Check for updates

Stroke: Vascular and Interventional Neurology

ORIGINAL RESEARCH

# Low-Field Portable Magnetic Resonance Imaging for Post-Thrombectomy Assessment of Ongoing Brain Injury

Nanthiya Sujijantarat, MD; Andrew B. Koo, MD; Ivan Jambor, MDPhD; Ajay Malhotra, MD; Mercy H. Mazurek, BS; Nethra Parasuram, BS; Vineetha Yadlapalli, BS; Isha R. Chavva, BS; Dheeraj Lalwani, BS; Julia Zabinska, BA; Joanna M. Roy, MBBS; Joseph P. Antonios, MDPhD; Aladine A. Elsamadicy, MD; Daniela Renedo, MD; Ryan M. Hebert, MD; Joseph L. Schindler, MD; Emily J. Gilmore, MD; Lauren H. Sansing, MD; Adam de Havenon, MDMS; Madelynne Olexa, BS; Steven J. Schiff, MDPhD; Juan Eugenio Iglesias, PhD; Matthew Rosen, PhD; William Taylor Kimberly, MDPhD; Nils H. Petersen, MD; Kevin N. Sheth, MD†; Charles C. Matouk, MD†

**BACKGROUND:** Timely imaging is essential for patients undergoing mechanical thrombectomy (MT). Our objective was to evaluate the safety and feasibility of low-field portable magnetic resonance imaging (pMRI) for bedside evaluation following MT.

**METHODS:** Patients with suspected large-vessel occlusion undergoing MT were screened for eligibility. All pMRI examinations were conducted in the standard ferromagnetic environment of the interventional radiology suite. Clinical characteristics, procedural details, and pMRI features were collected. Subsequent high-field conventional MRI within 72±12 hours was analyzed. If a conventional MRI was not available for comparison, computed tomography within the same time frame was used for validation.

**RESULTS:** Twenty-four patients were included (63% women; median age, 76 years [interquartile range, 69–84 years]). MT was performed with a median access to revascularization time of 15 minutes (interquartile range, 8–19 minutes), and with a successful outcome as defined by a thrombolysis in cerebral infarction score of ≥2B in 90% of patients. The median time from the end of the procedure to pMRI was 22 minutes (interquartile range, 16–32 minutes). The median pMRI examination time was 30 minutes (interquartile range, 17–33 minutes). Of 23 patients with available subsequent imaging, 9 had infarct progression compared with immediate post-MT pMRI and 14 patients did not have progression of their infarct volume. There was no adverse event related to the examination.

**CONCLUSION:** Low-field pMRI is safe and feasible in a post-MT environment and enables timely identification of ischemic changes in the interventional radiology suite. This approach can facilitate the assessment of baseline infarct burden and may help guide physiological interventions following MT.

**Key Words:** portable MRI ■ stroke ■ thrombectomy

Ascertainment of neurological status and neuromonitoring is essential for triage and clinical decision-making for patients with large-vessel occlusion (LVO) after mechanical thrombectomy (MT). Currently, there is no unified practice in an immediate post-MT setting. Ongoing brain injury, exposure to

Correspondence to: Charles C. Matouk, MD, Department of Neurosurgery, Yale School of Medicine, 333 Cedar Street, Tompkins Building, Room 415, New Haven, CT 06510. E-mail: charles.matouk@yale.edu

Supplementary Material for this article is available at https://www.ahajournals.org/doi/suppl/10.1161/SVIN.123.000921

†K.N. Sheth and C.C. Matouk are senior authors.

© 2023 The Authors. *Stroke: Vascular and Interventional Neurology* published by Wiley Periodicals LLC on behalf of American Heart Association and The Society for Vascular and Interventional Neurology. This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.

*Stroke: Vascular and Interventional Neurology* is available at: www.ahajournals.org/journal/svin

Downloaded from http://ahajournals.org by on July 26, 2023

anesthesia, and hemodynamic fluctuations may result in infarct expansion or hemorrhagic transformation during MT, especially if patients have also received thrombolysis.[1–3] Routine use and timing of computed tomography (CT) post-MT may vary. High-field conventional magnetic resonance imaging (cMRI) is less commonly obtained due to scanner availability. If available, it is often limited by both the feasibility and safety of transporting potentially unstable critically ill patients to the MRI suite. However, cMRI provides superior visualization of the extent of infarct, improves discrimination between hemorrhage and contrast staining, and serves as an essential tool in poststroke care.[4,5] Multimodality imaging helps to inform post-MT treatment pathways including initiation of antiplatelets and/or anticoagulation, blood pressure (BP) targets, and patient monitoring.

Most recently, a low-field portable magnetic resonance imaging (pMRI) has been used as a novel neuroimaging solution for dynamic bedside evaluation in patients with ischemic stroke.[6] Low-field pMRI can acquire T1-weighted imaging, T2-weighted imaging, fluid-attenuated inversion recovery (FLAIR), and diffusion-weighted imaging (DWI) with apparent diffusion coefficient sequences, capable of identifying both acute infarction and intracerebral hemorrhage.[6,7] In contrast to cMRI, pMRI operates at a very low magnetic field strength of 0.064 T, which reduces the projectile risk and can be used safely around standard ferromagnetic hospital equipment.[6,7] Prior reports included patients who underwent imaging at subacute time points in intensive care or stroke units, and none were evaluated in the immediate post-MT setting.[6,7]

In the present work, we report a systematic evaluation of low-field pMRI use in the immediate post-MT environment. The primary objectives of this analysis were to evaluate safety and complications associated with the deployment of pMRI in the interventional radiology (IR) suite and to evaluate feasibility of pMRI in the IR suite within an hour of MT.

### Nonstandard Abbreviations and Acronyms

| | |
|---|---|
| **ASPECTS** | Alberta Stroke Program Early CT Score |
| **cMRI** | conventional magnetic resonance imaging |
| **CTP** | computed tomography perfusion |
| **DWI** | diffusion-weighted imaging |
| **IR** | interventional radiology |
| **LVO** | large-vessel occlusion |
| **MT** | mechanical thrombectomy |
| **NCCT** | noncontrasted computed tomography |
| **NIHSS** | National Institutes of Health Stroke Scale |
| **pMRI** | portable magnetic resonance imaging |

### CLINICAL PERSPECTIVE

- We report the first systematic evaluation of low-field portable magnetic resonance imaging use in the immediate postmechanical thrombectomy environment and demonstrate that the study can be conducted safely and feasibly at bedside in the standard ferromagnetic environment of the interventional radiology suite.
- Low-field portable magnetic resonance imaging can facilitate timely identification of ischemic changes in the interventional radiology suite, which may help to direct physiological interventions postprocedurally and facilitate enrollment of patients into clinical trials.

## METHODS

The authors declare that all supporting data are available within the article and its online supplementary files. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines were used in reporting.

### Study Design, Participants, and Clinical Characteristics

This is a prospective observational study performed at Yale New Haven Hospital from December 2021 to August 2022. Low-field pMRI (Hyperfine, Inc. ) was used to obtain bedside imaging over an 8-month period in patients with LVO. Enrollment was not consecutive but specific to patients whose MT procedure was activated on Monday through Friday between 9 AM and 5 PM due to technician's availability. Low-field pMRI was obtained as part of routine clinical care without the need for research consent given US Food and Drug Administration's (FDA's) specific approval to the pMRI point-of-care use on August 11, 2020. All examinations were performed in accordance with the guidelines set by Yale Human Research Protection Program and the US FDA.

Downloaded from http://ahajournals.org by on July 26, 2023

Patients who underwent MT for suspected LVO were screened for eligibility. Exclusion criteria were body habitus exceeding pMRI dimensions[8] or presence of MRI contraindications such as cardiac pacemakers, insulin pumps, deep brain stimulators, or cochlear implants. Medical history, demographic information, baseline characteristics, and initial imaging were prospectively collected from the electronic medical record. Procedural details such as the target vessel, route of vascular access, MT technique, and revascularization scores were gathered from MT operative dictations. Portable MRI times were obtained from nursing flow sheets as well as review of electronic medical records and verified by study time stamps.

### Technical and Imaging Parameters

See Supplemental Methods for technical and imaging parameters.

### Imaging and Statistical Analysis

Preprocedural imaging consisted of noncontrasted CT (NCCT) and/or CT perfusion (CTP). Infarct core and perfusion assessments were made using either Alberta Stroke Program Early CT Score (ASPECTS) for CT or RAPID AI software (Schema View) at the time of acquisition.[9] Pre-MT imaging parameters were obtained from clinical neuroradiology reports and prospectively gathered from the electronic medical record. For patients with CTP, the core infarct was taken from areas of cerebral blood flow <30%, and the penumbra volume was taken from the mismatch between the time-to-maximum >6.0 seconds and the core infarct. Post-MT imaging data were reviewed by two blinded neuroradiologists (I.J. and A.M.) who independently evaluated low-field pMRI and high-field cMRI studies for presence of stroke and intracranial hemorrhage. Hemorrhagic sequelae were graded based on European Co-operative Acute Stroke Study II classification.[10] If cMRI was not available for comparison within 72±12 hours, a post-MT NCCT was used for validation. Volumetric analyses were performed using 3-dimensional Slicer Software (version 5.0.3), utilizing a level tracing segment editor tool, on an area of hyperintensity seen on FLAIR sequences. An increase of more than 5 mL in infarct volume was considered infarct progression. For patients without a pre-MT CTP, a pre-MT ASPECTS of 10 on CT with subsequent post-MT pMRI infarct volume of >5 mL was considered an infarct progression. For any ASPECTS <10, the presence of stroke progression was determined by the study neuroradiologists.

Statistical analyses were performed using SPSS version 28.0.0 (IBM). Descriptive statistics were reported using median and interquartile range (IQR). Mann-Whitney *U* test was used to compare the medians of continuous variables. Fisher exact test was used to compare independent dichotomous variables. A 2-sided *P* value was used. A *P* value of <0.05 is considered statistically significant.

## RESULTS

### Patient Characteristics, Procedural Details, and pMRI Features

Thirty-eight patients were screened for low-field pMRI studies. Thirteen patients (34%) were excluded after screening (Supplemental Results: Table S1). Low-field pMRI was used to obtain bedside imaging in 25 patients post-MT. One patient's legally authorized representative later denied consent for research after scanning and was excluded. There were 15 women (63%), and the median age was 76 years (IQR, 69–84 years). Demographics, ethnicity, baseline history, median National Institutes of Health Stroke Scale (NIHSS), intravenous tissue plasminogen activator use, and pre-MT imaging data are documented in Table 1. Sixteen patients (67%) underwent CTP before the procedure.

The median time from the end of the procedure to sequence acquisition initiation was 22 minutes (IQR, 16–32 minutes). DWI/apparent diffusion coefficient sequences were obtained as part of the standard clinical protocol starting in mid-January 2022. All studies had a FLAIR sequence; T2-weighted imaging sequence was obtained in 17 patients (71%), DWI/apparent diffusion coefficient sequences were obtained in 16 patients (67%), and T1-weighted imaging sequence was obtained in 16 patients (67%). Four studies were terminated earlier than expected due to patients' agitation or clinical status (n=3) and the need to use the IR suite for a subsequent emergent case (n=1). Of the studies that were terminated early, two patients only had a FLAIR sequence and two patients underwent FLAIR and DWI/apparent diffusion coefficient sequences. The median examination time was 30 minutes (IQR, 17–33 minutes). The median total time in the IR suite was 127 minutes (IQR, 110–148 minutes). Table 2 lists procedural and pMRI details. All examinations were performed in the IR suite containing ferromagnetic material while patients were connected to intravenous pump infusions and mechanical ventilators, with the clinical and research staff at bedside during image acquisition. No adverse event occurred.

### MRI Findings

Acute ischemic infarcts appear hyperintense on T2-weighted imaging, FLAIR, and DWI on low-field pMRI.[6] Ischemic stroke was detected in all immediate post-MT

Downloaded from http://ahajournals.org by on July 26, 2023

**Table 1. Patient Demographics and Clinical Characteristics**

| | n=24 |
|---|---|
| Age, median (IQR), y | 76 (69–84) |
| Women, no (%) | 15 (63) |
| Race and ethnicity, no. (%) | |
| White | 16 (67) |
| Black | 3 (13) |
| Hispanic | 3 (13) |
| Asian | 0 (0) |
| Other/not listed | 2 (8) |
| Ethnicity, no. (%) | |
| Hispanic | 3 (13) |
| Non-Hispanic/other | 21 (87) |
| Baseline medical history, no. (%) | |
| Atrial fibrillation | 7 (29) |
| Coronary artery disease | 3 (13) |
| Diabetes | 7 (29) |
| Hypertension | 18 (75) |
| Hyperlipidemia | 13 (54) |
| Prior stroke/TIA | 5 (21) |
| Smoking | 13 (54) |
| NIHSS at admission, median (IQR) | 13 (7–22) |
| Intravenous tPA given, no. (%) | 8 (33) |
| ASPECTS score, median (IQR) | 10 (9–10) |
| Core infarct on CT perfusion, median (IQR), mL | 0 (0–0) |
| Penumbra on CT perfusion, median (IQR), mL | 70 (34–112) |
| Location of occlusion, no. (%) | |
| ICA | 2 (8) |
| A1/A2 | 0 (0) |
| M1 | 10 (42) |
| M2 and beyond | 12 (50) |
| Vertebrobasilar | 0 (0) |
| Other | 0 (0) |

A1/A2 indicates anterior cerebral artery segment 1 and 2; ASPECTS, Alberta Stroke Program Early CT Score; CT, computed tomography; ICA, internal carotid artery; IQR, interquartile range; tPA, tissue plasminogen activator; M1/M2, middle cerebral artery segment 1 and 2; NIHSS, National Institutes of Health Stroke Scale; and TIA, transient ischemic attack.

**Table 2. Procedural and pMRI Details**

| | n=24 |
|---|---|
| Access site, no. (%) | |
| Transradial | 3 (13) |
| Transfemoral | 20 (83) |
| Direct carotid puncture | 1 (4) |
| Procedural time, median (IQR) | |
| LKW to access, h | 6 (4–17) |
| Access to revascularization, min | 15 (8–19) |
| Total procedure time, min | 25 (20–41) |
| Total time in angio suite, min | 127 (110–148) |
| TICI score, no. (%) | |
| TICI 0 | 1 (5) |
| TICI 1 | 0 (0) |
| TICI 2a | 1 (5) |
| TICI 2b | 9 (45) |
| TICI 2c | 3 (15) |
| TICI 3 | 6 (30) |
| pMRI time, median (IQR) | |
| Time from LKW to pMRI, h | 7 (4–18) |
| Time from the end of the procedure to pMRI, min | 22 (16–32) |
| pMRI examination time, min | 30 (17–33) |

IQR indicates interquartile range; LKW, last known well; pMRI, portable magnetic resonance imaging; and TICI, thrombolysis in cerebral infarction.

low-field pMRIs. Eight patients (33%) showed progression of stroke volume on immediate post-MT pMRI compared with infarct volume on pre-MT imaging (CT or CTP) (median pre-MT, 0 mL [IQR, 0–26 mL]; median post-MT pMRI, 17 mL [IQR, 6–65 mL]). In two of these patients, diagnostic angiogram findings demonstrated a spontaneous recanalization of their LVO, and further intervention was not performed. One patient's procedure was aborted due to middle cerebral artery segment 1 perforation. The infarct volumes remained stable from pre-MT imaging in the remaining 16 patients (67%) (median pre-MT, 0 mL [IQR, 0–0 mL], median post-MT pMRI, 3 mL [IQR, 0–5 mL]). One patient in this group had 2 low-field pMRIs, one immediately following the procedure and another within an hour of MT. Between these 2 low-field pMRIs, infarct volume increased from <1 to 11 mL. All but 2 patients from the stable infarct group had thrombolysis in cerebral infarction (TICI) scores of ≥2b. One patient from this group had spontaneous recanalization, while one had unsuccessful revascularization (TICI score of 0).

Twenty-three patients (96%) had subsequent imaging in the form of high-field cMRI or NCCT within 72±12 hours of MT. Nineteen patients (79%) had follow-up high-field cMRIs, while 4 patients (17%) did not have cMRI but had a follow-up NCCT. The median time between pMRI and subsequent imaging was 20 hours (IQR, 8–31). One patient (4%) who had intraprocedural perforation was transitioned to comfort measures after the procedure, obviating the need for follow-up imaging. Nine patients (39%) demonstrated an increase in infarct volume between immediate post-MT low-field pMRI and subsequent high-field cMRI or NCCT. Two patients in this group had hemorrhagic transformation resulting in parenchymal hematoma type 2. One patient who had unsuccessful revascularization exhibited an expected increase in infarct volume. Two patients from the infarct progression group had an increase in their infarct volumes between pre-MT CT/CTP and post-MT pMRI previously. Fourteen patients (61%) had stable infarct volumes between post-MT pMRI and subsequent conventional imaging. Excluding the 2 patients who had spontaneous recanalization, all but one of the remaining patients in the stable infarct group underwent successful MT with a TICI score of ≥2b. There was no

Downloaded from http://ahajournals.org by on July 26, 2023

**Table 3. Clinical and Imaging Characteristics Between the Group With Infarct Progression and the Group With Stable Stroke Volume Between the Immediate Post-MT Low-Field pMRI and Subsequent Conventional Imaging at 72±12 h.**

| Details, median (IQR) (unless stated otherwise) | Stroke volume progression (n=9) | Stable stroke volume (n=14) | *P* value |
|---|---|---|---|
| Immediate post-MT infarct volume on pMRI, mL | 4 (0–19) | 4 (0–8) | 1.000 |
| Infarct volume on subsequent conventional imaging at 72±12 h, mL | 52 (15–151) | 3 (0–10) | <0.001 |
| Baseline MAP, mm Hg | 99 (96–106) | 101 (86–113) | 0.913 |
| Baseline SBP, mm Hg | 153 (144–159) | 149 (135–170) | 0.913 |
| Conventional imaging modalities, cMRI/CT | 7/2 | 12/2 | 1.000 |

cMRI indicates conventional magnetic resonance imaging; CT, computed tomography; IQR, interquartile range; MAP, mean arterial pressure; MT, mechanical thrombectomy; pMRI, low-field portable magnetic resonance imaging; and SBP, systolic blood pressure.

statistically significant difference between the median prerevascularization median arterial pressure or systolic BP between the group with infarct volume progression and the group with stable infarct volume on subsequent imaging (median arterial pressure 99 mm Hg [IQR, 96–106] vs 101 mm Hg [IQR, 86–113], respectively, *P*=0.926; systolic BP 153 mm Hg [IQR, 144–159] vs 149 mm Hg [IQR, 135–170], respectively, *P*=0.877). Table 3 lists characteristics between the group with infarct progression versus the group with stable infarct volume. Figure 1 shows representative cases from the infarct progression group and the stable infarct group. Overall, 4 patients underwent more than 1 pMRI due to worsening clinical symptoms after the first pMRI. Figure 2 shows a representative case of a patient who had serial pMRIs. For all patients, median immediate post-MT pMRI infarct volume was 4 mL (IQR, 0–10 mL). Median infarct volume on subsequent post-MT imaging within 72±12 hours was 9 mL (IQR, 2–34 mL).

Of the 8 patients who had progression of stroke volume from pre-MT imaging on immediate post-MT pMRI, 2 went on to have further progression of their stroke volume on subsequent delayed imaging. One patient from this group died prior to subsequent imaging. The remaining 5 patients did not have further stroke progression. Table 4 lists TICI scores and volumes from pre-MT, immediate post-MT, and subsequent imaging for each patient.

Fifteen (65%) patients had hemorrhagic conversion on conventional imaging (hemorrhagic infarction type 1 = 8, hemorrhagic infarction type 2 = 2, parenchymal hematoma type 1 = 3, and parenchymal hematoma type 2 = 2). Three of these hemorrhagic conversions were identified on immediate post-MT pMRI. Six post-MT pMRI were not interpretable for intracranial hemorrhages. The pMRI studies for the remaining 6 patients were interpreted as no intracranial hemorrhage. Of these 6 patients, 4 had a hemorrhage volume of <2 cc, and 2 likely experienced hemorrhagic conversion after pMRI based on the review of clinical findings.

## DISCUSSION

We report the systematic use of low-field pMRI for patients with acute ischemic stroke in the post-MT environment. We demonstrate the feasibility of acquiring MRI for patients with stroke in the IR suite in order to ascertain the degree of brain injury present soon after MT. Post-MT pMRI provided clinical teams with an imaging benchmark for the assessment of stroke evolution using serial examinations.

Timely brain imaging is crucial to the clinical workflow of patients with LVO requiring MT. However, postprocedural imaging practices currently vary widely between institutions.[11] High-field cMRI is the imaging modality of choice to assess the final infarct volume and to detect subtle hemorrhagic sequelae that may otherwise not be appreciated on NCCT.[5] However, access to high-field cMRI can be limited due to multiple factors. The need to transport a potentially unstable patient to the stationary scanner is associated with multiple risks.[12,13] The high-field cMRI is also costly to purchase and operate due to the requirement for trained personnel,[14] which limits its access in smaller clinical sites. The use of low-field pMRI when these disadvantages prohibit safe access to the high-field cMRI has been shown to facilitate timely characterization of ischemic stroke volume and hemorrhagic complications.[6]

In the past, our group has successfully deployed low-field pMRI to detect ischemic strokes at bedside in multiple settings such as the emergency department, neuro intensive care unit, and coronavirus disease 2019 (COVID-19) intensive care unit. Low-field pMRI was able to detect ischemic strokes with an overall sensitivity of 90%.[6] Stroke volume measurements were also consistent between the low-field pMRI and high-field cMRI and were found to be significantly correlated with NIHSS as well as functional outcome at discharge. In a separate work, low-field pMRI was deployed to detect intracerebral hemorrhage with 80.4% sensitivity and 96.6% specificity.[7] Similarly, there was a significant correlation between the low-field pMRI and high-field cMRI intracerebral hemorrhage volume measurements.[7]

In this study, low-field pMRI was used to evaluate ischemic strokes in a post-MT environment. Since stroke volume measurements between low-field pMRI and high-field cMRI have been previously validated,[6]

Downloaded from http://ahajournals.org by on July 26, 2023

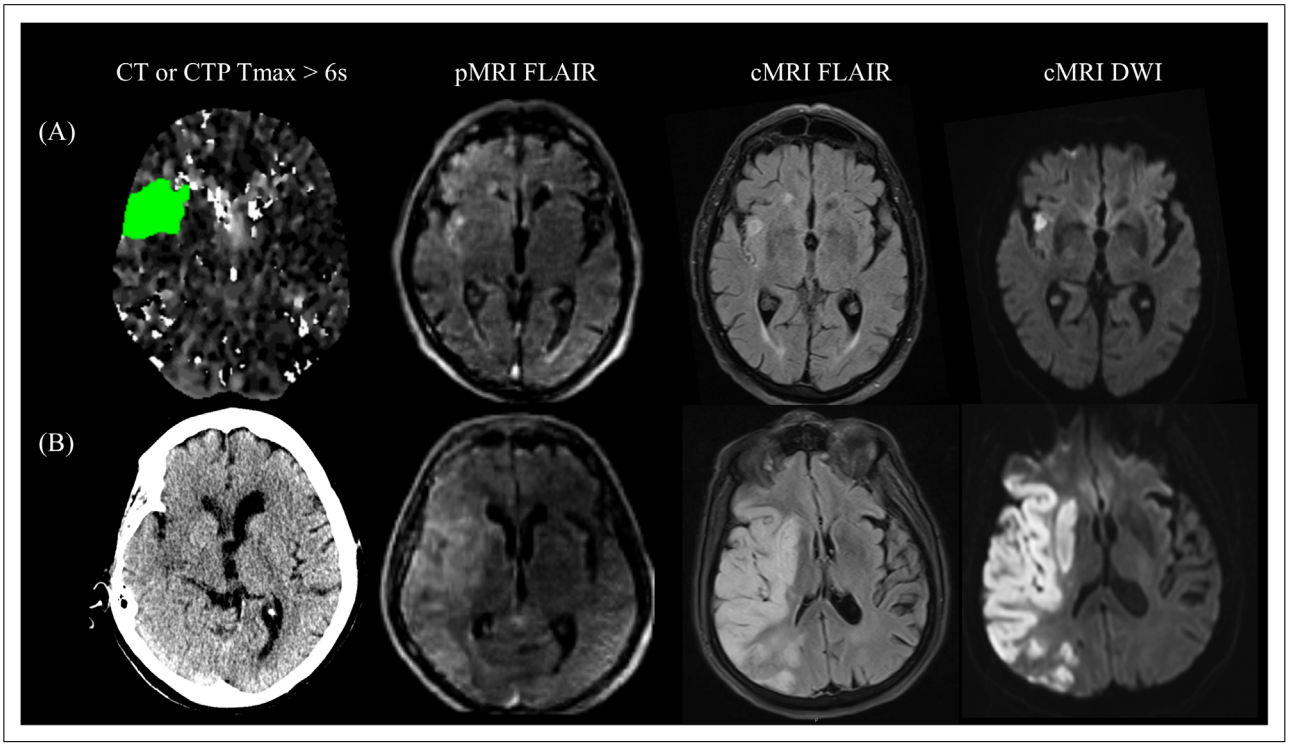


**Figure 1. Representative cases from the infarct progression group and the stable infarct group.**
**A**, An adult patient with a history of hypertension, myocardial infarction, and diabetes presented with aphasia and confusion and was found to have a right middle cerebral artery segment 2 occlusion. Computed tomography (CT) perfusion (CTP) showed 49 mL of penumbra. The patient underwent a thrombolysis in cerebral infarction (TICI) 2c revascularization with one pass. Following mechanical thrombectomy (MT), portable magnetic resonance imaging (pMRI) demonstrated minimal infarct. The patient had an uncomplicated postprocedural course in the intensive care unit. Results from conventional magnetic resonance imaging (cMRI) 1 day later demonstrated stable infarct volume. The patient was discharged to short-term rehabilitation in a short course. **B**, A patient with a history of hypercholesterolemia, presented with acute-onset left-sided weakness and was found to have a right middle cerebral artery segment 1 occlusion. CTP was not performed given presentation shortly after symptom onset. The patient received intravenous thrombolysis and underwent TICI2b revascularization. Post-MT pMRI demonstrated moderate stroke burden, which continued to evolve on a subsequent 72-hour cMRI. Despite radiographic progression, the patient made a remarkable recovery and was later discharged to an acute rehabilitation center in stable condition. DWI indicates diffusion-weighted imaging; and FLAIR, fluid-attenuated inversion recovery.

we set out to utilize the low-field pMRI study as a benchmark imaging tool to allow for serial examinations in an environment known to be highly dynamic and susceptible to physiological perturbations. Low-field pMRI studies were able to be acquired in the IR suite with no apparent complications in all cases, although 3 studies had to be terminated early due to patient agitation. All ferromagnetic equipment and clinical staff were able to remain in the room with no reported adverse events. Overall, examination time was ≈30 minutes and when including pMRI preparation time, added less than an hour overall to the time in the IR suite. This was found to be feasible for the clinical workflow at our institution even though there is only one designated neuro IR suite dedicated to MT. The relatively low immediate post-MT stroke volume may be contributed by the minimal core infarct in the majority of the patients in this cohort (median core infarct of 0 mL on CTP).

Multiple uses were observed from deploying a low-field pMRI as part of a routine evaluation of eligible patients post-MT at our institution. The immediate availability of baseline characteristics of brain injury allows triaging of care in multiple specific areas. A single patient from this cohort underwent acute carotid balloon angioplasty and stenting for carotid occlusion, as well as MT for the tandem intracranial occlusion. The patient was maintained on tirofiban. Results from an immediate low-field pMRI showed a trace subarachnoid hemorrhage. This patient underwent close follow-up imaging due to this finding. In acute ischemic stroke cases where anticoagulation may be needed but high-risk, the availability of baseline imaging to immediately characterize the injury can potentially direct discussions of risks versus benefits with the family. Of note, because our institutional practice is to use monitored anesthesia care as first line over general anesthesia during MT, the pMRI in our study was performed in the patients with MT who just emerged from monitored anesthesia care after acute restoration of cerebral blood flow and a highly stimulating femoral sheath pull, resulting in patient

Downloaded from http://ahajournals.org by on July 26, 2023

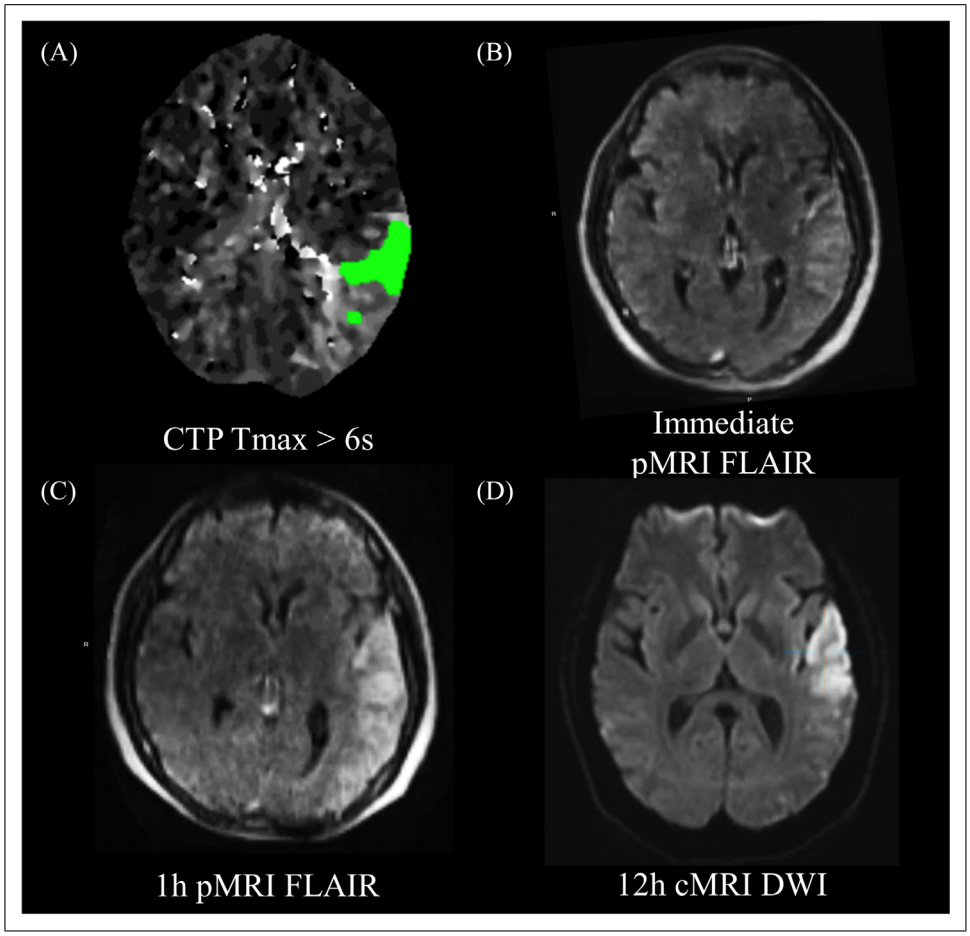


**Figure 2. A representative case of a patient who had serial pMRIs.**
An adult patient taking apixaban who had a history of multiple cancers and deep vein thrombosis presented with acute-onset speech difficulty in the context of having stopped apixaban for a minor procedure 2 days prior. Computed tomography perfusion (CTP) showed 33 mL of penumbra (**A**). The patient was found to have a left middle cerebral artery segment 2 occlusion and underwent a thrombolysis in cerebral infarction 2a revascularization. Results from immediate postmechanical portable magnetic resonance imaging (pMRI) (**B**) demonstrated minimal stroke. Due to worsening aphasia, repeat pMRI (**C**) was performed showing evolution of the stroke, which was later confirmed on 12-hour conventional magnetic resonance imaging (**D**). DWI indicates diffusion-weighted imaging; and FLAIR, fluid-attenuated inversion recovery.

agitation and even early terminations of the scans in some patients. Although we were able to capture sufficient lesion characteristics to facilitate neuroradiologist interpretation to call an infarct in all patients, interpreting hemorrhagic transformation will clearly require further study, especially in the context of motion artifact.

The use of low-field pMRI after MT also conveys immediate information regarding infarct size. This allows us to utilize the pMRI as an important benchmark in a highly dynamic periprocedural environment, where access to high-field cMRI may be limited or impossible. For example, after a successful MT, one patient in the cohort had a fluctuating clinical examination despite BP augmentation; however, a recent diagnosis of urosepsis was felt to be a potential confounder of his neurological examination. The decision was made to obtain another follow-up MRI but cMRI was not immediately available. A low-field pMRI was thus obtained showing no significant increase in the infarct volume, which led to the decision to continue with his current BP goal. In the results published by Regenhardt et al., infarct growth following MT decreased the odds of good outcomes in a multivariate analysis.[15] The authors suggested that infarct growth despite adequate reperfusion may represent a therapeutic target especially while the patients are still hospitalized. In our cohort, almost half of the patients (7 of 16) with stable infarct volumes from before to after MT, stroke volume progression was detected on the conventional imaging ≈20 hours after the first immediate post-MT pMRI, at which point the lesion may be considered more definitive. Because ischemic penumbra and core evolution is a dynamic process, the optimum time point for pMRI after MT should be further examined in a larger cohort. Nevertheless, the ability to perform pMRI at bedside can help to quickly inform clinical decisions and adjust targeted

Downloaded from http://ahajournals.org by on July 26, 2023

**Table 4. TICI Scores and Volumes From Pre-MT, Immediate Post-MT, and Subsequent Imaging for Each Patient**

| Patient number | TICI score | Pre-MT infarct volume on CTP, mL | Infarct volume on immediate post-MT pMRI, mL | Infarct volume on subsequent post-MT conventional imaging, mL (cMRI unless noted otherwise) |
|---|---|---|---|---|
| **1** | 2B | 35 | 29 | 57 |
| **2** | N/A* | N/A‡ASPECT 10 | 6 | 2 |
| **3** | N/A* | N/A‡ASPECT 10 | 4 | 155 (CT) |
| **4** | 2B | N/A‡ASPECT 10 | 0 | 13 |
| **5** | N/A† | 35 | 95 | N/A§ |
| **6** | 2B | N/A‡ASPECT 9 | 43 | 148 |
| **7** | 2B | 0 | 8 | 281 (CT) |
| **8** | 3 | 0 | 4 | 0 |
| **9** | 3 | 0 | 0 | 0 (CT) |
| **10** | 2C | 0 | 4 | 1 |
| **11** | 3 | 0 | 2 | 0 (CT) |
| **12** | 3 | 0 | 0 | 1 |
| **13** | 2B | 0 | 0 | 3 |
| **14** | 3 | 0 | 0 | 17 |
| **15** | 2B | 0 | 4 | 4 |
| **16** | 2B | 0 | 3 | 9 |
| **17** | 2C | N/A‡ASPECT 10 | 0 | 0 |
| **18** | 2B | 0 | 16 | 13 |
| **19** | 0 | N/A‡ASPECT 10 | 0 | 25 |
| **20** | N/A* | N/A‡ASPECT 10 | 69 | 43 |
| **21** | 3 | N/A‡ASPECT 9 | 5 | 5 |
| **22** | 2A | 0 | 19 | 20 |
| **23** | 2C | 0 | 5 | 52 |
| **24** | 2B | 0 | 6 | 9 |

*Spontaneous recanalization.
†Procedure aborted due to vessel perforation.
‡Only computed tomography (CT) available before mechanical thrombectomy (MT).
§Patient expired prior to subsequent imaging.
ASPECT indicates Alberta Stroke Program Early CT; cMRI, high-field conventional magnetic resonance imaging; CTP, computed tomography perfusion; N/A, not applicable; pMRI, low-field portable magnetic resonance imaging; and TICI, thrombolysis in cerebral infarction.

plans in patients who are at a high risk for stroke progression.

Low-field pMRI may be potentially useful in future studies examining the physiologic perturbations that may lead to stroke volume progression. For example, there remains a lack of consensus regarding BP targets following MT. Serial assessment of infarct volume provides the opportunity to identify correlations between interval physiological trajectories and lesion progression. In our cohort, a substantial number of patients with "successful" recanalization also later went on to have infarct progression according to the immediate post-MT pMRI as well as delayed conventional imaging. Investigation into the clinical factors influencing radiographic progression could help to elucidate which patients' clinical course could be modified with tailored post-MT care and which patients' stroke progression was due to a true "no-reflow" phenomenon despite successful recanalization.

Our study is subject to multiple limitations. First, the current cohort is a convenience sample at a single institution. These results require replication at multiple centers to validate the generalizability of this approach. Second, the differences in the timepoints and modality of conventional imaging (cMRI or CT) precluded a full understanding of the impact of integrating pMRI into the immediate post-MT workflow. A larger study with standardized timepoints and modalities for follow-up conventional imaging may be useful to address this limitation. Finally, despite its clinical potential, the DWI sequence on low-field pMRI in the current rendition needs further optimization. Due to its low diffusion preparation gradients, the DWI sequence inherently has a lower signal-to-noise ratio compared with other sequences and renders lower quality images, especially when taking into account the use of a lower magnetic field in pMRI compared with the high-field cMRI.[14]

Downloaded from http://ahajournals.org by on July 26, 2023

In conclusion, we were able to successfully deploy the low-field pMRI to evaluate the extent of brain injury in patients post-MT at bedside. The use of low-field pMRI was found to be safe and feasible in this setting and may convey multiple benefits in a highly dynamic post-MT environment. The information derived from the immediate post-MT imaging allows investigation into potential physiological perturbations that may impact ongoing brain injury. Future work with a larger cohort is needed to systematically clarify its impact on the MT workflow.

## ARTICLE INFORMATION

Received March 27, 2023; Accepted June 12, 2023

### Affiliations

Department of Neurosurgery, Yale School of Medicine, New Haven, CT (N.S., A.B.K., J.M.R., J.P.A., A.A.E., D.R., R.M.H., S.J.S., C.C.M.); Department of Radiology, Yale School of Medicine, New Haven, CT (I.J., A.M.); Department of Radiology, University of Turku, Turku, Finland (I.J.); Department of Neurology, Yale School of Medicine, New Haven, CT (M.H.M., N.P., V.Y., I.R.C., D.L., J.Z., J.L.S., E.J.G., L.H.S., A.H., M.O., N.H.P., K.N.S.); Department of Radiology, Massachusetts General Hospital, Harvard Medical School, Boston, MA (J.E.I., M.R.); Department of Neurology, Massachusetts General Hospital, Harvard Medical School, Boston, MA (W.T.K.)

### Acknowledgements

None.

### Source of Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

### Disclosures

J.P.A., I.R.C., A.A.E., E.J.G., R.M.H., J.E.I., I.J., A.B.K., D.L., A.M., M.H.M., M.O., N.P., D.R., J.M.R., L.H.S., J.L.S., N.S., V.Y., S.J.S., and J.Z. have nothing to disclose. A.D. received investigator-initiated clinical research funding from Regeneron, AMGEN, and AMAG pharmaceuticals; has received consultant fees from Integra and Novo Nordisk and royalty fees from UpToDate; and has equity in TitinKM and Certus. W.T.K. receives grants from Biogen and NControl Therapeutics. He holds equity in Woolsey Pharmaceuticals. C.C.M. is a consultant and a speaker for Penumbra and Silk Road Medical. M.S.R. is a founder and equity holder of Hyperfine, Inc. N.H.P. has received clinical research funding from Liminal Sciences. K.N.S. received grants administered to Yale from Bard, Hyperfine, and Biogen. He received consulting fees from Zoll and Sense for Data and Safety Monitoring Board activities outside the submitted work. He holds equity in Alva and Astrocyte.

### Supplemental Materials

Supplemental Methods
Supplemental Results
Table S1

## REFERENCES

1. Lyden P, Pryor KE, Coffey CS, Cudkowicz M, Conwit R, Jadhav A, Sawyer RN Jr, Claassen J, Adeoye O, Song S, et al. Final results of the rhapsody trial: a multi-center, phase 2 trial using a continual reassessment method to determine the safety and tolerability of 3k3a-apc, a recombinant variant of human activated protein c, in combination with tissue plasminogen activator, mechanical thrombectomy or both in moderate to severe acute ischemic stroke. *Ann Neurol*. 2019;85:125-136.
2. Petersen NH, Ortega-Gutierrez S, Wang A, Lopez GV, Strander S, Kodali S, Silverman A, Zheng-Lin B, Dandapat S, Sansing LH, et al. Decreases in blood pressure during thrombectomy are associated with larger infarct volumes and worse functional outcome. *Stroke*. 2019;50:1797-1804.
3. Simonsen CZ, Yoo AJ, Sørensen LH, Juul N, Johnsen SP, Andersen G, Rasmussen M. Effect of general anesthesia and conscious sedation during endovascular therapy on infarct growth and clinical outcomes in acute ischemic stroke: A randomized clinical trial. *JAMA Neurol*. 2018;75:470-477.
4. Butler WE, Piaggio CM, Constantinou C, Niklason L, Gonzalez RG, Cosgrove GR, Zervas NT. A mobile computed tomographic scanner with intraoperative and intensive care unit applications. *Neurosurgery*. 1998;42:1304-1310; discussion 1310-1301.
5. Kidwell CS. Comparison of mri and ct for detection of acute intracerebral hemorrhage. *JAMA*. 2004;292:1823-1830.
6. Yuen MM, Prabhat AM, Mazurek MH, Chavva IR, Crawford A, Cahn BA, Beekman R, Kim JA, Gobeske KT, Petersen NH, et al. Portable, low-field magnetic resonance imaging enables highly accessible and dynamic bedside evaluation of ischemic stroke. *Sci Adv*. 2022;8:eabm3952.
7. Mazurek MH, Cahn BA, Yuen MM, Prabhat AM, Chavva IR, Shah JT, Crawford AL, Welch EB, Rothberg J, Sacolick L, et al. Portable, bedside, low-field magnetic resonance imaging for evaluation of intracerebral hemorrhage. *Nat Commun*. 2021;12:5119.
8. Prabhat AM, Crawford AL, Mazurek MH, Yuen MM, Chavva IR, Ward A, Hofmann WV, Timario N, Qualls SR, Helland J, et al. Methodology for low-field, portable magnetic resonance neuroimaging at the bedside. *Front Neurol*. 2021;12.
9. Nogueira RG, Jadhav AP, Haussen DC, Bonafe A, Budzik RF, Bhuva P, Yavagal DR, Ribo M, Cognard C, Hanel RA, et al. Thrombectomy 6 to 24 hours after stroke with a mismatch between deficit and infarct. *N Engl J Med*. 2017;378:11-21.
10. Larrue V, Von Kummer Rü, MüLler A, Bluhmki E. Risk factors for severe hemorrhagic transformation in ischemic stroke patients treated with recombinant tissue plasminogen activator. *Stroke*. 2001;32:438-441.
11. Leslie-Mazwi T, Chen M, Yi J, Starke RM, Hussain MS, Meyers PM, Mctaggart RA, Pride GL, Ansari SA, Abruzzo T, et al. Post-thrombectomy management of the elvo patient: Guidelines from the society of neurointerventional surgery. *J NeuroInterv Surg*. 2017;9:1258-1266.
12. Braman SS. Complications of intrahospital transport in critically ill patients. *Ann Intern Med*. 1987;107:469-473.
13. Veiga VC, Postalli NF, Alvarisa TK, Travassos PP, da Silva Vale RT, de Oliveira CZ, Rojas SSO. Adverse events during intrahospital transport of critically ill patients in a large hospital. *Rev Bras Ter Intensiva*. 2019;31:15-20.
14. Sarracanie M, Lapierre CD, Salameh N, Waddington DEJ, Witzel T, Rosen MS. Low-cost high-performance mri. *Sci Rep*. 2015;5:15177.
15. Regenhardt RW, Etherton MR, Das AS, Schirmer MD, Hirsch JA, Stapleton CJ, Patel AB, Leslie-Mazwi TM, Rost NS. Infarct growth despite endovascular thrombectomy recanalization in large vessel occlusive stroke. *J Neuroimaging*. 2021;31:155-164.

Downloaded from http://ahajournals.org by on July 26, 2023