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ORIGINAL RESEARCH

Low-Field (64mT) Portable MRI for Rapid Point-of-Care Diagnosis of DIS in Patients Presenting with Optic Neuritis

Timothy Reynold Lim[1], Suradech Suthiphosuwan[1], Jonathan Micieli[2,3,4], Reza Vosoughi[5], Raphael Schneider[5,6], Amy W. Lin[1], Yingming Amy Chen[1], Alexandra Muccilli[5], James J. Marriott[5], Daniel Selchen[5,6], Shobhit Mathur[1,6], Jiwon Oh[5,7], and Aditya Bharatha[1]

ABSTRACT

BACKGROUND AND PURPOSE: Low-field 64mT portable brain MRI (pMRI) has recently shown diagnostic promise for MS. This study aimed to evaluate the utility of pMRI in assessing dissemination in space (DIS) in patients presenting with optic neuritis and determine whether deploying pMRI in the MS clinic can shorten the time from symptom onset to MRI.

MATERIALS AND METHODS: Newly diagnosed optic neuritis patients referred to a tertiary academic MS center from July 2022 to January 2024 underwent both point-of-care pMRI and subsequent conventional 3T MRI (cMRI). Images were evaluated for periventricular (PV), juxtacortical (JC) and infratentorial (IT) lesions. DIS was determined on brain MRI per 2017 McDonald criteria. Test characteristics were computed using cMRI as the reference. Interrater and intermodality agreement between pMRI and cMRI were evaluated using Cohen's kappa. Time from symptom onset to pMRI and cMRI during the study period was compared to the preceding 1.5 years before pMRI implementation using Kruskal-Wallis with post-hoc Dunn's tests.

RESULTS: Twenty patients (median age: 32.5 [IQR, 28-40]; 80% females) were included, of whom 9 (45%) and 5 (25%) had DIS on cMRI and pMRI, respectively. Median time interval between pMRI and cMRI was 7 days (IQR, 3.5-12.5). Interrater agreement was very good for PV (95%, κ=0.89), and good for JC and IT lesions (90%, κ=0.69 for both). Intermodality agreement was good for PV (90%, κ=0.80) and JC (85%, κ=0.63), and moderate for IT lesions (75%, κ=0.42) and DIS (80%, κ=0.58). pMRI had a sensitivity of 56% and specificity of 100% for DIS.

The median time from symptom onset to pMRI was significantly shorter (8.5 days [IQR 7-12]) compared to the interval to cMRI before pMRI deployment (21 days [IQR 8-49], n=50) and after pMRI deployment (15 days [IQR 12-29], n=30) (both $p<0.01$). Time from symptom onset to cMRI in those periods was not significantly different ($p=0.29$).

CONCLUSIONS: In optic neuritis patients, pMRI exhibited moderate concordance, moderate sensitivity and high specificity for DIS compared to cMRI. Its integration into the MS clinic reduced the time from symptom onset to MRI. Further studies are warranted to evaluate the role of pMRI in expediting early MS diagnosis and as an imaging tool in resource-limited settings.

ABBREVIATIONS: pMRI = portable MRI; cMRI = conventional MRI; pwMS = patients with MS; PV = periventricular; JC= juxtacortical; IT = infratentorial; DIS = dissemination in space

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From the Division of Neuroradiology (T.R.L, S.S., A.W.L., Y.A.C., S.M., A.B.), Department of Medical Imaging; Department of Ophthalmology (J.M.); and Division of Neurology (R.V., R.S., A.M. J.J.M., D.S., J.O.), Department of Medicine, University of Toronto - St. Michael's Hospital, Toronto, Ontario, Canada; Kensington Vision and Research Center (J.M.), Toronto, Ontario, Canada; Li Ka Shing Knowledge Institute and Keenan Research Centre for Biomedical Science (R.S., D.S., S.M.), Toronto, Ontario, Canada; and Department of Neurology (J.O.), John Hopkin's University, Baltimore, Maryland, USA.

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Please address correspondence to Aditya Bharatha, MD, FRCPC, Department of Medical Imaging, University of Toronto – St. Michael's Hospital, 36 Queen St E, Toronto, Ontario, Canada, M5B 1W8; e-mail: Aditya.Bharatha@unityhealth.to

SUMMARY SECTION

PREVIOUS LITERATURE: Access to MRI remains a barrier to early multiple sclerosis (MS) diagnosis, particularly in low- and middle-income countries. The use of pMRI enables increased accessibility to MRI, and the potential clinical applications of pMRI has been increasing, especially in emergency and acute care settings. Recent studies have also demonstrated that white matter lesions can be detected using low-field portable MRI (pMRI) including in patients with MS.

KEY FINDINGS: In 20 patients with new optic neuritis, pMRI enabled diagnosis of dissemination in space (DIS) in 5/9 patients (56%). Furthermore, it showed moderate concordance and high specificity for dissemination in space (DIS) compared to conventional MRI (cMRI) and reduced the time from symptom onset to MRI.

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KNOWLEDGE ADVANCEMENT: Integrating pMRI into clinical practice may complement cMRI by providing timelier neuroimaging at the point of care, which could facilitate early DIS diagnosis in patients presenting with typical demyelinating syndromes.

INTRODUCTION

Multiple sclerosis (MS) is the leading cause of non-traumatic disability in young and middle-aged adults. Early diagnosis with prompt initiation of disease-modifying therapy leads to reduced relapse rates and disability progression in patients with MS[1,2]. Contemporary diagnostic criteria in MS are anchored on the principles of dissemination in space (DIS) and dissemination in time (DIT). MRI is currently the most useful paraclinical test to establish an MS diagnosis, substituting for clinical findings in the determination of DIS or DIT in patients presenting with typical symptoms. Specifically, MRI DIS criteria require the presence of at least one T2-hyperintense lesion in at least two of the following anatomical locations: periventricular, cortical/juxtacortical, and infratentorial brain regions, as well as the spinal cord. DIT criteria can be fulfilled by the simultaneous presence of enhancing and non-enhancing lesions at any time or by a new lesion on follow-up MRI with reference to a baseline scan[3]. In a survey conducted by the MS International Federation between 2019-2020[4], lack of awareness of MS symptoms among the public and healthcare professionals and insufficient healthcare professionals with the necessary expertise to diagnose MS were reported as major barriers to early MS diagnosis. Furthermore, access to fixed conventional MRI (cMRI) remains an obstacle to early MS diagnosis in up to one-third of surveyed countries, particularly in low- to middle-income countries (LMICs).

Recently, low field portable MRI (pMRI) has been shown to be a safe, cost-effective technology which enables point-of-care neuroimaging. It has been successfully deployed in intensive care units, emergency departments, as well as in resource-limited and geographically remote settings [5–9]. Its clinical applications include detection of intracranial hemorrhages[10,11], ischemic strokes[6,12,13], midline shift[14], hypoxic-ischemic brain injury[15], and assessment of optic chiasm decompression following endoscopic endonasal surgery[16]. Furthermore, despite suffering from reduced signal-to-noise ratio (SNR) and lower spatial resolution compared to cMRI, pMRI has shown diagnostic promise for identification of white matter lesions in patients with MS (pwMS)[17]. In a recent study, pMRI was able to depict lesions in 31/33 (94%) of pwMS with established lesions on 3T cMRI and had 100% sensitivity for lesions >5 mm[18]. pMRI was also proven to have moderate agreement with cMRI for depicting moderate to severe leukoariosis[19].

In this study, we evaluated the diagnostic utility of pMRI in determining DIS in patients presenting with optic neuritis, which is a common initial presenting symptom of pwMS and may be accompanied by disseminated white matter lesions in 50-60%[20]. We also evaluated whether deploying pMRI in the MS clinic can shorten the time interval from symptom onset to the MRI scan.

MATERIALS AND METHODS

Study setting and participants

This study was done as part of a quality improvement initiative at St. Michael's Hospital looking into image quality, accuracy, turnaround time, clinical impact, and cost associated with the utilization of 64mT pMRI system (Swoop, Hyperfine Inc., Guilford, CT) compared to conventional CT and MRI obtained in standard clinical care. This initiative was formally reviewed and approved by institutional authorities at Unity Health Toronto and deemed to neither require formal Research Ethics Board approval nor written informed consent from participants. We performed a retrospective analysis of all consecutive patients referred to our academic MS center for newly diagnosed optic neuritis from July 2022 to January 2024 who underwent both point-of-care pMRI in the MS clinic and subsequent 3T cMRI (MAGNETOM Skyra, Siemens, Erlangen, Germany) in the radiology department. It is our institutional practice to scan all patients with suspected and confirmed MS on 3T machines to facilitate easier and accurate comparisons between scans.

Optic neuritis was considered based on visual acuity, Humphrey visual field testing, pupillary and optic nerve clinical information as evaluated by a fellowship-trained neuro-ophthalmologist (J.M.). All patients met criteria for optic neuritis published in the landmark Optic Neuritis Treatment Trial study[21]. Alternative causes of retinal or optic nerve disease were ruled out, and objective changes of optic neuritis were confirmed with optical coherence tomography (OCT) after one month.

MRI protocols and imaging assessment

The pMRI examinations were performed as a clinical study at the time of the patient's initial assessment in the MS clinic. The scans were conducted by a radiological technologist in a clinical examination room either before or after the clinical assessment by a MS neurologist. Imaging was performed using an 8-channel head coil using the manufacturer's standard protocol which included the following sequences: axial and sagittal T2-FLAIR (repetition time msec/echo time msec/inversion time [TR/TE/TI] = 4000/234/1400 msec; in-plane resolution = 1.6 x 1.6 mm; slice thickness = 5 mm; acquisition time = 9:35 min per acquisition plane) and axial T2-weighted fast spin echo (T2-FSE) (TR/TE = 2000/243 msec; in-plane resolution = 1.5 x 1.5 mm; slice thickness = 5 mm; acquisition time = 6:50 min) with total scan time of approximately 26 minutes. All pMRI exams were interpreted by a neuroradiologist at the time of scanning, and the results were readily available to the treating neurologist.

The cMRI examinations were acquired subsequently as an elective outpatient exam with a 20-channel head-neck coil using our institutional demyelination protocol which includes a 3D T2-FLAIR sequence (TR/TE/TI = 4800/352/1800 msec; in-plane resolution = 1 x 1 mm; slice thickness = 1 mm; acquisition time = 6:26 min).

T2-FLAIR and T2-FSE pMRI images were reviewed by two fellowship-trained neuroradiologists (T.L. and S.S.) for the presence of periventricular (PV), juxtacortical (JC), and infratentorial (IT) lesions. Raters were blinded to the cMRI findings and clinical report of pMRIs. Raters were not involved in the clinical reporting of the pMRI scans. Disagreements were adjudicated by a third observer experienced in pMRI interpretation (A.B.). Adjudicated ratings were also compared with the findings on the actual real-world clinical report of the pMRIs. DIS was determined on brain MRI according to the 2017 McDonald criteria[3]. The size of the largest and smallest

lesions on pMRI and cMRI were measured on T2-FLAIR sequences.

Time from symptom onset to first MRI

To assess whether the deployment of pMRI in the MS clinic can shorten wait times for MRI, the time from clinical onset of symptoms to either pMRI or cMRI was compared in patients presenting with new onset optic neuritis during our study period (n=30) and in the preceding 1.5 years before pMRI implementation (January 2021 to June 2022; n=50).

Statistical analysis

Statistical analyses were done using Stata® Statistical Software: Release 14 (College Station, TX: StataCorp LLC). Test characteristics were computed using cMRI as the reference standard. Interrater agreement as well as intermodality agreement between pMRI and cMRI were estimated using Cohen's kappa (0.00–0.20 indicates poor; 0.21-0.40, fair; 0.41–0.60, moderate; 0.61–0.80, good; and 0.81-1.00, very good agreement). Mean lesion sizes were compared using Mann-Whitney U test. Time from symptom onset to pMRI or cMRI between the different groups was compared using Kruskal-Wallis test, with post hoc Dunn's test.

RESULTS

Patient and MRI characteristics

A total of 20 patients underwent pMRI during the duration of study with median age of 32.5 (IQR, 28-40); 16 (80%) were females. Median time interval between pMRI and cMRI was 7 days (IQR, 3.5-12.5). PV lesions were seen in 8 (40%), JC in 4 (20%) and IT in 3 (15%) on 64mT pMRI; McDonald criteria for DIS on pMRI was met in 5 (25%) of these patients. On fixed 3T cMRI, 10 (50%) had PV, 7 (35%) had JC, 8 (40%) had IT lesions, with 9 (45%) fulfilling DIS criteria. The mean size of the largest lesions identified on pMRI (10.4 ± 3.1 mm) and cMRI (8.4 ± 4.0 mm) was not significantly different ($p=0.24$), but the mean size of the smallest lesions detected on cMRI (3.2 ± 0.9 mm) was significantly smaller than on pMRI (5.3 ± 1.0 mm, $p<0.01$). Of the 9 patients who met DIS criteria on cMRI, 5/9 (55%) also satisfied DIT criteria for MS: 4/9 (44%) have gadolinium-enhancing lesions on cMRI and 1/9 (11%) was positive for CSF-specific oligoclonal bands. Orbital MRI was performed concurrent with cMRI of the brain in 18/20 (90%) patients, all of which had findings consistent with optic neuritis. All patients also had objective findings of prior optic neuritis on OCT done one month after.

Interobserver and intermodality agreement

Interrater agreement was very good for PV lesions (95%, $\kappa=0.89$), and good for JC and IT lesions (90%, $\kappa=0.69$ for both); agreement for DIS was good (90%, $\kappa=0.69$) (See supplementary Figure 1). Similarly, the agreement between the raters in this study and the real-world clinical radiology reports of the pMRI scans was very good for PV (95%, $\kappa=0.89$) and JC lesions (100%, $\kappa=1$), good for IT lesions (90%, $\kappa=0.69$), and very good for DIS diagnosis (95%, $\kappa=0.88$).

Between pMRI and cMRI, agreement was good for PV (90%, $\kappa=0.80$) and JC (85%, $\kappa=0.63$), and moderate for IT lesions (75%, $\kappa=0.42$). Agreement for DIS was moderate (80%, $\kappa=0.58$). Discordance between pMRI and cMRI findings was mainly from small PV, JC, and IT lesions that were not depicted on pMRI in 2/10 (20%), 2/7 (28.6%), and 5/8 (62.5%) patients, respectively. The mean size of the largest lesions missed on pMRI was 4.2 mm for PV, 4.5 mm for JC and 4.4 mm for IT lesions, all of which are smaller than the acquisition slice thickness (5mm) of the pMRI sequences. Examples of concordant and discordant MRI findings are shown in Figures 1 and 2, respectively.

Sensitivity and specificity of pMRI lesions for DIS

DIS criteria were met on cMRI on 9/20 (45%) of patients, of which 5/9 (55.6%) were true positives and 4/9 (44.4%) were false negatives on pMRI. In the four patients who were false negative on pMRI, 2/4 (50%) showed PV lesions, but JC and IT lesions were not detected in 2/4 (50%) and 3/4 (75%) on pMRI, respectively. There were no false positives for DIS on pMRI.

Test characteristics are summarized in Table 3. The presence of JC and IT lesions as well as fulfilling DIS criteria on pMRI had high specificity (SP) and positive predictive values (PPV) (all 100%) for DIS on cMRI. However, sensitivity (SN) was relatively low for these imaging features (44.4% for JC, 33.3% for IT and 55.6% for DIS). PV lesions had high SP (90.9%), SN (77.8%) and PPV (87.5%) for DIS.

Time from symptom onset to first MRI

The median time from onset of optic neuritis to imaging was 8.5 (IQR 7-12) days for pMRI, 21 (IQR 8-49) days for cMRI before pMRI deployment and 15 (IQR 12-29) days for cMRI after pMRI deployment. Kruskal-Wallis test showed significant time differences between the groups ($p=0.004$). Pairwise comparison using Dunn's test showed significantly shorter time from symptom onset to pMRI compared to symptom onset to cMRI before and after pMRI implementation (both $p<0.01$). On the other hand, the time difference from symptom onset to cMRI in those two periods was not significantly different ($p=0.29$) (Figure 3).

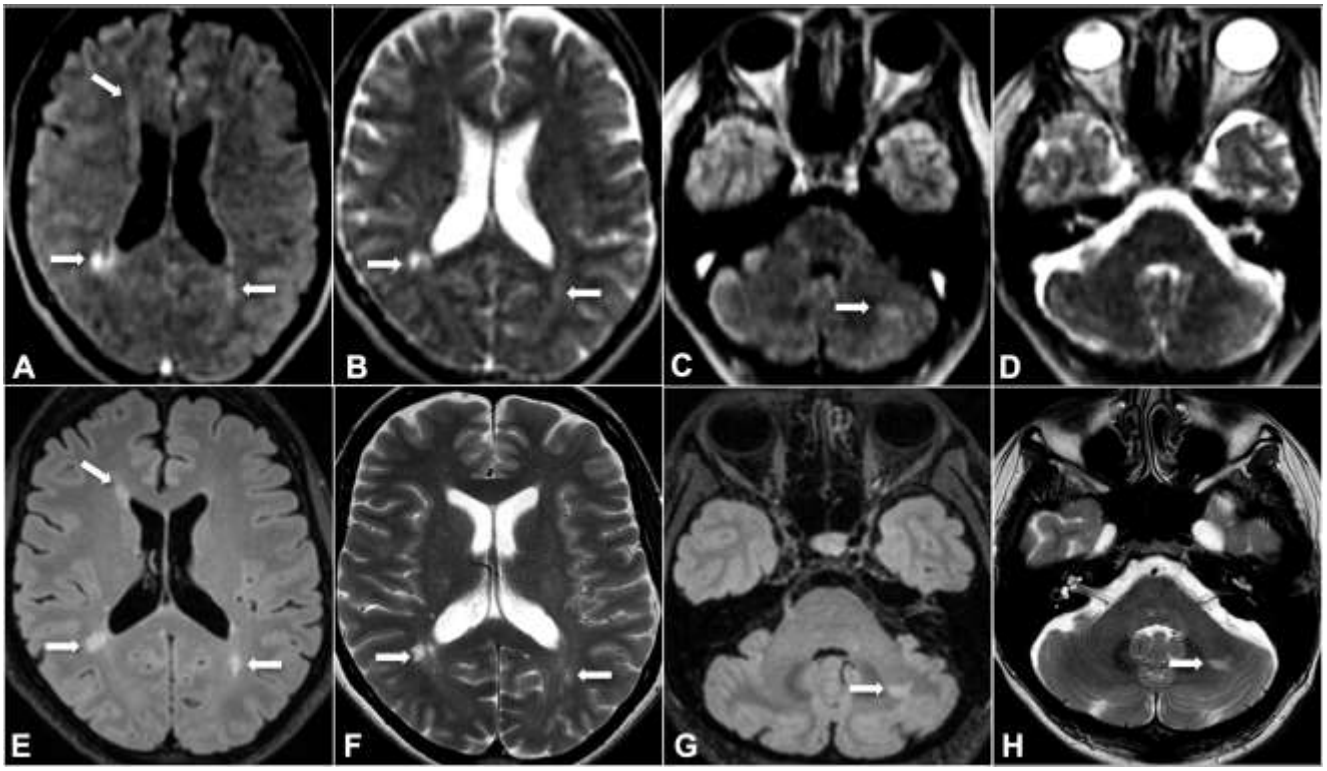

Figure 1. Concordant DIS in 47-year-old female with optic neuritis. Axial T2-FLAIR (A, C, E, G) and T2-FSE (B, D, F, H) images on 64mT pMRI (top row, A-D) and 3T cMRI (bottom row, E-H) show multiple supratentorial lesions (A, B, E, F) and a left cerebellar lesion (C, G, H) identified on both 64mT and 3T. The left cerebellar lesion was seen on the T2-FLAIR (C) but not well depicted on the T2-FSE (D) pMRI sequence.

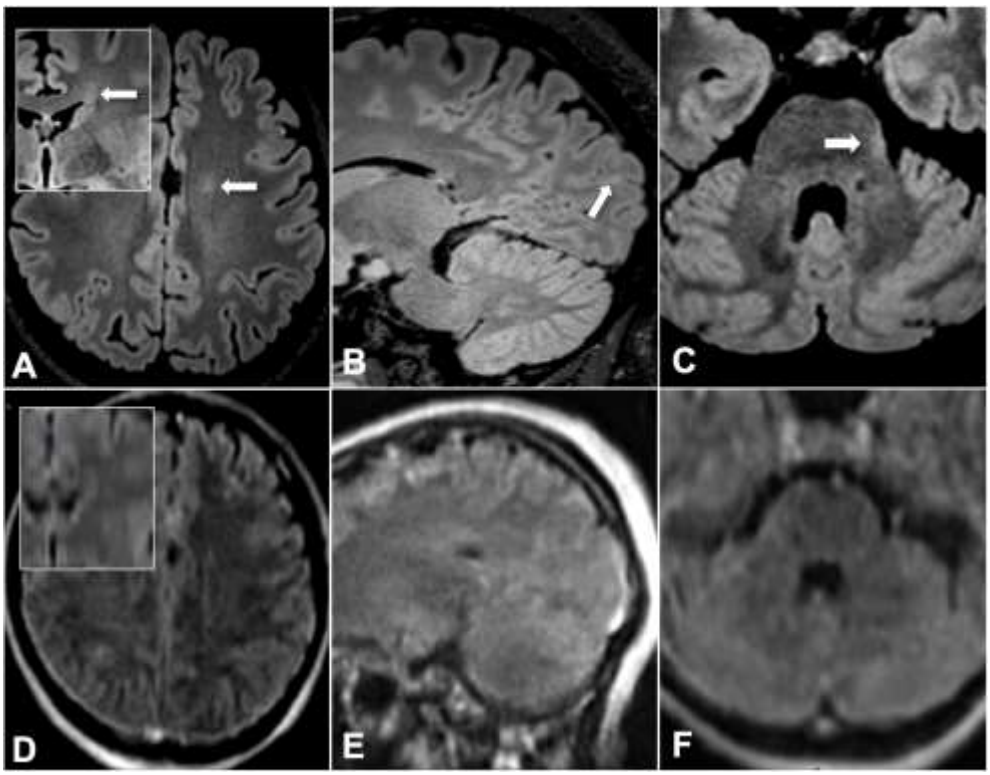

Figure 2. Examples of discordant findings. Axial T2-FLAIR (A, C, D, F) and sagittal T2-FLAIR images (B, E) on cMRI (top row, A-C) and pMRI (bottom row, D-F); insets in A and D are coronal reconstructions. Small left frontal periventricular (A, D), left occipital juxtacortical (B, E) and left pontine lesions (C, F) were only depicted on cMRI but not pMRI.

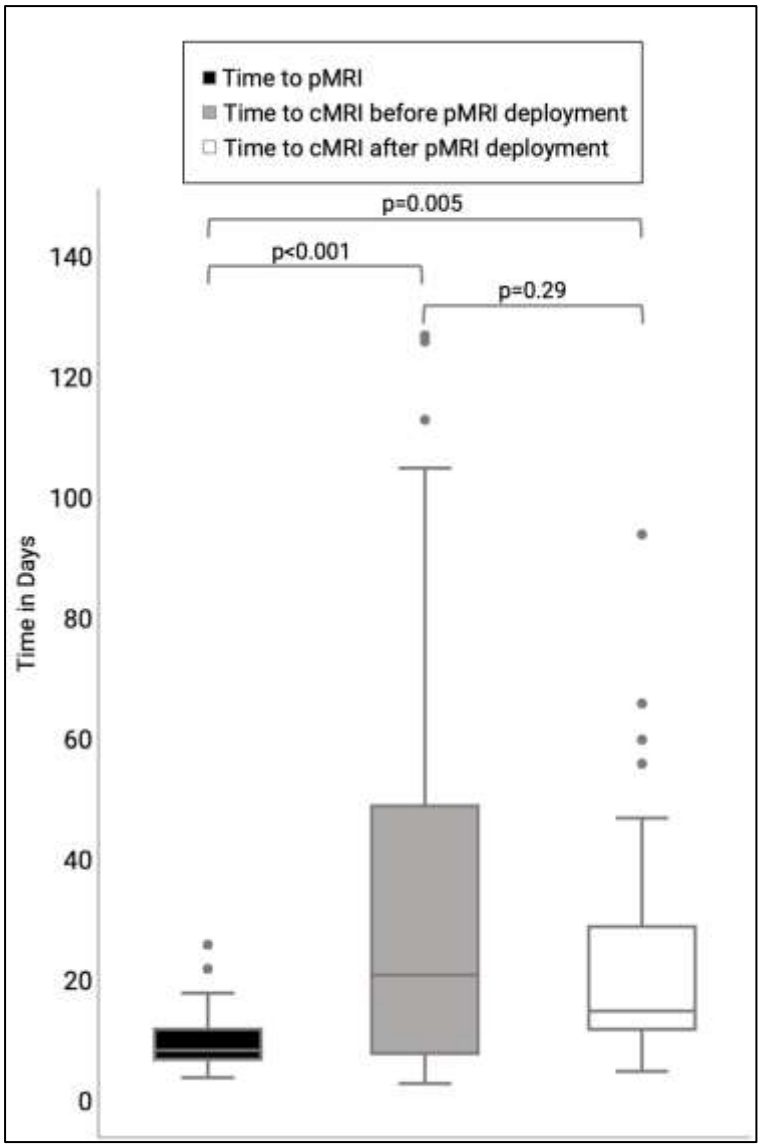

Figure 3. Time from Symptom Onset to First MRI. pMRI, portable MRI; cMRI, conventional MRI.

DISCUSSION

Low-field pMRI is a relatively new technology with growing clinical applications[5,6,11–16,18,19]. It offers the advantage of imaging at the point-of-care over cMRI. In this study, we explored the potential clinical impact of pMRI in MS clinical practice to see whether it can provide an earlier point-of-care diagnosis of DIS in patients presenting with optic neuritis, a common early presentation of MS[20]. Our results showed moderate concordance of pMRI with cMRI for DIS (80%, κ=0.58) and that pMRI had high specificity and PPV (both 100%) for DIS. Not surprisingly, pMRI had lower SN (55.6%) for DIS resulting from inability to depict small lesions, particularly IT lesions. Of note, time to pMRI was significantly shorter compared to cMRI since it occurred contemporaneously with the initial assessment in the MS clinic, facilitating an earlier diagnosis of DIS for some patients.

In recent years, the importance of timely diagnosis of MS and early initiation of treatment has become clear, as early treatment leads to better outcomes in pwMS[1,2]. MRI is the most important paraclinical tool in establishing an MS diagnosis[3], but access to MRI remains a major cause of delayed diagnosis, particularly in LMICs[4]. High cost and infrastructure requirements, as well as the need for highly trained personnel to operate high-field MRI machines limit their availability in resource-limited settings[22,23]. Even in Canada, a high income country where healthcare is primarily government funded, wait times for medical treatment and imaging studies have steadily increased in the past several years: in 2023 alone, the average national wait time for a MRI was 12.9 weeks[24]. Low-field pMRI may play a role in addressing these barriers.

High-field MRI machines using superconducting magnets typically cost around US$1 million per Tesla, while low-field machines using permanent magnets or electromagnets cost only a fraction of this to manufacture. Additionally, low-field MRI systems have lower installation costs and maintenance requirements, as they often do not need shielding or cryogenic cooling and consume less energy[22,25,26]. These factors make low-field MRI more accessible in LMICs and may augment cMRI in high-income countries. However, literature on the cost-effectiveness of pMRI is limited. A cost-analysis study conducted in a remote area in Northern Canada showed potential substantial savings of $854,841 with pMRI deployment compared to transporting patients to a center with cMRI based on an estimation of 50 patients undergoing portable pMRI examinations over one year. Over five years, total savings were estimated at $7,835,162,

assuming a gradual increase in utilization from 50 to 100 patients over that period[8]. A recent retrospective semi-quantitative descriptive analysis also indicated that implementing pMRI for select neurological indications in the ICU could potentially replace fixed CT scans in 21% and fixed MRIs in 26.5% of cases, allowing an additional 1,676 and 234 patients to undergo fixed CT scans and fixed MRIs, respectively[9].

As a proof of concept, Mateen et al. used a 80mT MRI to detect white matter lesions in two patients with known demyelinating disease in the brain.[17] Arnold et al. further compared the sensitivity of 64mT pMRI to 3T cMRI. Lesions as small as 5.7 ± 1.3 mm could be manually detected in 31/33 (94%) of pwMS with lesions on 3T MRI. Their study also showed that while lesion conspicuity was similar between the different field strengths, there was significantly more background noise and blurring on low-field images, mainly due its lower spatial resolution[18]. Consistent with their results, the largest lesions identified on pMRI and cMRI exhibited similar sizes; but as expected, the smallest lesions detected on cMRI was significantly smaller compared to those on pMRI. Moreover, we found moderate to good concordance of 64mT pMRI with 3T cMRI for detecting MS lesions and diagnosing DIS, but small lesions were not reliably detected. This aligns with prior studies which also showed that small hemorrhages and infarcts measuring up to 1 cm can be missed on pMRI[6,10–12]. The smallest lesions in our study measured 5.3 ± 1.0 mm, comparable to those observed by Arnold et al., and approached the spatial resolution of the pMRI scanner. Care must be taken to ensure that lesions smaller than this size are not from volume averaging. Although formal evaluation of quantitative metrics of image quality was not done in this study, most lesions were noticeably more conspicuous on T2-FLAIR compared to T2-FSE sequences, even in the infratentorial brain (see Figure 1). This is probably related to the lower TR on the T2-FSE compared to T2-FLAIR (2000 msec versus 4000 msec) on the default parameters set by the manufacturer and decreased CSF pulsation artifacts on pMRI T2-FLAIR images[27]. Venous structures also appear hyperintense on pMRI[8,18] and should not be mistaken for lesions, particularly superficial cortical veins.

Although lower sensitivity for MS lesion was not surprising, all the patients in this study were expected to undergo a cMRI examination, which is currently the standard of care for MS diagnosis and required for establishing a baseline for future comparison, so missing small MS lesions on pMRI would not have affected patient management. However, one of the objectives of this study was to determine whether pMRI can provide patients with newly diagnosed optic neuritis an expedited point-of-care diagnosis of DIS at the MS clinic prior to the cMRI. Interestingly, not only meeting DIS criteria, but even having any single PV, JC or IT lesion on pMRI had high specificity and PPV for definite DIS on cMRI. Moreover, DIS was able to be established at the point of care in 5/9 (55.6%) patients. Recent prospective studies suggest that inclusion of the optic nerve as a fifth area for DIS improves the performance of the MS diagnostic criteria[28–30], and this is being considered as a proposed modification for the upcoming revision of McDonald criteria. If the optic nerve were included as another topology in the MS diagnostic criteria, then DIS could also have been diagnosed on a further 2/4 (50%) individuals in our study who were falsely negative for DIS but demonstrated PV lesions on pMRI, enabling a point-of-care identification of DIS in 7/9 (77.8%) of patients presenting with optic neuritis. Taken together, our findings support a role for pMRI in MS clinical practice.

Although its low magnetic field strength makes pMRI more accessible and enables point-of-care imaging, it also results in decreased image SNR and resolution and results in longer scan times[25]. As a result, cMRI remains the standard of care in pwMS. Our study suggests that pMRI when positive is highly specific for DIS, although it does not rule out DIS if negative. This points to a potential complementary role in expediting the diagnosis. Moreover, continued improvement in the device hardware and software, including use of advanced machine learning and super-resolution reconstruction methods[31–33], and possible future use of contrast agents at low-field[34,35] may expand the clinical role of pMRI in the future.

Our study had several limitations. First, this was a small, single-center study evaluating only patients presenting with new onset optic neuritis and may therefore be subject to selection bias. Second, we did not perform per lesion analysis, but focused on the practical ability of pMRI to detect MS lesions in the anatomic locations of the brain required to meet the McDonald DIS criteria. Third, DIT could not be assessed as we did not include gadolinium contrast which in usual doses is not well detected on low-field MRI, although currently an area of active investigation[25,35]. Fourth, wait times for cMRI before and after pMRI implementation might have also been affected by institutional workflow changes over time. Fifth, cost-benefit analysis was not performed. Lastly, workflow and imaging wait times differ among different institutions, sites and settings which may affect generalizability of these findings, underscoring the importance of context-specific evaluations when considering pMRI application in different healthcare environments.

CONCLUSIONS

When compared to 3T cMRI, pMRI had moderate concordance, moderate sensitivity and very high specificity for DIS in patients presenting with new onset optic neuritis. The implementation of pMRI in the MS clinic also reduced the time from symptom onset to a first MRI scan, although whether this is clinically significant remains uncertain. These findings imply that integrating pMRI into clinical practice may complement cMRI, offering more timely neuroimaging at the point of care, which could facilitate early diagnosis. Additional studies are warranted to thoroughly assess the potential role,limitations and cost-effectiveness of pMRI for both early diagnosis and as an imaging tool in resource-limited settings.

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N/A

Table 1. Patient Demographics and MRI Characteristics

Characteristics	Value
Total sample, n	20
Age, median (IQR)	32.5 (28-40)
Sex, n (%)	
Female	16 (80)
Male	4 (20)
Median time interval between pMRI and cMRI in days, median (IQR)	7 (3.5-12.5)
Findings on pMRI	
Periventricular lesions, n (%)	8 (40%)
Juxtacortical lesions, n (%)	4 (20%)
Infratentorial lesions, n (%)	3 (15%)
DIS, n (%)	5 (25%)
Largest lesion dimension, mm (mean ± SD)	10.4 ± 3.1
Smallest lesion dimension, mm (mean ± SD)	5.3 ± 1.0
Findings on cMRI	
Periventricular lesions, n (%)	10 (50%)
Juxtacortical lesions, n (%)	7 (35%)
Infratentorial lesions, n (%)	8 (40%)
DIS, n (%)	9 (45%)
Largest lesion dimension, mm (mean ± SD)	8.4 ± 4.0
Smallest lesion dimension, mm (mean ± SD)	3.2 ± 0.9

pMRI, portable MRI; cMRI, conventional MRI; DIS, dissemination in space; IQR, interquartile range; SD, standard deviation

Table 2. Interrater and Intermodality Agreement

MRI finding	Interrater Agreement on pMRI		Agreement between raters and clinical report of pMRI		Intermodality Agreement between pMRI and cMRI	
	Agreement (%)	Cohen's κ	Agreement (%)	Cohen's κ	Agreement (%)	Cohen's κ
Periventricular lesions	95	0.89	95	0.89	90	0.80
Juxtacortical lesions	90	0.69	100	1	85	0.63
Infratentorial lesions	90	0.69	90	0.69	75	0.42
DIS	90	0.69	95	0.88	80	0.58

pMRI, portable MRI; cMRI, conventional MRI; DIS, dissemination in space

Table 3. Test characteristics of pMRI findings for DIS on cMRI

MRI finding	SN (95% CI)	SP (95% CI)	PPV (95% CI)	NPV (95% CI)
Periventricular lesions	77.8% (59.6-96.0)	90.9 (78.3-100)	87.5 (73.0-100)	83.3 (67.0-99.7)
Juxtacortical lesions	44.4 (22.7-66.2)	100% (100-100)	100% (100-100)	68.8 (48.4-89.1)
Infratentorial lesions	33.3 (12.7-54.0)	100% (100-100)	100% (100-100)	64.7 (43.8-85.7)
DIS	55.6 (33.8-77.3)	100% (100-100)	100% (100-100)	73.3 (54.0-92.7)

pMRI, portable MRI; cMRI, conventional MRI; DIS, dissemination in space; SN, sensitivity; SP, specificity; PPV, positive predictive value; NPV, negative predictive value

REFERENCES

1. Giovannoni G, Butzkueven H, Dhib-Jalbut S, et al. Brain health: time matters in multiple sclerosis. *Multiple Sclerosis and Related Disorders* 2016;9:S5–48.

2. Filippi M, Amato MP, Centonze D, et al. Early use of high-efficacy disease-modifying therapies makes the difference in people with multiple sclerosis: an expert opinion. *J Neurol* 2022;269:5382–94.

3. Thompson AJ, Banwell BL, Barkhof F, et al. Diagnosis of multiple sclerosis: 2017 revisions of the McDonald criteria. *The Lancet Neurology* 2018;17:162–73.

4. Solomon AJ, Marrie RA, Viswanathan S, et al. Global Barriers to the Diagnosis of Multiple Sclerosis: Data From the Multiple Sclerosis International Federation Atlas of MS, Third Edition. *Neurology* 2023;101.

5. Sheth KN, Mazurek MH, Yuen MM, et al. Assessment of Brain Injury Using Portable, Low-Field Magnetic Resonance Imaging at the Bedside of Critically Ill Patients. *JAMA Neurol* 2021;78:41.

6. Kuoy E, Glavis-Bloom J, Hovis G, et al. Point-of-Care Brain MRI: Preliminary Results from a Single-Center Retrospective Study. *Radiology* 2022;305:666–71.

7. Chetcuti K, Chilingulo C, Goyal MS, et al. Implementation of a Low-Field Portable MRI Scanner in a Resource-Constrained Environment: Our Experience in Malawi. *AJNR Am J Neuroradiol* https://doi.org/10.3174/ajnr.A7494.

8. DesRoche CN, Johnson AP, Hore EB, et al. Feasibility and Cost Analysis of Portable MRI Implementation in a Remote Setting in Canada. *Can J Neurol Sci* https://doi.org/10.1017/cjn.2023.250.

9. Islam O, Lin AW, Bharatha A. Potential application of ultra-low field portable MRI in the ICU to improve CT and MRI access in Canadian hospitals: a multi-center retrospective analysis. *Front Neurol* 2023;14:1220091.

10. Mazurek MH, Cahn BA, Yuen MM, et al. Portable, bedside, low-field magnetic resonance imaging for evaluation of intracerebral hemorrhage. *Nat Commun* 2021;12:5119.

11. Mazurek MH, Parasuram NR, Peng TJ, et al. Detection of Intracerebral Hemorrhage Using Low-Field, Portable Magnetic Resonance Imaging in Patients With Stroke. *Stroke* 2023;54:2832–41.

12. Yuen MM, Prabhat AM, Mazurek MH, et al. Portable, low-field magnetic resonance imaging enables highly accessible and dynamic bedside evaluation of ischemic stroke. *Sci Adv* 2022;8:eabm3952.

13. Sujijantarat N, Koo AB, Jambor I, et al. Low-Field Portable Magnetic Resonance Imaging for Post-Thrombectomy Assessment of Ongoing Brain Injury. *SVIN* 2023;3:e000921.

14. Sheth KN, Yuen MM, Mazurek MH, et al. Bedside detection of intracranial midline shift using portable magnetic resonance imaging. *Sci Rep* 2022;12:67.

15. Beekman R, Crawford A, Mazurek MH, et al. Bedside monitoring of hypoxic ischemic brain injury using low-field, portable brain magnetic resonance imaging after cardiac arrest. *Resuscitation* 2022;176:150–8.

16. Hong CS, Lamsam LA, Yadlapalli V, et al. Portable MRI to assess optic chiasm decompression after endoscopic endonasal resection of sellar and suprasellar lesions. *Journal of Neurosurgery* https://doi.org/10.3171/2023.5.JNS23174.

17. Mateen FJ, Cooley CZ, Stockmann JP, et al. Low-field portable brain MRI in CNS demyelinating disease. *Multiple Sclerosis and*

Related Disorders 2021;51:102903.

18. Arnold TC, Tu D, Okar SV, et al. Sensitivity of portable low-field magnetic resonance imaging for multiple sclerosis lesions. *NeuroImage: Clinical* 2022;35:103101.

19. De Havenon A, Parasuram NR, Crawford AL, et al. Identification of White Matter Hyperintensities in Routine Emergency Department Visits Using Portable Bedside Magnetic Resonance Imaging. *JAHA* 2023;12:e029242.

20. Toosy AT, Mason DF, Miller DH. Optic neuritis. *Lancet Neurol* 2014;13:83–99.

21. The Clinical Profile of Optic Neuritis: Experience of the Optic Neuritis Treatment Trial. *Arch Ophthalmol* 1991;109:1673.

22. Jalloul M, Miranda-Schaeubinger M, Noor AM, et al. MRI scarcity in low- and middle-income countries. *NMR in Biomedicine* 2023;36:e5022.

23. Geethanath S, Vaughan JT. Accessible magnetic resonance imaging: A review. *Magnetic Resonance Imaging* 2019;49.

24. Moir, Mackenzie, Barua, Bacchus B. Waiting Your Turn: Wait Times for Health Care in Canada, 2023 Report. 2023. [Epub ahead of print].

25. Arnold TC, Freeman CW, Litt B, et al. Low-field MRI: Clinical promise and challenges. *Magnetic Resonance Imaging* 2023;57:25–44.

26. Murali S, Ding H, Adedeji F, et al. Bringing MRI to low- and middle-income countries: Directions, challenges and potential solutions. *NMR in Biomedicine* https://doi.org/10.1002/nbm.4992.

27. Lecler A, El Sanharawi I, El Methni J, et al. Improving Detection of Multiple Sclerosis Lesions in the Posterior Fossa Using an Optimized 3D-FLAIR Sequence at 3T. *AJNR Am J Neuroradiol* 2019;40:1170–6.

28. Brownlee WJ, Miszkiel KA, Tur C, et al. Inclusion of optic nerve involvement in dissemination in space criteria for multiple sclerosis. *Neurology* 2018;91.

29. Vidal-Jordana A, Rovira A, Calderon W, et al. Adding the Optic Nerve in Multiple Sclerosis Diagnostic Criteria: A Longitudinal, Prospective, Multicenter Study. *Neurology* 2024;102:e200805.

30. Bsteh G, Hegen H, Altmann P, et al. Diagnostic Performance of Adding the Optic Nerve Region Assessed by Optical Coherence Tomography to the Diagnostic Criteria for Multiple Sclerosis. *Neurology* 2023;101.

31. Iglesias JE, Schleicher R, Laguna S, et al. Quantitative Brain Morphometry of Portable Low-Field-Strength MRI Using Super-Resolution Machine Learning. *Radiology* 2023;306:e220522.

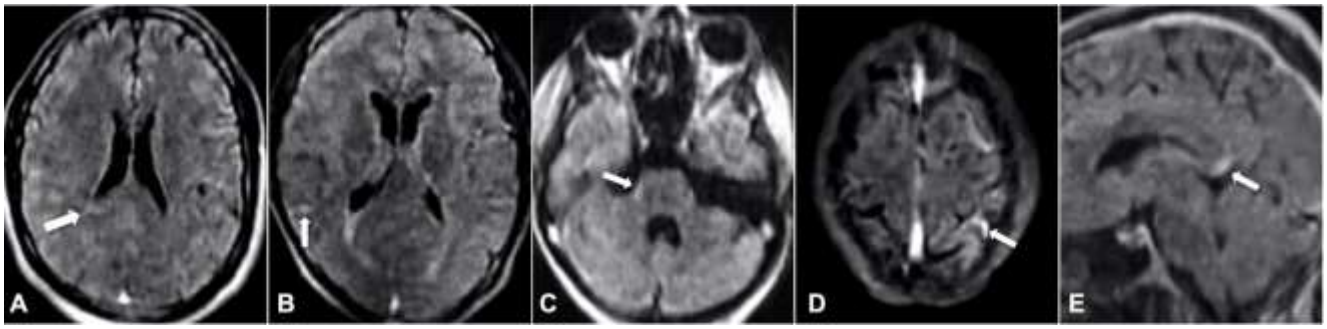
32. Lau V, Xiao L, Zhao Y, et al. Pushing the limits of low-cost ultra-low-field MRI by dual-acquisition deep learning 3D superresolution. *Magnetic Resonance in Med* 2023;90:400–16.

33. Islam KT, Zhong S, Zakavi P, et al. Improving portable low-field MRI image quality through image-to-image translation using paired low- and high-field images. *Sci Rep* 2023;13:21183.

34. Waddington DEJ, Boele T, Maschmeyer R, et al. High-sensitivity in vivo contrast for ultra-low field magnetic resonance imaging using superparamagnetic iron oxide nanoparticles. *Sci Adv* 2020;6:eabb0998.

35. Van Zandwijk JK, Simonis FFJ, Heslinga FG, et al. Comparing the signal enhancement of a gadolinium based and an iron-oxide based contrast agent in low-field MRI. Vegh V, ed. *PLoS ONE* 2021;16:e0256252.

SUPPLEMENTAL FILES



Supplemental Figure 1. T2-FLAIR images showing equivocal and misleading findings. (A-C) Discordant periventricular (A), juxtacortical (B) and infratentorial (C) lesions between raters. Venous structures appear hyperintense on pMRI FLAIR images and should not be mistaken for lesions, particularly cortical veins (D) and the normal internal cerebral vein as a corpus callosum splenium lesion (E).