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RESEARCH SUBMISSIONS

Headache neuroimaging: A survey of current practice, barriers, and facilitators to optimal use

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Abstract

Objective: The objective of this study was to understand current practice, clinician understanding, attitudes, barriers, and facilitators to optimal headache neuroimaging practices.

Background: Headaches are common in adults, and neuroimaging for these patients is common, costly, and increasing. Although guidelines recommend against routine headache neuroimaging in low-risk scenarios, guideline-discordant neuroimaging is still frequently performed.

Methods: We administered a 60-item survey to headache clinicians at the Veterans Affairs health system to assess clinician understanding and attitudes on headache neuroimaging and to determine neuroimaging practice patterns for three scenarios describing hypothetical patients with headaches. Descriptive statistics were used to summarize responses, stratified by clinician type (physicians or advanced practice clinicians [APCs]) and specialty (neurology or primary care).

Results: The survey was successfully completed by 431 of 1426 clinicians (30.2% response rate). Overall, 317 of 429 (73.9%) believed neuroimaging was overused for patients with headaches. However, clinicians would utilize neuroimaging a mean (SD) 30.9% (31.7) of the time in a low-risk scenario without red flags, and a mean 67.1% (31.9) of the time in the presence of minor red flags. Clinicians had stronger beliefs in the potential benefits (268/429, 62.5%) of neuroimaging compared to harms (181/429, 42.2%) and more clinicians were bothered by harms stemming from the omission of neuroimaging (377/426, 88.5%) compared to commission (329/424, 77.6%). Additionally, APCs utilized neuroimaging more frequently than physicians and were more receptive to potential interventions to improve neuroimaging utilization.

Conclusions: Although a majority of clinicians believed neuroimaging was overused for patients with headaches, many would utilize neuroimaging in low-risk scenarios with a small probability of changing management. Future studies are needed to define the role of currently used red flags given their importance in neuroimaging decisions. Importantly, APCs may be an ideal target for future optimization efforts.

Abbreviations: ANOVA, analysis of variance; APCs, advanced practice clinicians; CDSS, clinical decision support systems; EHR, electronic health record; MRI, magnetic resonance imaging; NP, nurse practitioner; PA, physician assistant; REDCap, Research Electronic Data Capture; SD, standard deviation; TDF, Theoretical Domains Framework; VA, Veterans Affairs.

KEYWORDS
headache, healthcare utilization, magnetic resonance imaging, neuroimaging, red flags

INTRODUCTION

Headaches are common in adults, with a 93% lifetime prevalence, including 15% having severe headaches or migraine.[1,2] Neuroimaging for these patients is common, costly, and increasing: occurring in 5.1% of headache visits in 1995, increasing to 14.7% in 2010, and costing almost $1 billion per year.[3] Given that the prevalence of abnormalities in patients with chronic headaches is comparable to that in a healthy population,[4–7] guidelines recommend against routine headache neuroimaging in low-risk scenarios.[8,9] Additionally, a systematic review performed by the American Headache Society resulted in recommendations against performing neuroimaging in patients with a normal neurologic examination and without "red flags."[10] Despite this evidence, guideline-discordant neuroimaging is still frequently performed for patients with headaches, likely resulting in downstream harms.[11]

Many factors may contribute to the risk of guideline discordant neuroimaging. For example, the guidelines themselves are limited. Whereas guidelines recommend against headache neuroimaging except in patients with various red flags, different guidelines identify different red flags and many red flags have limited evidence to support their use.[12] Additionally, clinical guidelines without multifaceted implementation strategies are often ineffective.[13] Beyond the guidelines themselves, other clinician characteristics, such as experience level, belief in harm vs. benefit tradeoff, knowledge of guidelines, financial incentives, consideration of patient preferences, and limited time or personnel resources, may result in guideline-discordant utilization.[14–16] Although clinical decision support systems (CDSS) generally lead to modest increases in appropriateness and reduced overall use of diagnostic imaging in a variety of clinical contexts,[17] a number of additional strategies (including shared decision-making,[18] electronic specialty referrals,[19] restrictions of magnetic resonance imaging (MRI) ordering,[20] less time pressure,[21] and other guideline implementation strategies[22]) may effectively optimize neuroimaging decisions and/or be preferred by clinicians.

The goal of this study was to inform future implementation efforts that optimize headache neuroimaging. Therefore, we aimed to better understand current practice, clinician understanding and attitudes, and barriers and facilitators to optimal headache neuroimaging practices through a clinician survey of primary care physicians, neurologists, and advanced practice clinicians (APCs). We hypothesized that current practice, clinician understanding and attitudes, and barriers and facilitators to optimal headache neuroimaging practices would differ between primary care physicians and neurologists, and between physicians and APCs. We administered the survey at the Veterans Affairs (VA) health system, where headache neuroimaging is common,[23] and implementation interventions may be easier to enact. Currently, the specific factors that drive headache neuroimaging decisions for clinicians are largely unknown. Additionally, more evidence is needed to determine which implementation strategies are most likely to be effective and acceptable to headache neuroimaging clinicians.

METHODS

Survey instrument

We developed a 60-item survey following the Theoretical Domains Framework (TDF).[24] The TDF was specifically designed for the purpose of improving clinician behavior in implementation research, has been rigorously validated,[25] has been used to understand clinician behavior in a variety of contexts,[26,27] and successfully applied in prior implementation initiatives.[28–30] Survey items were developed through a consensus process with the study authors, along with qualitative feedback provided by two neurologists and two primary care clinicians on survey clarity, simplicity, and alignment with key questions. The survey consisted of Likert Scale questions assessing clinician opinions on the harms, benefits, confidence, barriers, and attitudes toward MRI utilization for patients with headaches. The survey also posed three different headache neuroimaging scenarios to determine how often clinicians believed they would order an MRI, find abnormalities, find tumors, and cause harm or benefit to the patient. The risk scenarios describe hypothetical patients with low risk of management changing lesions (migraine with normal neurologic examination) and high risk (lung cancer, subacute onset, and incoordination). There is no consensus definition of red flags for headache neuroimaging, however, to understand the effect that potential red flags with limited evidence to support their use have on neuroimaging decisions, we created another low-risk scenario with three such potential red flags (tingling in both hands, worse with exertion, and new onset in a 65-year-old patient) that have been suggested in previous studies. The complete survey instrument is included as Supporting File S1.

Sampling design

Eligible clinicians were identified using the VA Corporate Data Warehouse. Specifically, we identified all nonresident clinicians in primary care and neurology that saw at least three patients with headaches in the preceding 6 months. This included physicians (authors M.D. and D.O.) and APC. The APCs included those that identified themselves as a nurse practitioner (NP) or physician assistant (PA). Our a priori power calculations determined that by targeting 1500 clinicians, at a 50% response rate, with a type 1 error rate of 0.05, for a given response on a five-response Likert scale survey item, if the "true" proportions varied from 10% to 50%, we could estimate parameters within the following 95% confidence intervals (CIs): 10%, 7.9%–12.4%, 20%, 17.1%–23.1%, 30%, 26.7%–33.5%, 40%, 36.4%–43.7%, and 50%, 46.3%–53.7%. On September 11, 2018, a prenotification email was sent to the survey population describing the survey and informing them a link will be sent the following week. On September 19, 2018, each member of the survey population received an email containing a

link to an anonymous, online, closed survey using Research Electronic Data Capture (REDCap). From September 27, 2018, to October 18, 2018, nonresponders received four email reminders. The REDCap survey did not include a completeness check or review step. On October 29, 2018, and November 30, 2018, nonresponders were sent a follow-up paper survey via mail. Respondents were entered into a lottery for a chance to win one of fifteen $100 gift cards. The analysis included all survey responses, including those that were not fully completed.

Statistical analysis

Descriptive statistics were used to summarize survey responses, stratified by clinician type (physicians or APCs, NPs, and PAs) and specialty (physicians: neurology or primary care). Specifically, for categorical survey responses, we reported the frequency and percentage of each survey item response. To summarize ordinal survey items, we also calculated the median, 25th, and 75th percentile of responses. For the continuous responses corresponding to the three headache neuroimaging scenarios, we have reported the mean and SD (mean (SD)), percentage of time clinicians reported that they would order an MRI, find abnormalities, find tumors, and cause harm or benefit to the hypothetical patient.

Wilcoxon rank sum tests were used to compare responses to ordinal survey questions between clinician types (APC vs. physicians) and specialties (physicians: neurology vs. primary care). One-way analysis of variance (ANOVA) was used to assess differences in responses to the three headache neuroimaging scenarios across clinician groups (APC, neurologists, and primary care). Paired *t*-tests were used to assess within-clinician changes in the percentage of time clinicians expected to order an MRI, find abnormalities, find tumors, and cause harm or benefit across the three headache neuroimaging scenarios. Assumptions of normality for the one-way ANOVA and paired *t*-tests were assessed using histograms. In the case of non-normality, Wilcoxon signed rank tests and Kruskal-Wallis tests were used instead of paired *t*-tests and one-way ANOVA, respectively.

Available case analysis was used to compare survey responses between clinician types (APC vs. physicians) and specialties (physicians: neurology vs. primary care). In addition, two-tailed *p* values were calculated and statistical significance was determined using a *p* value threshold of 0.05.

The primary analyses were to describe clinician responses to the three neuroimaging scenarios. All other analyses were secondary. All analyses were specified a priori, and these data are not in publication or reported elsewhere.

All analyses were completed using R version 3.6.1.

Ethics approval and participant consent

This study was approved by the VA Institutional Review Board. Given that this study posed no more than minimal risk to clinicians, the Institutional Review Board deemed that it was not necessary to obtain written informed consent.

RESULTS

Survey respondent characteristics

The survey was successfully completed by 431 of 1426 clinicians (30.2% response rate). Physicians accounted for 76.0% of responders and APCs accounted for 24.0% (nurse practitioners: 18.0% and physician assistants: 6.1%). Clinician specialties were neurology in 45.5%, primary care in 50.3% and other specialties in 4.2%. There were 183 (43.1%) clinicians that made headache neuroimaging decisions less than once per week, 92 (21.7%) once per week, 100 (23.5%) multiple times per week, 11 (2.6%) once per day, and 39 (9.2%) multiple times per day. The frequency of missing responses for individual survey items, stratified by clinician specialty and clinician type are reported in Tables 1–4. Two clinicians did not report their specialty (neurology, primary care, or other) or type (physician or APC). Across individual survey items, nonresponse rate ranged from 0.01% to 7.9% with a mean of 5.4%.

Harms and benefits of MRI

In patients with a normal neurologic examination, the median (25th percentile and 75th percentile) clinician reported finding any abnormality in 6%–10% (1%–5%, 11%–30%) of patients, an abnormality that caused changes in management in 1%–5% (<1%, 1%–5%) of patients and a brain tumor in less than <1% (<1% and <1%) of patients. APCs reported identifying brain tumors (APCs: <1% [<1%, 1%–5%] vs. physicians: <1% [<1%, <1%], $p = 0.001$) and abnormalities that resulted in changed patient management (APCs: 1%–5% [<1%, 1%–5%] vs. physicians: 1%–5% [<1%, 15–5%], $p = 0.009$) more often than physicians. Compared with primary care clinicians, neurologists more frequently reported identifying abnormalities (neurology: 6%–10% [1%–5%, 11%–30%] vs. primary care: 6%–10% [1%–5%, 11%–30%], $p < 0.001$), although management changes were inversely related (neurology: 1%–5% [<1%, 1%–5%] vs. primary care: <1% [<1%, 1%–5%], $p = 0.027$). Nevertheless, both primary care clinicians and neurologists reported similar rates of identifying a brain tumor ($p = 0.196$; Table 1).

Overall, more clinicians believe that patients with headaches benefit (occasionally/often/always: 62.5%) from decisions stemming from MRI results than are harmed (occasionally/often/always: 42.2%). Clinicians believed the most common harms stemming from false positive results included unnecessary consultations (often/always: 17.0%), tests (often/always: 11.9%), procedures (often/always: 5.8%), and medications (often/always: 4.0%). The definition of a false positive result was not specified in the survey but may have included both incidental and nonspecific findings. Neurologists reported harms less frequently than primary care clinicians (neurology: rarely [rarely, occasionally] vs. primary care: occasionally [rarely, occasionally], $p = 0.004$). Specifically, neurologists believed there were fewer unnecessary medications (neurology: rarely [rarely, rarely] vs. primary care: rarely [rarely, occasionally], $p = 0.020$) and

TABLE 1 Clinician opinions regarding harms and benefits of MRI, stratified by clinician type and specialty

Survey question	Overall ($N = 431$)	Advanced practice clinicians ($n = 103$)	Physicians ($n = 326$)	Wilcoxon rank sum test p value: APCs vs. physicians	Neurologists ($n = 177$)	Primary care clinicians ($n = 140$)	Wilcoxon rank sum test p value: neurologists vs. primary care clinicians
In patients with headaches and a normal neurologic examination, how often does an MRI identify …							
Any abnormality at all							
<1%	64 (14.9%)	19 (18.5%)	45 (13.9%)	0.039	14 (7.9%)	30 (21.4%)	<0.001
1%–5%	116 (27.0%)	38 (36.9%)	78 (24.0%)		38 (21.5%)	38 (27.1%)	
6%–10%	78 (18.2%)	15 (14.6%)	63 (19.4%)		32 (18.1%)	30 (21.4%)	
11%–30%	86 (20.1%)	10 (9.7%)	76 (23.4%)		53 (29.9%)	20 (14.3%)	
31%–50%	33 (7.7%)	6 (5.8%)	27 (8.3%)		17 (9.6%)	10 (7.1%)	
51%–70%	19 (4.4%)	3 (2.9%)	15 (4.6%)		10 (5.7%)	4 (2.9%)	
71%–89%	16 (3.7%)	4 (3.9%)	12 (3.7%)		7 (4.0%)	5 (3.6%)	
90%–94%	9 (2.1%)	4 (3.9%)	5 (1.5%)		4 (2.3%)	1 (0.7%)	
95%–99%	4 (0.9%)	2 (1.9%)	2 (0.6%)		1 (0.6%)	1 (0.7%)	
>99%	4 (0.9%)	2 (1.9%)	2 (0.6%)		1 (0.6%)	1 (0.7%)	
Missing	2	0	1		0	0	
Brain tumor							
<1%	346 (82.0%)	73 (71.6%)	272 (85.3%)	0.001	152 (87.4%)	113 (82.5%)	0.196
1%–5%	57 (13.5%)	19 (18.6%)	38 (11.9%)		20 (11.5%)	18 (13.1%)	
6%–10%	2 (0.5%)	1 (1.0%)	1 (0.3%)		1 (0.6%)	0 (0.0%)	
11%–30%	0 (0.0%)	0 (0.0%)	0 (0.0%)		0 (0.0%)	0 (0.0%)	
31%–50%	2 (0.5%)	1 (1.0%)	1 (0.3%)		0 (0.0%)	1 (0.7%)	
51%–70%	1 (0.2%)	0 (0.0%)	1 (0.3%)		0 (0.0%)	0 (0.0%)	
71%–89%	3 (0.7%)	1 (1.0%)	2 (0.6%)		1 (0.6%)	1 (0.7%)	
90%–94%	3 (0.7%)	2 (2.0%)	1 (0.3%)		0 (0.0%)	1 (0.7%)	
95%–99%	5 (1.2%)	3 (2.9%)	2 (0.6%)		0 (0.0%)	2 (1.5%)	
>99%	3 (0.7%)	2 (2.0%)	1 (0.3%)		0 (0.0%)	1 (0.7%)	
Missing	9	1	7		3	3	

TABLE 1 (Continued)

Survey question	Overall (*N* = 431)	Advanced practice clinicians (*n* = 103)	Physicians (*n* = 326)	Wilcoxon rank sum test *p* value: APCs vs. physicians	Neurologists (*n* = 177)	Primary care clinicians (*n* = 140)	Wilcoxon rank sum test *p* value: neurologists vs. primary care clinicians
An abnormality that changes management of the patient							
<1%	168 (39.6%)	29 (28.4%)	139 (43.3%)	0.009	65 (37.1%)	70 (51.1%)	0.027
1%–5%	170 (40.1%)	49 (48.0%)	120 (37.4%)		74 (42.3%)	44 (32.1%)	
6%–10%	55 (13.0%)	10 (9.8%)	45 (14.0%)		25 (14.3%)	18 (13.1%)	
11%–30%	14 (3.3%)	3 (2.9%)	11 (3.4%)		10 (5.7%)	1 (0.7%)	
31%–50%	7 (1.7%)	7 (6.9%)	0 (0.0%)		0 (0.0%)	0 (0.0%)	
51%–70%	5 (1.2%)	1 (1.0%)	4 (1.3%)		1 (0.6%)	2 (1.5%)	
71%–89%	1 (0.2%)	1 (1.0%)	0 (0.0%)		0 (0.0%)	0 (0.0%)	
90%–94%	1 (0.2%)	1 (1.0%)	0 (0.0%)		0 (0.0%)	0 (0.0%)	
95%–99%	3 (0.7%)	1 (1.0%)	2 (0.6%)		0 (0.0%)	2 (1.5%)	
>99%	0 (0.0%)	0 (0.0%)	0 (0.0%)		0 (0.0%)	0 (0.0%)	
Missing	7	1	5		2	3	
How often do you believe headache patients …							
Are harmed by MRI due to subsequent decisions based on MRI results?							
Never	31 (7.2%)	11 (10.8%)	20 (6.1%)	0.204	10 (5.7%)	7 (5.0%)	0.004
Rarely	217 (50.6%)	52 (51.0%)	164 (50.3%)		101 (57.1%)	60 (42.9%)	
Occasionally	149 (34.7%)	32 (31.4%)	117 (35.9%)		59 (33.3%)	56 (40.0%)	
Often	31 (7.2%)	7 (6.9%)	24 (7.4%)		7 (4.0%)	16 (11.4%)	
Almost always	1 (0.2%)	0 (0.0%)	1 (0.3%)		0 (0.0%)	1 (0.7%)	
Missing	2	1	0		0	0	
Benefit from MRI due to improved management decisions based on MRI results?							
Never	8 (1.9%)	3 (2.9%)	5 (1.5%)	<0.001	2 (1.1%)	3 (2.1%)	0.816
Rarely	153 (35.7%)	18 (17.7%)	134 (41.1%)		74 (41.8%)	59 (42.1%)	
Occasionally	179 (41.7%)	49 (48.0%)	130 (39.9%)		77 (43.5%)	51 (36.4%)	
Often	74 (17.3%)	28 (27.5%)	46 (14.1%)		18 (10.2%)	23 (16.4%)	
Almost always	15 (3.5%)	4 (3.9%)	11 (3.4%)		6 (3.4%)	4 (2.9%)	
Missing	2	1	0		0	0	

TABLE 1 (Continued)

Survey question	Overall (*N* = 431)	Advanced practice clinicians (*n* = 103)	Physicians (*n* = 326)	Wilcoxon rank sum test *p* value: APCs vs. physicians	Neurologists (*n* = 177)	Primary care clinicians (*n* = 140)	Wilcoxon rank sum test *p* value: neurologists vs. primary care clinicians
Among patients I have cared for receiving MRI for headache, how often have the following harms occurred?							
Difficulty tolerating the MRI scan itself							
Never	29 (6.8%)	18 (17.5%)	11 (3.4%)	0.008	3 (1.7%)	7 (5.0%)	0.105
Rarely	137 (32.1%)	31 (30.1%)	105 (32.5%)		50 (28.7%)	51 (36.4%)	
Occasionally	216 (50.6%)	44 (42.7%)	172 (53.3%)		104 (59.8%)	66 (47.1%)	
Often	45 (10.5%)	10 (9.7%)	35 (10.8%)		17 (9.8%)	16 (11.4%)	
Almost always	0 (0.0%)	0 (0.0%)	0 (0.0%)		0 (0.0%)	0 (0.0%)	
Missing	4	0	3		3	0	
Unnecessary tests due to false positive findings							
Never	37 (8.7%)	20 (19.4%)	17 (5.3%)	<0.001	10 (5.7%)	6 (4.3%)	0.086
Rarely	165 (38.6%)	49 (47.6%)	115 (35.6%)		66 (37.7%)	46 (33.1%)	
Occasionally	174 (40.8%)	27 (26.2%)	147 (45.5%)		82 (46.9%)	62 (44.6%)	
Often	50 (11.7%)	7 (6.8%)	43 (13.3%)		17 (9.7%)	24 (17.3%)	
Almost always	1 (0.2%)	0 (0.0%)	1 (0.3%)		0 (0.0%)	1 (0.7%)	
Missing	4	0	3		2	1	
Unnecessary procedures due to false positive findings							
Never	76 (17.7%)	30 (29.1%)	46 (14.2%)	<0.001	26 (14.8%)	19 (13.6%)	0.228
Rarely	213 (49.7%)	50 (48.5%)	162 (49.9%)		91 (51.7%)	66 (47.1%)	
Occasionally	115 (26.8%)	17 (16.5%)	98 (30.2%)		53 (30.1%)	43 (30.7%)	
Often	24 (5.6%)	6 (5.8%)	18 (5.5%)		6 (3.4%)	11 (7.9%)	
Almost always	1 (0.2%)	0 (0.0%)	1 (0.3%)		0 (0.0%)	1 (0.7%)	
Missing	2	0	1		1	0	
Unnecessary medications due to false positive findings							
Never	86 (20.1%)	27 (26.2%)	59 (18.2%)	0.264	39 (22.2%)	19 (13.6%)	0.020
Rarely	237 (55.3%)	51 (49.5%)	185 (56.9%)		100 (56.8%)	80 (57.1%)	
Occasionally	89 (20.8%)	21 (20.4%)	68 (20.9%)		33 (18.8%)	34 (24.3%)	
Often	16 (3.7%)	4 (3.9%)	12 (3.7%)		4 (2.3%)	6 (4.3%)	
Almost always	1 (0.2%)	0 (0.0%)	1 (0.3%)		0 (0.0%)	1 (0.7%)	
Missing	2	0	1		1	0	

TABLE 1 (Continued)

Survey question	Overall (*N* = 431)	Advanced practice clinicians (*n* = 103)	Physicians (*n* = 326)	Wilcoxon rank sum test *p* value: APCs vs. physicians	Neurologists (*n* = 177)	Primary care clinicians (*n* = 140)	Wilcoxon rank sum test *p* value: neurologists vs. primary care clinicians
Unnecessary consultations due to false positive findings							
Never	37 (8.6%)	16 (15.5%)	21 (6.5%)	<0.001	16 (9.1%)	4 (2.9%)	0.002
Rarely	153 (35.7%)	46 (44.7%)	106 (32.6%)		66 (37.5%)	36 (25.7%)	
Occasionally	166 (38.7%)	34 (33.0%)	132 (40.6%)		63 (35.8%)	68 (48.6%)	
Often	63 (14.7%)	7 (6.8%)	56 (17.2%)		29 (16.5%)	25 (17.9%)	
Almost always	10 (2.3%)	0 (0.0%)	10 (3.1%)		2 (1.1%)	7 (5.0%)	
Missing	2	0	1		1	0	
How emotionally bothersome would you find it if one of your patients …							
Was harmed by treatment for a finding discovered by a guideline-supported headache MRI							
Not at all	14 (3.3%)	2 (2.0%)	12 (3.7%)	<0.001	7 (4.0%)	5 (3.6%)	0.701
Slightly	81 (19.1%)	8 (8.0%)	73 (22.6%)		41 (23.3%)	31 (22.5%)	
Moderately	131 (30.9%)	29 (29.0%)	101 (31.3%)		51 (29.0%)	47 (34.1%)	
Very much	145 (34.2%)	43 (43.0%)	102 (31.6%)		56 (31.8%)	41 (29.7%)	
Extremely	53 (12.5%)	18 (18.0%)	35 (10.8%)		21 (11.9%)	14 (10.1%)	
Missing	7	3	3		1	2	
Was harmed by a guideline-supported decision not to perform headache MRI							
Not at all	9 (2.1%)	1 (1.0%)	8 (2.5%)	0.002	6 (3.4%)	2 (1.4%)	0.376
Slightly	40 (9.4%)	6 (5.9%)	34 (10.5%)		12 (6.8%)	21 (15.1%)	
Moderately	114 (26.8%)	21 (20.8%)	93 (28.7%)		53 (30.1%)	38 (27.3%)	
Very much	175 (41.1%)	43 (42.6%)	131 (40.4%)		72 (40.9%)	54 (38.9%)	
Extremely	88 (20.7%)	30 (29.7%)	58 (17.9%)		33 (18.8%)	24 (17.3%)	
Missing	5	2	2		1	1	

Abbreviations: APCs, advanced practice clinicians; MRI, magnetic resonance imaging.

TABLE 2 Expected improvement in MRI utilization upon implementation of various interventions, stratified by clinician type and specialty

Survey question	Overall ($N = 431$)	Advanced practice clinicians ($n = 103$)	Physicians ($n = 326$)	Wilcoxon rank sum test p value: APCs vs. physicians	Neurologists ($n = 177$)	Primary care clinicians ($n = 140$)	Wilcoxon rank sum test p value: neurologists vs. primary care clinicians
How much do you think your headache MRI use would improve if the following environmental changes were implemented …							
Link to clinical practice guidelines in the electronic health record							
Not at all	51 (11.9%)	2 (1.9%)	49 (15.1%)	<0.001	38 (21.6%)	10 (7.2%)	0.002
Slightly	103 (24.1%)	12 (11.7%)	90 (27.8%)		50 (28.4%)	39 (28.1%)	
Moderately	132 (30.8%)	37 (35.9%)	95 (29.3%)		47 (26.7%)	44 (31.7%)	
Very much	117 (27.3%)	38 (36.9%)	79 (24.4%)		34 (19.3%)	42 (30.2%)	
Extremely	25 (5.8%)	14 (13.6%)	11 (3.4%)		7 (4.0%)	4 (2.9%)	
Missing	3	0	2		1	1	
Better clinical practice guidelines							
Not at all	35 (8.2%)	1 (1.0%)	34 (10.6%)	<0.001	27 (15.4%)	6 (4.4%)	<0.001
Slightly	82 (19.3%)	10 (9.7%)	72 (22.4%)		44 (25.1%)	27 (19.6%)	
Moderately	142 (33.3%)	32 (31.1%)	109 (33.9%)		56 (32.0%)	49 (35.5%)	
Very much	142 (33.3%)	44 (42.7%)	98 (30.4%)		42 (24.0%)	53 (38.4%)	
Extremely	25 (5.9%)	16 (15.5%)	9 (2.8%)		6 (3.4%)	3 (2.2%)	
Missing	5	0	4		2	2	
Restriction on imaging ordering within the electronic health record							
Not at all	135 (32.0%)	20 (19.4%)	114 (35.9%)	<0.001	72 (41.4%)	39 (28.9%)	0.008
Slightly	96 (22.8%)	19 (18.5%)	77 (24.2%)		39 (22.4%)	37 (27.4%)	
Moderately	89 (21.1%)	25 (24.3%)	64 (20.1%)		41 (23.6%)	21 (15.6%)	
Very much	84 (19.9%)	29 (28.2%)	55 (17.3%)		19 (10.9%)	33 (24.4%)	
Extremely	18 (4.3%)	10 (9.7%)	8 (2.5%)		3 (1.7%)	5 (3.7%)	
Missing	9	0	8		3	5	
Streamlined specialty referral protocols							
Not at all	58 (13.7%)	3 (2.9%)	55 (17.1%)	<0.001	52 (30.1%)	2 (1.4%)	<0.001
Slightly	74 (17.4%)	9 (8.7%)	64 (19.9%)		42 (24.3%)	21 (15.1%)	
Moderately	108 (25.4%)	25 (24.3%)	83 (25.9%)		39 (22.5%)	41 (29.5%)	
Very much	143 (33.7%)	52 (50.5%)	91 (28.4%)		35 (20.2%)	53 (38.1%)	
Extremely	42 (9.9%)	14 (13.6%)	28 (8.7%)		5 (2.9%)	22 (15.8%)	
Missing	6	0	5		4	1	

TABLE 2 (Continued)

Survey question	Overall ($N = 431$)	Advanced practice clinicians ($n = 103$)	Physicians ($n = 326$)	Wilcoxon rank sum test p value: APCs vs. physicians	Neurologists ($n = 177$)	Primary care clinicians ($n = 140$)	Wilcoxon rank sum test p value: neurologists vs. primary care clinicians
Increased availability of informal neurologist input prior to headache MRI							
Not at all	78 (18.6%)	5 (4.9%)	72 (22.8%)	<0.001	65 (38.2%)	5 (3.7%)	NA
Slightly	64 (15.2%)	7 (6.8%)	57 (18.0%)		34 (20.0%)	23 (16.8%)	
Moderately	90 (21.4%)	21 (20.4%)	69 (21.8%)		37 (21.8%)	29 (21.2%)	
Very much	123 (29.3%)	41 (39.8%)	82 (26.0%)		28 (16.5%)	50 (36.5%)	
Extremely	65 (15.5%)	29 (28.2%)	36 (11.4%)		6 (3.5%)	30 (21.9%)	
Missing	11	0	10		7	3	
Patient education materials regarding risks/benefits of headache MRI							
Not at all	38 (9.0%)	4 (4.0%)	34 (10.6%)	<0.001	21 (12.0%)	11 (8.0%)	0.111
Slightly	122 (28.8%)	18 (17.8%)	103 (32.0%)		56 (32.0%)	46 (33.3%)	
Moderately	124 (29.3%)	26 (25.7%)	98 (30.4%)		60 (34.3%)	34 (24.6%)	
Very much	105 (24.8%)	38 (37.6%)	67 (20.8%)		28 (16.0%)	37 (26.8%)	
Extremely	35 (8.3%)	15 (14.9%)	20 (6.2%)		10 (5.7%)	10 (7.3%)	
Missing	7	2	4		2	2	
Clinical decision support in the electronic health record to help with headache MRI decisions based on the patient's clinical scenario							
Not at all	48 (11.2%)	1 (1.0%)	47 (14.6%)	<0.001	35 (19.9%)	10 (7.3%)	<0.001
Slightly	89 (20.8%)	14 (13.6%)	74 (22.9%)		51 (29.0%)	23 (16.7%)	
Moderately	130 (30.5%)	31 (30.1%)	99 (30.7%)		49 (27.8%)	45 (32.6%)	
Very much	127 (29.7%)	42 (40.8%)	85 (26.3%)		30 (17.1%)	53 (38.4%)	
Extremely	33 (7.7%)	15 (14.6%)	18 (5.6%)		11 (6.3%)	7 (5.1%)	
Missing	4	0	3		1	2	
Shared decision-making tool to help patients with headache neuroimaging decisions							
Not at all	43 (10.1%)	5 (4.9%)	38 (11.8%)	<0.001	25 (14.3%)	11 (7.9%)	0.002
Slightly	112 (26.2%)	16 (15.5%)	95 (29.4%)		61 (34.9%)	34 (24.5%)	
Moderately	120 (28.1%)	29 (28.2%)	91 (28.2%)		47 (26.9%)	41 (29.5%)	
Very much	123 (28.8%)	37 (35.9%)	86 (26.6%)		35 (20.0%)	47 (33.8%)	
Extremely	29 (6.8%)	16 (15.5%)	13 (4.0%)		7 (4.0%)	6 (4.3%)	
Missing	4	0	3		2	1	

TABLE 2 (Continued)

Survey question	Overall ($N = 431$)	Advanced practice clinicians ($n = 103$)	Physicians ($n = 326$)	Wilcoxon rank sum test p value: APCs vs. physicians	Neurologists ($n = 177$)	Primary care clinicians ($n = 140$)	Wilcoxon rank sum test p value: neurologists vs. primary care clinicians
Less time pressure in clinic							
Not at all	47 (11.0%)	2 (1.9%)	44 (13.6%)	<0.001	33 (18.9%)	9 (6.5%)	<0.001
Slightly	90 (21.1%)	13 (12.6%)	77 (23.8%)		55 (31.4%)	22 (15.8%)	
Moderately	104 (24.4%)	32 (31.1%)	72 (22.3%)		31 (17.7%)	38 (27.3%)	
Very much	111 (26.0%)	28 (27.2%)	83 (25.7%)		41 (23.4%)	38 (27.3%)	
Extremely	75 (17.6%)	28 (27.2%)	47 (14.6%)		15 (8.6%)	32 (23.0%)	
Missing	4	0	3		2	1	
Reminders about optimal practice patterns in the electronic health record							
Not at all	79 (18.8%)	7 (6.9%)	72 (22.6%)	<0.001	44 (25.6%)	26 (18.8%)	0.066
Slightly	128 (30.5%)	18 (17.8%)	109 (34.3%)		61 (35.5%)	47 (34.1%)	
Moderately	111 (26.4%)	37 (36.6%)	74 (23.3%)		40 (23.3%)	32 (23.2%)	
Very much	79 (18.8%)	26 (25.7%)	53 (16.7%)		21 (12.2%)	29 (21.0%)	
Extremely	23 (5.5%)	13 (12.9%)	10 (3.2%)		6 (3.5%)	4 (2.9%)	
Missing	11	2	8		5	2	

Abbreviations: APCs, advanced practice clinicians; MRI, magnetic resonance imaging.

TABLE 3 Clinician attitudes and confidence towards MRI utilization, stratified by clinician type and specialty

Survey question	Overall ($N = 431$)	Advanced practice clinicians ($n = 103$)	Physicians ($n = 326$)	Wilcoxon rank sum test p value: APCs vs. physicians	Neurologists ($n = 177$)	Primary care clinicians ($n = 140$)	Wilcoxon rank sum test p value: neurologists vs. primary care clinicians
How would you rate your knowledge of guideline recommendations for headache neuroimaging?							
Poor	62 (14.5%)	22 (21.4%)	40 (12.3%)	<0.001	9 (5.1%)	29 (20.7%)	<0.001
Fair	165 (38.5%)	50 (48.5%)	114 (35.1%)		42 (23.9%)	69 (49.3%)	
Good	127 (29.6%)	23 (22.3%)	104 (32.0%)		66 (37.5%)	34 (24.3%)	
Very good	60 (14.0%)	7 (6.8%)	53 (16.3%)		46 (26.1%)	7 (5.0%)	
Excellent	15 (3.5%)	1 (1.0%)	14 (4.3%)		13 (7.4%)	1 (0.7%)	
Missing	2	0	1		1	0	
Evaluate your agreement with the following statements:							
MRI is overused in patients presenting with headaches							
Strongly disagree	7 (1.6%)	2 (2.0%)	5 (1.5%)	<0.001	1 (0.6%)	2 (1.4%)	0.723
Disagree	31 (7.2%)	16 (15.7%)	15 (4.6%)		9 (5.1%)	5 (3.6%)	
Neutral	74 (17.3%)	30 (29.4%)	44 (13.5%)		25 (14.1%)	16 (11.4%)	
Agree	208 (48.5%)	38 (37.3%)	170 (52.2%)		87 (49.2%)	81 (57.9%)	
Strongly agree	109 (25.4%)	16 (15.7%)	92 (28.2%)		55 (31.1%)	36 (25.7%)	
Missing	2	1	0		0	0	
It is important to reduce overall use of MRI in patients presenting with headaches							
Strongly disagree	4 (0.9%)	0 (0.0%)	4 (1.2%)	0.007	1 (0.6%)	2 (1.4%)	0.227
Disagree	37 (8.7%)	15 (14.9%)	22 (6.8%)		13 (7.4%)	6 (4.3%)	
Neutral	107 (25.1%)	31 (30.7%)	76 (23.4%)		46 (26.1%)	27 (19.3%)	
Agree	202 (47.3%)	42 (41.6%)	160 (49.2%)		81 (46.0%)	77 (55.0%)	
Strongly agree	77 (18.0%)	13 (12.9%)	63 (19.4%)		35 (19.9%)	28 (20.0%)	
Missing	4	2	1		1	0	
Given how headaches are currently evaluated, it is common that an underlying headache-causing diagnosis is missed during initial evaluation							
Strongly disagree	22 (5.2%)	1 (1.0%)	21 (6.5%)	<0.001	15 (8.5%)	6 (4.3%)	<0.001
Disagree	160 (37.7%)	25 (25.0%)	135 (41.7%)		88 (50.0%)	46 (33.1%)	
Neutral	116 (27.3%)	31 (31.0%)	84 (25.9%)		41 (23.3%)	39 (28.1%)	
Agree	103 (24.2%)	37 (37.0%)	66 (20.4%)		25 (14.2%)	38 (27.3%)	
Strongly agree	24 (5.7%)	6 (6.0%)	18 (5.6%)		7 (4.0%)	10 (7.2%)	
Missing	6	3	2		1	1	

(Continues)

TABLE 3 (Continued)

Survey question	Overall ($N = 431$)	Advanced practice clinicians ($n = 103$)	Physicians ($n = 326$)	Wilcoxon rank sum test p value: APCs vs. physicians	Neurologists ($n = 177$)	Primary care clinicians ($n = 140$)	Wilcoxon rank sum test p value: neurologists vs. primary care clinicians
It is my responsibility to never miss a brain tumor causing headache							
Strongly disagree	9 (2.1%)	1 (1.0%)	8 (2.5%)	0.211	5 (2.8%)	3 (2.2%)	0.286
Disagree	26 (6.1%)	5 (4.9%)	21 (6.5%)		11 (6.2%)	10 (7.2%)	
Neutral	49 (11.5%)	6 (5.9%)	42 (12.9%)		19 (10.7%)	21 (15.1%)	
Agree	213 (49.8%)	58 (56.9%)	155 (47.7%)		84 (47.5%)	66 (47.5%)	
Strongly agree	131 (30.6%)	32 (31.4%)	99 (30.5%)		58 (32.8%)	39 (28.1%)	
Missing	3	1	1		0	1	
When it comes to medical care, in general, more is usually better							
Strongly disagree	64 (16.1%)	8 (8.5%)	56 (18.5%)	0.010	29 (17.1%)	27 (21.6%)	0.457
Disagree	222 (55.9%)	54 (57.5%)	168 (55.5%)		96 (56.5%)	69 (55.2%)	
Neutral	77 (19.4%)	17 (18.1%)	60 (19.8%)		39 (22.9%)	18 (14.4%)	
Agree	31 (7.8%)	14 (14.9%)	17 (5.6%)		5 (2.9%)	10 (8.0%)	
Strongly agree	3 (0.8%)	1 (1.1%)	2 (0.7%)		1 (0.6%)	1 (0.8%)	
Missing	34	9	23		7	15	
When it comes to diagnostic tests, more is usually better							
Strongly disagree	89 (21.0%)	12 (12.0%)	77 (23.9%)	0.020	40 (23.1%)	37 (26.4%)	0.896
Disagree	217 (51.3%)	55 (55.0%)	162 (50.3%)		92 (53.2%)	68 (48.6%)	
Neutral	86 (20.3%)	25 (25.0%)	61 (18.9%)		33 (19.1%)	24 (17.1%)	
Agree	26 (6.2%)	7 (7.0%)	19 (5.9%)		7 (4.1%)	9 (6.4%)	
Strongly agree	5 (1.2%)	1 (1.0%)	3 (0.9%)		1 (0.6%)	2 (1.4%)	
Missing	8	3	4		4	0	
I am confident in my ability to:							
Take a history to identify "red flags" suggesting a possible intracranial mass lesion							
Strongly disagree	1 (0.2%)	0 (0.0%)	1 (0.3%)	<0.001	1 (0.6%)	0 (0.0%)	<0.001
Disagree	4 (0.9%)	4 (3.9%)	0 (0.0%)		0 (0.0%)	0 (0.0%)	
Neutral	24 (5.6%)	12 (11.8%)	12 (3.7%)		2 (1.1%)	9 (6.4%)	
Agree	242 (56.4%)	61 (59.8%)	180 (55.2%)		75 (42.4%)	99 (70.7%)	
Strongly agree	158 (36.8%)	25 (24.5%)	133 (40.8%)		99 (55.9%)	32 (22.9%)	
Missing	2	1	0		0	0	

TABLE 3 (Continued)

Survey question	Overall (*N* = 431)	Advanced practice clinicians (*n* = 103)	Physicians (*n* = 326)	Wilcoxon rank sum test *p* value: APCs vs. physicians	Neurologists (*n* = 177)	Primary care clinicians (*n* = 140)	Wilcoxon rank sum test *p* value: neurologists vs. primary care clinicians
Identify abnormalities on neurologic examination that suggest a possible intracranial mass lesion							
Strongly disagree	2 (0.5%)	1 (1.0%)	1 (0.3%)	<0.001	1 (0.6%)	0 (0.0%)	<0.001
Disagree	6 (1.4%)	4 (3.9%)	2 (0.6%)		0 (0.0%)	2 (1.4%)	
Neutral	43 (10.1%)	17 (16.7%)	25 (7.7%)		2 (1.1%)	23 (16.4%)	
Agree	240 (56.1%)	69 (67.7%)	171 (52.6%)		71 (40.3%)	92 (65.7%)	
Strongly agree	137 (32.0%)	11 (10.8%)	126 (38.8%)		102 (58.0%)	23 (16.4%)	
Missing	3	1	1		1	0	
Make decisions about whether to obtain MRI in headache patients							
Strongly disagree	1 (0.2%)	0 (0.0%)	1 (0.3%)	<0.001	1 (0.6%)	0 (0.0%)	<0.001
Disagree	12 (2.8%)	7 (6.9%)	5 (1.5%)		0 (0.0%)	5 (3.6%)	
Neutral	27 (6.3%)	14 (13.7%)	13 (4.0%)		0 (0.0%)	13 (9.3%)	
Agree	275 (64.1%)	68 (66.7%)	206 (63.2%)		96 (54.2%)	102 (72.9%)	
Strongly agree	114 (26.6%)	13 (12.8%)	101 (31.0%)		80 (45.2%)	20 (14.3%)	
Missing	2	1	0		0	0	
Discuss whether to obtain MRI with a patient that wants MRI, but I believe it is not clinically indicated							
Strongly disagree	3 (0.7%)	2 (2.0%)	1 (0.3%)	0.016	1 (0.6%)	0 (0.0%)	<0.001
Disagree	19 (4.5%)	6 (5.9%)	13 (4.0%)		2 (1.1%)	10 (7.3%)	
Neutral	58 (13.7%)	16 (15.8%)	41 (12.7%)		16 (9.0%)	25 (18.3%)	
Agree	258 (60.7%)	64 (63.4%)	194 (60.1%)		98 (55.4%)	89 (65.0%)	
Strongly agree	87 (20.5%)	13 (12.9%)	74 (22.9%)		60 (33.9%)	13 (9.5%)	
Missing	6	2	3		0	3	
Interpret and appropriately act on brain MRI reports							
Strongly disagree	2 (0.5%)	1 (1.0%)	1 (0.3%)	<0.001	1 (0.6%)	0 (0.0%)	<0.001
Disagree	27 (6.3%)	14 (13.7%)	13 (4.0%)		1 (0.6%)	11 (7.9%)	
Neutral	37 (8.7%)	16 (15.7%)	21 (6.5%)		2 (1.1%)	19 (13.6%)	
Agree	224 (52.3%)	60 (58.8%)	164 (50.5%)		69 (39.2%)	90 (64.3%)	
Strongly agree	138 (32.2%)	11 (10.8%)	126 (38.8%)		103 (58.5%)	20 (14.3%)	
Missing	3	1	1		1	0	

Abbreviations: APCs, advanced practice clinicians; MRI, magnetic resonance imaging.

TABLE 4 Other considerations for MRI ordering: Patient, time, and other concerns, stratified by clinician type and specialty

Survey question	Overall ($N = 431$)	Advanced practice clinicians ($n = 103$)	Physicians ($n = 326$)	Wilcoxon rank sum test p value: APCs vs. physicians	Neurologists ($n = 177$)	Primary care clinicians ($n = 140$)	Wilcoxon rank sum test p value: neurologists vs. primary care clinicians
How commonly do you order MRI for a patient presenting with headaches …							
When a patient requests the test							
Never	27 (6.3%)	8 (7.8%)	19 (5.8%)	0.480	5 (2.8%)	13 (9.3%)	0.003
Rarely	140 (32.6%)	32 (31.4%)	108 (33.1%)		55 (31.1%)	51 (36.4%)	
Occasionally	192 (44.8%)	50 (49.0%)	142 (43.6%)		79 (44.6%)	60 (42.9%)	
Often	51 (11.9%)	8 (7.8%)	42 (12.9%)		27 (15.3%)	13 (9.3%)	
Almost always	19 (4.4%)	4 (3.9%)	15 (4.6%)		11 (6.2%)	3 (2.1%)	
Missing	2	1	0		0	0	
When a patient requests the test, but you believe it is not clinically indicated							
Never	74 (17.4%)	14 (13.9%)	60 (18.5%)	0.992	30 (17.1%)	28 (20.1%)	0.095
Rarely	203 (47.7%)	54 (53.5%)	149 (46.0%)		78 (44.3%)	69 (49.6%)	
Occasionally	120 (28.2%)	28 (27.7%)	91 (28.1%)		51 (29.0%)	36 (25.9%)	
Often	19 (4.5%)	3 (3.0%)	16 (4.9%)		11 (6.3%)	5 (3.6%)	
Almost always	10 (2.4%)	2 (2.0%)	8 (2.5%)		6 (3.4%)	1 (0.7%)	
Missing	5	2	2		1	1	
For your patients that have received an MRI for headaches, how often did you believe it was the right decision to order the MRI							
Never	2 (0.5%)	0 (0.0%)	2 (0.6%)	0.021	1 (0.6%)	1 (0.7%)	0.329
Rarely	37 (8.8%)	3 (3.0%)	34 (10.7%)		21 (12.2%)	12 (8.7%)	
Occasionally	111 (26.5%)	23 (23.2%)	88 (27.6%)		42 (24.4%)	46 (33.3%)	
Often	199 (47.5%)	54 (54.6%)	144 (45.1%)		76 (44.2%)	61 (44.2%)	
Always	70 (16.7%)	19 (19.2%)	51 (16.0%)		32 (18.6%)	18 (13.0%)	
Missing	12	4	7		5	2	
On average, how much time does it take							
To discuss, order, interpret and follow-up an MRI for a patient presenting for headaches							
0–5 min per patient	37 (8.7%)	3 (3.0%)	34 (10.5%)	0.023	16 (9.1%)	17 (12.1%)	0.969
6–10 min per patient	132 (31.0%)	28 (28.0%)	104 (32.0%)		62 (35.2%)	39 (27.9%)	
10–20 min per patient	168 (39.4%)	44 (44.0%)	123 (37.9%)		62 (35.2%)	59 (42.1%)	
20+ min per patient	89 (20.9%)	25 (25.0%)	64 (19.7%)		36 (20.5%)	25 (17.9%)	
Missing	5	3	1		1	0	

TABLE 4 (Continued)

Survey question	Overall ($N = 431$)	Advanced practice clinicians ($n = 103$)	Physicians ($n = 326$)	Wilcoxon rank sum test p value: APCs vs. physicians	Neurologists ($n = 177$)	Primary care clinicians ($n = 140$)	Wilcoxon rank sum test p value: neurologists vs. primary care clinicians
To NOT order an MRI for a patient presenting with headaches? (e.g., discussing decision with patient, implementing alternative management strategies)							
0–5 min per patient	62 (14.6%)	9 (9.1%)	53 (16.3%)	0.055	41 (23.3%)	12 (8.6%)	<0.001
6–10 min per patient	141 (33.2%)	30 (30.3%)	111 (34.2%)		67 (38.1%)	40 (28.6%)	
10–20 min per patient	141 (33.2%)	39 (39.4%)	101 (31.1%)		42 (23.9%)	55 (39.3%)	
20+ min per patient	81 (19.1%)	21 (21.2%)	60 (18.5%)		26 (14.8%)	33 (23.6%)	
Missing	6	4	1		1	0	
How often are the following considerations relevant to your decisions to order MRI in patients presenting with headache							
Malpractice concerns							
Never	70 (16.4%)	15 (14.6%)	55 (17.0%)	0.334	33 (18.8%)	20 (14.4%)	0.038
Rarely	125 (29.2%)	27 (26.2%)	98 (30.3%)		57 (32.4%)	40 (28.8%)	
Occasionally	118 (27.6%)	31 (30.1%)	87 (26.9%)		50 (28.4%)	34 (24.5%)	
Often	88 (20.6%)	24 (23.3%)	63 (19.4%)		28 (15.9%)	33 (23.7%)	
Almost always	27 (6.3%)	6 (5.8%)	21 (6.5%)		8 (4.6%)	12 (8.6%)	
Missing	3	0	2		1	1	
Financial incentives							
Never	360 (84.7%)	77 (75.5%)	282 (87.6%)	0.002	155 (88.6%)	119 (86.2%)	0.564
Rarely	45 (10.6%)	14 (13.7%)	31 (9.6%)		15 (8.6%)	16 (11.6%)	
Occasionally	15 (3.5%)	8 (7.8%)	7 (2.2%)		4 (2.3%)	3 (2.2%)	
Often	4 (0.9%)	3 (2.9%)	1 (0.3%)		1 (0.6%)	0 (0.0%)	
Almost always	1 (0.2%)	0 (0.0%)	1 (0.3%)		0 (0.0%)	0 (0.0%)	
Missing	6	1	4		2	2	
Requirements prior to specialist referral							
Never	111 (26.4%)	11 (10.7%)	99 (31.3%)	<0.001	93 (55.4%)	6 (4.3%)	<0.01
Rarely	56 (13.3%)	6 (5.8%)	50 (15.8%)		40 (23.8%)	9 (6.5%)	
Occasionally	71 (16.9%)	17 (16.5%)	54 (17.1%)		26 (15.5%)	28 (20.1%)	
Often	107 (25.5%)	42 (40.8%)	65 (20.6%)		7 (4.2%)	55 (39.6%)	
Almost always	75 (17.9%)	27 (26.2%)	48 (15.2%)		2 (1.2%)	41 (29.5%)	
Missing	11	0	10		9	1	

Abbreviations: APCs, advanced practice clinicians; MRI, magnetic resonance imaging.

consultations (neurology: occasionally [rarely, occasionally] vs. primary care: occasionally [rarely, occasionally], $p = 0.002$), but not tests (neurology: occasionally [rarely, occasionally] vs. primary care: occasionally [rarely, occasionally], $p = 0.086$) or procedures (neurology: rarely [rarely, occasionally] vs. primary care: rarely [rarely, occasionally], $p = 0.228$) following a false positive MRI finding. APCs believed patients with headaches were more likely to benefit from neuroimaging compared to physicians (APCs: occasionally [occasionally, often] vs. physicians: occasionally [rarely, occasionally], $p < 0.001$). Additionally, APCs less frequently reported patients having difficulty tolerating the MRI itself (APCs: occasionally [rarely, occasionally] vs. physicians: occasionally [rarely, occasionally], $p = 0.008$), and having unnecessary tests (APCs: rarely [rarely, occasionally] vs. physicians: occasionally [rarely, occasionally], $p < 0.001$), procedures (APCs: rarely [never, rarely] vs. physicians: rarely [rarely, occasionally], $p < 0.001$), and consultations (APCs: rarely [rarely, occasionally] vs. physicians: occasionally [rarely, occasionally], $p < 0.001$) due to false positive findings.

Overall, clinicians were more often emotionally burdened by harms from a guideline-supported decision to not perform (moderately/very much/extremely: 88.5%) than by harms from a decision to perform an MRI (moderately/very much/extremely: 77.6%). APCs were more often emotionally burdened when patients were harmed by performing (APC: very much [moderately, very much] vs. physicians: moderately [slightly, very much], $p < 0.001$) or not performing an MRI (APCs: very much [moderately, extremely] vs. physicians: very much [moderately, very much], $p = 0.002$) compared with physicians. There was no difference in the emotional burden between specialties following a decision stemming from an MRI.

Implementation interventions

Interventions that most clinicians believed would very much or extremely improve MRI utilization included increased access to neurologist consultations (44.8%), less time pressure in the clinic (43.6%), and streamlined referral protocols (43.5%). The least popular interventions included restrictions on neuroimaging ordering within the electronic health record (EHR) (not at all/slightly: 54.7%), reminders about optimal practice patterns in the EHR (not at all/slightly: 49.3%) and patient education materials regarding the risks/benefits of headache MRI (not at all/slightly: 37.7%). APCs and primary care clinicians were consistently more receptive to the interventions compared with physicians and neurologists, respectively ($p < 0.05$ for 17/19 comparisons in Table 2).

Clinician attitude and confidence towards MRI utilization

Neurologists (good [fair, very good]) reported having significantly better knowledge of headache neuroimaging guidelines compared with primary care clinicians (fair [fair, good], $p < 0.001$) and physicians (good [fair, good]) reported having significantly better knowledge of guidelines compared to APCs (fair [fair, good], $p < 0.001$) (Table 3).

Most clinicians agree or strongly agree that, for patients with headaches, MRI is overused (73.9%) and that it is important to reduce MRI utilization (65.3%), but that it was their responsibility to never miss a brain tumor (80.4%). More physicians believed that MRIs are overused compared with APCs (physicians: agree [agree, strongly agree] vs. APCs: agree [neutral, agree], $p < 0.001$). Physicians were more likely to endorse that MRIs should be reduced in patients with headaches compared with APCs (physicians: agree [neutral, agree] vs. APCs: agree [neutral, agree], $p = 0.007$). There were no differing opinions of excess MRI utilization between neurologists and primary care clinicians.

Physicians had more confidence in their abilities to identify red flags (physicians: agree [agree, strongly agree] vs. APCs: agree [agree, agree], $p < 0.001$), identify abnormalities on a neurologic examination (physicians: agree [agree, strongly agree] vs. APCs: agree [agree, agree], $p < 0.001$), determine whether to order an MRI in patients with headaches (physicians: agree [agree, strongly agree] vs. APCs: agree [agree, agree], $p < 0.001$), discuss the decision not to order an MRI with patients with headaches (physicians: agree [agree, agree] vs. APCs: agree [agree, agree], $p = 0.016$), and interpret and appropriately act on MRI reports (physicians: agree [agree, strongly agree] vs. APCs: agree [neutral, agree], $p < 0.001$) compared with APCs. Neurologists had significantly more confidence in their abilities to identify red flags (neurology: strongly agree [agree, strongly agree] vs. primary care: agree [agree, agree], $p < 0.001$), identify abnormalities on a neurologic examination (neurology: strongly agree [agree, strongly agree] vs. primary care: agree [agree, agree], $p < 0.001$), determine whether to order an MRI in patients with headaches (neurology: agree [agree, strongly agree] vs. primary care: agree [agree, agree], $p < 0.001$), discuss the decision not to order an MRI with patients with headaches (neurology: agree [agree, strongly agree] vs. primary care: agree [neutral, agree], $p < 0.001$), and interpret and appropriately act on MRI reports (neurology: strongly agree [agree, strongly agree] vs. primary care: agree [agree, agree], $p < 0.001$), compared with primary care clinicians (Table 4).

Other considerations for MRI ordering: Patient, time, and other concerns

Neurologists were more likely to order an MRI upon patient request (neurology: occasionally [rarely, occasionally] vs. primary care: occasionally [rarely, occasionally], $p = 0.003$), but there were no differences when the MRI was not clinically indicated (neurology: rarely [rarely, occasionally] vs. primary care: rarely [rarely, occasionally], $p = 0.095$).

Clinicians reported spending a median of 10–20 min to both order and not order an MRI for patients with headaches. Physicians spent less time ordering (physicians: 10–20 min [6–10 min, 10–20 min] vs. APC: 10–20 min [6–10 min, 20+ min], $p = 0.023$) and a similar amount of time not ordering (physicians: 6–10 min [6–10 min, 10–20 min] vs.

APC: 10–20 min [6–10 min, 10–20 min], $p = 0.055$) MRIs for patients with headaches compared with APCs. Among specialties, there were no differences in time to order an MRI (neurology: 10–20 min [6–10 min, 10–20 min] vs. primary care: 10–20 min [6–10 min, 10–20 min], $p = 0.969$), however, neurologists were faster when not ordering an MRI (e.g., discussing the decision with patients and implementing alternative management strategies) compared with primary care clinicians (neurology: 6–10 min [6–10 min, 10–20 min] vs. primary care: 10–20 min [6–10 min, 10–20 min], $p < 0.001$).

Most clinicians never/rarely (95.3%) considered financial incentives when deciding whether to order an MRI for patients with headaches. Across clinician types and specialties, a similar proportion of clinicians often/always considered malpractice concerns when deciding whether to order an MRI (APCs: 29.1%, physicians: 25.9%, neurology: 20.5%, and primary care: 32.4%). Requirements prior to a specialist referral were often/always considered for 69.1% of non-neurologists (Table 4).

Scenarios of patients with headaches

In the low-risk scenario without red flags, on average, clinicians would order an MRI 30.9% (SD = 31.7 and missing = 7) of the time. In contrast, clinicians would order an MRI 91.7% (SD = 16.2 and missing = 8) of the time in the high-risk scenario ($n = 420$ and mean [SD] difference: 60.6%, SD = 33.8, and Wilcoxon signed rank test p value < 0.001). Clinicians also reported increased beliefs of finding abnormalities (21.2% [SD = 20.9 and missing = 6] vs. 70.4% [SD = 24.6 and missing = 11], $n = 417$, mean [SD] difference: 48.9% [SD = 29.1], Wilcoxon signed rank test p value < 0.001), and tumors (10.1% [SD = 19.9 and missing = 8] vs. 53.9% [SD = 29.2 and missing = 13], $n = 413$, mean [SD] difference: 43.9% [SD = 30.8], Wilcoxon signed rank test p value < 0.001) in the high-risk scenario compared with the low risk scenario without red flags.

Clinician beliefs in harms were similar (13.2% [SD = 15.5 and missing = 9] vs. 16.6% [SD = 17.6 and missing = 16], $n = 411$, mean [SD] difference: 3.3% [SD = 16.3], Wilcoxon signed rank test p value < 0.001] but belief in benefits (25.1% [SD = 28.7 and missing = 12] vs. 68.2% [SD = 27.3 and missing = 18], $n = 408$, mean [SD] difference: 43.1% [SD = 32.4], Wilcoxon signed rank test p value < 0.001) increased substantially in the high-risk scenario compared with a low risk scenario without red flags. In the low-risk scenario without red flags, APCs had higher utilization (38.6% [SD = 32.9 and missing = 2]) compared with neurologists (28.7% [SD = 32.8 and missing = 3]) and primary care physicians (26.4% [SD = 28.0 and missing = 2], Kruskal-Wallis test p value = 0.009).

In the presence of three potential red flags with limited evidence, clinician behavior changed substantially. MRI utilization increased by a mean (SD) of 36.3% (SD = 37.1, from 30.9% [SD = 31.7 and missing = 7] to 67.1% [SD = 31.9 and missing = 7], $n = 421$, Wilcoxon signed rank test p value < 0.001). This was accompanied by an increased belief in finding abnormalities (21.2% [SD = 20.9 and missing = 6] to 46.3% [SD = 28.3 and missing = 11], $n = 417$, mean [SD] difference: 24.8% [SD = 28.1], Wilcoxon signed rank test p value < 0.001), tumors (10.1% [SD = 19.9 and missing = 8] to 18.3% [SD = 23.3 and missing = 10], $n = 418$, mean [SD] difference: 8.1% [SD = 19.1], Wilcoxon signed rank test p value < 0.001) and perceived benefits (25.1% [SD = 28.7 and missing = 12] to 43.6% [SD = 31.1 and missing

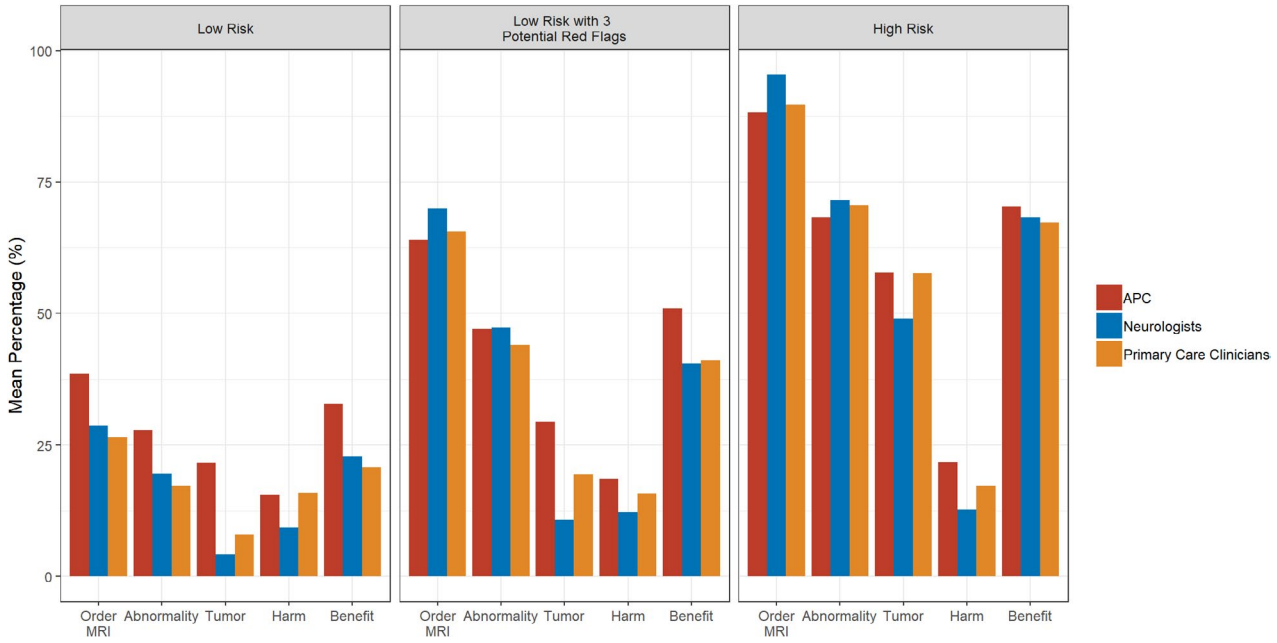

FIGURE 1 Utilization, findings, and benefits of MRI in three headache neuroimaging scenarios. Mean percentage of time clinicians would order an MRI, find any abnormality (including false positives), find a brain tumor, and the percentage of time the MRI would result in any harm or benefit for three headache neuroimaging scenarios stratified by clinician type and specialty (APCs, neurologists, and primary care clinicians). APCs, advanced practice clinicians; MRI, magnetic resonance imaging [Color figure can be viewed at wileyonlinelibrary.com]

= 15], $n = 411$, mean [SD] difference: 18.6% [SD = 28.5], paired t-test p value < 0.001) compared to the low risk scenario without red flags.

Across scenarios, neurologists consistently had the smallest belief in harms from an MRI (low risk without red flags: neurology: 9.2% [SD = 10.5 and missing = 5], APCs: 15.5% [SD = 17.4 and missing = 0], primary care: 15.8% [SD = 17.6 and missing = 4], Kruskal-Wallis test p value < 0.001; low risk with three potential red flags: neurology: 12.3% [SD = 13.7 and missing = 6], APCs: 18.5% [SD = 18.1 and missing = 0], primary care: 15.8% [SD = 14.7 and missing = 4], Kruskal-Wallis test $p$value = 0.002; and high risk: neurology: 12.8% [SD = 14.2 and missing = 5], APCs: 21.7% [SD = 22.2 and missing = 2], primary care: 17.3% [SD = 16.3 and missing = 9], Kruskal-Wallis test p value = 0.002; Figure 1).

DISCUSSION

Neuroimaging is overused in patients with headaches, however, factors that lead to suboptimal utilization are unknown. We administered a survey to 431 VA headache clinicians and found that a majority of clinicians believed that neuroimaging is overused for patients with headaches and generally believed that much neuroimaging is low value, yet many clinicians still indicated they would order neuroimaging in low-risk scenarios where the probability of changing patient management is small. Conflicting guidelines that lack details regarding neuroimaging utilization in the presence of red flags, asymmetric valuation of harms via omission than commission, and unbalanced beliefs in neuroimaging harms and benefits likely contribute to overutilization. Importantly, potential red flags without strong evidence led to much higher neuroimaging; therefore, future studies are needed to further define the role of currently used red flags. We also found that APCs indicate use of headache neuroimaging more often than physicians and are more amenable to possible interventions, making them an ideal target for future optimization efforts.

In the hypothetical scenarios for patients with headaches, the presence of potential red flags resulted in increased neuroimaging utilization. We found that clinicians typically were able to correctly identify patients at high risk of finding management changing lesions and subsequently decide whether to perform neuroimaging. However, all clinician types indicated that they would order neuroimaging over 25.0% of the time in patients with migraine headaches and no red flags despite guidelines that explicitly recommend against this practice. Furthermore, there was a substantial jump in utilization for patients with potential red flags. Specifically, we found that clinicians indicated they would order neuroimaging 67.1% of the time in scenarios with red flags that have limited evidence to support their use. The use of "red flags" to identify underlying medical conditions originated in back pain,[31,32] but has been extended to a number of settings,[33] including other neurologic conditions, such as Parkinson's disease[34] and cauda equina syndrome.[35] In conditions other than headache, systematic reviews typically find that red flags result in low sensitivity and a high false positive rate.[31,34,35] On the other hand, the use of red flags are particularly important to primary care physicians who need to surveil a wide range of potential conditions.[36] Current guidelines recommend against neuroimaging for patients with headaches, except in the presence of red flags; however, red flags are inconsistently described across guidelines and are based on limited or non-existing evidence,[37] which likely results in overutilization of neuroimaging and subsequent false positive findings. One retrospective study found that 77% of patients with headaches had at least one red flag that justified neuroimaging, but only 3.4% of those patients had an abnormal MRI finding,[38] suggesting that relying on red flags may lead to more harms than benefits. Another study assessed the diagnostic accuracy of different red flags in patients with headaches,[39] finding limited sensitivity and specificity even when considering the best combination of red flags. More studies with larger sample sizes are needed to validate these results and ultimately update clinical guidelines. Our study provides additional evidence that headache clinicians rely on red flags to make neuroimaging decisions. Therefore, more evidence is needed to determine which red flags are consistently associated with benefits following neuroimaging that exceeds any harms associated with these tests.

The majority of clinicians believed that neuroimaging was overused in patients with headaches, but also believed that the likelihood of benefits was greater than the likelihood of harms in all three different clinical scenarios. Although clinicians may believe neuroimaging is broadly overused for patients with headaches, ordering neuroimaging is the sensible clinical decision when the perceived likelihood of benefits outweighs harms. These contradictory beliefs imply disagreements with headache neuroimaging guidelines, which is a primary reason clinicians make guideline-discordant decisions according to a systematic review.[14] Therefore, interventions should attempt to align clinicians' perceptions of neuroimaging harms and benefits more closely with the best available data, which may ultimately improve decision making. In addition to improving the guidelines themselves, embedding decision-making rules through a CDSS in the EHR could improve neuroimaging utilization.[17,40] Specifically, including an algorithm that uses patient characteristics to predict the probability of harm, benefit and potential for change in management could correct clinicians' perceptions of neuroimaging harms and benefits and ultimately increase guideline-concordant neuroimaging decisions.[41] Our survey also indicated that many clinicians were open to interventions that provide reminders of optimal use within the EHR.

Despite following headache neuroimaging guidelines, more clinicians were bothered by harms stemming from the omission of neuroimaging (88.5% of respondents) compared to commission (77.6% of respondents). This was surprising as examples of "omission bias"[42] are common in healthcare[43,44] and result in clinician inaction when caring for patients. Interestingly, a multicenter study at VA health care systems, found that harms via omission were more common and typically more serious compared with harms via commission.[45] The unbalanced burden of omission and commission likely results in overutilization of neuroimaging and may be explained by the fact

that 29.9% of clinicians believed underlying headache-causing diagnoses are missed during the initial evaluation and 80.4% believed it is their responsibility to never miss a headache caused by a brain tumor. In addition, this perception of clinician responsibility directly contradicts sentiments that headache neuroimaging is overutilized. Unfortunately, the frequency and severity of harms stemming from headache neuroimaging decisions are not well known. Future studies that determine the downstream harms of guideline-discordant neuroimaging may decrease the current imbalance of perceived harms via commission and omission. Given that VA clinicians have immunity from malpractice liability as part of the United States Federal Tort Claims Act, it was surprising to find that 26.9% of clinicians often/almost always consider malpractice concerns when making headache neuroimaging decisions. One possible explanation may be that clinicians had dual appointments at the VA and outside institutions, without the protections of the Federal Tort Claims Act. Nonetheless, this surprising result in this population highlights the importance that malpractice concerns have in headache neuroimaging decisions, which may further contribute to the differences in burden from acts of omission versus commission, especially in healthcare systems other than the VA.

Compared with physicians, we found that APCs overutilized neuroimaging more often in low-risk scenarios. A similar conclusion was made in a study of Medicare clinicians, where APCs were more likely to order diagnostic imaging compared with primary care clinicians.[46] Overutilization by APCs may have been driven by strong beliefs in neuroimaging benefits, smaller beliefs in harms stemming from a false positive MRI finding, less confidence in the ability to make decisions to obtain an MRI, and less awareness of neuroimaging overutilization. In addition, the fact that APCs believed they would identify a brain tumor in 21.6% of patients with a normal neurologic examination and no other red flags, suggests that these clinicians lack accurate knowledge regarding the likelihood of finding abnormalities and brain tumors in patients with headaches, which may ultimately drive overutilization. Although guideline-discordant neuroimaging decisions were common amongst APCs, these clinicians were consistently more receptive to implementation interventions compared to physicians, especially those involving improved guidelines. Specifically, only 30.1% of APCs reported having good knowledge of headache neuroimaging guidelines, but 89.3% believed updated guidelines would improve optimal utilization. Therefore, APCs are an ideal target population to improve neuroimaging utilization and should be the focus of future implementation initiatives.

In three separate headache neuroimaging scenarios, we found that neurologists would utilize neuroimaging at similar rates to primary care clinicians. This was particularly surprising in the low-risk scenario with minor red flags, given that neurologists reported having significantly better knowledge of headache neuroimaging guidelines. This apparent contradiction may be explained by findings from a systematic review, which found that specialists were more likely to follow clinical guidelines, but were also more likely to perform diagnostic testing compared with general practitioners.[47] For neurologists, the decreased testing associated with guideline adherence is likely offset by the increased diagnostic testing that is typically performed by specialists. Although neurologists stated that they had a better knowledge of clinical guidelines, their belief that neuroimaging resulted in a higher likelihood of changed management and smaller likelihood of harms, false positive findings, unnecessary procedures, and unnecessary consultations may have increased their guideline-discordant utilization. Neurologists also had increased confidence to order, interpret, and act on MRI findings, and ordered neuroimaging upon patient request more often than primary care clinicians, which may also have increased utilization beyond guideline recommendations. Another possibility is that neurologists overestimated their actual knowledge of headache neuroimaging guidelines, which may explain the apparent contradiction. Importantly, primary care clinicians were consistently more accepting of the potential interventions to improve neuroimaging decisions compared with neurologists. Therefore, separate strategies are necessary to improve patterns of headache neuroimaging utilization for neurologists and primary care clinicians. For neurologists, improving the clinical guidelines themselves is essential, especially with increased consistency regarding red flags and increased details of the potential harms and the likelihood of changes in patient management. For primary care clinicians, they are more likely to respond to a variety of implementation strategies to reduce unnecessary neuroimaging for patients with headaches.

Study limitations include the potential for nonresponse bias. However, our response rate was comparable to other physician surveys. Other limitations include the lack of generalizability to clinicians outside of the VA. Specifically, it is unknown whether malpractice concerns for VA clinicians are generalizable to other healthcare systems. Furthermore, we were able to identify all VA neurologists and a representative sample of VA primary care and APC clinicians, which makes generalizability within the VA robust. Our survey only details what clinicians indicate they would do, but this does not necessarily reflect their actual practice. Moreover, the limited clinical information in our survey's scenarios may not have adequately accounted for the diverse presentations that occur in routine care. Although survey items were developed by following the well-validated TDF, the reliability and validity of the individual survey items are unknown. In addition, we were unable to account for potential reporting bias, especially in regard to the importance of financial incentives in neuroimaging decision making. In addition, the online survey did not include a review step or completeness check, which is a limitation of the survey design. We also investigated many comparisons without statistical corrections; however, these results are meant to be hypothesis generating and not definitive.

CONCLUSION

In a survey of 431 headache clinicians at the VA health system, we found that a majority of clinicians believed neuroimaging was overused for patients with headaches; however, many would utilize neuroimaging in low-risk scenarios that have a small probability for

change in patient management. Utilization of guideline-discordant neuroimaging may have been driven by clinicians' beliefs that the benefits outweigh the harms of headache neuroimaging even in low-risk scenarios, and their preference towards errors of commission rather than omission. Because potential red flags greatly influence decision making, improved evidence on which red flags should influence neuroimaging decisions is desperately needed. This information would allow future guidelines to be more precise in describing the specific clinical scenarios that should prompt neuroimaging. Additionally, CDSS that include details of headache neuroimaging guidelines and patient-specific assessments of neuroimaging benefits/risks may reduce unnecessary neuroimaging, especially for APCs who had high utilization and were the most accepting of such interventions.

CONFLICT OF INTEREST

Dr. Reynolds reports no disclosures. Dr. Burke has received compensation from Astra Zeneca for his role on the adjudication committee of the SOCRATES trial. Ms. Evans reports no disclosures. Dr. Syed reports no disclosures. Dr. Liao reports no disclosures. Dr. Lobo reports no disclosures. Dr. Cooper reports no disclosures. Dr. Charleston has served as consultant, advisory board member, or has received honoraria from AbbVie/Allergan, Alder/Lundbeck, and Biohaven; is on the advisory board of BrainWeekend and Ctrl M Health; has performed medical legal consultation for the Vaccine Injury Compensation Program; and is an Associate Editor of *Headache*: The Journal of Head and Face Pain. He reports no relevant conflict of interest for this manuscript. Dr. Callaghan consults for a PCORI grant, DynaMed, receives research support from the American Academy of Neurology and performs medical legal consultations including consultations for the Vaccine Injury Compensation Program.

AUTHOR CONTRIBUTIONS

Study concept and design: Evan L. Reynolds, James F. Burke, Brian C. Callaghan. *Acquisition of data*: James F. Burke, Lacey Evans, Faiz I. Syed, Brian C. Callaghan. *Analysis and interpretation of data*: Evan L. Reynolds, James F. Burke, Lacey Evans, Faiz I. Syed, Eric Liao, Remy Lobo, Wade Cooper, Larry Charleston IV, Brian C. Callaghan. *Drafting of the manuscript*: Evan L. Reynolds, James F. Burke, Brian C. Callaghan. *Revising it for intellectual content*: Evan L. Reynolds, James F. Burke, Lacey Evans, Faiz I. Syed, Eric Liao, Remy Lobo, Wade Cooper, Larry Charleston IV, Brian C. Callaghan. *Final approval of the completed manuscript*: Evan L. Reynolds, James F. Burke, Lacey Evans, Faiz I. Syed, Eric Liao, Remy Lobo, Wade Cooper, Larry Charleston IV, Brian C. Callaghan.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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