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AJNR Am J Neuroradiol published online 21 June 2024
http://www.ajnr.org/content/early/2024/06/21/ajnr.A8386

Published June 21, 2024 as 10.3174/ajnr.A8386

ORIGINAL RESEARCH

NeuroMix with MR Angiography: A Fast MR Protocol to Reduce Head and Neck CT Angiography for Patients with Acute Neurological Presentations

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ABSTRACT

BACKGROUND AND PURPOSE: Background and Purpose: Overuse of computed tomography (CT)-based cerebrovascular imaging in the emergency department (ED) and inpatient settings, notably CT angiography of the head and neck (CTAHN) for minor and non-focal neurological presentations, stresses imaging services and exposes patients to radiation and contrast. Furthermore, such CT-based imaging is often insufficient for definitive diagnosis, necessitating additional MR imaging. Recent advances in fast MRI may allow for timely assessment and reduced need for CTAHN in select populations.

MATERIALS AND METHODS: We identified inpatients or ED patients who underwent CTAHN (including non-contrast and post-contrast CTH, with or without CT perfusion [CTP] imaging) followed within 24 hours by a 3T MRI study that included NeuroMix (an unenhanced 2.5 min multi-contrast sequence) and intracranial time-of-flight MR angiography (MRA; a 5 min sequence) during a 9-month period (April to December 2022). Cases were classified by 4 radiologists in consensus as to whether NeuroMix and NeuroMix+MRA detected equivalent findings, detected unique findings, or missed findings relative to CTAHN.

RESULTS: 174 cases (mean age 67±16 yrs; 56% female) met the inclusion criteria. NeuroMix alone and NeuroMix+MRA protocols were determined to be equivalent or better compared to CTAHN in 71% and 95% of patients, respectively. NeuroMix always provided equivalent or better assessment of the brain parenchyma, with unique findings on NeuroMix and NeuroMix+MRA in 35% and 36% of cases, respectively, most commonly acute infarction or multiple microhemorrhages. In 8/174 cases (5%), CTAHN identified vascular abnormalities not seen on the NeuroMix+MRA protocol due to CTAHN's wider coverage of the cervical arteries.

CONCLUSIONS: A fast MR imaging protocol consisting of NeuroMix+MRA provided equivalent or better information compared to CTAHN in 95% of cases in our population of patients with an acute neurological presentation. The findings provide a deeper understanding of the benefits and challenges of a fast unenhanced MR-first approach with NeuroMix+MRA, which could be used to design prospective trials in select patient groups, with the potential to reduce radiation dose, mitigate adverse contrast-related patient and environmental effects, and lessen the burden on radiologists and healthcare systems.

ABBREVIATIONS: CTAHN = CTA Head and Neck including non-contrast and delayed post-contrast CT Head with or without CT perfusion, NeuroMix = unenhanced multi-contrast MR brain sequence.

Received month day, year; accepted after revision month day, year.
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Greg Zaharchuk is a co-founder and has equity interest in Subtle Medical, is a consultant with Bracco, and has received funding from GE Healthcare, all of which are unrelated to the current manuscript.

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SUMMARY SECTION

PREVIOUS LITERATURE: The use of CT angiography of the head and neck has been expanding, increasing patient risks and putting strain on radiologists and the medical system. Fast MR brain protocols have been developed at multiple institutions, initially for pediatrics but more recently for adults. In adults, such fast MR brain protocols are primarily compared to conventional MRI protocols, demonstrating significant time savings without significant loss in diagnostic quality. No studies to date have compared a fast MR brain protocol with typical CTAHN protocols for adult patients presenting with acute neurological symptoms.

KEY FINDINGS: A fast MR imaging protocol consisting of unenhanced multi-contrast NeuroMix and TOF-MRA sequences detected all structural and almost all vascular findings seen with CTAHN, while detecting unique findings in over a third of cases. Cervical vascular findings were rare, and were missed due to the NeuroMix+MRA protocol's anatomic coverage

KNOWLEDGE ADVANCEMENT: Non-contrast fast MR brain protocols such as NeuroMix+MRA may diagnostically substitute for CTAHN protocols. Significant cervical vascular findings were rare in our population. The current findings can inform the development of prospective trials to evaluate whether fast MR protocols can replace CTAHN in defined patient populations.

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INTRODUCTION

Increased use of CT imaging in the emergency department (ED) and inpatient settings places growing demands on imaging services resources[1–3]. These include increased healthcare costs and radiologist burnout[4], as well as patient safety concerns related to radiation and contrast-related risks[5,6]. This is particularly evident in the setting of minor and non-focal neurological symptoms[7], where CT angiography of the head and neck (CTAHN) is increasingly performed[8,9]. This preference for broad CTA utilization may be partly due to increased ordering by non-MD advanced practice providers[10,11].

CTAHN studies typically consist of thousands of images, requiring lengthy evaluation by radiologists. Nonetheless, these studies often yield insufficient diagnostic information[2,10], leading to subsequent evaluation with MRI. In this study, we retrospectively assessed the performance of fast MR protocols based on a 2.5 min unenhanced multi-contrast sequence (NeuroMix)[12] acquired alongside standard MRI sequences and performed within 24 hours of a contrast-enhanced CTAHN in patients with acute neurological presentations to better understand the benefits and challenges of a "fast MR first" approach in select patient groups.

MATERIALS AND METHODS

Patient Population

We performed an IRB-approved, retrospective review of data from a single institution. Sequential inpatient or emergency department (ED) patients who received an MRI scan that included NeuroMix[12] (a 2.5 min unenhanced multi-contrast sequence) and intracranial TOF-MRA within 24 hours of CTAHN with or without CTP between April and December 2022 were identified by querying our electronic medical record (Figure 1). All CTAHN studies included non-contrast CTH and 5-minute post-contrast CTH. For patients with multiple CT studies in the 24 hours prior to MRI, only the exam closest in time to the MRI was included. Imaging time was defined as time between first and last acquired image. For stroke codes, this time includes the delay after initial non-contrast CTH to communicate presence of hemorrhage and determination to proceed to CTAHN.

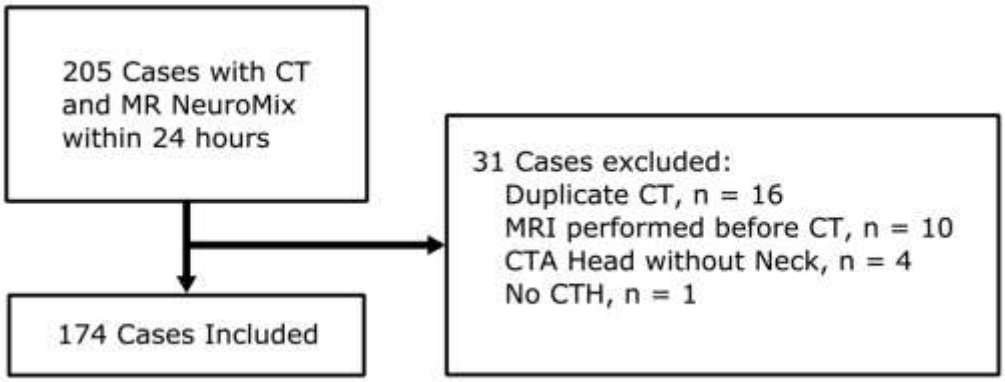

FIG 1. Flow chart shows collection of cases by initial inclusion criteria, subsequent exclusion, and total cases that underwent analysis.

Chart review was performed to collect demographic data and presenting symptoms. Presenting symptoms were categorized by ABCD^2 risk stratification[13]: ABCD+ (focal weakness or speech disturbance), non-ABCD (sensory loss, dizziness, altered mental status, gait abnormality, headache, or vision loss), or other (follow-up exam or trauma). In cases where a stroke code was initiated, we recorded the presenting NIHSS and whether thrombolytic therapy was ultimately administered.

Imaging Protocols

CTAHN was performed on two scanners (Revolution, GE Healthcare; Somatom Force, Siemens Healthcare). Parameters were as follows: non-contrast and post-contrast CT: slice thickness (ST) 0.625-0.75 mm, dual energy 80 and 150 kVp; CTA ST 0.625-0.75 mm, 80 kVp; CTP ST 10 mm, 70 kVp. Typical dose-length-product was 3000-5000 mGy-cm. Typical iodinated contrast dose was 100 ml. CTP studies had split-dose contrast administration.

3T MRI was performed on one of three scanners (Premier (n=2), MR750 (n=1), GE Healthcare, Waukesha, WI). NeuroMix is a fast segmented GRE-EPI and SSFSE acquisition with 5 standard and 3 optional tissue contrasts[12]. This requires 2.5 min for 5 mm ST, 1-1.3 mm in-plane resolution, and 2 selected optional contrasts. Standard contrasts are axial EPI-DWI, T1w FLAIR, T2w and T2-FLAIR SSFSE, and T2*w-EPI. Selected optional contrasts included sagittal T1w 3D-EPI using ST of 1.2 mm and axial SWI 3D-EPI using ST of 2.5 mm (Figure 2). Intracranial non-contrast TOF-MRA parameters were 3 slabs, TR/TE 22/2.6 ms, ST 1.2 mm, imaging duration approximately 5 min. While cervical MRA was occasionally performed, we only assessed the intracranial MRA information as this was common to all MR imaging studies.

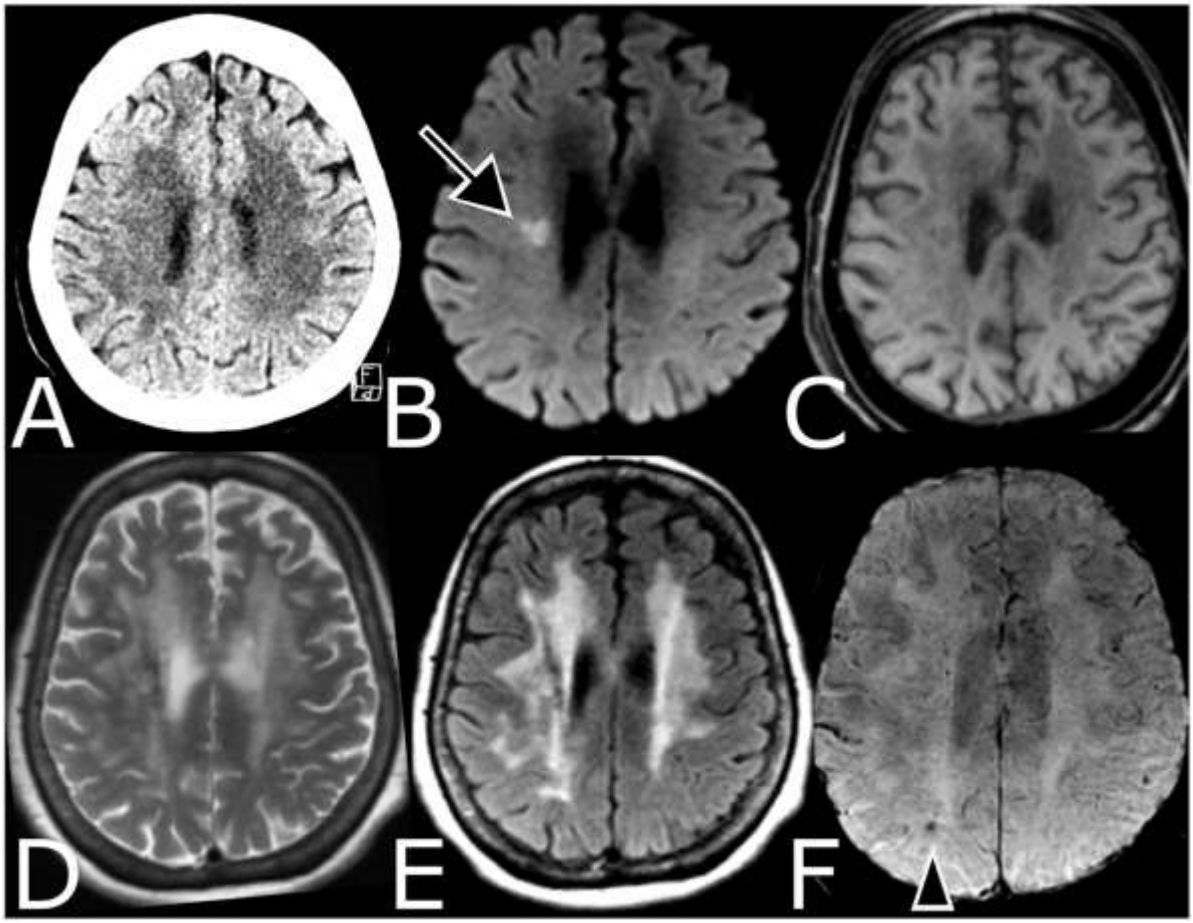

FIG 2. Unenhanced multi-contrast NeuroMix sequence compared to CT in a 67-year-old female with history of prior strokes and worsened left-sided weakness and dysarthria. Graded as unique NeuroMix information regarding acute infarct (arrow) and microhemorrhages (long arrowhead, other sites not shown). A) Axial non-contrast CT head without focal hypoattenuation or CTP deficit (not shown). B) DWI with diffusion restriction in the right corona radiata (arrow). C) Axial reconstruction of NeuroMix sagittal 3D T1 weighted acquisition. D) T2-weighted and E) T2-FLAIR images show confluent subcortical white matter hyperintensity. F) SWI shows a right parietal microhemorrhage (arrowhead).

Data and Statistical Analysis

Four radiologists reviewed all studies in consensus. Abnormalities were categorized as structural (e.g., infarct, hemorrhage, microhemorrhage) or angiographic (e.g., >50% arterial stenosis, occlusion, aneurysm, dissection). Comparisons were made to determine whether CT and MR protocols provided equivalent or unique diagnostic information. For example, when CT imaging with CTP suggested acute infarct that was confirmed by MRI and limited to the same vascular territory, this was considered equivalent. Otherwise, DWI-positive acute infarcts were recorded as unique MR information if the findings on CT were not visible, equivocal, or favored to be chronic. Conversely, if CT suggested an acute infarct which was disproven on MRI, this was considered unique MRI information. Results are presented for the entire cohort, as well as the following subgroups: patients who presented as stroke codes; as non-stroke codes; with presenting NIHSS of 0, 1-6, or >6; with focal weakness or speech disturbance (ABCD+); and those with other symptoms (non-ABCD). Confidence intervals were calculated using the modified Wald method[14].

RESULTS

Two-hundred and five (205) matched CT and MR cases met our initial criteria, of which 31 were excluded, resulting in analysis of 174 cases (Figure 1). The primary reason for excluding individual cases was when a patient had more than 1 CTAHN study within the 24-hour period prior to MRI (n=16). Most (75%) cases were from the ED, 56% were female, 47% self-identified as white, and mean age was 67 years (range: 20-102 years). The most common presentation was focal weakness (16%), followed by speech disturbance (15%), sensory abnormality (13%), dizziness (13%), and altered mental status (11%) (Table 1).

CTAHN, NeuroMix, and MRA sequences were interpretable in all cases. MR studies were acquired 6.5±4.5 hours after the CT study. Five MR studies were prematurely halted due to patient factors, though after acquisition of NeuroMix and MRA. Mean imaging time, as defined in the Methods section, was 12±5 min for CTAHN without CTP, 17±6 min for CTAHN with CTP, and 33±10 min for conventional MRI.

Overall, 43 cases (25%) were normal or had irrelevant incidental findings on both MRI and CTAHN, while another 10 cases (6%) demonstrated obviously chronic findings. The remaining 121 cases (70%) had potentially relevant diagnostic information on either CTAHN or NeuroMix+MRA, 98 with structural findings and 59 with angiographic findings (Table 2). NeuroMix-only and NeuroMix+MRA protocols were deemed equivalent or better than CTAHN in 71% and 95% of patients, respectively (Online Supplemental Data). Unique findings were seen on NeuroMix alone and NeuroMix+MRA in 35% and 36% of patients, respectively, most commonly acute infarction not identified on the CT (Figure 3) or findings seen only on SWI (Figure 4). Unique findings were seen on CTAHN in 8/174 cases (5%) compared to NeuroMix+MRA, with findings of high-grade carotid bifurcation (n=3) or proximal vertebral artery (n=5) stenosis outside the MRA field of view.

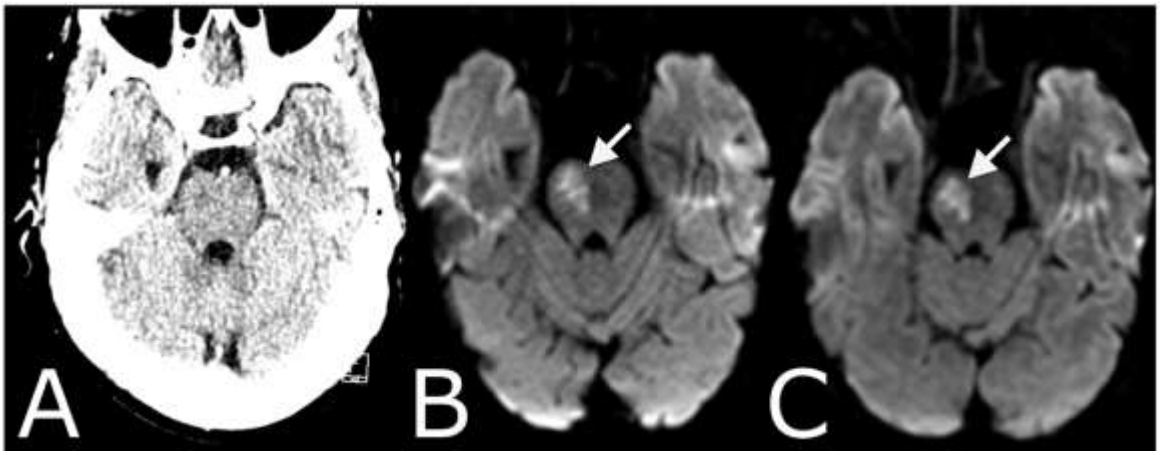

FIG 3. Unique NeuroMix information (pontine infarct) in a 62-year-old male presenting with 1 day of left sided weakness and tingling. A) Axial non-contrast CT without structural abnormality. CT angiography and perfusion were also unremarkable. B) NeuroMix axial DWI shows diffusion restriction within the right pons compatible with acute infarct (arrow). C) Conventional axial DWI similarly shows the acute right pontine infarct.

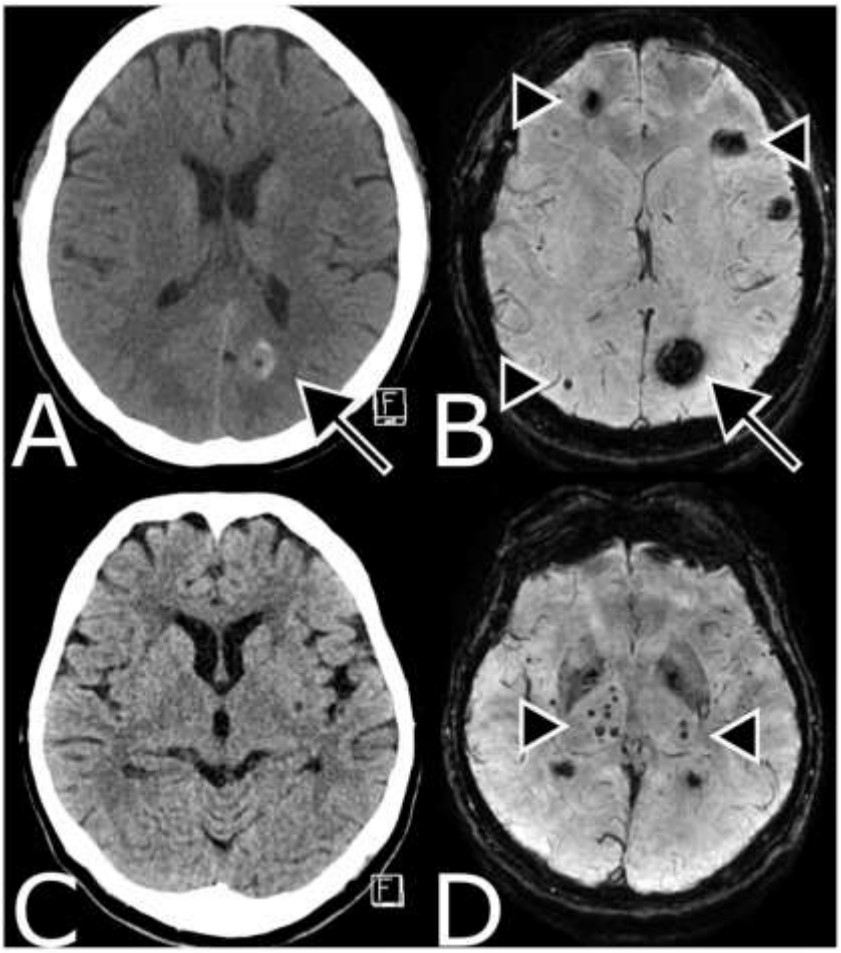

FIG 4. Two cases with unique and useful NeuroMix information on SWI. A-B) 49-year-old female presenting with worsening multifocal pain, weakness and numbness not confined to a particular neurovascular territory. A) Axial non-contrast CT head shows a heterogeneously hyperattenuating lesion in the left parieto-occipital white matter (arrow). B) Axial NeuroMix SWI shows blooming of this lesion (arrow) as well as multiple lesions not evident on CT (arrowheads), consistent with multiple cavernous vascular malformations. C-D) 74-year-old female with transient left facial droop and dysarthria. C) Axial non-contrast CT without significant structural abnormality. D) Axial NeuroMix SWI shows central-predominant foci of susceptibility (arrowheads) suspicious for hypertensive microhemorrhages.

In most of our cases (106/174, 61%), a stroke code prompted CTAHN. Ten patients (6%) received intravenous thrombolysis. No patients underwent thrombectomy. 75% had an NIHSS score of 6 or below. Of note, half (34/68) of all non-stroke code cases also included CTP. Intracranial hemorrhage (ICH) was noted in 23 cases, all identified by both CT and NeuroMix. NeuroMix-based SWI detected a superimposed pattern of multiple microhemorrhage suggesting cerebral amyloid angiopathy or chronic hypertension in 4 cases.

DISCUSSION

We compared MR studies that included the fast unenhanced multi-contrast NeuroMix and MRA sequences with a recently performed CTAHN (including non-contrast CTH, often with CTP, and delayed post-contrast CTH) in patients with acute neurological presentations. In 95% of these cases, the fast MR-based protocol provided equivalent or better information relative to CTAHN, detecting unique structural findings such as acute infarcts or microhemorrhages in over a third of cases, while detecting all intracranial vascular findings. Neuromix+MRA missed a total of 8 (4.6%) findings, all of which were extra-cranial vascular findings not included in the MRA field-of-view; of these, only 3 (1.7%) had a vascular finding that would change management (i.e., high-grade carotid stenosis). This suggests there may be a role for fast MR-first protocols in patients with acute neurological presentations, which could be further assessed with prospective evaluation.

CTAHN has undergone dramatic growth in recent years[8,9], being generally fast and widely available. However, CTAHN as a first study for patients with neurological symptoms exposes patients to ionizing radiation and iodinated contrast. Lengthy evaluation times for CTAHN studies, concurrent with increasing demands for rapid report turn-around-times[15] and overall rising volumes[2], increases pressure on radiologists and contributes to workload and burnout[4]. The number of studies without relevant findings is also increasing[9], possibly due to less emphasis on physical examination and clinical judgment and more reliance on physician extenders in the ED[10]. MRI allows for faster and more definitive reporting of acute ischemic stroke due to DWI. If timely MRI access can be facilitated, a "fast MR-first" approach for certain acute neurological presentations may benefit multiple stakeholders with more definitive and potentially lower cost imaging. Additionally, an unenhanced NeuroMix+MRA protocol would avoid contrast material injection, saving imaging time, avoiding contrast reaction or extravasation, and reducing environmental/water pollution downstream from sites with high concentration of imaging centers[16,17].

We found that NeuroMix+MRA provided unique information in over a third of cases relative to CTAHN[18]. This estimate is likely conservative, as we did not specifically consider the clinical value of a negative DWI, which allows for more definitive management decisions and might facilitate more rapid patient discharge. These advantages must be weighed against a low rate of missed cervical vascular findings, as some pathways suggest a benefit of early intervention in patients with transient ischemic attack or stroke and >50% carotid bifurcation stenosis[19,20]. This issue could be largely mitigated if non-contrast MRA coverage extended from the Circle of Willis to the carotid bifurcation, or with non-emergent follow-up imaging of neck vessels. The benefit of imaging vertebral arteries for posterior circulation symptoms[21,22] is less clear given lack of benefit of vascular intervention[23] over medical therapy[24]. Depending on the clinical scenario, NeuroMix-based protocols may be variably appropriate, and this observational study can serve as a foundation to explore their application to different patient populations with prospective trial designs.

Long wait and acquisition times have limited traditional MR exams in the ED setting. Abbreviated MRI exams have been validated in the pediatric setting to expeditiously evaluate for hydrocephalus[25] and trauma[26,27], though CT retains some advantages over MRI in trauma depending on the clinical scenario[28]. Accelerated protocols often rely on GRE-only echo planar imaging[29–33] to provide multi-contrast imaging. NeuroMix[12], with both GRE-EPI and SSFSE-based acquisition, has decreased susceptibility artifact at the skull base. A recent study using a deep-learning-augmented fast MR protocol was shown to be effective in patients presenting with stroke-like symptoms relative to standard MRI[34]. NeuroMix+MRA had comparable imaging time compared to the average CTAHN (non-contrast-CTH, head and neck CTA, +/- CT Perfusion, delayed contrast-enhanced-CTH) in our cohort: NeuroMix+MRA at 7.5 min "gradient-on-time", CTAHN without CTP at 12 min, and CTAHN with CTP at 17 min. This lengthy CT time is largely driven by the number of stroke codes in our cohort and the associated required care team communications. CT imaging time will likely be reduced if fewer stroke codes are included, and prospective trials comparing CT and NeuroMix-based protocols will need to account for total imaging time (room time, order to report, or presentation to disposition) to determine feasibility and utility of NeuroMix-based protocols. Nevertheless, we believe that there is roughly similar table time for these two approaches, with the potential of further speeding up of the MRA study, which was not optimized for fast imaging, but was rather our routine clinical sequence. Other issues, including access to MRI would need to be addressed in a prospective trial.

Triaging patients to NeuroMix+MRA over CTAHN may reduce length of stay (LOS), a critical metric and driver of imaging. EDs are structured to provide short door-to-CT times generally[15] and for trauma and stroke particularly[35]. Conventional MRI is viewed as increasing LOS[36], but having dedicated ED MR scanners[37], protocols[30,31], and workflows has shown to result in overall decreased hospital LOS[36]. One study showed equivalent ED LOS between CT and MR work-up to evaluate for hip fracture, with more definitive management after MR[38]. A recent model analysis suggests that specialized MRI is the most cost-effective evaluation of ED patients with dizziness[7]. Nevertheless, patient screening, scanner availability, and staffing are potential barriers to expedited MR access in the ED setting, even when MR is the more appropriate study, though access to MRI improves when individual patient examinations are shortened[39].

A NeuroMix+MRA fast-imaging protocol is not meant to replace comprehensive MRI, and this study was not designed to evaluate for these differences. Nevertheless, NeuroMix was acquired alongside conventional MRIs, allowing for an evaluation of NeuroMix findings compared with conventional MR protocols in our cohort. We found that 9% of cases had findings on conventional MRI that were not evident or not fully evaluated on NeuroMix+MRA. In 8/16 (50%) of cases, this was related to non-detection or incomplete characterization of enhancing lesions, which is expected given the non-contrast nature of the abbreviated protocol. Other discrepancies included new information in 6/16 cases derived from ASL perfusion imaging, while in 2/16 cases, subtle punctate infarcts were seen on comprehensive 3 mm DWI but not on 5 mm NeuroMix DWI. NeuroMix has the option of acquiring images at thinner slice thickness (3 or 4 mm) with slightly increased imaging duration, such that the extra imaging time must be weighed against the need to visualize tiny infarcts. If a fast MRI-first protocol is implemented, this may enable more informed decisions to be made regarding the need for further imaging evaluation, such as CTAHN, neck ultrasound, and/or conventional MRI. The risk exists that ordering providers may excessively rely on the fast MRI without understanding potential limitations, and education around protocols will be important.

Several patients in our cohort were found to have acute intracranial hemorrhage (ICH). Non-contrast CT remains a bedrock of evaluating patients for acute ICH, but clinically significant hemorrhage can be equally well or better assessed with MRI using gradient-echo and SWI[40,41]. No cases of ICH were missed by NeuroMix. In 4 cases of CT-evident ICH, SWI revealed a microhemorrhage pattern consistent with hypertension or cerebral amyloid angiopathy, thereby adding important clinical information. A theoretical concern exists regarding delay in ICH diagnosis due to differences in access to MRI versus CT, and this should be monitored when assessing fast MR-first protocols in patients with mild neurological presentations.

Our study has several limitations. First, requiring two imaging exams within 24 hours selects for follow-up MRIs based on non-definitive CTAHN (work-up bias), but a short-time window between exams is necessary to limit the changes that can occur between exams

solely based on time. Additionally, cases for which a negative CTAHN was considered definitive or cases with symptoms or CTAHN findings too severe to have warranted or tolerated additional short-interval MRI were not included. Furthermore, at our institution, this selection criterion excludes patients who undergo thrombectomy and therefore is biased against large-vessel-occlusion cases. This design was meant to enrich for less severe presentations, with the assumption that prospective NeuroMix+MRA trials would target patients with minor neurological symptoms. For example, meta-analyses have shown a high negative predictive value for large vessel occlusion using clinical symptoms, such as NIHSS<4[42]. Another limitation is that we were unable to retrospectively quantify wait time for CT or MRI or overall room time, though this would not have much meaning given that initial time-sensitive triage was performed with CT. While imaging time for NeuroMix+MRA (7.5 min) and full CTAHN (17 min; inclusive of non-contrast stroke code communication and IV thrombolysis decision-making) were comparable, patients can typically access CT scanners more quickly than MR scanners due to differences in patient screening and availability of scanners. These important timing considerations require a prospective trial to fully understand.

CONCLUSIONS

In our patient population, NeuroMix+MRA provided equivalent to or better than CTAHN in 95% of cases, detecting unique findings in 36% of cases. These results, along with comparable acquisition times, indicate that NeuroMix+MRA can be considered as an alternative to CTAHN in patients with acute neurological presentations. Future prospective work is needed to confirm this hypothesis and define appropriate patient populations for such a protocol.

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Table 1: Patient Demographics and Presenting Symptoms

	Mean	SD
Age (yrs)	66.7	15.9
	N	%
Total	174	100
Gender		
F	97	55.7
M	77	44.3
Race		
White	82	47.1
Asian	42	24.1
Latino	23	13.2
Black	6	3.4
Native Hawaiian or Other Pacific Islander	2	1.1
Other	10	5.7
Multiple Races	8	4.6
Decline to State	1	0.6
Emergency	131	75.3
Inpatient	43	24.7
Presenting Symptoms		
*ABCD^2+	70	31.2
Unilateral Weakness	44	
Speech Difficulty	26	
Non-ABCD^2	90	60.6
**Sensory Abnormality	23	
***Dizziness	22	
^Altered Mental Status	20	
^^Gait Abnormality	10	
Headache	9	
Vision Loss	5	
Other	14	8.2
^^^Follow-up	11	
Trauma	3	

* ABCD^2+: symptoms scored by the ABCD^2 TIA assessment tool.
** Numbness, tingling, tremor, pain, dysphoria, lightheadedness, blurry vision.
*** Dizziness, disequilibrium, vertigo.
^ Altered mental status, confusion, general weakness, unresponsiveness.
^^ Ataxia, balance issues, unsteadiness, difficulty walking.
^^^ Intracranial hemorrhage, infarct, vasculitis.

Table 2. Imaging Findings

				N (174)	%
Normal				43	24.7
Chronic				10	5.9
Potentially Relevant*				121	68.8
Structural				98	55.9
Angiographic				59	33.5
Unique Findings on Conventional MRI				16	9.4
Structural Findings**	CT and NeuroMix Equivalent (N)	NeuroMix Unique (N)	CT Unique (N)	N	%
Infarct	22	37	0	59	34.1
Microhemorrhages	0	25	0	25	13.5
Intracranial Hemorrhage	23	0	0	23	13.5
Mass	6	0	0	6	3.5
CT reported acute infarct which was disproved by MRI	0	4	0	4	2.4
Angiographic Findings***	CTA / MRA Equivalent (N)	MRA Unique (N)	CTA Unique (N)	N	%
Stenosis / Occlusion	30	0	8^	38	22.4
Aneurysm	14	2	0	16	9.4
Procedural Changes	6	0	0	6	3.5
Discrepant Angiographic^^	0	2	0	2	1.2
Shunting Lesion	1	0	0	1	0.6

* 41 cases with potentially relevant findings had both structural and angiographic findings.
** 15 cases with structural findings had >1 finding.
*** 3 cases with angiographic findings had >1 finding.
^ 3 cases of >50% carotid bulb stenosis and 5 cases of proximal vertebral artery stenosis by CTA were outside the FOV of the intracranial MRA.
^^ CTA incorrectly reported 1 case of reversible cerebral vasospasm syndrome and 1 case of aneurysm that were normal on subsequent MRA.

SUPPLEMENTAL MATERIALS:

Online Supplemental Data. CTAHN and NeuroMix MR Comparison: Subgroup Analysis

	2.5 min NeuroMix Only			7.5 min NeuroMix+MRA		
	N	%	Walds CI	N	%	Walds CI
Full Cohort (N=174)						
Equivalent	63	36.2	29.4, 43.6	104	59.8	52.3, 66.8
CTA Unique	51	29.3	23.1, 36.5	8	4.6	2.2, 9
NeuroMix Unique	60	34.5	27.8, 41.8	62	35.6	28.9, 43
Stroke-code (N = 106)*						
Equivalent	32	30.2	22.3, 39.5	63	59.4	49.9, 68.3
CTA Unique	35	33.0	24.8, 42.5	4	3.8	1.2, 9.7
NeuroMix Unique	39	37.9	29.1, 47.5	39	37.9	29.1, 47.5
NIHSS 0 (N=27)						
Equivalent	7	25.9	13.1, 45	15	55.6	37.3, 72.4
CTA Unique	11	40.7	24.6, 59.3	3	11.1	3.2, 29.1
NeuroMix Unique	9	36.0	20.3, 55.6	9	36.0	20.3, 55.6
NIHSS 1-6 (N=51)						
Equivalent	17	33.3	22, 47.1	33	64.7	50.9, 76.3
CTA Unique	16	31.4	20.3, 45.1	0	0.0	0, 8.6
NeuroMix Unique	18	35.3	23.7, 49.1	18	35.3	23.7, 49.1
NIHSS > 6 (N=26)						
Equivalent	7	26.9	13.6, 46.4	13	50.0	32.1, 67.9
CTA Unique	7	26.9	13.6, 46.4	1	3.8	0, 20.7
NeuroMix Unique	12	48.0	30.1, 66.5	12	48.0	30.1, 66.5
Non-Stroke Code (N=68)						
Equivalent	31	45.6	34.3, 57.3	41	60.3	48.4, 71.1
CTA Unique	16	23.5	15, 35	4	5.9	1.9, 14.7
NeuroMix Unique	21	30.9	21.2, 42.7	23	33.8	23.7, 45.7
ABCD^2+ Symptoms (N=70)**						
Equivalent	24	34.3	24.3, 46	40	57.1	45.5, 68
CTA Unique	20	28.6	19.3, 40.1	4	5.7	1.9, 14.3
NeuroMix Unique	26	37.1	26.8, 48.9	26	37.1	26.8, 48.9
Non-ABCD^2 Symptoms (N=90)						
Equivalent	33	36.7	27.5, 47	58	64.4	54.1, 73.5
CTA Unique	30	33.3	24.5, 43.6	4	4.4	1.4, 11.3
NeuroMix Unique	27	30.0	21.5, 40.2	28	31.1	22.5, 41.3

*Two cases with stroke code did not have an NIHSS documented

** ABCD^2+ symptoms included unilateral motor weakness and/or speech difficulty. Non-ABCD^2 symptoms include all others, including sensory symptoms. 14 cases were not included as they were follow-up studies and symptoms were not involved in the decisions to perform imaging.