Published in final edited form as:

AJR Am J Roentgenol. 2013 July ; 201(1): W75–W80. doi:10.2214/AJR.12.10238.

Two-Tiered Approach to MRI for Headache: A Cost-Effective Way to Use an Expensive Technology

Aseem Sharma^{1,2,3}, Martin Reis⁴, Matthew S. Parsons^{1,2,3}, Franz J. Wippold II^{1,2,3,5}, John Chrisinger⁶, Todd J. Schwedt⁷, and Thomas K. Pilgram⁸

¹Mallinckrodt Institute of Radiology, Washington University School of Medicine, Campus Box 8131, 510 S Kingshighway Blvd, St. Louis, MO 63110

²Department of Radiology, Barnes-Jewish Hospital South, St. Louis, MO

³Department of Radiology, St. Louis Children's Hospital, St. Louis, MO

⁴Department of Radiology, Saint Louis University School of Medicine, St. Louis, MO

⁵Department of Radiology/Nuclear Medicine, F. Edward Hébert School of Medicine, Uniformed Services University of the Health Sciences, Bethesda, MD

⁶Department of Pathology, Washington University School of Medicine, St. Louis, MO

⁷Department of Neurology, Mayo Clinic, Scottsdale, AZ

⁸Department of Anthropology, Washington University in St. Louis, St. Louis, MO

Abstract

OBJECTIVE—The purpose of this study was to compare the diagnostic efficacy and cost implications of a proposed two-tiered approach to MRI in patients with headache.

MATERIALS AND METHODS—We identified 245 consecutive patients with headache using MRI studies performed at a tertiary care facility between October 2009 and July 2011. Three radiologists prospectively used FLAIR sequences from these MR studies to diagnose underlying abnormality or to identify the need for a comprehensive MRI study. We compared the diagnostic efficacy and the cost implications of such a two-tiered approach with those of conventional MRI from the perspectives of the payer, the patient, and the imaging facility.

RESULTS—The sensitivity and specificity for two-tiered (83.3% and 100%, respectively) and conventional (91% and 97.8%, respectively) MRI approaches were not significantly different. Assuming a 50% reduction in the payment for the initial limited MRI performed as a first step of the two-tiered approach, this approach would have resulted in 44.8% savings to the payer. A substantial reduction in the scanner utilization time from 4168 minutes to 1249 minutes for the two-tiered approach would have enabled increased throughput at the imaging facility. Although 27 (11%) patients would have been recalled for a comprehensive MRI study in the two-tiered approach, the average time spent in the scanner by each patient would have been less for the two-tiered approach (5.1 minutes vs 17.0 minutes).

© American Roentgen Ray Society

Address correspondence to A. Sharma (sharmaa@mir.wustl.edu).

The opinions and assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of Defense.

WEB

This is a web exclusive article.

CONCLUSION—A two-tiered approach to MRI can serve as a viable cost-effective alternative to the conventional approach.

Keywords

cost-effectiveness; headache; health care cost; health care policy; MRI

Advanced diagnostic imaging has been recognized as one of the significant contributors to our nation's rising health care costs [1–3]. In addition to minimizing inappropriate use of imaging [4], solutions must also focus on more efficient implementation of expensive diagnostic imaging tools, such as MRI.

MRI typically involves acquisition of multiple time-intensive sequences that provide somewhat complementary information. Although some patients with complex underlying disease definitely benefit from multiple sequences, many of these may prove unnecessary in other straightforward situations. If a particular MRI sequence could reliably identify the subgroup of patients likely to benefit from additional imaging sequences, it could potentially enable more efficient utilization of the scanner time, potential cost reduction, and less burden on patients. The feasibility and implications for such an approach from the patient, payer, and the imaging facility perspective have not been studied.

In this exploratory study, we compared the diagnostic efficacy and potential cost implications of a two-tiered MRI approach with conventional MRI in management of patients with headache. Despite the presence of guidelines suggesting a limited role of neuroimaging for patients with headache [5–7], several factors, including relatively high prevalence of this symptom, patient dissatisfaction, and medicolegal environment, may make it challenging to limit the use of imaging for patients with chronic headaches [6, 8]. We hypothesize that a proposed two-tiered approach that involves proceeding to a comprehensive MRI only if the results of an initial MR scan obtained using the FLAIR sequence indicate it can provide the diagnostic information in these patients in a more cost-effective manner compared with the conventional approach.

Materials and Methods

This study was approved by our institutional review board and conducted in compliance with HIPAA. The need for obtaining consent was waived for use of the preexisting data.

Methodology

Using an electronic search engine that searches the entire radiology report database at our institution, we identified 251 consecutive adult patients with headache as the reported indication for MRI performed at our hospital from October 2009 through July 2011. We excluded patients with known malignancy, HIV infection/AIDS, or significant neurologic deficits at the time of MRI. Six patients did not have images available at the time of review, resulting in the final study group of 245 patients including 86 men and 159 women with a mean age of 46.3 years (range, 18–87 years). We transferred the FLAIR images in these studies to a separate viewing platform (Vital Connect, Vital Images), where three readers (a neuroradiology fellow and two neuroradiologists with experience of more than 5 and 10 years) evaluated these images independently, blinded to the original report or remaining MR sequences. In addition to listing the abnormalities on the FLAIR sequence, the readers made recommendations regarding the need for a more comprehensive MRI study (Table 1).

Definition of Disease

A neurologist with extensive experience in managing patients with headache read the reports of the original comprehensive MRI and categorized these reports into positive and negative categories. A positive category meant that the reported findings on the original MRI report were a likely cause of headache and were best shown by MRI. All patients with normal reports, reports with truly incidental findings (considered definitely not to be related to headache), and reports with incidental findings (such as sinus disease) that did not necessarily require MRI even if these findings could potentially cause headaches, were all categorized as negative. Similarly, positive cases were also identified on the basis of review of the FLAIR images alone. The clinical and imaging data of all positive cases was reviewed by a senior member of the radiology department with more than 25 years of experience who had not participated in the review of FLAIR images. All patients categorized as positive were considered to have “disease,” unless the basis for positive characterization was proven to be invalid on subsequent clinical or imaging follow-up. Patients categorized as negative on both the original report and on the review of FLAIR images were assumed to be “disease-free.”

Evaluation of Diagnostic Efficacy

We calculated sensitivity and specificity for the conventional and two-tiered approaches for each reader and compared differences for statistical significance using the Fisher exact two-tailed test, with a p value of < 0.05 considered to represent significant difference.

For each reader, the two-tiered approach was considered successful in identifying the disease if the reader either identified the abnormality under consideration on FLAIR imaging alone (Category 2 in Table 1) or recommended comprehensive imaging that would have led to detection of the abnormality (Category 4 in Table 1).

For overall assessment of the two-tiered approach, this approach was considered successful in identification of disease if two or all three readings were true-positive. As is standard practice at our institution, all the original reports were generated after evaluation by a radiology resident or neuroradiology fellow and an attending neuroradiologist. Medical charts were reviewed for all patients who were not diagnosed with the two-tiered approach to determine the implications of the missed diagnoses.

Comparative Analysis

Baseline analysis—Potential savings from the payer’s perspective were calculated as percentage decrease from the current strategy. We calculated the cost of conventional MRI using Centers for Medicare and Medicaid Services (CMS) reimbursement rates for 2012 and taking into account the actual number of studies performed without or with IV contrast administration. The indirect cost for any additional imaging performed in false-positive cases was included in the cost assessment. Calculations for the two-tiered approach included the assumed cost of initial FLAIR imaging in all patients and the cost of any subsequent comprehensive MRI performed as a second step. Baseline analysis was performed with the technical fee for FLAIR sequence set at 50% of the 2012 CMS reimbursement rate for MRI of the brain without contrast administration. We assumed that the reimbursement of the comprehensive MRI performed as the second step would be identical to conventional MRI. We assumed that comprehensive MRI without and with contrast administration would be performed as a second step of the two-tiered approach for all patients in category 4 and for 50% of patients in category 3 (Table 1). We did not evaluate the time taken for interpretation of the limited study and assumed that the professional component of the reimbursement for interpretation of the FLAIR imaging would be equivalent to that for brain MRI without contrast administration.

To assess the imaging facility's perspective, we calculated scanner utilization time and reimbursement per minute of scanner utilization for each approach. We assumed that all patients had been scanned using the least time-consuming general brain protocol at our institution. Because of the variety of scanners at our institution, we based our analysis on average scanning time for MRI of the brain without contrast administration (13.5 minutes), MRI of the brain without and with contrast administration (18 minutes), and FLAIR imaging (3.5 minutes). The contrast utilization rate was determined from the actual data for the conventional MRI approach. Again, we assumed that all patients in category 4 and 50% of those in category 3 would undergo subsequent comprehensive MRI without and with contrast administration. Only the technical reimbursement was considered to calculate the reimbursement per minute of scanner utilization.

From the patient's perspective, we assessed average scanning time, rate of IV contrast injection, and chance of having to return for additional imaging (recall rate). We did not perform analysis of any additional costs incurred by the patient. In addition, we also compared the rate of contrast utilization with each approach.

Sensitivity analysis—We performed additional sensitivity analysis for the following parameters: First, we analyzed the effects of different levels of reimbursement for the initial FLAIR sequence, setting it at 25% and 75% of the 2012 CMS reimbursement rates for MRI of brain without contrast administration. Second, to assess the possibility that a higher fraction of patients undergoing the abbreviated scan could be recalled, we studied the impact of the recall rate set at a level two SDs higher than the mean recall rate of the three readers in the study. Third, we studied the effects of 50% lower disease prevalence by basing the recall rate for this hypothetical scenario on the average rate at which the additional imaging was recommended for patients with and without disease. Fourth, the impact of an alternate approach in which a 2-minute sagittal T1-weighted sequence across the midline is added to the initial abbreviated MRI was studied.

Results

Diagnostic Efficacy

A total of 24 patients were found to have disease (Table 2). The sensitivity and specificity of the two-tiered approach were found to be comparable to those of conventional MRI (Table 3). Sensitivity (75%, 79.2%, and 79.2%) and specificity values (100% for all) for the individual readers after the two-tiered approach were not significantly different compared with the conventional imaging.

In their assessment of FLAIR images, three readers categorized 20, 15, and 20 patients as category 4 and categorized 8, 18, and 28 patients as category 3. On the basis of these results, an average of 27 patients would have required a comprehensive MRI as a second step of the two-tiered approach.

Comparative Analysis

Baseline analysis—Use of the two-tiered approach would have resulted in a 44.8% reduction in the cost to the payer compared with the conventional approach (Table 4). Scanner utilization time for the two-tiered approach was 1249 minutes, a 70% reduction from 4168 minutes of scanner utilization for the conventional approach (Table 4). Two-tiered imaging would have resulted in a lower total technical reimbursement for the imaging facility but at a substantially higher rate per minute of scanner utilization (Table 4). The patients would have spent much less time in the scanner, with a lower chance of IV contrast administration but with a higher recall rate with the two-tiered approach. The patient recall

rates varied from 9.8% to 13.8% for different readers, with an overall rate of 11.0% (Table 4). Patients with disease were recalled at a much higher rate of 60% (50–71%) when compared with a recall rate of 6% (4.5–7.7%) for patients without disease.

Sensitivity analysis—The sensitivity analysis showed robustness of savings for the payer and improved technical reimbursement per minute of scanner utilization for all alternate scenarios considered (Table 4).

Discussion

Our results show that a two-tiered MRI approach in the evaluation of patients with headache can provide diagnostic accuracy comparable to that of conventional MRI (Table 3), while achieving a substantial cost reduction for the payer (Table 4), assuming that the limited MRI obtained as the first step of this two-tiered approach would be reimbursed at a reduced rate. For a modification in health care practice to have a better chance of being adopted, its impact on all parties involved in health care should be evaluated. A two-tiered approach to MRI can be attractive from a busy imaging facility's perspective, given that the impact of the anticipated reduced reimbursements with this approach can be significantly offset by the higher throughput made possible by a commensurate reduction in scanner utilization time per patient.

In a wide variety of scenarios that we considered, the technical reimbursement rate per minute of scanner utilization was projected to increase with the two-tiered approach (Table 4). Scanner utilization from an imaging facility's perspective can potentially be considered in terms of an expense because it not only determines the time for which expensive equipment is being used but also the time for which other resources, such as the technologists' services, are needed. However, given the relatively fixed cost of the MRI equipment irrespective of its use, the increased throughput afforded by the two-tiered imaging may not be able to mitigate the negative effects of technical reimbursement if a sufficient supply of patients is lacking. The two-tiered approach can also be beneficial to the patients in terms of reduced time spent in the scanner, avoiding the discomfort related to the IV contrast injection, and reduced payments for those with insurance coverage requiring copayments for imaging studies. At the same time, approximately 11% of the patients would have been recalled in the two-tiered approach, a prospect that can be both inconvenient and potentially anxiety provoking. These negative effects from the patient's perspective could potentially be minimized if FLAIR images were read soon after the MRI is done. In addition, it is worth noting that the recall rate for the conventional approach was not entirely zero. In our study, 2% of patients with false-positive diagnoses on conventional imaging had to return for additional tests, including not only additional MRI but also more invasive catheter angiography.

The results of the sensitivity analysis showed that, depending on the level to which the reimbursement for the initial MRI is reduced in the two-tiered approach, the cost savings for the payer can potentially range from 28.6% to 61% (Table 4). Even at a 75% reduction in the technical component for the initial MRI, the technical reimbursement per minute of scanner utilization was maintained. In addition to the level at which the reimbursement of the initial step of the two-tiered approach is set, the percentage of patients being recalled for additional scanning can be expected to have a major impact on the cost of the two-tiered approach. Our results indicate that the recall rate can be affected both by the subjective differences between individual readers and by the disease prevalence. The sensitivity analysis shows the robustness of savings for the payer as well as technical reimbursement per minute of scanner utilization, for a much higher recall rate (Table 4).

Given that our study was completed at a tertiary care center without taking into consideration where the patients were being seen at the time of referral for MRI, the disease prevalence in a typical community hospital is likely to be much lower than our rate of 10%. For example, other investigators have estimated this to be as low as 1.5% [9]. In a scenario with a disease prevalence rate of around 5%, our sensitivity analysis projected both a higher level of savings for the payer and an increase in per-minute technical reimbursement for the imaging facility compared with the baseline analysis (Table 4). None of the missed findings in our study would have added any cost to the payer because none of these proved to be significant for individual patients. This, however, cannot be generalized to other groups.

Interestingly, all of the missed diagnoses could have been detected on midline sagittal images. An argument could be made that FLAIR images should be supplemented by a few midsagittal T1-weighted images to further improve the sensitivity of this first step, at a cost of reduced per-minute technical reimbursement for a given total reimbursement rate (Table 4). However, our results also indicate that acquiring additional sequences could result in additional artifacts and false-positive interpretations, prompting additional tests. Conventional MRI was, in fact, less specific than the two-tiered approach and led to additional MRI in three patients and even cerebral angiography in two patients. Even if potentially missed Chiari 1 malformations were considered a major drawback of applying the two-tiered approach to MRI in headache patients, a reasonable alternative might include additional imaging in patients with persistent symptoms that may suggest Chiari 1 malformation, such as posttussive headaches.

Despite comparable diagnostic efficacy of the conventional and two-tiered approaches, important differences in the potential reasons for missed diagnoses in each approach should be considered. The findings missed on the two-tiered approach could not be detected on axial FLAIR images even retrospectively because both Chiari 1 malformation and platybasia are best recognized on the sagittal imaging plane. In contrast, the two missed cases on conventional imaging were mainly due to interpretation error rather than failure of the imaging. Although we do not know the reason behind the missed findings on the conventional MR images, it may be possible that an abbreviated MRI study allows a more focused review by the radiologists.

Much of the interest in containing escalating imaging costs has focused on curbing overutilization by reducing inappropriate tests [2, 4, 10–16]. In view of prior studies pointing to low likelihood of finding significant abnormality on imaging in uncomplicated headache [5, 9, 17, 18], both the American College of Radiology (ACR) and the American Association of Neurology have recommended limited use of neuroimaging in patients with headache [5, 6]. More recently, headache is one of the symptoms for which the ACR has recommended against routine imaging as a part of the Choose Wisely campaign [7]. By aiming for a more efficient utilization of the imaging modalities, our proposed approach can complement these efforts for decreasing imaging-related health care costs. Although our study has dealt with only one indication for MRI, a similar approach can be applicable to a number of other neurologic and nonneurologic indications. For example, previous studies have shown the high diagnostic efficacy of abbreviated MRI protocols in diagnosis of patients with stroke, suspected cord compression, sensori-neural hearing loss, and others [19–21].

Some methodologic details and limitations of our study merit discussion. We did not consider the implications of the incidental findings because we think that the diagnostic utility of a particular imaging modality should be guided by its ability to answer the clinical question rather than the detection of all the unexpected findings for which the rest of the population would not be screened. Our study did not methodically evaluate whether the time

taken to interpret and report the MRI findings would be different for the abbreviated study. Accordingly, we assumed that the professional component of reimbursement for the interpretation of the initial abbreviated study in the two-tiered approach would not be altered. However, if the professional component were also to be reduced, the cost benefits for the two-tiered approach can be expected to be even higher than what we have projected. Finally, prospective studies will be needed to identify the acceptance of such a model among patients and physicians and determine the long-term sustainability of the potential cost benefits as well as the diagnostic efficacy associated with the two-tiered approach.

References

1. United States Government Accountability Office website. [Accessed March 8, 2013] Report to Congressional requesters: Medicare Part B imaging services—rapid spending growth and shift to physician offices indicated need for CMS to consider additional management practices (GAO-08-452). www.gao.gov/new.items/d08452.pdf. Published June 2008
2. Emanuel EJ, Fuchs VR. The perfect storm of overutilization. *JAMA*. 2008; 299:2789–2791. [PubMed: 18560006]
3. Iglehart JK. Health insurers and medical-imaging policy: a work in progress. *N Engl J Med*. 2009; 360:1030–1037. [PubMed: 19264694]
4. Hendee WR, Becker GJ, Borgstede JP, et al. Addressing overutilization in medical imaging. *Radiology*. 2010; 257:240–245. [PubMed: 20736333]
5. Jordan, JE.; Wippold, FJ., II; Cornelius, RS., et al. [Accessed March 8, 2013] Expert Panel on Neurologic Imaging. ACR appropriateness criteria: headache. www.acr.org/Quality-Safety/Appropriateness-Criteria. Published 2008
6. Frishberg, BM.; Rosenberg, JH.; Matchar, DB., et al. Evidence-based guidelines in the primary care setting: neuroimaging in patients with nonacute headache. American Academy of Neurology, U.S. Headache Consortium; website. www.aan.com/professionals/practice/pdfs/g10088.pdf. Published 2000 [Accessed March 8, 2013]
7. [Accessed March 8, 2013] Consumer Reports website. Choosing Wisely: an initiative of the American Board of Internal Medicine Foundation. consumerhealthchoices.org/wp-content/uploads/2012/04/ChoosingWisely-HeadachesACR.pdf. Published April 2012
8. Fitzpatrick R, Hopkins A. Referrals to neurologists for headaches not due to structural disease. *J Neurol Neurosurg Psychiatry*. 1981; 44:1061–1067. [PubMed: 7334400]
9. Jordan JE, Ramirez GF, Bradley WG, Chen DY, Lightfoote JB, Song A. Economic and outcomes assessment of magnetic resonance imaging in the evaluation of headache. *J Natl Med Assoc*. 2000; 92:573–578. [PubMed: 11202760]
10. Lu MT, Tellis WM, Fidelman N, Qayyum A, Avrin DE. Reducing the rate of repeat imaging: import of outside images to PACS. *AJR*. 2012; 198:628–634. [PubMed: 22358003]
11. Armao D, Semelka RC, Elias J Jr. Radiology's ethical responsibility for healthcare reform: tempering the overutilization of medical imaging and trimming down a heavyweight. *J Magn Reson Imaging*. 2012; 35:512–517. [PubMed: 22180215]
12. Diamond F. Mandatory imaging program takes aim at overutilization: holding physicians to best-practice guidelines with the threat of refusing to pay for unnecessary tests reaps dividends. *Manag Care*. 2011; 20:61–62. [PubMed: 22180901]
13. Sura A, Ho A. Enforcing quality metrics over equipment utilization rates as means to reduce Centers for Medicare and Medicaid Services imaging costs and improve quality of care. *J Clin Imaging Sci*. 2011; 1:28. [PubMed: 21966625]
14. Lehnert BE, Bree RL. Analysis of appropriateness of outpatient CT and MRI referred from primary care clinics at an academic medical center: how critical is the need for improved decision support? *J Am Coll Radiol*. 2010; 7:192–197. [PubMed: 20193924]
15. Sodickson A, Opraseuth J, Ledbetter S. Outside imaging in emergency department transfer patients: CD import reduces rates of subsequent imaging utilization. *Radiology*. 2011; 260:408–413. [PubMed: 21507903]

16. Friedman DP, Smith NS, Bree RL, Rao VM. Experience of an academic neuroradiology division participating in a utilization management program. *J Am Coll Radiol*. 2009; 6:119–124. [PubMed: 19179241]
17. Strain JD, Strife JL, Kushner DC, et al. Headache: American College of Radiology—ACR Appropriateness Criteria. *Radiology*. 2000; 215(suppl):855–860. [PubMed: 11037510]
18. Weingarten S, Kleinman M, Elperin L, Larson EB. The effectiveness of cerebral imaging in the diagnosis of chronic headache. *Arch Intern Med*. 1992; 152:2457–2462. [PubMed: 1456857]
19. Johnson AJ, Ying J, El Gammal T, Timmerman RD, Kim RY, Littenberg B. Which MR imaging sequences are necessary in determining the need for radiation therapy for cord compression? A prospective study. *AJNR*. 2007; 28:32–37. [PubMed: 17213420]
20. Kovacovics B, Davidsson L, Harder H, Magnuson B, Ledin T. MRI screening of the cerebello-pontine angle and inner ear with fast spin-echo T2 technique. *Arch Ital Biol*. 2000; 138:87–92. [PubMed: 10604036]
21. Johnson AJ, Kido DK, Shannon WD, et al. Evaluation of a reduced MR imaging sequencing protocol in adult patients with stroke. *Radiology*. 2001; 218:791–797. [PubMed: 11230658]

TABLE 1

Guidelines Used for Categorization of Patients After Evaluation of FLAIR Sequence as Part of Two-Tiered Approach to MRI

Category	Abnormality ^a	Comprehensive Study Needed
1	No	No
2	Yes	No
3	Yes	If clinically indicated
4	Yes	Yes

^a All abnormalities noticed on MRI including incidental findings.

TABLE 2

Description of Disease Encountered in 245 Patients With Headache

Patient No.	Age (y)	Sex	Disease Description
10	19	F	Nonenhancing white matter lesions out of proportion to patient's age
29	29	M	Tectal mass with ventriculomegaly
54	50	M	Multiple rim-enhancing masses with surrounding edema
57	68	M	Extraaxial posterior fossa mass
63	30	M	Abnormal signal intensity within cortical sulci suggestive of leptomeningeal disease
66	22	F	Nonenhancing white matter lesions out of proportion to patient's age
79	39	M	Nonenhancing white matter lesions out of proportion to patient's age
82	87	M	Large intraaxial mass suggestive of glioma
87	83	M	Extensive microangiopathic changes in white matter
88	35	M	Cavernous malformation in left parietal lobe
96	77	M	Bilateral cerebellar subacute infarctions
101	52	M	Left mastoiditis
117	47	F	Extraaxial mass involving left cavernous sinus
138	52	F	Abnormal signal intensity within cortical sulci suggestive of leptomeningeal disease
148	52	M	Multiple bony lesions—likely metastases
154	37	F	Chiari 1 malformation with cerebellar tonsils 7 mm below foramen magnum
160	24	F	Platybasia
161	36	F	Chiari 1 malformation with cerebellar tonsils 5 mm below foramen magnum
166	48	F	Focal left parietal lobe lesion suggestive of primary glial neoplasm or encephalitis
170	47	M	Leptomeningeal disease
185	68	F	Extraaxial mass in right cerebellar pontine angle cistern
216	54	M	Multiple intraaxial masses—likely metastatic disease
222	29	F	Chiari 1 malformation with cerebellar tonsils 6 mm below foramen magnum
235	50	M	Complex extraaxial fluid collection—likely subdural hematoma

TABLE 3

Diagnostic Performance of Conventional and Two-Tiered MRI Approaches

Parameter	Conventional MRI		Two-Tiered MRI	
	Positive	Negative	Positive	Negative
Disease	22	2	20	4
No disease	5	216	0	221
Sensitivity (%)	91.7		83.3 ($p = 0.67$) ^a	
Specificity (%)	97.8		100 ($p = 0.06$) ^a	
Missed diagnoses	<ol style="list-style-type: none"> 1 Leptomenigeal disease, diagnosed 5 days later on CSF analysis as neurosarcoidosis 2 Small subdural hematoma; no therapeutic intervention needed 		<ol style="list-style-type: none"> 1 Chiari 1 malformation with 7-mm tonsillar ectopia; considered incidental; no intervention done 2 Chiari 1 malformation with 5-mm tonsillar ectopia; considered incidental; no intervention done 3 Chiari 1 malformation with 6-mm tonsillar ectopia; no intervention done 4 Platybasia 	

^a p value represents comparison with conventional approach.

TABLE 4
Comparative Impact of Two Approaches to MRI in 245 Patients Presenting With Headache

Parameter	Conventional MRI	Two-Tiered MRI	Sensitivity Analysis for Two-Tiered MRI				
			Technical Component for FLAIR at 75% of Current Rate	Technical Component for FLAIR at 25% of Current Rate	Higher Recall Rate	50% Lower Disease Prevalence	Added Midline Sagittal T1-Weighted Image
Total cost to payer ^{a,b} (\$)	155,771	85,986	111,295	60,679	92,570	82,695	85,986
Savings for payer with two-tiered approach (%)	NA	44.8	28.6	61.0	40.5	46.9	44.8
Technical component of reimbursement (\$)	126,313	65,287	90,597	39,977	70,719	62,571	65,287
Scanner utilization time (min)	4168	1249	1249	1249	1394	1177	1739
Reimbursement per minute of scanner utilization ^a (\$)	30.3	52.3	72.5	32.0	50.7	53.2	37.5
Patients returning for follow-up imaging (%)	5 (2.0)	27 (11.0)	27 (11.0)	27 (11.0)	37 (15.1)	22 (8.9)	27 (11)
Patients requiring IV contrast injection (%)	181 (73.8)	27 (11.0)	27 (11.0)	27 (11.0)	37 (15.1)	22 (8.9)	27 (11)
Average time in scanner per patient (min)	17.0	5.1	5.1	5.1	5.7	4.8	7.1

Note—Data in parentheses are percentages. NA = not applicable.

⁷ Unless otherwise specified, projections are based on reimbursement for technical component of initial abbreviated MRI study of two-tiered approach set at 50% of the 2012 Centers for Medicare and Medicaid Services reimbursement rate for MRI of brain without contrast administration.

2. Total cost of conventional imaging includes the cost of three follow-up MRI studies and two cerebral angiography examinations that were needed to resolve false-positive findings by conventional imaging.