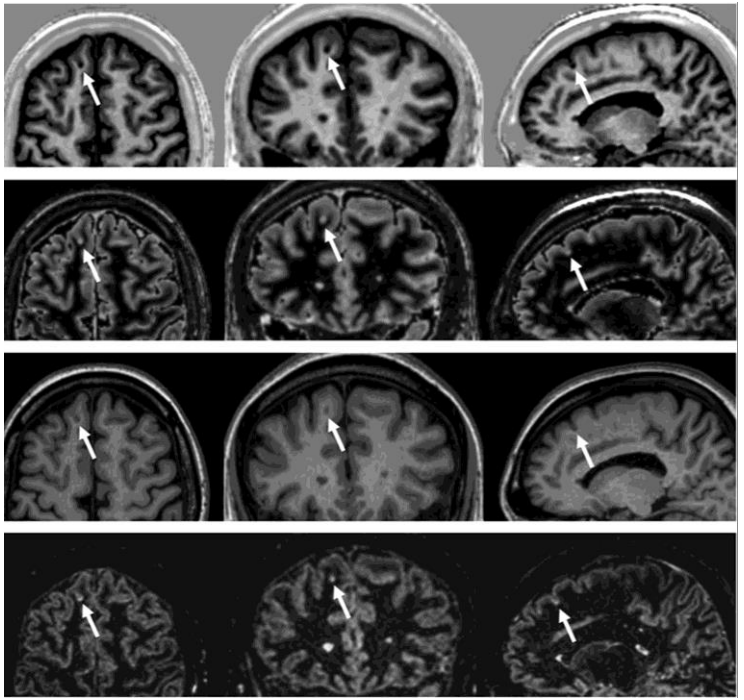
MRI and MS: *brain*



Sagittal Cube T2 FLAIR HS
1 x 1 x 1 mm | 184 slices
4:34 min

MRI and MS: *brain*

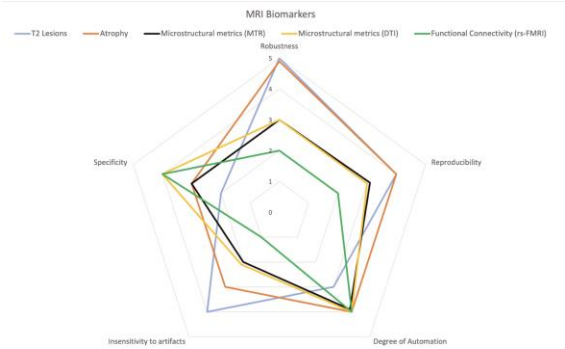




✓ **3D synthetic MRI** could serve as an alternative to conventional MRI in evaluating MS with a **reduced scan time**.

Toledano-Massiah S., et Al.: *Accuracy of the Compressed Sensing Accelerated 3D-FLAIR for the Detection of MS Plaques at 3T..AJNR 2018*

MRI and MS: *brain*



Sources of variability related to MRI scan acquisition and analysis and recommendation to reduce their impact for the most common imaging biomarkers used in MS.

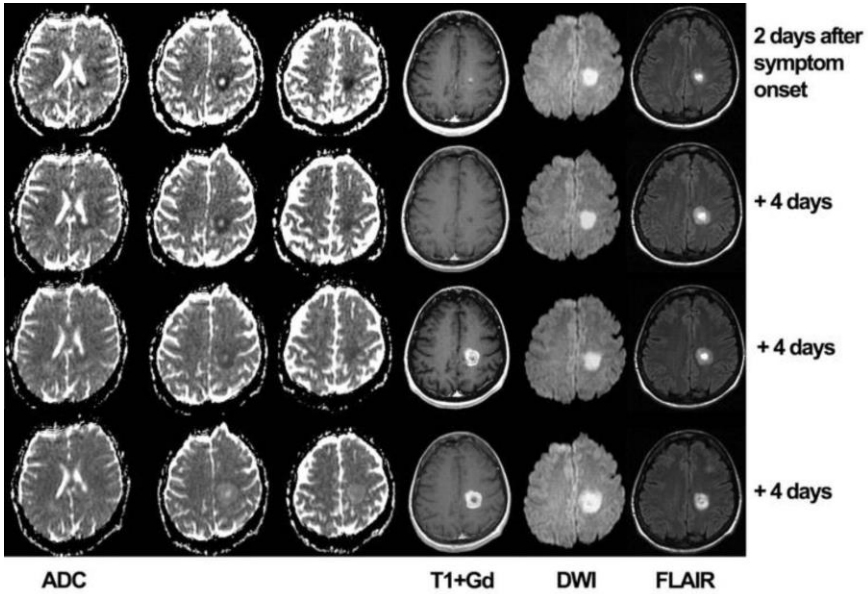
Biomarkers	Sources of variability in MRI acquisition	Sources of variability in MRI analysis	Recommendations for harmonization of MRI acquisition and analysis
WM lesions	• Different acquisition protocols • Different magnetic field strengths • Different scanners • B0 or B1 inhomogeneity	• Inter rater variability in manual lesion segmentation • Variability in voxel intensity • Lack of deep learning generalizability • Registration pipelines (when used)	• Standardization of imaging acquisition protocols (i.e., use of isotropic 3D FLAIR with spatial resolution of 1 mm^3 acquired at minimum 1.5 Tesla) • Inhomogeneity and intensity normalization • Careful QC before the analysis • Use of machine learning-based algorithms on images similar to those of the training dataset • Inclusion of magnetic field strength and image characteristics when merging lesions outputs from different scanners
Atrophy	• Different acquisition protocols • Different magnetic field strengths • Different scanners • B0 or B1 inhomogeneity	• Presence of black holes • Variability in voxel intensity • Defacing • Software variability • Lack of automated segmentation generalizability • Registration pipelines (when used)	• Standardization of imaging acquisition protocols and minimal hardware or software changes • Bias-field correction and intensity normalization • Careful QC before the analysis • Use of lesion-filled isotropic 3D T1-weighted images acquired at magnet *iso*-center

✓ The **standardization** of imaging protocols may **potentially improve the performance** of these tools and help the identification of very small lesions while reducing the number of false positives

De Stefano N., et Al.: *MAGNIMS recommendations for harmonization of MRI data in MS multicenter studies.* Neuroimage: Clinical 2022

MRI and MS: *brain*

- ✓ **DWI** is frequently incorporated into brain imaging protocols for diagnosis and monitoring of multiple sclerosis, but its **value is low**.

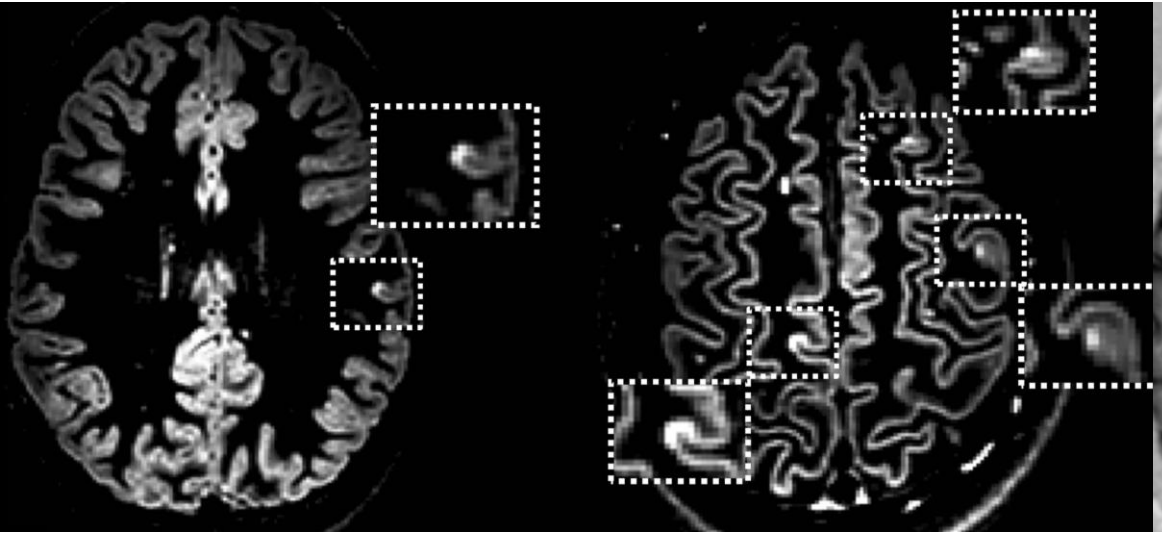


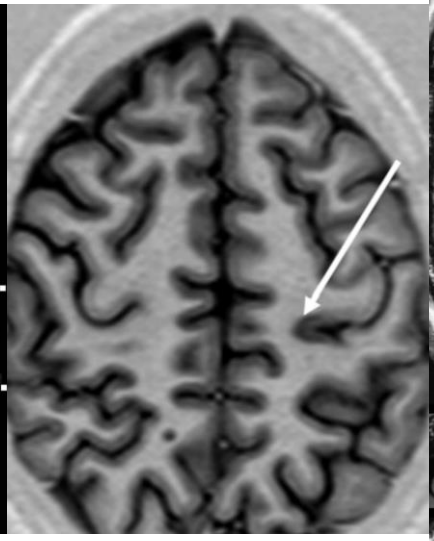
- ✓ DWI should **not be used** as an alternative to gadolinium-enhanced T1-w imaging to show acute demyelinating lesions

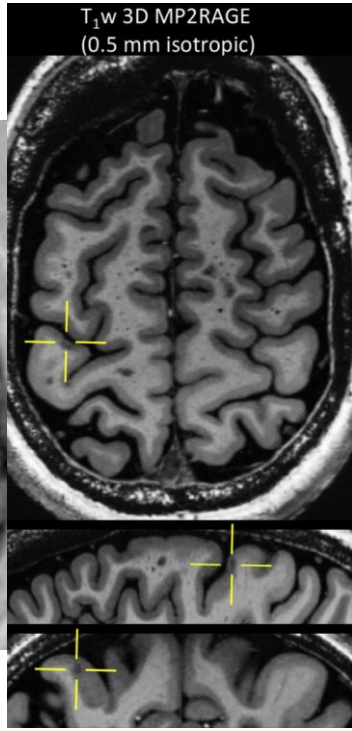
Eisele P, et Al.: *Reduced diffusion in a subset of acute MS lesions: a serial multiparametric MRI study.* AJNR 2012

MRI and MS: *brain*

- ✓ **3D DIR** and **3D-T1 PSIR**, can **improve the detection of cortical** MS **lesions**







Filippi M, et Al.: *Assessment of lesions on magnetic resonance imaging in multiple sclerosis: practical guidelines.* Brain 2019

MRI and MS: *brain*

- ✓ As **acquisition** and **interpretation** of these sequences, particularly **DIR**, can be **challenging** and are associated with **high inter-rater variability**, the use of these sequences **should be restricted** to centres with a sufficient level of expertise with standardisation of image acquisition

Filippi M, et Al.: *Assessment of lesions on magnetic resonance imaging in multiple sclerosis: practical guidelines.* Brain 2019

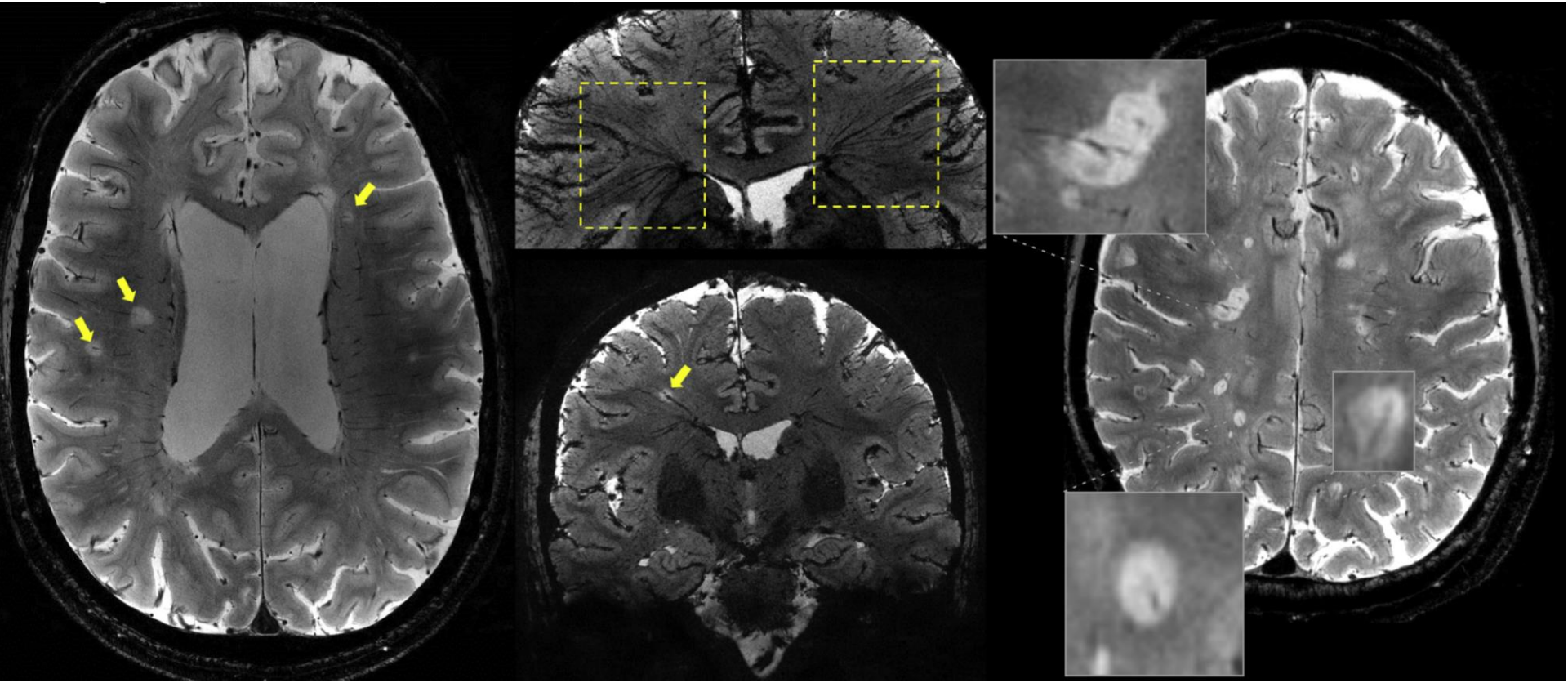
MRI and MS: *brain*

- ✓ The use of **T2*-weighted** or **susceptibility-weighted sequences**, preferably at 3 T in combination with FLAIR sequences to produce so-called **FLAIR* images**, can show the so-called **central vein sign.**

- ✓ Valuable diagnostic marker for MS, since **a high proportion of lesions** with the central vein sign suggests multiple sclerosis rather than its mimics.

Sati P, et Al.: *FLAIR*: a combined MR contrast technique for visualizing white matter lesions and parenchymal veins.* Radiology 2012

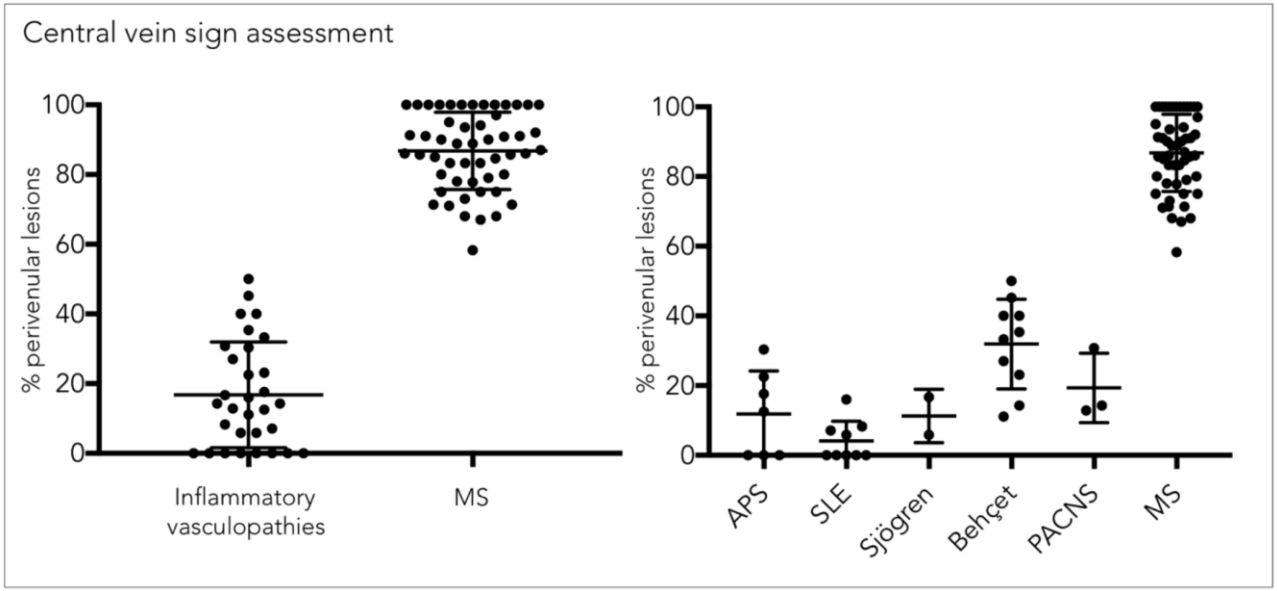
MRI and MS: *brain*



Sati P, et Al.: *FLAIR*: a combined MR contrast technique for visualizing white matter lesions and parenchymal veins.* Radiology 2012

MRI and MS: *brain*

- ✓ The "central vein sign" differentiates inflammatory CNS vasculopathies from MS at standard clinical MR field strengths



- ✓ When a threshold of 50% perivenular lesions was applied, CVS discriminated MS from inflammatory vasculopathies with diagnostic accuracy of 100%.

Maggi P., et Al.: *The central vein sign differentiates MS from CNS inflammatory vasculopathies.* Ann Neurology, 2018

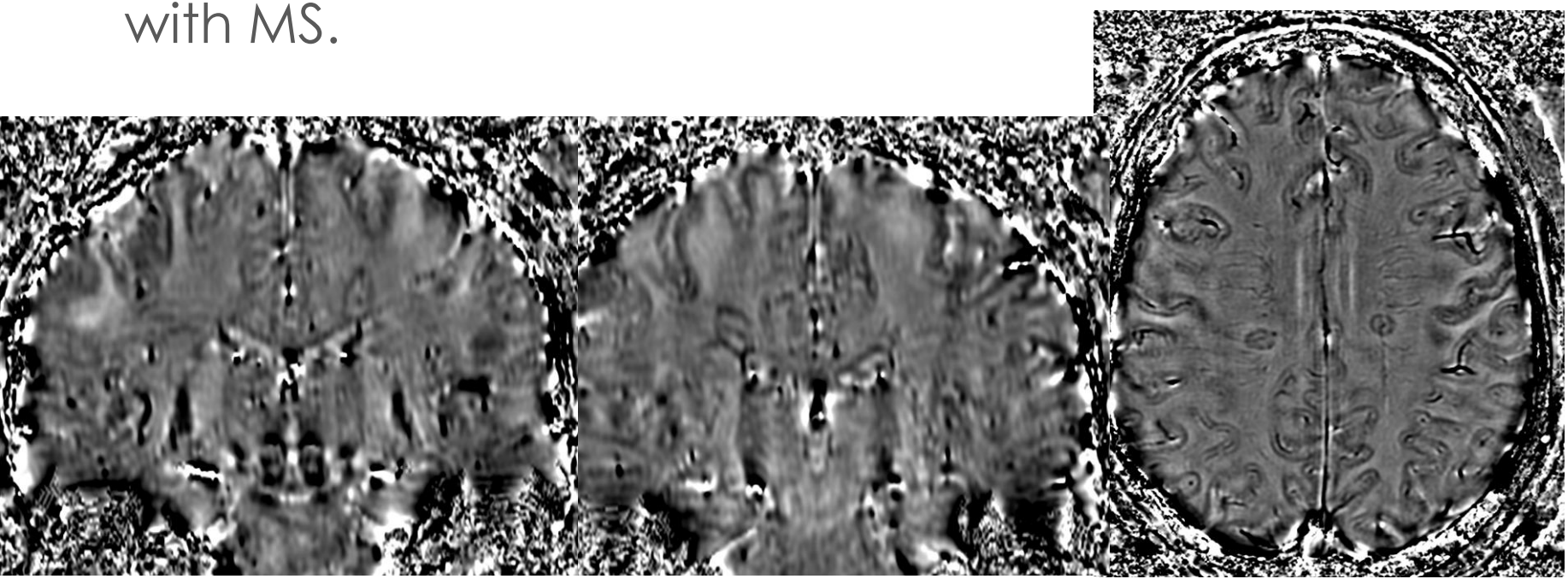
MRI and MS: *brain*

- ✓ Optimal pulse sequences for detecting this sign are **not yet widely available** on clinical scanners.
- ✓ its use is **not recommended** for routine clinical use

Sati P, et Al.: *FLAIR*: a combined MR contrast technique for visualizing white matter lesions and parenchymal veins.* Radiology 2012

MRI and MS: *brain*

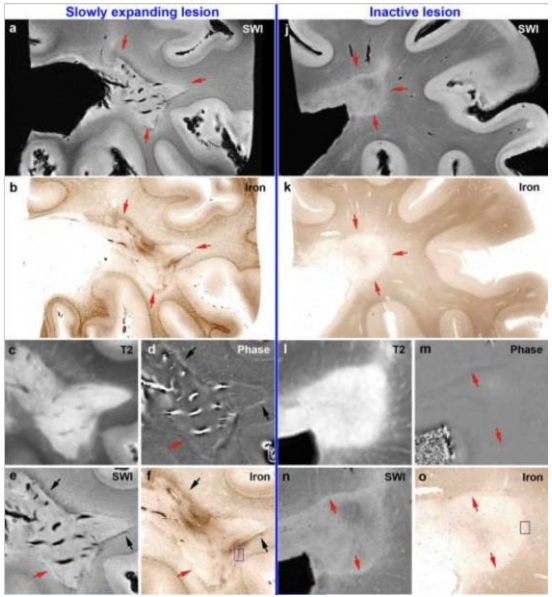
- ✓ **Susceptibility-weighted** sequences at 3 T can identify **paramagnetic rim lesions** in around 50% of patients with MS.

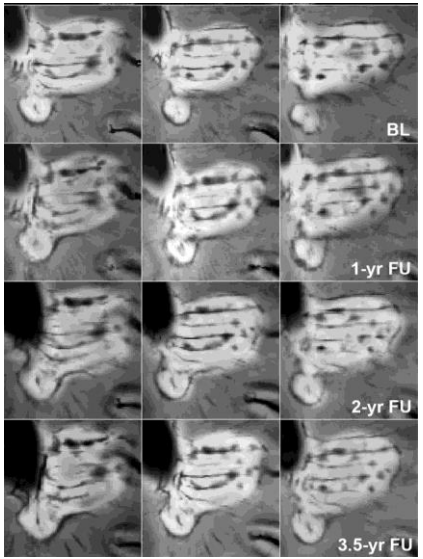


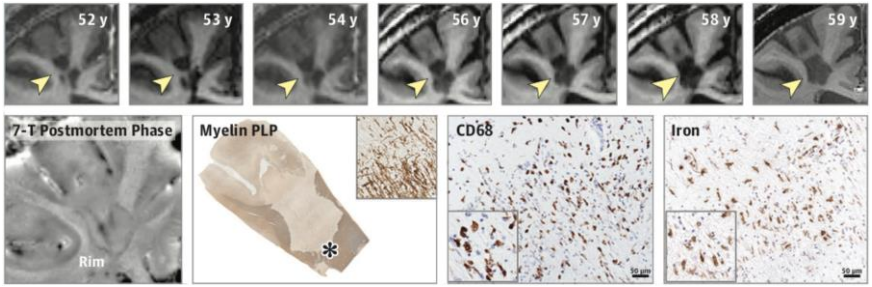
Maggi P., et Al.: *Paramagenetic rim lesions are specific to multiple sclerosis: an international multicenter 3T MRI study*. Ann Neurol 2020

MRI and MS: *brain*

- ✓ This feature, reflecting **iron within phagocytes** at the edge of **chronic active lesions**, rarely occurs in other neurological conditions and therefore has the potential to increase the MRI specificity in differentiating MS from other conditions.





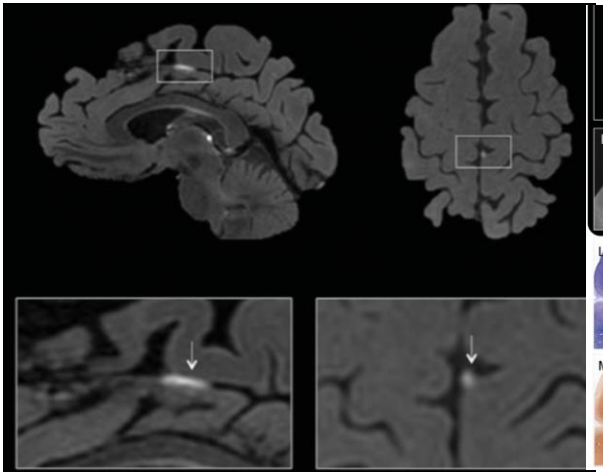


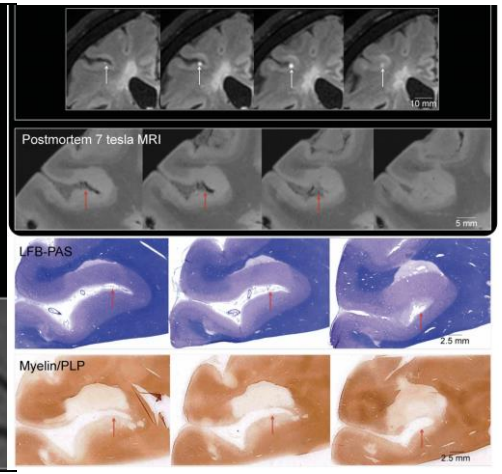
- ✓ Further studies are required to **validate this feature** as a diagnostic imaging marker.

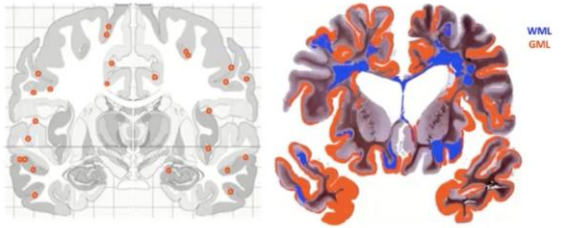
Dal Bianco A., et Al.: *Slow expansion of multiple sclerosis iron rim lesions: pathology and 7 T MRI.* Acta Neuropathol 2017

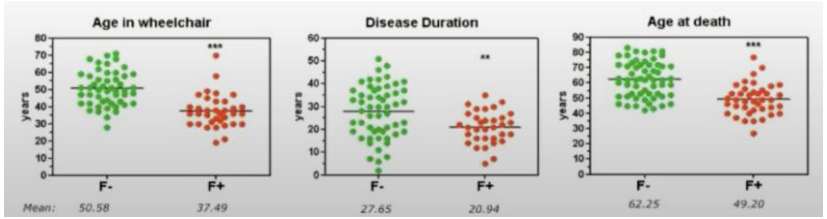
MRI and MS: *brain*

- ✓ Post-contrast T2-FLAIR focal **leptomeningeal enhancement**, possibly reflecting subpial demyelination and cortical atrophy, has been found in 25% of MS patients at 3T, with a higher frequency in PMS (33%) than RRMS (19%), and in up to 90% of MS patients at 7T.









Absinta M., et Al.: *Gadolinium-based MRI characterization of leptomeningeal inflammation in multiple sclerosis* . Neurology 2015

MRI and MS: *brain*

- ✓ The association between leptomeningeal inflammation and cortical pathology is **still controversial**.
- ✓ Leptomeningeal enhancement on MRI can also be **observed in other chronic neuroinflammatory diseases** (NMOSD, MOG-antibody- associated disease, and Susac syndrome)
- ✓ His putative imaging marker of leptomeningeal inflammation is currently **not recommended** for diagnostic (ie, it cannot be used to show DIS and DIT), prognostic, or monitoring purposes.

Absinta M., et Al.: *Gadolinium-based MRI characterization of leptomeningeal inflammation in multiple sclerosis* . Neurology 2015

MRI and MS: *spinal cord*

- ✓ The value of **spinal cord MRI** for the **diagnosis of MS** has been **unequivocally shown**, and it is a key component of the 2017 McDonald criteria

- ✓ **Spinal cord MRI** is important not only for showing **DIS** and **DIT** but also for **exclusion of alternative diagnoses** (eg, vascular diseases, spinal cord compression, and inflammatory diseases).

Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

MRI and MS: *spinal cord*

Spinal Cord Sequences	Diagnostic workup	Follow Up	Safety Monitoring
Sagittal at least 2 of T_2, PD or STIR	**2 sequences Recommended**	Optional	Not Required
Sagittal 3D T_1 (PSIR, MP-RAGE) cervical only	Optional (substitutes for one of above)	Optional	Not Required
Axial T2 or T2*	Optional (through lesions)	Optional	Not Required
Pre-Gd Sagittal T_1	Optional	Optional	Not Required
Post-Gd Sagittal T_1	**Recommended**	Optional	Not Required
Post-Gd axial T_1	Optional	Optional	Not Required

T_2 (TSE/FSE, turbo/fast spin echo)
Gd macrocyclic agent, 0.1mm/kg body weight, minimum delay 5-10 minutes. No additional Gd needed if following Post-Gd brain examination
T_1 (TSE/FSE)
STIR (short tau inversion recovery)
PD (proton-density, TSE/FSE)
T_2* (T_2 gradient recalled echo)

Magnims Magnetic Resonance Imaging in Multiple Sclerosis

CMSC The Consortium of Multiple Sclerosis Centers

NAIMS North American Imaging in MS Cooperative

Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

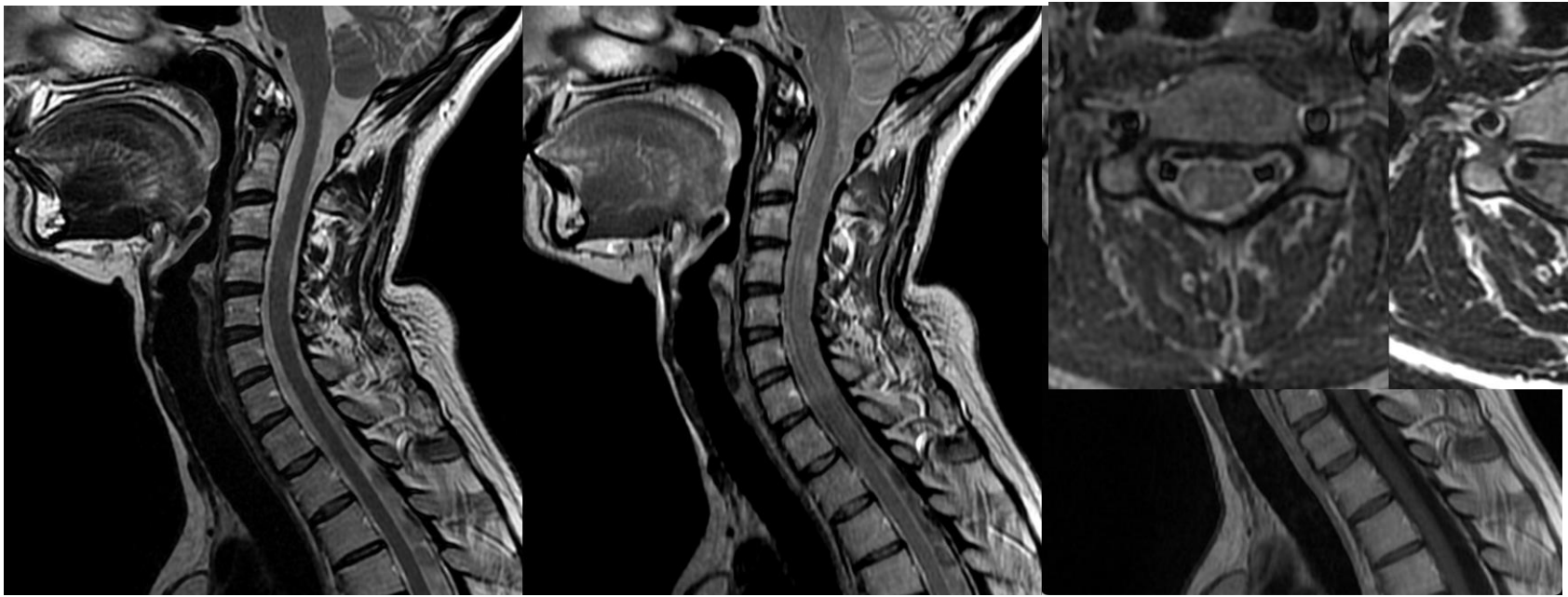
MRI and MS: *spinal cord*

- ✓ The **single acquisition** of a **T2-w** sequence is **not sufficient**, due to its limited sensitivity in depicting signal abnormalities and because a second sequence (PD or STIR) is required to confirm the presence of lesions and exclude artifacts;

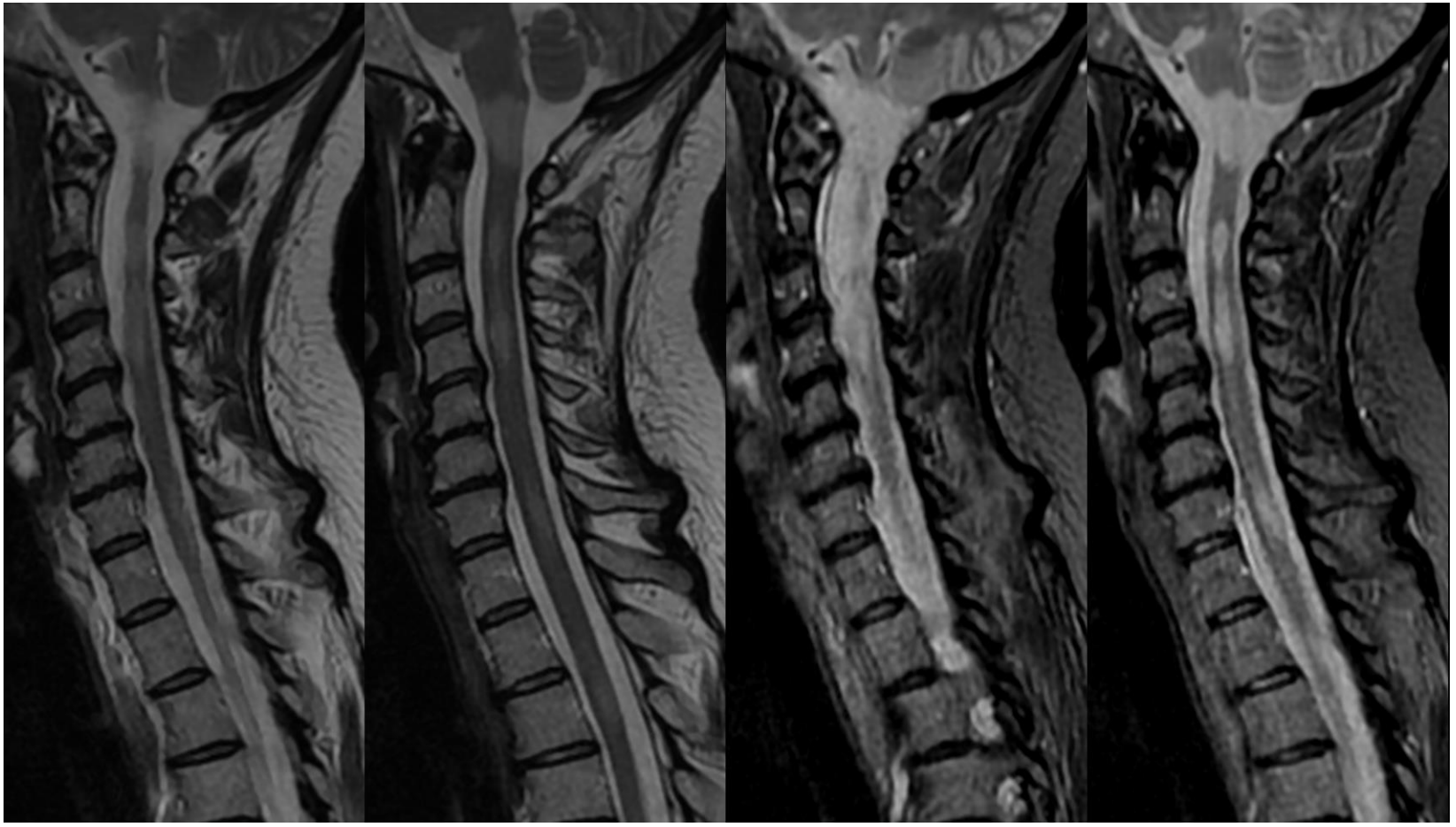
- ✓ **Axial T2-w** spin echo sequences can further **improve diagnostic certainty**, differentiating MS from mimics (NMOSD, MOG-antibody-associated disease) on the basis of lesion extension and topography

Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

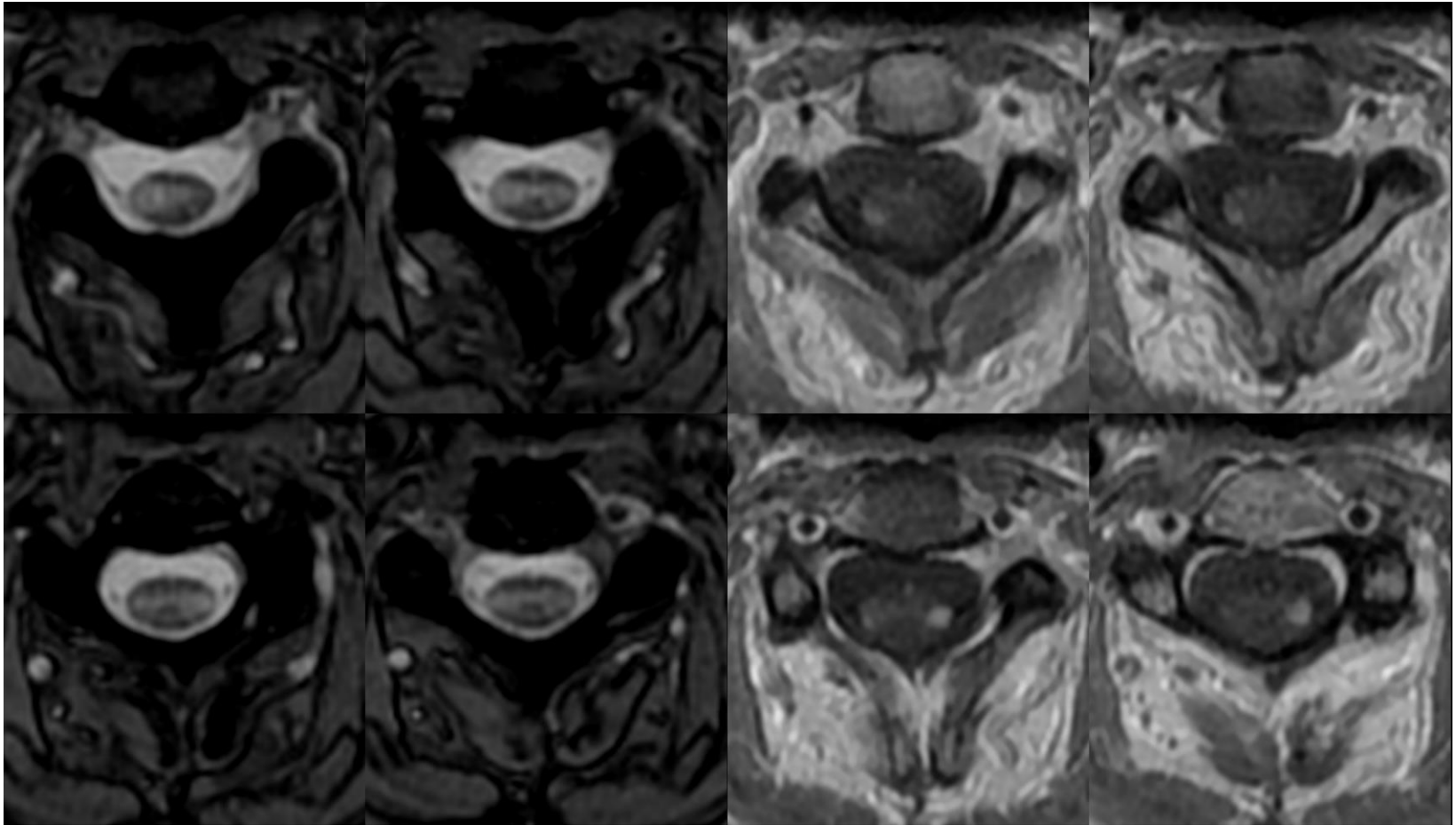
MRI and MS: *spinal cord*



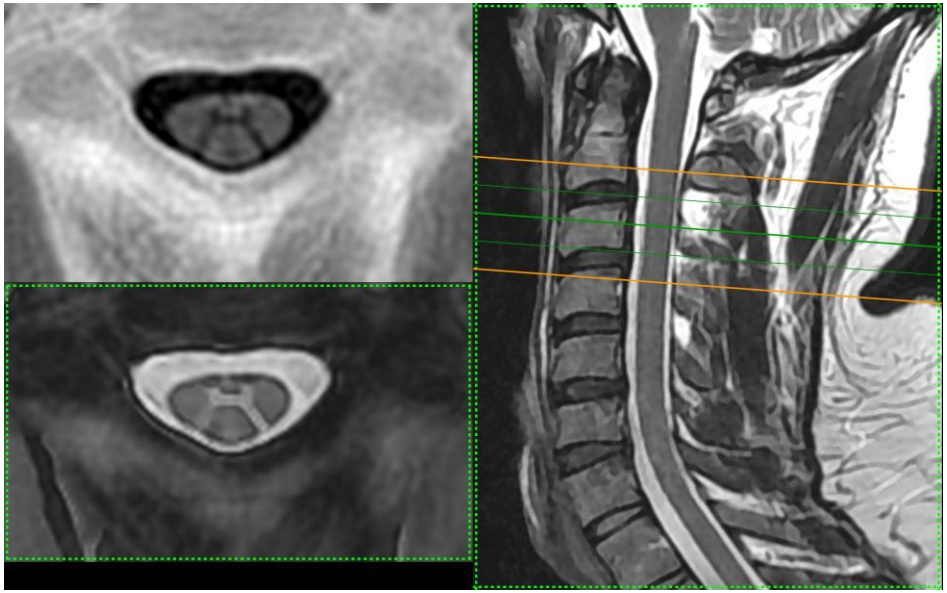
MRI and MS: *spinal cord*

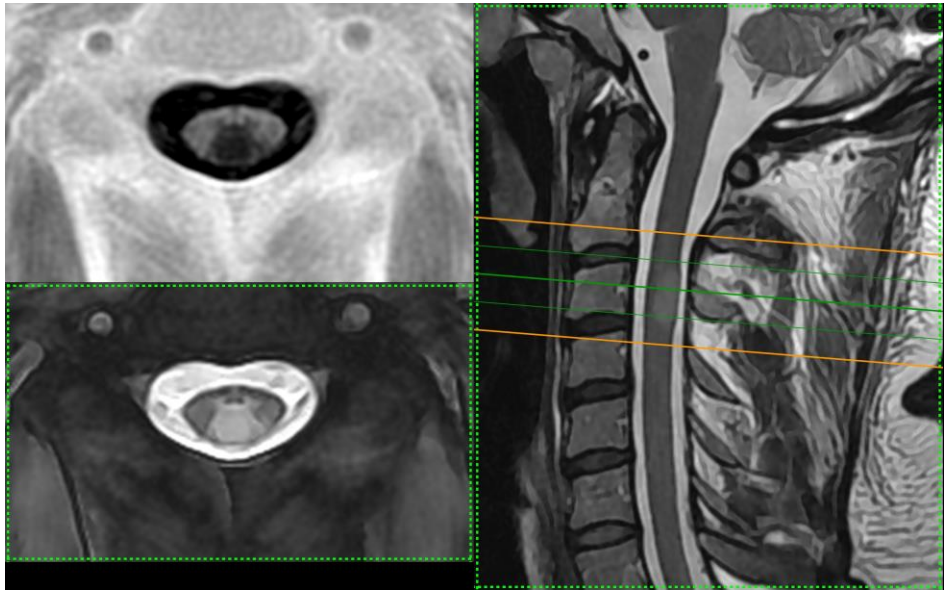


MRI and *MS: spinal cord*

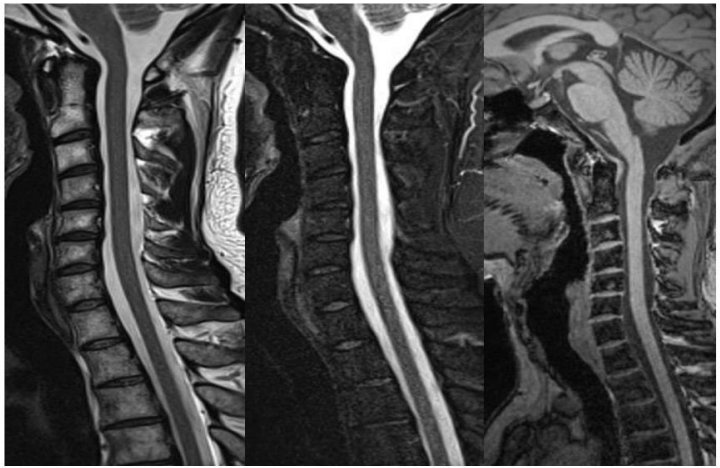


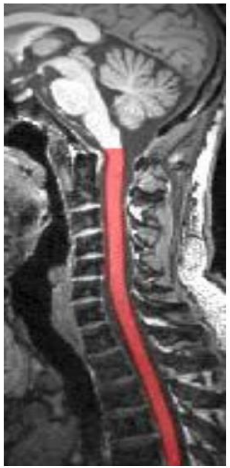
MRI and MS: *spinal cord*



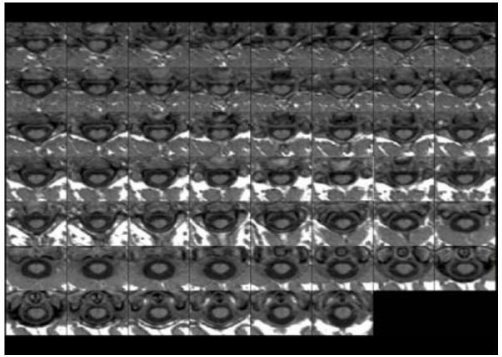


MRI and MS: *spinal cord*

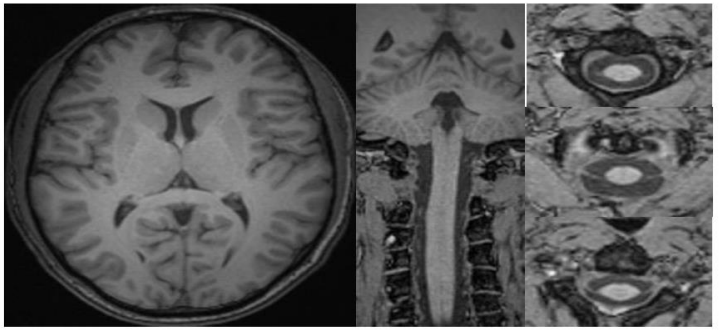




3D IR T1



C1-C5
Cord length: 67.43 mm
Cord volume: 5015.25 mm^3



Combined brain and cord atrophy using single 3D-T1

Spinal cord atrophy can be measured at the cervical level (C2-C3) using brain volumetric scans with sufficient field-of-view

Caveat: geometric deformity due to non-linear gradients at off-centre position

Liu Z, et Al.: *Cervical cord area measurement using volumetric brain magnetic resonance imaging in multiple sclerosis.* Mult Scler Relat Disord 2015

MRI and MS: *spinal cord*

- ✓ Spinal cord lesions are prognostically important but **difficult to identify and quantify**
- ✓ Good quality spinal cord MRI is **technically challenging and time-consuming**
- ✓ Limits the value of spinal cord MRI for monitoring disease evolution in clinical practice

Rocca MA, et Al.: *What role should spinal cord MRI take in the future of multiple sclerosis surveillance?*. Exp Rev Neurother ,2020

MRI and MS: *spinal cord*

Routine **spinal cord follow-up MRI cannot** yet be recommended unless:

- ✓ Significant clinical activity/worsening with no/few changes on brain MRI
- ✓ Spinal cord relapse if detection of (new) lesions could affect treatment decisions
- ✓ Patients with a predominant spinal cord MS phenotype
- ✓ Rule out alternative cause for progressive myelopathy

Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

MRI and MS: *Optic nerve*

2021 MAGNIMS-CMSC-NAIMS consensus recommendations on the use of MRI in patients with multiple sclerosis

Optic Nerve Sequences	Diagnostic workup	Follow Up	Safety Monitoring
Axial & Coronal fat-suppressed T_2 or STIR	Optional	Not Required	Not Required
Post-Gd Axial & Coronal fat-suppressed T_1	Optional	Not Required	Not Required

T_2 (TSE/FSE, turbo/fast spin echo)
Gd macrocyclic agent, 0.1mm/kg body weight, minimum delay 5-10 minutes. No additional Gd needed if following a Post-Gd brain examination
T_1 (TSE/FSE)
STIR (short tau inversion recovery)

Magnims
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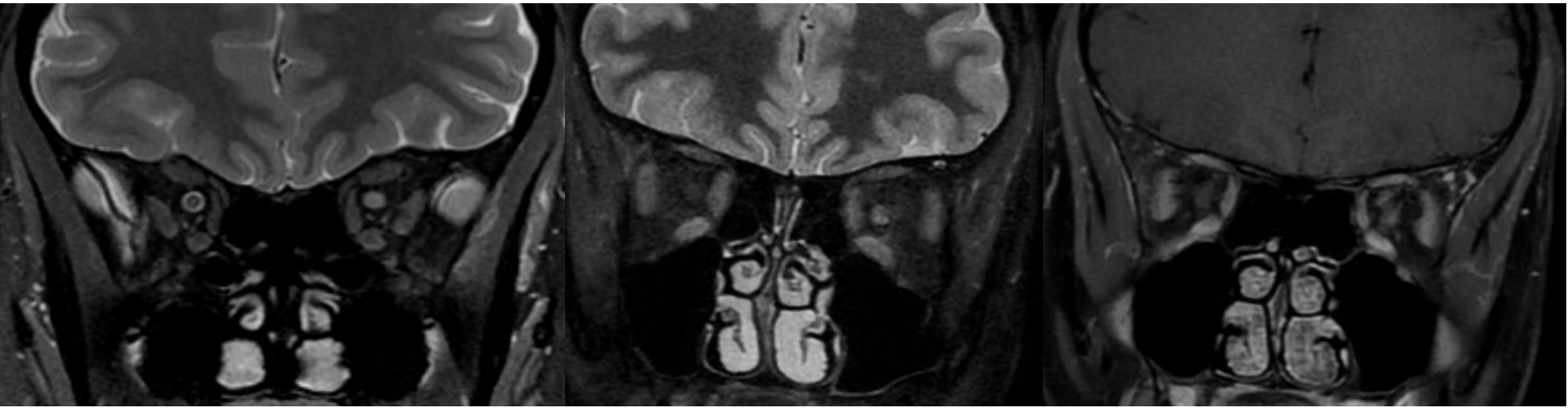
Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

MRI and MS: *Optic nerve*

- ✓ MAGNIMS has suggested including **optic nerve involvement** in the **DIS criteria** for patients with a **first clinical attack**



Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

MRI and MS: *Optic nerve*

- ✓ This recommendation was **not adopted** in the **2017 McDonald criteria**
- ✓ There are some indications for which **optic nerve imaging can be useful**

Optic nerve

Diagnosis

Clinically isolated syndrome: differential diagnosis

- Atypical isolated optic neuritis; relapsing isolated optic neuritis; chronic relapsing inflammatory optic neuropathy
- Other diseases or factors affecting the optic nerve (eg, neuromyelitis optica spectrum disorders, infectious diseases, vaccination, sarcoidosis, tumours, etc)

Optic neuritis in paediatric patients

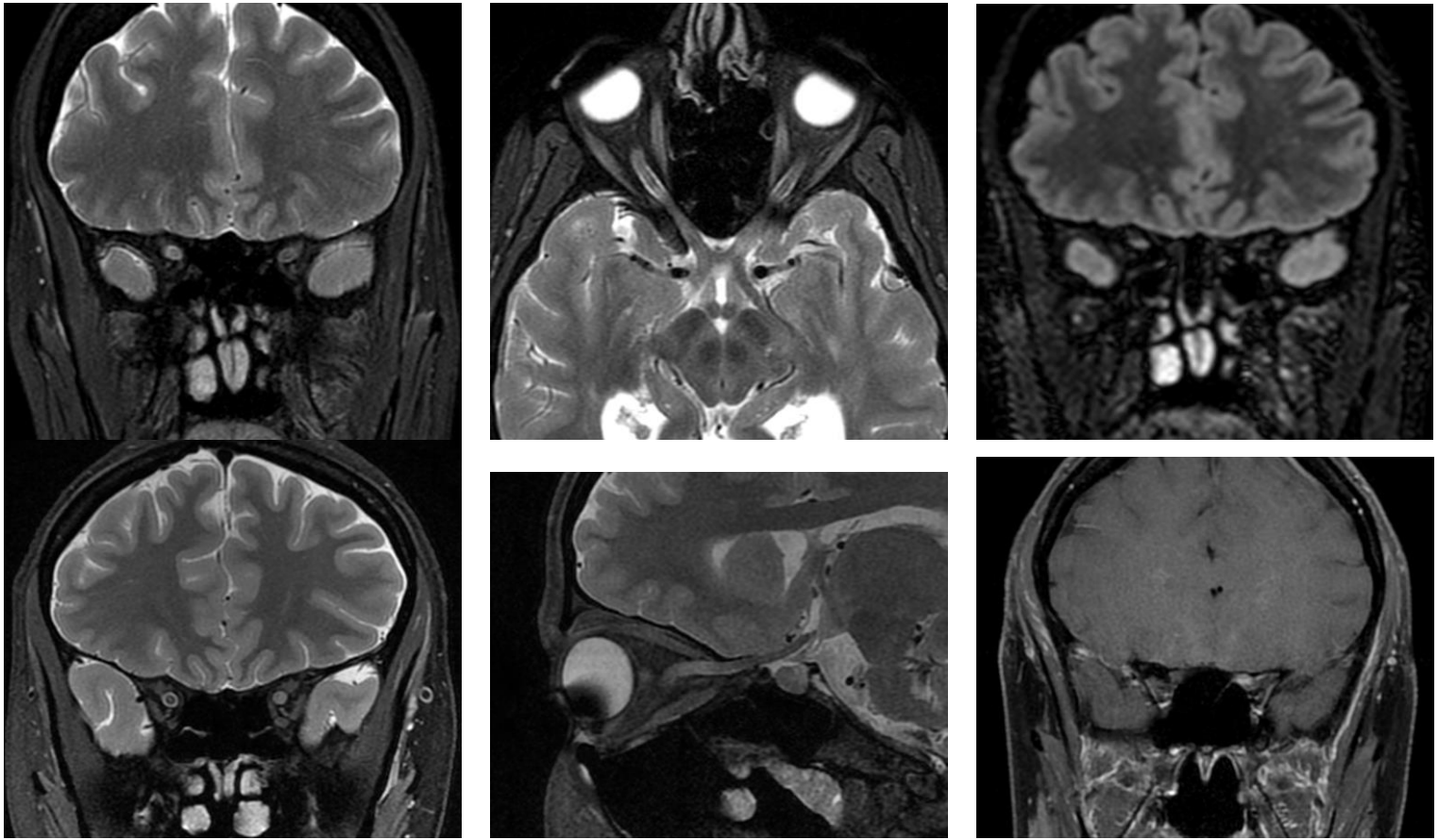
- Exclusion of alternative diagnosis (eg, neuromyelitis optica spectrum disorders and MOG-antibody-associated demyelination)

Monitoring

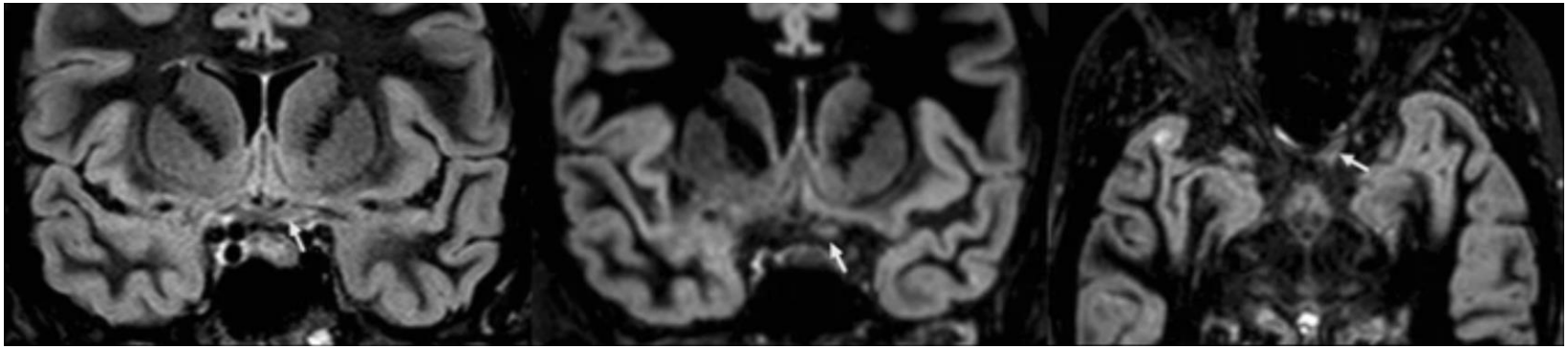
- Patients with multiple sclerosis and new visual symptoms that are suggestive of comorbidity affecting the optic nerve
- Patients with multiple sclerosis and chronic progressive optic nerve symptoms
- Patients with multiple sclerosis and repeated isolated optic nerve relapses

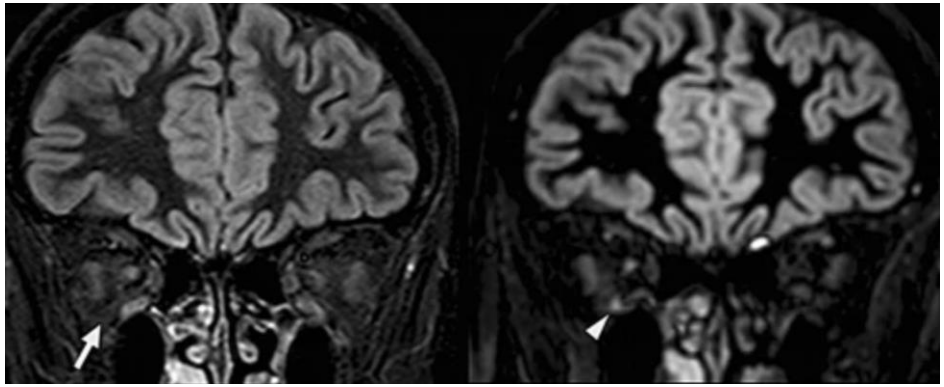
Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

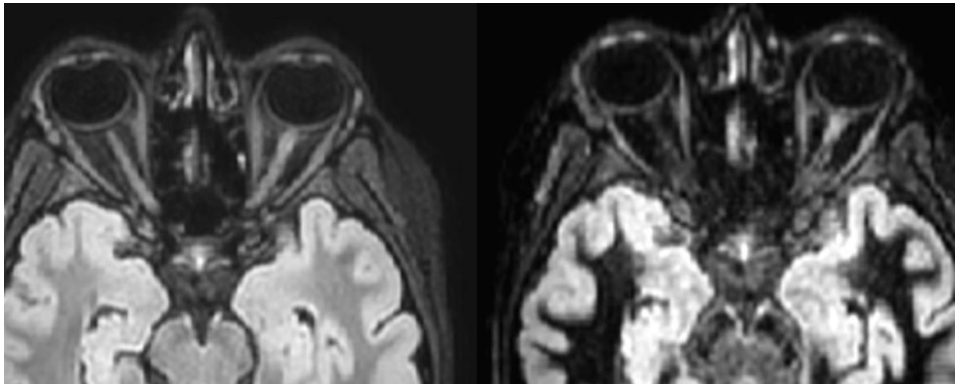
MRI and MS: *Optic nerve*



MRI and MS: *Optic nerve*







Murumkar V, et Al.: *Comparison of 3D DIR versus 3D FLAIR in precise diagnosis of acute optic neuritis.* Eur J Radiology 2022

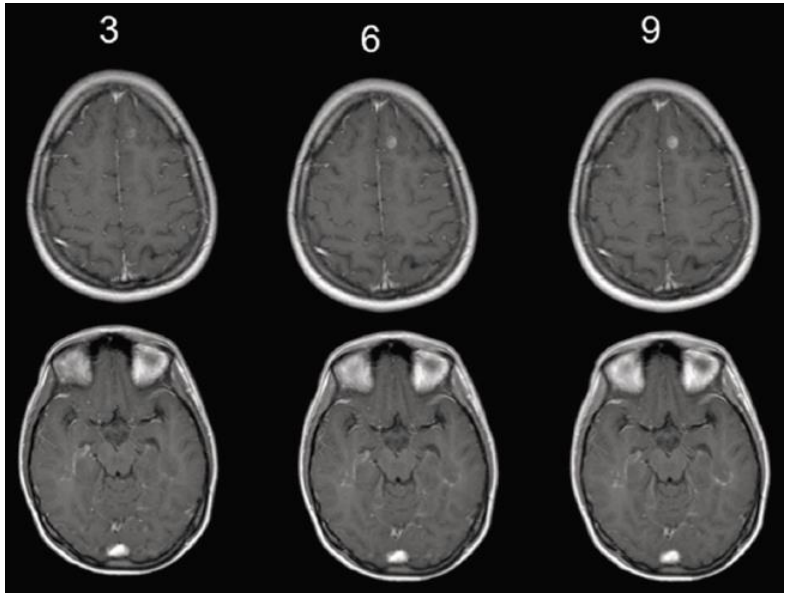
MRI and MS: *gadolinium*

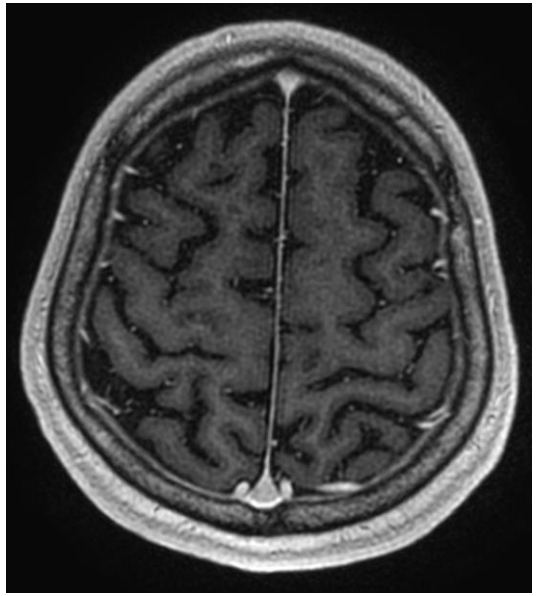
- ✓ The recognition of **Gd deposition** in the CNS has led to specific recommendations on its use by the EMA and the US FDA
- ✓ The **use of GBCAs** continues to be invaluable during the initial investigation of MS to show **DIT** and to exclude alternative diagnoses
- ✓ Gb **high doses** are not appropriate in clinical practice

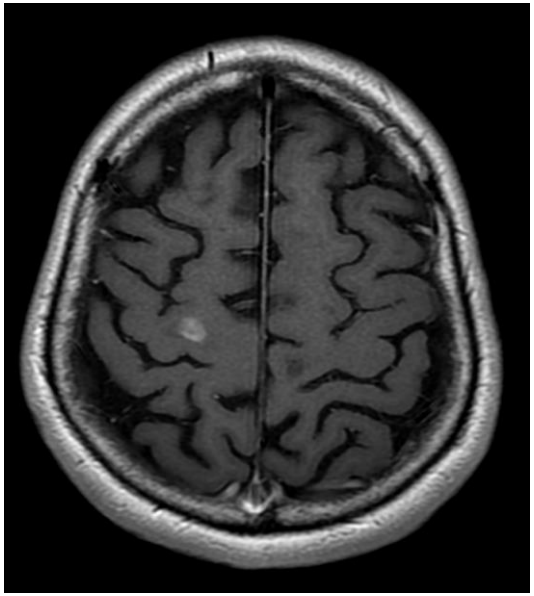
Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

MRI and MS: *gadolinium*

- ✓ The **time delay** between contrast administration and T1-w acquisition should be identical during follow-up scans and not shorter than 5 min (ideally 10 minutes)







Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

MRI and MS: *gadolinium*

Panel 2: **Recommendations on the use of gadolinium-based contrast agents in the diagnosis and monitoring of multiple sclerosis**

Diagnosis

The use of gadolinium-based contrast agents is recommended:

- To show dissemination in time on the baseline MRI scan.
- To contribute to differential diagnosis (ie, on the basis of the pattern of enhancement).
- To predict future disease activity and to some extent disease progression.
- For phenotyping patients with progressive disease (ie, active or inactive), if a recent (ie, within 1 year) MRI is not available, and if this information affects treatment decisions.

Monitoring

The use of gadolinium-based contrast agents is recommended:

- In the first year of follow-up (ie, after treatment initiation) if a new baseline MRI scan (ie, usually 3–6 months after treatment initiation) was not obtained, particularly in patients on interferon beta or glatiramer acetate (which are less effective in reducing MRI activity than are other therapies).
- If detection or confirmation of clinical disease activity is required in patients without a recent reference brain MRI scan (done ≤3–6 months ago). MRI should be ideally done as soon as possible and before steroid treatment.
- If showing disease activity with presence of gadolinium-enhancing lesions is required to initiate or change a specific disease-modifying treatment.
- In patients with diffuse and confluent chronic multiple sclerosis lesions (ie, large lesion burden), in which detection of disease activity is required but difficult to show on the basis of new or enlarged T2 lesions.
- For progressive multifocal leukoencephalopathy screening, if there has been a suspicious lesion detected on the standard monitoring or screening brain MRI scan.
- In monitoring of progressive multifocal leukoencephalopathy and detection and monitoring of progressive multifocal leukoencephalopathy-immune reconstitution inflammatory syndrome.

The use of gadolinium-based contrast agents is not recommended:

- To show dissemination in time on serial MRI scans. In case of standard monitoring for subclinical disease activity, if a previous and recent (ie, within approximately 1 year) MRI scan is available that was done with similar technical parameters.
- In new baseline (ie, usually 3–6 months after treatment initiation) MRI scan.
- In short follow-up MRI (ie, within 6 months) done to confirm disease activity in patients with isolated MRI activity on the previous MRI scan.
- For progressive multifocal leukoencephalopathy screening.
- During pregnancy (strictly contraindicated) and lactation (ie, indicated only if essential for patient management).

Wattjes MP, et Al.: *Imaging MAGNIMS–CMSC–NAIMS consensus recommendations on the use of MRI in patients with MS.* Lancet Neurol 2021

MRI and MS

- ✓ **3D-FLAIR** brain MRI most important for diagnosis and monitoring;
- ✓ **Gd** used restricted to diagnosis and early monitoring;
- ✓ **Spinal cord** MRI important for diagnosis and prognosis; dual contrast
- ✓ **Re-baseline brain MRI** after switching treatment (no Gd)
- ✓ **Annual brain MRI** while on treatment;
- ✓ **PML monitoring** every 3-4 months with abbreviated protocol;
- ✓ **Central vein sign**, **cortical lesions**, **brain volume** change quantification not yet recommended.

MRI and MS

- ✓ **Standardisation** and **implementation** of **new** and potentially more sensitive and **specific imaging techniques** than those that are currently used represent two of the greatest challenges but also two of the greatest opportunities in the near future, particularly as new treatments focusing on neuroprotection, remyelination, and neuronal repair emerge.