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ORIGINAL RESEARCH

Identification of White Matter Hyperintensities in Routine Emergency Department Visits Using Portable Bedside Magnetic Resonance Imaging

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BACKGROUND: White matter hyperintensity (WMH) on magnetic resonance imaging (MRI) of the brain is associated with vascular cognitive impairment, cardiovascular disease, and stroke. We hypothesized that portable magnetic resonance imaging (pMRI) could successfully identify WMHs and facilitate doing so in an unconventional setting.

METHODS AND RESULTS: In a retrospective cohort of patients with both a conventional 1.5 Tesla MRI and pMRI, we report Cohen's kappa (κ) to measure agreement for detection of moderate to severe WMH (Fazekas ≥2). In a subsequent prospective observational study, we enrolled adult patients with a vascular risk factor being evaluated in the emergency department for a nonstroke complaint and measured WMH using pMRI. In the retrospective cohort, we included 33 patients, identifying 16 (49.5%) with WMH on conventional MRI. Between 2 raters evaluating pMRI, the interrater agreement on WMH was strong (κ=0.81), and between 1 rater for conventional MRI and the 2 raters for pMRI, intermodality agreement was moderate (κ=0.66, 0.60). In the prospective cohort we enrolled 91 individuals (mean age, 62.6 years; 53.9% men; 73.6% with hypertension), of which 58.2% had WMHs on pMRI. Among 37 Black and Hispanic individuals, the Area Deprivation Index was higher (versus White, 51.8±12.9 versus 37.9±11.9; $P<0.001$). Among 81 individuals who did not have a standard-of-care MRI in the preceding year, we identified WMHs in 43 of 81 (53.1%).

CONCLUSIONS: Portable, low-field imaging could be useful for identifying moderate to severe WMHs. These preliminary results introduce a novel role for pMRI outside of acute care and the potential role for pMRI to reduce disparities in neuroimaging.

Key Words: magnetic resonance imaging ■ neuroimaging ■ vascular neurology ■ white matter hyperintensities

Brain health is the leading concern of healthy aging.[1,2] Magnetic resonance imaging (MRI)-detected white matter hyperintensity (WMH) seen on T2-weighted and fluid-attenuated inversion recovery sequences is present to some degree in over half of community-based adults aged >60 years.[3–6] WMH is a primary risk factor for vascular cognitive impairment and dementia and in a recent meta-analysis was a superior biomarker of vascular cognitive impairment and dementia risk compared with other neuroimaging biomarkers.[7] WMH is also an independent risk factor for cardiovascular disease and stroke.[8–11]

Black and Hispanic patients have the highest prevalence of dementia in the United States[12] and a higher incidence of cardiovascular disease and stroke.[13,14] In patients with dementia, WMH is more common in

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CLINICAL PERSPECTIVE

What Is New?

- Our results show that it is possible to identify moderate to severe white matter hyperintensity of the brain on portable magnetic resonance imaging (MRI) with moderate agreement compared with conventional 1.5 Tesla MRI and that a diverse cohort of patients can be swiftly enrolled in a screening study using point-of-care portable MRI.

What Are the Clinical Implications?

- The implication of these preliminary findings is that portable MRI could be used either to determine the burden of white matter hyperintensity in populations where it may be challenging to perform conventional MRI or to identify white matter hyperintensities for the purpose of clinical trial inclusion.

Nonstandard Abbreviations and Acronyms

ARIC	Atherosclerosis Risk in Communities
cMRI	conventional MRI
LADIS	Leukoaraiosis and Disability
pMRI	portable MRI
WMH	white matter hyperintensity

Hispanic and non-Hispanic Black individuals.[15] Because the accumulation of WMH can be slowed by control of hypertension and vascular risk factor optimization,[16–19] MRI-based identification of WMH will become increasingly important. However, studies have shown that Black and Hispanic and socioeconomically disadvantaged patients are less likely to get diagnostic imaging.[20–24] The emergency department (ED) is a safety-net setting where underrepresented individuals often present with poorly controlled hypertension and other chronic medical conditions.[20–24] Patient engagement in this location could provide a unique context for identification of individuals with WMH who are at high risk for the neurologic consequences of inadequate vascular risk factor control.[25]

Portable MRI (pMRI) is a cost-effective and accessible technology with the capability to be deployed in point-of-care settings.[26] Beginning in 2018, we deployed the world's first prototype pMRI into a clinical setting. This low magnetic field approach is compact enough to fit into a patient room, rolls on wheels, and operates on a standard 120-volt wall plug (Figure 1). The scanner operates at a static field strength of 64 milliTesla and requires no radiofrequency shielding. The fluid-attenuated inversion recovery sequence used to identify WMH takes 9 minutes to acquire. We have published feasibility and performance results of pMRI in 5 hospital-based cohorts with neurologic disease.[27–31] Recently, a study of 36 adults with known or suspected multiple sclerosis demonstrated that pMRI could detect >90% of white matter lesions seen on conventional MRI (cMRI).[32]

In the current study, we hypothesized that pMRI fluid-attenuated inversion recovery images would be sufficient for identifying the presence of moderate to severe WMH. Contingent on demonstrating the first hypothesis, we secondarily hypothesized that we would be able to enroll a diverse cohort and identify moderate to severe WMH at the point-of-care in ED rooms.

METHODS

Study Design

We conducted a 2-stage cross-sectional study. The first stage aimed at evaluating pMRI (Swoop, Hyperfine, Inc., Guilford, CT) as a tool to identify moderate to severe WMH and included patients who underwent both 1.5 Tesla cMRI and pMRI as part of standard clinical care. The second stage used pMRI to identify moderate to severe WMH at the point of care in a patient population without acute neurologic pathology.

First Stage

We performed a retrospective analysis of a convenience sample of patients who received a pMRI and cMRI (1.5 Tesla) while hospitalized at Yale–New Haven Hospital during 2021 to determine the interrater and intermodality agreement for the presence of moderate to severe WMH, defined as a Fazekas score ≥2, which is referred to as WMH in the remainder of the manuscript.[33] These patients were admitted to the hospital for stroke or strokelike symptoms, but none had large-vessel occlusion or large territorial stroke. Fluid-attenuated inversion recovery images on the cMRI were graded by a board-certified neuroradiologist (S.P.), and the pMRI images were graded by 2 board-certified vascular neurologists (A.D. and R.S.). All raters were blinded to clinical diagnoses and other imaging sequences. For this analysis, we report Cohen's kappa (κ) to measure agreement for detection of WMH between the 2 pMRI raters (interrater) as well as the intermodality agreement between 1 rater for cMRI and the 2 raters for the pMRI.

Second Stage

The second-stage cohort was prospectively enrolled between December 13, 2021 and July 6, 2022 in the Yale New Haven Hospital ED, a busy tertiary care urban ED. Inclusion criteria included a nonstroke complaint

Figure 1. 64 milliTesla low-field portable magnetic resonance imaging in a patient room in the emergency department.

for ED admission; a body habitus that permitted positioning within the scanner's head coil; and a vascular risk factor, including a prior diagnosis of hypertension, actively taking an antihypertensive medication, a recorded systolic blood pressure ≥160 mm Hg, hyperlipidemia, atrial fibrillation, congestive heart failure, or diabetes. We excluded 4 patients from this cohort, 2 of whom declined to self-report race and 2 of whom reported Asian race, which was not a large enough sample to be informative.

The study procedures were performed in an ED room at the point of care, while patients received their unrelated clinical workup. A board-certified neuroradiologist (S.P. or G.S.) interpreted the pMRI for the presence or absence of WMH and was blinded to the patient diagnosis. We compared demographics, the Area Deprivation Index, and Montreal Cognitive Assessment score between individuals with and without WMH using Student's *t* test and the chi-squared or Fisher's exact test depending on frequency. The Area Deprivation Index is based on a measure created by the Health Resources and Services Administration >3 decades ago, refined by researchers at the University of Wisconsin–Madison in 2018,[34] that reflects social determinants of health at a neighborhood level. We mapped the participant's zip code to the corresponding Area Deprivation Index value. All analyses were performed in Stata 17.0 (StataCorp, College Station, TX).

Standard Protocol Approvals, Registrations, and Patient Consents

First Stage: Because this study was retrospective and used standard-of-care clinical data, informed consent was not obtained, but the protocol was approved by the Yale institutional review board.

Second Stage: The pMRI was not part of standard care, so informed consent was obtained by the participant before a Montreal Cognitive Assessment test and a research pMRI were conducted, under the auspices of the Yale institutional review board.

Data Availability

Anonymized study data will be available to qualified investigators from the corresponding author upon reasonable request.

RESULTS

In the first-stage cohort, we included 33 hospitalized patients with both a cMRI and pMRI, identifying 16 (49.5%) individuals with WMHs (Fazekas ≥2) on cMRI (Figure 2). The 2 raters of the pMRIs had strong interrater agreement on the presence of WMHs (κ=0.81). Compared with the cMRI, the pMRI reviewers had moderate intermodality agreement on the presence of WMHs (κ=0.66, 0.60).

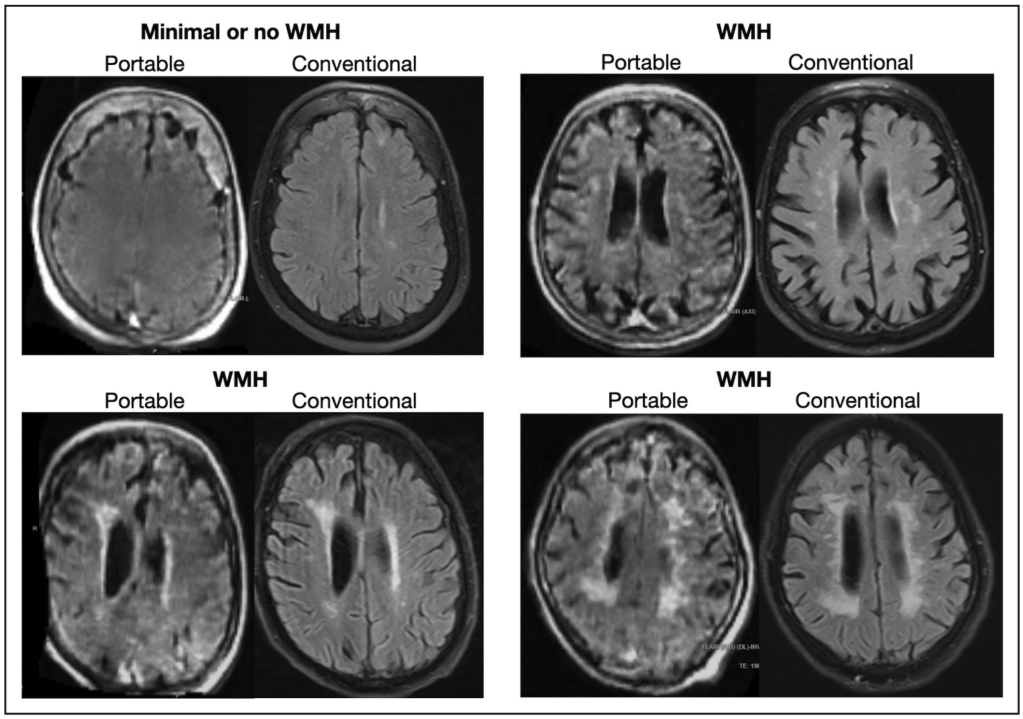

Figure 2. An example of patients with a portable and conventional magnetic resonance imaging showing minimal appreciable burden of WMH (top left) and examples of WMH on both modalities.
WHM indicates white matter hyperintensity.

Of the 91 individuals in the prospectively enrolled cohort, 53 (58.2%) had WMHs identified on pMRI. In those with WMHs (versus without WMHs), the mean age was older (66.8 versus 56.7 years; $P<0.001$) and there was a higher rate of hyperlipidemia (82.7% versus 63.2%; $P=0.036$) and atrial fibrillation (26.4% versus 7.9%; $P=0.030$). Other baseline covariates were not significantly different between the subgroups (Table). Of the 91 individuals, 10 (11.0%) had a standard-of-care brain MRI in the year preceding enrollment. Among the 81 individuals who did not have a standard-of-care MRI in the preceding year, we identified WMHs in 43 of 81 (53.1%).

After stratifying by race and ethnicity, there were 54 non-Hispanic White, 22 non-Hispanic Black, and 15 Hispanic individuals. Among the 37 Black and Hispanic individuals, the Area Deprivation Index was significantly higher (51.8±12.9 versus 37.9±11.9; $P<0.001$), insured status was numerically lower (86.5% versus 96.3%; $P=0.085$), and the rate of college- or graduate-level education was significantly lower (21.6% versus 44.4%; $P=0.025$).

DISCUSSION

Our results show that it may be possible to identify moderate to severe WMHs on pMRI and that a diverse cohort can be swiftly enrolled using point-of-care pMRI. In the 81 individuals who did not have a standard-of-care MRI brain in the year preceding study enrollment, we identified moderate to severe WMHs in 53.1%. The implication of these findings is that pMRI could be used either to determine the burden of WMHs in populations where it may be challenging to perform cMRI or to identify WMHs for the purpose of clinical trial inclusion. Even with existing knowledge regarding population-level risk for the presence of WMH, the challenges of using conventional MRI-based ascertainment are significant. Patients are required to travel to a facility with an available MRI and schedule the exam. Claustrophobia and costs (device and technical/professional fees) are often prohibitive. These barriers subsequently manifest in real-world settings.

Portable MRI offers a potential solution to many of the complications posed by cMRI. To reach patients who live far from MRI facilities or face other travel-related obstacles, future efforts could involve bringing the pMRI to the patient. The pMRI has been successfully loaded onto a modified cargo van and used to scan individuals at their residence.[26] Additionally, pMRI's open geometry provides a less confined space than the typical cMRI bore, thus alleviating claustrophobia. In this study, we demonstrate the feasibility of using pMRI in ED patient rooms in a high-volume tertiary care environment. The ED environment is an excellent example of a point of care where there is higher socioeconomic diversity and is a safety net for many patients who may not otherwise have access to medical care or neuroimaging.[35–37]

Table. Comparison of Demographics* After Stratification by WMH Presence on Portable MRI

Variable	No WMH (n=38)	WMH (n=53)	*P* value
Age	56.7±11.6	66.8±13.1	<0.001
Race or ethnicity			0.301
White	19 (50.0)	35 (66.0)	
Black	11 (29.0)	11 (20.8)	
Hispanic	8 (21.0)%	7 (13.2)	
Male sex	22 (57.9)	27 (50.9)	0.512
≥College education	12 (31.6)	20 (37.7)	0.544
Employment status			0.042
Employed	18 (47.3)	20 (37.8)	
Unemployed	11 (23.7)	28 (9.4)	
Retired	9 (29.0)	5 (52.8)	
Insured	36 (94.7)	48 (90.6)	0.352
Area Deprivation Index (n=87)	43.8±15.2	43.9±13.4	0.986
Hypertension	27 (71.1)	40 (75.5)	0.637
Antihypertensive medication	26 (68.4)	38 (71.7)	0.736
Diabetes	11 (29.0)	17 (32.1)	0.750
Hyperlipidemia (n=90)	24 (63.2)	43 (82.7)	0.036
Atrial fibrillation	3 (7.9)	14 (26.4)	0.030
Congestive heart failure	7 (18.4)	5 (9.4)	0.228
Smoking (n=89)	4 (11.1)	8 (15.1)	0.589
Montreal Cognitive Assessment (n=77)	23 (22–26)	23 (21–26)	0.402

MRI indicates magnetic resonance imaging; and WMH, white matter hyperintensity.

*Binary variables presented as n (%); ordinal variables as median (interquartile range); and continuous variables as mean±SD.

Black, Hispanic and socioeconomically disadvantaged patients are less likely to get diagnostic imaging in both the ED and outpatient settings.[20–24] This is a major concern because in a large histopathologic study of patients with dementia, a burden of cerebrovascular disease sufficient to contribute to dementia was present in 28% of non-Hispanic White versus 54% of Hispanic subjects and 40% of non-Hispanic Black patients.[15] Portable MRI in the ED allowed us to efficiently enroll 91 individuals and identify 53 with WMH, of which 34% (18/53) were non-Hispanic Black or Hispanic, 9.4% (5/53) lacked medical insurance, and 62.3% (33/53) had less than a college degree. The ability to enroll underserved participants is vital for the generalizability of future WMH research.

The 58.2% prevalence of WMHs in this study is comparable to prior population-level estimates of WMH. In the ARIC (Atherosclerosis Risk in Communities) study, the prevalence of any WMH was 64.8% in participants, with a mean age of 62.5 years.[8] Among 578 individuals in the LADIS (Leukoaraiosis and Disability) study, the prevalence of moderate WMH was 55% in participants, with a mean age of 74.1 years.[38] The small differences in prevalence between these studies and our cohort likely reflect the distinct definitions of WMH presence. Nonetheless, the prevalence of WMH recorded in our study is consistent enough that it bolsters the argument that point-of-care pMRI can provide valuable information on brain health.

This study has several limitations that warrant mention. The most important is that we conducted the study in a health care setting, albeit a nontraditional one for MRI scanning (ED patient room). The second limitation is that we enrolled individuals presenting for emergency medical care, which may create a selection bias. Finally, we did not adjudicate degrees of WMH in this study, which is important for patient-level risk stratification. At present, the signal-to-noise ratio of pMRI is not high enough to provide accurate gradation of WMH, so we focused on the ability of pMRI to identify moderate to severe WMH, not quantify its severity. We also did not attempt to identify patients with mild WMH (Fazekas 1), as the false negative rates would be too high with the current signal-to-noise. As postprocessing of pMRI improves, accurately quantifying WMH burden may be possible in future iterations, but the extent of potential improvement remains unknown.

Despite these limitations, there are several potential future applications of pMRI in this context that warrant discussion. pMRI can be used in other settings where it is challenging to perform cMRI due to cost and travel barriers, such as outreach clinics, health care fairs, or lower-resourced international settings. Because pMRI can be loaded onto a modified cargo van and used to scan individuals at their residence, it could reach patients who live far from health care facilities or face other travel-related obstacles. pMRI could be used to identify WMHs for the purpose of clinical trial inclusion, which would increase the diversity of participants and make the trial results more generalizable. Finally, the pMRI's open-geometry design provides a less confined space than the typical cMRI bore, which may alleviate claustrophobia and make the imaging experience more comfortable for patients, including for those previously deterred from having MRI. This could also increase the number of patients who are willing to undergo neuroimaging studies, particularly in a longitudinal research or clinical setting with the need for repeated examinations such as monitoring WMHs over time.

CONCLUSIONS

pMRI is a potentially viable tool for identifying moderate to severe WMHs at point-of-care settings and can facilitate rapid enrollment of diverse and understudied

participants when strategically deployed. These preliminary results introduce a novel role for pMRI outside of acute care scenarios and the potential role for portable MRI to reduce neuroimaging health care disparities.

ARTICLE INFORMATION

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