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ABSTRACT

Innovations that introduce new knowledge domains face greater barriers to adoption, often requiring investment in infrastructure, training/education and cultural change. Sustaining and scaling an advanced clinical vessel wall MR imaging program requires technical resources and sub-specialized neuroradiologists with advanced cerebrovascular expertise. A multifaceted educational program, including lectures, reporting templates and an online resource, was implemented within a large academic neuroradiology division to address neuroradiology workforce readiness. Seven neuroradiology faculty "super-users" interested in cerebrovascular imaging were identified to facilitate case discussions and provide daily support for colleagues, clinicians, and MR technologists. Impact was assessed through a 12-month pre-/post-intervention survey measuring confidence levels in (a) evaluating VWI exam appropriateness, (b) assessing image quality, and (c) diagnostic interpretations. Results showed division-wide increases in self-reported confidence and statistically significant increases among the super-users. These results show that a structured, expert-led peer-support model can enhance clinical readiness and sustain advanced imaging programs.

ABBREVIATIONS: VWI = vessel wall magnetic resonance imaging.

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INTRODUCTION

Sustaining and scaling advanced imaging programs can be challenging, particularly when implementation requires new subspecialized expertise and knowledge. Failures to launch, sustain, and scale are at least three junctures at which strategic initiatives and programs can stall.[1] Following implementation, health and imaging programs may struggle to progress or scale due to insufficient infrastructure for clinical integration, limited workforce expertise, or high costs associated with advanced imaging technologies or time requirements.[2] In contrast to innovations that automate or replace workflows, such as deep-learning-based automatic intracranial hemorrhage detection on CT or accelerated pulse sequences serving to replace familiar sequences, innovations that introduce new knowledge domains face steeper barriers to adoption. Thus, innovations can fail to become routine practice without structured education and infrastructure.

Despite growing evidence for vessel wall MR imaging (VWI)'s diagnostic value, institutions attempting to implement these protocols face implementation barriers. The ASNR Vessel Wall Imaging Study Group identified leading challenges as: "lack of radiologist time/interest for protocol development," "limited personal knowledge of applications/value," and "limited interpretation expertise."[3] Addressing workforce readiness for imaging techniques that require new knowledge and training is critical for the initial stages of adoption and to scale up to meet clinical demands.

To address these challenges, we implemented a multifaceted educational program that included didactic and case-based lectures, an accessible online resource hub, and the establishment of a "super-user" group of neuroradiology experts with cerebrovascular interests to support a large academic neuroradiology division, clinicians, and MR technologists. A structured survey was used to measure the program's impact over 12-months to assess changes in self-reported confidence in evaluating VWI exam appropriateness, image quality, and diagnostic interpretation.

MATERIALS AND METHODS

Methods

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The data that support the findings of this study are available from the corresponding author upon reasonable request. The project was reviewed and qualified as quality improvement by the Penn Medicine institutional review board.

Educational Tools

First, didactic lectures focused on technique, interpretation pearls, and artifact/pitfalls, structured as a 45-minute lecture and interactive 90-minute case-based lectures were delivered. Quarterly lectures were open to the neuroradiology section, including clinical fellows and faculty. Second, an accessible online resource was created to facilitate ordering and provide downloadable 1-2 page guides for each VWI exam type (brain, neck/carotid, and scalp/temporal arteries) detailing the common clinical indications and VWI interpretation pearls/pitfalls (**Supplemental Material**). Third, reporting templates were disseminated. Fourth, a Microsoft Teams group was created to share cases and questions. Finally, seven neuroradiology faculty with interest in advanced cerebrovascular imaging agreed to be "super-users." The super-users could facilitate case discussions and provide daily needs, coverage, and support for the ordering clinicians, MR technologists, and other neuroradiology faculty.

Survey Instrument

The anonymous web-based survey was developed on the Qualtrics platform (**Supplemental Material**). The survey was distributed in July 2023 and August 2024 to the Neuroradiology Division. Faculty were informed that the online survey tool was anonymous and confidential. Four weeks were allotted for survey completion. One email reminder was sent to encourage participation. The survey queried the self-perceived confidence for (a) evaluating VWI exam appropriateness/indications, (b) checking image quality for MR technologists, and (c) image interpretations for VWI brain, neck/carotid, and scalp exams. Scores were measured on a sliding scale [0% (not confident) to 100% (very confident)]. The survey included three additional questions about topics of interest for VWI (technique, interpretation, indications, or not interested), and an optional free-text comment box for feedback/concern. The 2024 survey also included a question about the number of VWI exams read in 2023 (up to 10, 20, or 20+ VWI exams).

Survey Respondents

Survey link was emailed to all Neuroradiology attending faculty and instructors in 2023 (N=24) and 2024 (N=29).

Statistical Analysis

Survey response rates were calculated by the number of respondents divided by the total number of Neuroradiology faculty/instructors and the seven super-users for subgroup analysis. Respondents who started but did not complete at least half of the survey questions were excluded from analyses. Mean scores and standard deviations (SD) are reported. Independent two-sample Student's t-test was used to compare mean scores. Significance was set at $p<0.05$. Stata (v18, StataCorp, College Station, Texas) was used for analyses. As this was a quality improvement initiative, a power calculation was not performed. Given the study's exploratory nature, no formal correction for multiple comparisons was applied.

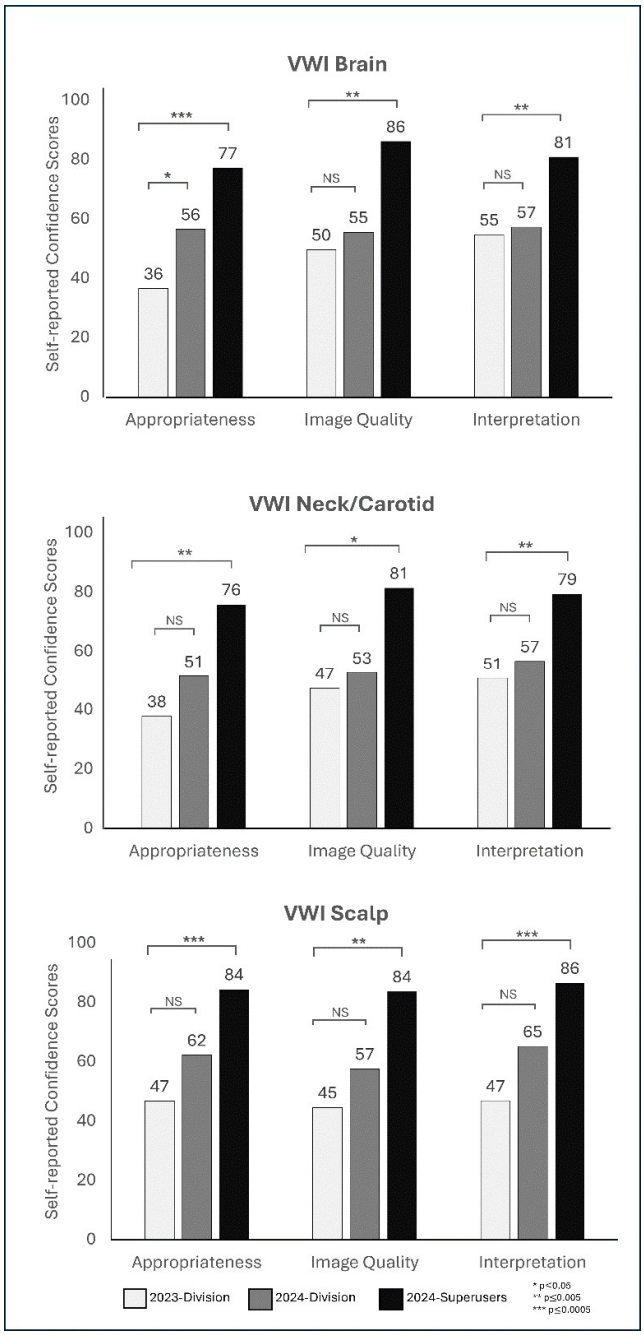

Fig 1. Mean Scores of Self-Reported Confidence Levels of a Neuroradiology Division before (2023) and after (2024) a VWI Educational Program

RESULTS

Survey response rates were 61% (2023-Divison), 52% (2024-Division) and 100% (2024, Super-users). Among topics of interest, respondents were most interested in learning about interpretation pearls/pitfalls [41% (2023), 37% (2024)] followed by VWI indications/appropriate use [31% (2023), 37% (2024)] and technique/pulse sequence [25% (2023), 26% (2024)]. In 2023, 3% of respondents reported no interest in VWI, which decreased to 0% in 2024.

Mean scores for evaluating appropriateness/indications, image quality, and diagnostic interpretations for all VWI exam types increased over 12-months (**Figure 1**). Within the entire Division, mean scores trended upwards after 12-months with a significant increase for assessing appropriateness/indications for VWI Brain exams (36.4 vs 56.4, p=0.04). Subgroup analyses with mean scores among the super-users showed significant increases for all VWI exam types (VWI Brain: appropriateness, 36.4 ± 23.7 vs 77.1 ± 12.5, p<0.001), image quality, 49.5 ± 30.3 vs 86.0 ± 9.9, p<0.01; interpretation, 54.6 ± 19.2 vs 80.7 ± 11.0, p<0.01), VWI Neck/Carotid: appropriateness, 37.7 ± 24.5 vs 75.7 ± 18.1, p<0.01; image quality, 47.3 ± 29.4 vs 81.3 ± 15.5, p=0.01; interpretation, 50.6 ± 20.3 vs 79.3 ± 16.4, p<0.01; VWI Scalp: appropriateness, 46.7 ± 21.5 vs 84.3 ± 12.7, p<0.01; image quality, 44.5 ± 28.6 vs 83.6 ± 14.4, p<0.01; interpretation, 46.7 ± 21.7 vs 86.4 ± 11.8, p<0.001). The online resource/website was reported to be extremely useful for protocoling and interpretation tips [mean scores 96%, SD 9.5 (2023) and 93%, SD 7.8 (2024)].

DISCUSSION

The successful impact of the multifaceted educational strategy was measured in a large Neuroradiology Division and self-reported confidence levels were shown to increase over 12-months in 3 domains: ability to assess exam appropriateness, evaluating image quality, and formulating diagnostic interpretations for VWI brain, neck/carotid, and scalp exams. For the VWI super-users, confidence levels increased significantly in all domains, reaching up to 86% out of 100%. Modeled after within-specialty subspecializations, we established a team of cerebrovascular VWI-super-users aligned with individual academic or clinical interests. The super-users ensured consistency, supported divisional needs, and helped meet the 24/7 clinical demands of acute stroke imaging, often initiated through the Emergency Department or inpatient services. This team-based approach strengthened workforce readiness and supported sustainable program growth.

Common challenges to scaling and sustaining such initiatives include meeting needs for workflow/infrastructure integration and subspecialty expertise. Our prior work reported the establishment of an infrastructure for ordering and protocoling VWI exams to facilitate operations. We created fit-for-purpose exam codes with "vessel wall imaging" in the labels, revised the EPIC interfaces, created order sets, and updated both protocol interfaces for the neuroradiologist and MR technologists to streamline workflows.[4] We also educated clinical teams about indications and diagnostic value to address utilization and appropriateness.[4] Our previously published institutional survey of ordering clinicians showed that 91.3% agreed, "Vessel wall MR imaging has changed and helped my clinical diagnostic confidence of diagnosing and managing my patients."[4] A rise in clinical requests highlighted the need to meet growing demand as the program scaled.

The successful mainstream adoption of innovations is influenced by organizational culture, particularly the perception that the innovation adds value and users feel confident and competent with the new tool.[5] For advanced imaging techniques such as VWI, the perceived confidence to interpret and generate a radiology report of diagnostic value is key. Thus, this initiative aimed to improve the neuroradiology workforce's readiness by enhancing confidence through education. Furthermore, we prioritized preparation for common scenarios between neuroradiologists and MR technologists or ordering clinicians, recognizing that a neuroradiologist's ability to navigate these conversations effectively is key to strengthening interprofessional relationships and collaborative practice.

First, to support referring clinicians seeking guidance from neuroradiologists on the clinical indications and appropriate use of VWI, case-based lectures and online educational materials outlining the diagnostic utility of VWI were developed. Second, to address the needs of MR technologists requesting neuroradiologist input on image quality and pulse sequence prioritization, particularly in cases with motion degradation, we implemented case-based conferences focused on what pulse sequences should be prioritized for differentiating vasculopathies. Third, recognizing the neuroradiologist's consultative role in providing diagnostic interpretations with referring clinicians, interpretation tip-sheets were provided, reporting templates refined, and efforts prioritized to enhance the quality of these interactions. Finally, we concentrated VWI case exposure within a core group of neuroradiology faculty, rather than distributing it across the entire division. This focused strategy led to significantly higher perceived confidence among the super-users, likely driven by consistent case exposure and accumulated experience.

Additionally, confidence is a necessary early marker of clinical readiness. Based on the Technology Acceptance Model, user confidence and attitude drive behavioral change.[6] As neuroradiologists serve as gatekeepers for MRI exam approval and requests for protocols, increased confidence is a prerequisite for clinical adoption. A lack of confidence can discourage exam utilization, limiting opportunities to gain experience and clinical exposure. While increased confidence does not equate to competence or diagnostic accuracy, confidence is nonetheless a meaningful metric in this early-phase study.

This study has several limitations. First, the 52%-61% survey response rates from the Division seem low but are comparable and higher than most physician surveys.[7] Additionally, the lower response rate in 2024 may be explained by new hires who had no or limited experience with VWI at the time of the follow-up survey and did not respond. Second, given the anonymous nature of the survey, each respondent's follow-up response was not paired in the analysis. Future studies will incorporate anonymous response codes to allow paired analysis while maintaining confidentiality, further strengthening longitudinal comparisons. Third, while the perceived confidence for diagnostic interpretations was measured, the accuracy was not evaluated among the respondents or super-users. Discussions with the ordering providers and review of complex cases during multidisciplinary case conferences were learning opportunities shared at case conferences. However, as one respondent commented in the free-text survey, regular structured feedback for continuous improvement and discussions was desired. Future studies will assess diagnostic performance through a peer-learning program that collects clinically verified cases and outcome data. This approach will complement confidence metrics with objective performance measures. Peer-learning opportunities are advantageous for system improvements, increase team engagement, foster a culture of growth, and improve patient outcomes.[8,9] Fourth, baseline and follow-up knowledge assessments were not included, limiting our ability to objectively measure

knowledge gain. The program was designed to support sustained clinical adoption of a new imaging technique through a longitudinal and multidisciplinary approach. Future interventions will incorporate image-based assessments focused on imaging pitfalls to evaluate learner performance. Fifth, increased confidence levels may be multifactorial as respondents may have also self-educated themselves by reading published literature or watching society-sponsored educational and scientific lectures on VWI. The structured institutional material may not be the sole reason for increased confidence levels. Future follow-up surveys will include a question assessing external educational exposure to evaluate the specific contribution of institutional interventions. Sixth, this study was conducted at a single, large academic institution, which may limit the generalizability. However, the educational framework developed is intended to be scalable and adaptable. Future work is needed to assess the effectiveness and feasibility of this model across a broader range of institutions with different sizes, resource levels, and subspecialty availability.

In conclusion, we describe the success of a multifaceted educational strategy implemented over 12-months in a Neuroradiology Division that showed improvements in neuroradiologists' confidence levels for evaluating indications/appropriateness, assessing image quality and interpreting VWI cases. The establishment of a core group of cerebrovascular super-user experts for VWI was modeled after the structure of a large neuroradiology division with subspecialists in, for example, head/neck and brain tumor. Indeed, confidence levels were significantly higher after 12-months within the cerebrovascular VWI-super-users. To meet rising clinical requests and provide timely care for the emergency/inpatient stroke patients, addressing neuroradiology workforce readiness is key to ensuring the program can continue and VWI remains an advanced non-invasive diagnostic imaging option at a Comprehensive Stroke Center.

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ACKNOWLEDGMENTS

None.

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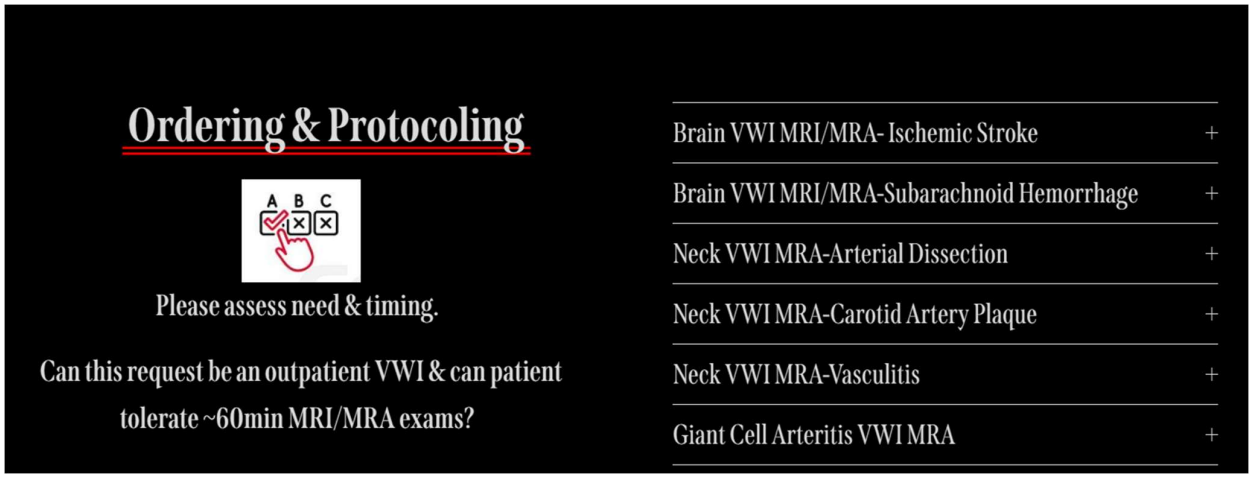
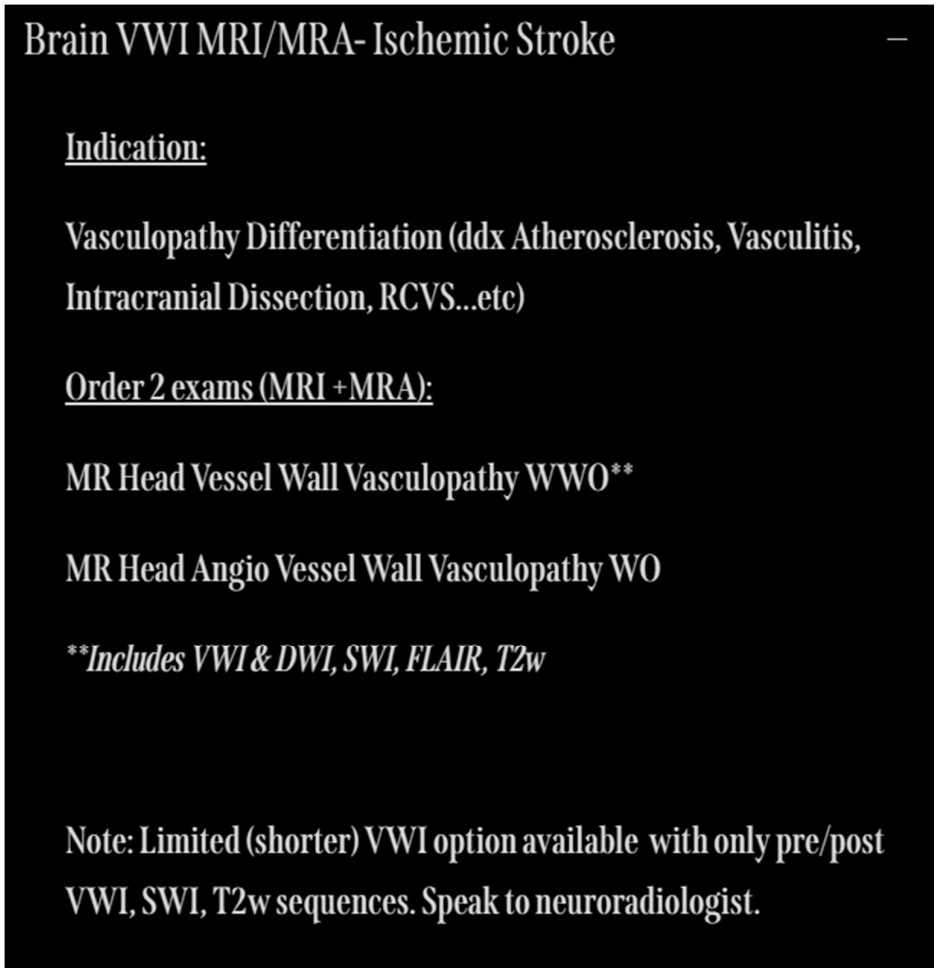
SUPPLEMENTAL FILES

Supplemental Material 1

Examples of Online Resource Guide for Ordering and Protocoling by Exam Type



(+) Expands by Exam Type to Explain Common Indications and How to Order



Brain VWI MRI/MRA-Subarachnoid Hemorrhage —

Indication:

Angiogram-negative (CTA/DSA negative) atraumatic SAH.

VWI can be performed as adjunct to & after recommended work-up. See 2023 AHA/ASA Guidelines & (algorithm), & ACR Appropriateness Criteria).

Evaluate for blister/perforator aneurysms, dissecting aneurysm, occult AVF/AVM, or multiple aneurysms.

Order 2 exams (MRI + MRA):

MR Head Vessel Wall (SAH) WWO**

MR Head **Angio** Vessel Wall (SAH) WO

***Includes VWI & DWI, SWI, FLAIR, T2w*

Optional:

MR Cervical Spine WWO (includes sag T1 pre/post, sag T2 only) can be ordered if posterior fossa SAH. This is to screen for a cervicomedullary AVF/AVMs.†* **This is an additional 30-min MR slot.**

†DSA is gold standard for AVF/AVM.

*MRA neck evaluates cervical carotid & vertebral artery lumen (eg stenosis). MRA neck is the incorrect order for this indication.

Neck VWI MRA-Arterial Dissection

Indication: Concern for cervical carotid or vertebral artery dissection.

Order (1 exam):

MR Neck Angio Vessel Wall (Dissection) WWO

*In comments, please write which arteries and segments are of concern (carotid vs vertebral; origin, mid, skull-base/craniocervical)

Neck VWI MRA-Carotid Artery Plaque

Indication: Concern for unstable carotid artery plaque (intraplaque hemorrhage), carotid web

Order (1 exam):

MR Neck Angio Vessel Wall (Plaque) WWO

Neck VWI MRA-Vasculitis

Indication: Concern for carotid or vertebral artery vasculitis, TIPIC (carotidynia)

Order (1 exam):

MR Neck Angio Vessel Wall (Vasculitis) WWO

Giant Cell Arteritis VWI MRA

Indication: Evaluate for temporal arteritis (temporal and occipital arteries in the scalp only)

Order (1 exam):

MR Head Angio Giant Cell Arteritis WWO

Notes:

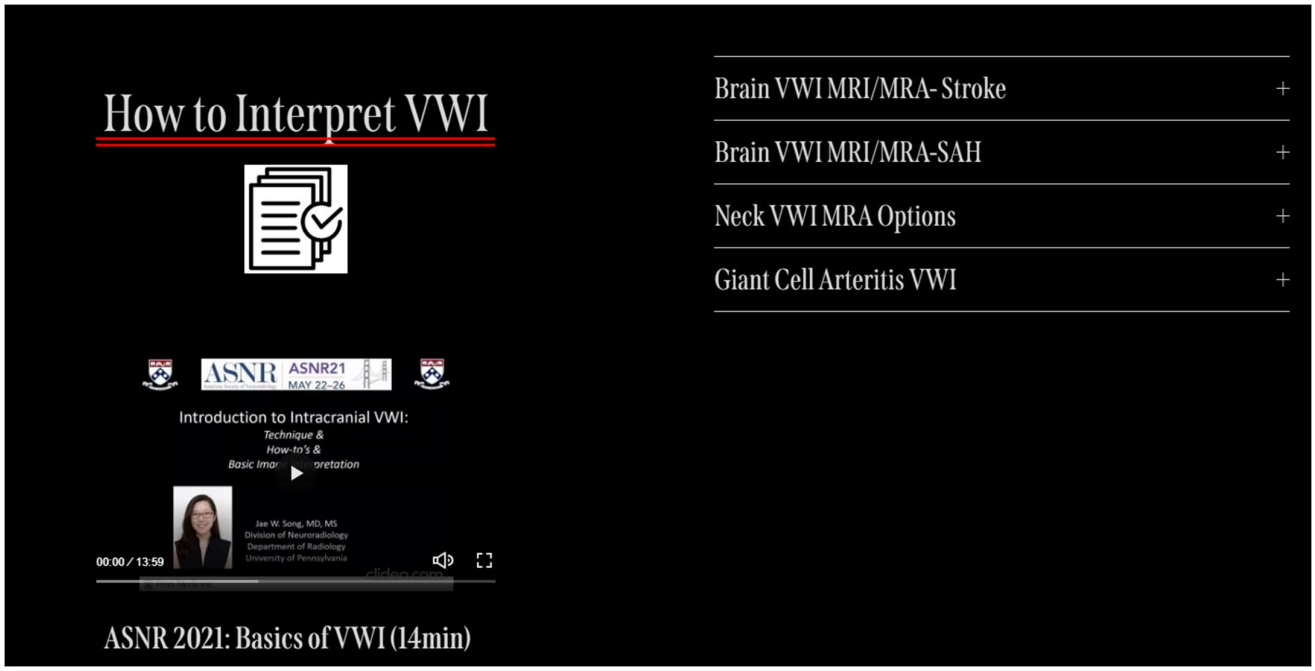
MR Brain (routine) or MR Brain Rapid Stroke can be ordered if concern for stroke.

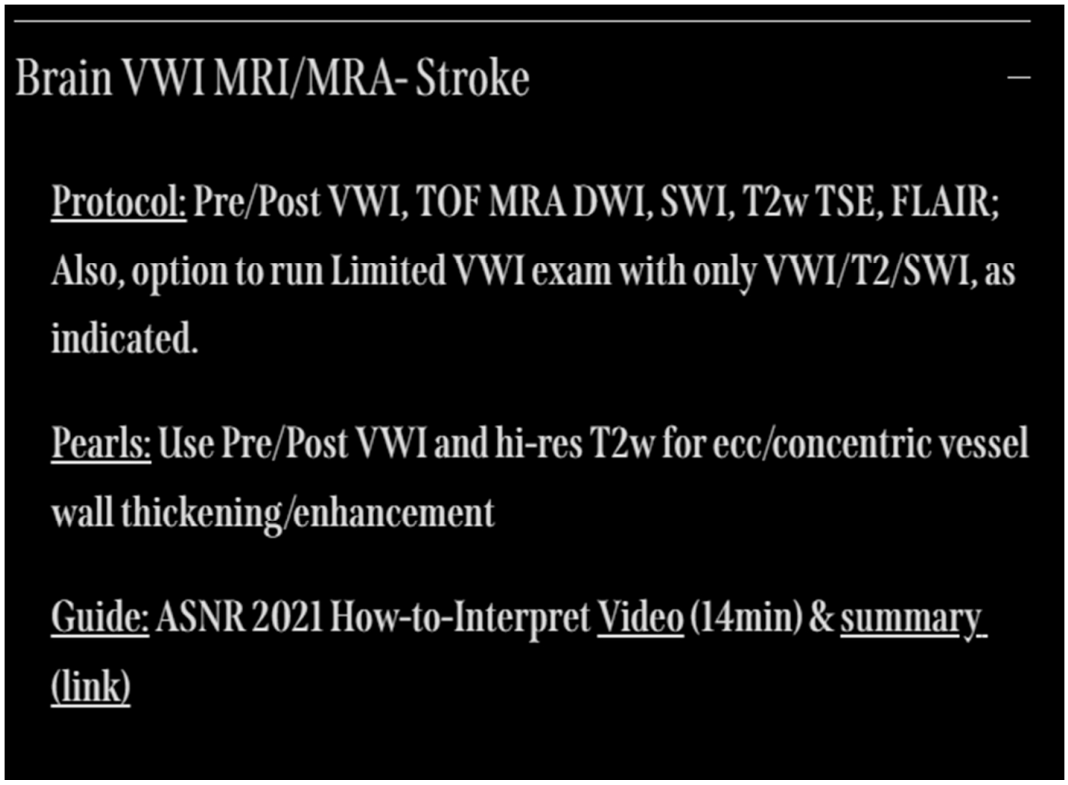
MR Orbits (routine) can be ordered if visual deficits present.

Example of Online Resource Guide for Interpretation*

**Website also hosts a recording of a 14-minute lecture shared at the 2021 American Society of Neuroradiology Virtual Meeting about the "Basics of Vessel Wall Imaging"*

(+) Expands by Exam Type to Detail (1) Protocol & Pulse Sequences, (2) Interpretation Pearls, and (3) A downloadable 1-2 page tip-sheet with published references for additional reading.





Brain VWI MRI/MRA-SAH

Protocol: Pre/Post VWI, TOF MRA, DWI, SWI/3DT2STAR, T2w TSE, FLAIR

Limited C-spine: Pre/Post sag T1w, sag T2

Pearls: Use Pre/Post VWI (enhancing clot, wall irregularity) & SWI (epicenter of hemorrhage).

Limited C-spine (optional): look for dAVF/AVM (serpiginous flow voids, cord edema)

Guide: VWI-SAH Interpretation (link)

Neck VWI MRA Options

Protocol: Pre/Post cor VWI, Dynamic post MRA

Options include:

Dissection: Ax Pre T1 TSE FS (mural hematoma)

Carotid Plaque: Cor pre T1 MPRAGE FS (intraplaque hemorrhage)

Vasculitis: Ax STIR (wall edema)

Guide: Neck VWI Interpretation Tip Sheet (WIP)

Giant Cell Arteritis VWI

MRA GCA (Scalp Imaging):

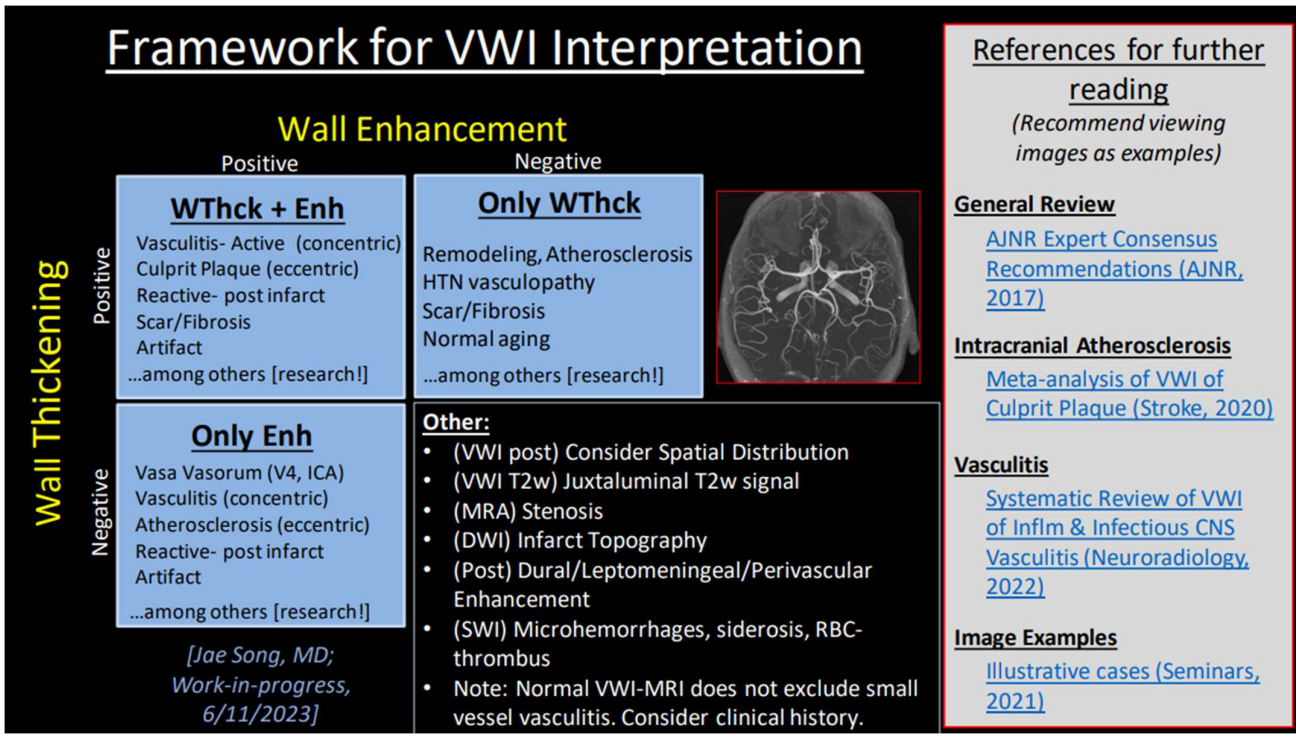
Protocol: TOF MRA, post VWI

Pearls: Evaluate temporal and occipital arteries. Confirm artery on TOF MRA (not vein).

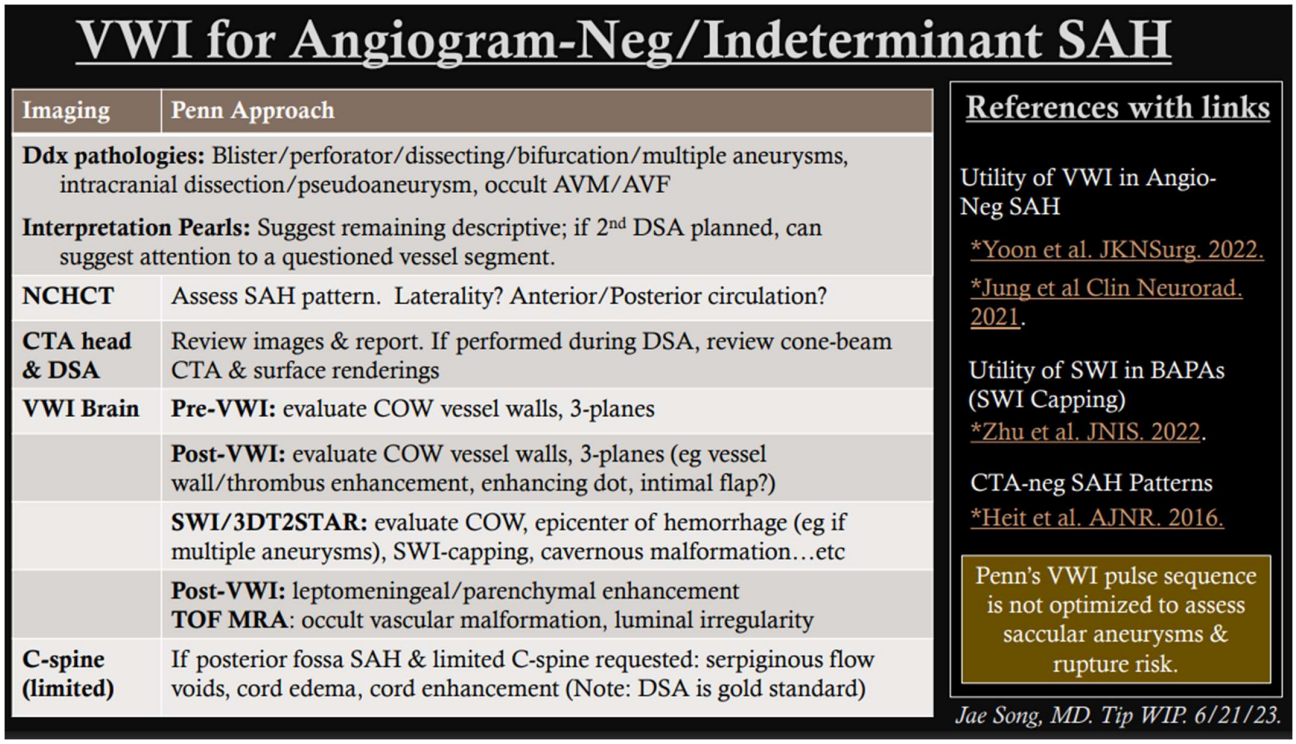
Guide: GCA Interpretation (link)

Example Tipsheets

Framework for VWI Brain Interpretation (Vasculopathy Differentiation) with Hyperlinks to References



Framework for VWI Brain Interpretation (Angiogram-Negative Subarachnoid Hemorrhage) with Hyperlinks to References



Supplemental Material 2

Qualtrics Survey Distributed in 2023

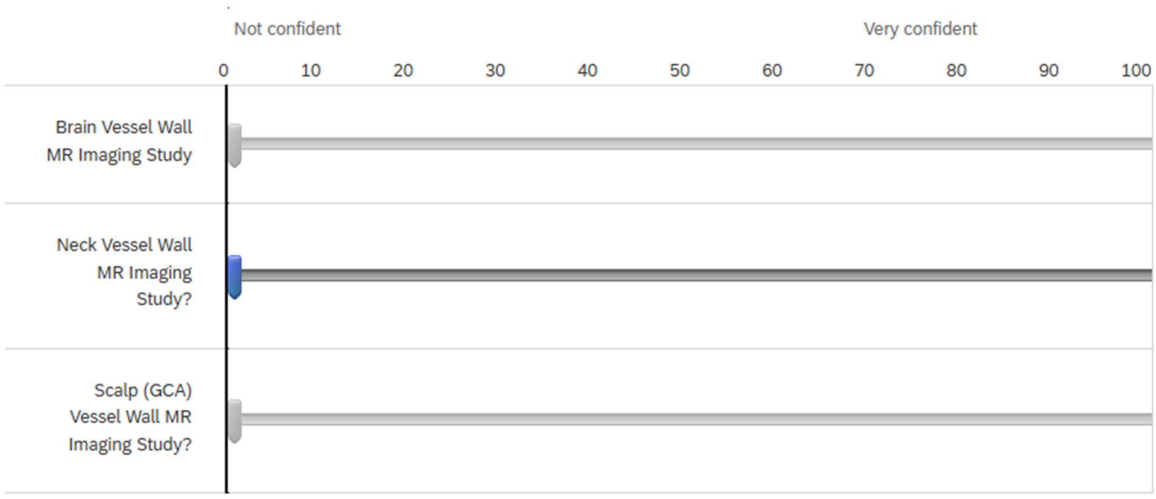
1: Topics

What topics are you most interested in learning about for vessel wall MR Imaging? (Click all topics that apply)

- [ ] Technique/Pulse Sequences
- [ ] Diagnostic Interpretations/Pitfalls
- [ ] Indications/Appropriate Use
- [ ] I am not interested.

2: Appropriateness

How confident are you in your ability to assess appropriate clinical indications and protocol a...
(e.g., appropriateness of diagnostic indication, timing, VWI orders)



3: Quality

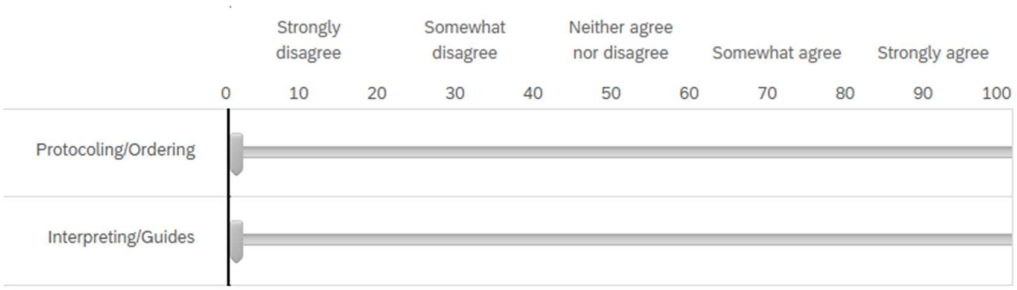
How confident are you in your ability to quality check a VWI study for a MR technologist for a... (e.g., check field-of-view, image quality/degree of motion, which pulse sequences to prioritize)

4: Interpretation

How confident are you in your ability to provide a diagnostic interpretation of a...

5: Tools

It is helpful to have an online, web-based guide for...
(*https://www.thesonglabbrain.com/penn-vwi*)



6:

How long have you been in clinical practice as an Attending:

- [ ] 0-5 years
- [ ] 6-10 years
- [ ] 11+ years

7: Penn Experience

Approximately how many VWI exams have you read in the past year (2023-2024):

- ○ 0-10 VWI exams
- ○ 11-20 VWI exams
- ○ more than 20 VWI exams

Page Break

8: Optional-feedback

Please share any feedback or concerns you may have.