Reducing Unnecessary Shoulder MRI Examinations Within a Capitated Health Care System: A Potential Role for Shoulder Ultrasound

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Reducing Unnecessary Shoulder MRI Examinations Within a Capitated Health Care System: A Potential Role for Shoulder Ultrasound

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Abstract

Purpose: MRI is frequently overused. The aim of this study was to analyze shoulder MRI ordering practices within a capitated health care system and explore the potential effects of shoulder ultrasound substitution.

Methods: We reviewed medical records of 237 consecutive shoulder MRI examinations performed in 2013 at a Department of Veterans Affairs tertiary care hospital. Using advanced imaging guidelines, we assessed ordering appropriateness of shoulder MRI and estimated the proportion of examinations for which musculoskeletal ultrasound could have been an acceptable substitute, had it been available. We then reviewed MRI findings and assessed if ultrasound with preceding radiograph would have been adequate for diagnosis, based on literature reports of shoulder ultrasound diagnostic performance.

Results: Of the 237 examinations reviewed, 106 (45%) were deemed to be inappropriately ordered, most commonly because of an absent preceding radiograph (n = 98; 92%). Nonorthopedic providers had a higher frequency of inappropriate ordering (44%) relative to orthopedic specialists (17%) (P = .016; odds ratio = 3.15, 95% confidence interval = 1.24-8.01). In the 237 examinations, ultrasound could have been the indicated advanced imaging modality for 157 (66%), and most of these (133/157; 85%) could have had all relevant pathologies characterized when combined with radiographs. Regardless of indicated modality, ultrasound could have characterized 80% of all cases ordered by nonorthopedic providers and 50% of cases ordered by orthopedic specialists (P = .007).

Conclusions: Advanced shoulder imaging is often not ordered according to published appropriateness criteria. While nonorthopedic provider orders were more likely to be inappropriate, inappropriateness persisted among orthopedic providers. A combined ultrasound and radiograph evaluation strategy could accurately characterize shoulder pathologies for most cases.

Key Words: Shoulder, MRI, ultrasound, utilization, costs

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INTRODUCTION

Overutilization of medical imaging increases costs of health care delivery and often poses unnecessary risks to patients without improving clinical outcomes [1]. Initiatives such as the *Choosing Wisely* campaign of the American Board of Internal Medicine Foundation provide goals for reducing overutilization of high-cost and/or low-value imaging examinations [2]. Medical imaging constitutes a

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significant expense within the US Department of Veterans Affairs (VA): $2.23 billion was spent on VA medical imaging during fiscal year 2013, with $19,427,720 of that for upper extremity joint MRI examinations. In capitated systems such as the VA, unnecessary medical imaging poses resource burdens that could limit veterans' access to timely care.

Guidelines such as the ACR Appropriateness Criteria® and the Society of Radiologists in Ultrasound consensus conference statement provide well-defined criteria for selection of the most appropriate advanced imaging modality (AIM) for shoulder evaluation [3-5]. These guidelines are designed to eliminate low-clinical-yield examinations and substitute less costly and potentially safer examinations such as ultrasound (US) for MRI. Studies have demonstrated efficacy of various clinical findings and physical examination maneuvers for diagnosing shoulder pathologies. However, differences in performance and interpretation of these examinations by clinicians who are not orthopedic specialists limit their utility in the primary care setting [6-8]. Ambiguous clinical diagnoses and the relatively high prevalence of asymptomatic pathologies—up to 40% in some cases [9] —suggest that guideline adherence is essential for appropriate imaging utilization, especially to determine surgical versus nonsurgical treatment [8].

Radiographs are most often the initial examination of choice per established guidelines [3,4]. To evaluate the most common sources of shoulder pain in adults, US and MRI often demonstrate similar efficacy as next steps for diagnosing shoulder soft tissue injury, including the rotator cuff and long head biceps tendon. This suggests that US could be a more cost-effective initial AIM [10-16]. MRI uncommonly alters clinical care beyond diagnostic US, with studies showing a 5% MRI follow-up rate primarily to exclude intra-articular pathology [17].

Thus, our objective was to retrospectively apply appropriateness criteria for shoulder imaging examinations to assess adherence to imaging guidelines, and explore the potential role for diagnostic shoulder US as a complementary and cost-effective alternative to MRI.

METHODS

Data Collection

After institutional review board approval, a literature review was performed to standardize the lexicon, grading, and adequate imaging to characterize shoulder pathologies (Table 1). We then obtained data on all shoulder MRI examinations performed at the study site during the 2013 calendar year. The ordering provider, order indications, timing of the order and examination execution dates, and findings listed in the radiology report were recorded. We also reviewed electronic health records (EHR) for patient demographics, relevant clinical notes describing symptoms, injury chronicity, physical examination findings, and treatment history.

Each shoulder MRI examination and corresponding radiograph, if available, were also retrospectively evaluated independently by a single, fellowship-trained musculoskeletal radiologist with six years of experience, and all relevant findings were categorized and then recorded as a binary dependent variable ("absent" or "present"). Potential discrepancies between the retrospective interpretation and the original radiology report were resolved via consensus with an MRI-specialist radiologist with 25 years of musculoskeletal imaging experience.

Study Outcomes

Each MRI examination order was initially evaluated for ordering appropriateness per established guidelines. We determined if requisite imaging recommendations had been followed and if clinical criteria warranted advanced imaging consideration. Examinations were deemed inappropriate if: (1) a preceding radiograph was not obtained prior to MRI ordering for patients with shoulder trauma, or for nontraumatic shoulder pain in patients over 40 years of age [3,4]; (2) radiographs and MRI orders were placed concurrently, as this would preclude the use of radiograph findings to inform decision making when ordering MRI; (3) prior imaging established the suspected diagnosis without interval worsening of symptoms or reinjury (eg, suspected rotator cuff tear was diagnosed on prior imaging); (4) the suspected diagnosis could be established via clinical examination and radiograph (eg, suspected osteoarthritis or adhesive capsulitis); (5) the examination ordered would likely prove inadequate to address the indication (eg, unenhanced MRI for suspected tumor or infection).

We then analyzed the clinical indications and radiographic findings to determine the most appropriate initial AIM. Because shoulder US was not available at the study site during the study year, all patients referred for advanced imaging underwent MRI. A consolidated version of the Society of Radiologists in Ultrasound consensus conference statement and ACR Appropriateness Criteria guidelines were retrospectively applied to determine if US or MRI would have been the indicated

Table 1. Types of imaging data with corresponding diagnostic imaging modalities adequate for diagnosis, and associated shoulder pathology prevalence within the study population

MRI Findings	Radiograph Findings	Adequate Diagnostic Modalities*	# (%) Injuries in Study Population[†]
Rotator cuff			
Tendinosis	Irregular greater tuberosity	US, MRI [18,19]	183 (77.2)
Calcific tendinosis	Calcific tendinosis	Radiograph, US, MRI [20]	18 (7.6)
Partial tear		US, MRI [11-14,19]	156 (65.8)
Full-thickness tear	High riding humeral head	US, MRI [11-14,19]	97 (40.9)
Muscle atrophy/fatty infiltration		US, MRI [21]	90 (38.0)
Long head biceps tendon			
Tendinosis/tenosynovitis		Arthroscopy (US = MRI) [15,22]	100 (42.2)
Partial tear		Arthroscopy (US = MRI) [15, 22]	72 (30.4)
Rupture		US, MRI [10,15]	19 (8)
Dislocation		US, MRI [10]	39 (16.5)
Glenohumeral joint			
Moderate/severe cartilage degeneration	Severe cartilage degeneration	Clinical examination and radiograph [23,24]	46 (19.4)
Focal cartilage lesion		MRI [25]	14 (5.9)
Synovitis		US, MRI [26]	41 (17.3)
Capsule/labrum			
Adhesive capsulitis		Clinical examination (dx of exclusion) [27]	15 (6.3)
SLAP tear		MRA, MRI [28]	23 (9.7)
Bankart variant or destabilizing glenoid/labral injury	Osseous Bankart or Hill-Sachs lesion	MRA, MRI [28]	22 (9.3)
Acromioclavicular joint			
Osteolysis	Osteolysis	Radiograph [29]	4 (1.7)
Os acromiale	Os acromiale	Radiograph, CT, MRI [30]	9 (3.8)
Moderate/severe degeneration	Severe degeneration	Radiograph, MRI [5,31]	78 (32.9)
Separation	Separation	Radiograph, MRI [32]	2 (0.8)
Other			
Bursitis		US, MRI [33]	114 (48.1)
Fracture	Fracture	Radiograph, MRI [34]	3 (1.3)
Tumor	Tumor	MRI [35]	2 (0.8)
Osteomyelitis/abscess	Osteomyelitis	MRI [36]	0 (0)
Septic arthritis	Effusion, osseous destruction	US, MRI [4]	0 (0)

Note: MRA = magnetic resonance angiography; SLAP = superior labrum anterior to posterior; US = ultrasound.
*Adequate diagnostic imaging modalities were determined via literature review.
[†]Injury numbers for each category are independent (ie, multiple pathologies can coexist within a single patient).

initial AIM, had US been available (Fig. 1). The assigned AIM was subsequently correlated with the MRI findings to estimate the incidence of incompletely characterized injuries, based on published efficacy of radiographs, US, and MRI for these same pathologies within the literature (Table 1).

Data Analysis

We calculated statistics for provider ordering patterns by categories including orthopedic specialists (physician [MD], nurse practitioner [NP], and physician assistant [PA]), nonorthopedic medical specialty providers (MD, NP, PA), emergency medicine providers (MD), and primary care providers (MD, NP, PA) to determine relative rates of inappropriate examination ordering and estimated adequacy of ultrasound substitution. Because at our center all trainees order imaging under direct attending physician supervision, trainee orders were attributed to the attending physician. Significance testing was performed with the generalized estimating equation and the χ^2 and Kruskal-Wallis tests using STATA version 14.0 (Statacorp LP), controlling for clustering of orders on a per-provider basis, with a P value of .05 deemed significant.

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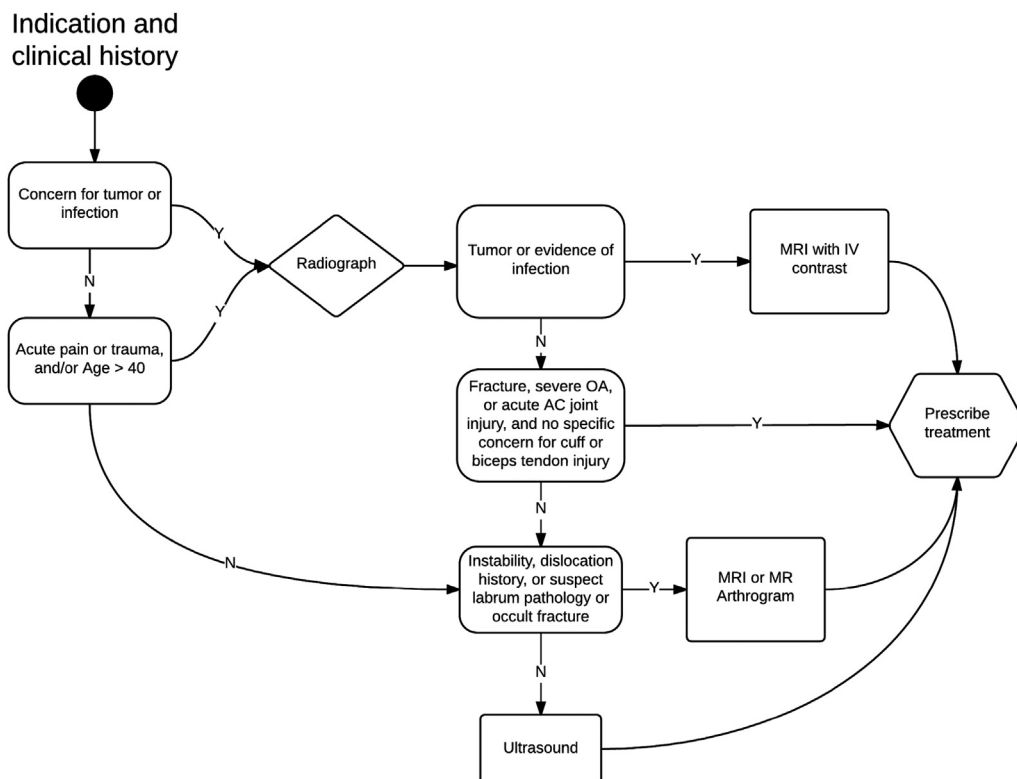
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Fig 1. Advanced imaging modality (AIM) assignment algorithm. AIM assignment is driven by the imaging indication and clinical history, combined with the radiograph findings, if applicable. Note: OA = osteoarthritis; AC = acromioclavicular.

RESULTS

A total of 237 shoulder MRI examinations were performed at the study site during 2013, constituting approximately 8% (237/3075) of all MRI examinations. Most subjects were male (n = 217; 92%) and mean age was 56 years (median 60 years, mode 66 years). MRI examinations were performed on average 30 days after the order was placed (median 26 days, mode 42 days).

On review, 106 shoulder MRI examinations (45%) were determined to be ordered inappropriately. Ninety-eight of these (92%) were deemed inappropriate because of the absence of a preceding radiograph (Table 2); 83 of them (83/98; 85%) were instead obtained during the same imaging appointment. There was significantly higher frequency of inappropriate ordering among nonorthopedic providers relative to orthopedic specialists for any reason (P = .016; odds ratio [OR] = 3.15, 95% confidence interval [CI] = 1.24-8.01), notably, failing to obtain a preceding radiograph in 44% and 17% of cases, respectively. Among primary care providers, no significant difference was seen in ordering appropriateness between physicians and nonphysician providers (P = .353).

Retrospective review of subjects' shoulder MRI studies demonstrated rotator cuff tearing and/or atrophy in 167 (70%) and of long head biceps tendon tearing and/or dislocation in 98 (41%). MRI-identified pathologies in the study population are listed in Table 1.

Based on ordering indications and clinical histories correlated with radiograph findings and guidelines, US would be the indicated initial AIM in 66% of cases, MRI would be indicated in 21% of cases, and no AIM would be indicated in 13% of cases (Table 3). There was no difference between specialties (P = .515), or between physician and nonphysician primary care provider ordering (P = .467), as to whether or not advanced imaging was indicated. However, orthopedic provider orders were more likely to have MRI deemed the indicated AIM relative to nonorthopedic providers (P = .014; OR = 2.11, 95% CI = 1.16-3.81).

The estimated adequacy of US to diagnose all of the abnormal MRI findings per subject differed significantly based on the retrospectively assigned AIM for all specialties. Ultrasound could be expected to adequately diagnose 85% of case pathologies when US itself was the indicated AIM, 77% when no AIM was indicated, but only 53% when MRI was the indicated AIM (P < .001)

Table 2. Inappropriate imaging ordering by provider specialty

	All Specialties	Orthopedics	Emergency Medicine	Primary Care	Rheumatology	Medical Specialists	Neurology	General Surgery
# Providers	79	11	6	51	7	2	1	1
# MRI orders	237	24	10	180	19	2	1	1
# (%) Inappropriate*								
— For any reason	106 (45)	5 (21)	5 (50)	83 (46)	9 (47)	2 (100)	1 (100)	1 (100)
— NPR	98 (41)	4 (17)	5 (50)	78 (43)	8 (42)	2 (100)	1 (100)	0 (0)
— KNOWN	12 (5)	2 (8)	0 (0)	10 (6)	0 (0)	0 (0)	0 (0)	0 (0)
— CLIN/RAD DX	7 (3)	0 (0)	0 (0)	5 (3)	2 (11)	0 (0)	0 (0)	0 (0)
— WRONGEXAM	6 (3)	1 (4)	0 (0)	3 (2)	0 (0)	1 (50)	0 (0)	1 (100)

Note: CLIN/RAD DX = imaging ordered to make a diagnosis that is best made with clinical examination and/or radiographs; KNOWN = known pathology previously diagnosed without intervening injury; NPR = no prior radiograph; WRONGEXAM = imaging examination ordered is inappropriate to make the requested diagnosis.

*A total of 17 of 237 orders were deemed inappropriate for two reasons, and thus summed values for each inappropriateness reason may exceed the specialty totals.

(Table 3). Regardless of AIM assignment, US and radiograph could be expected to adequately diagnose all pathologies in 80% of cases from nonorthopedic providers but only 50% of orthopedic cases ($P = .007$; OR = 3.75, 95% CI = 1.44-9.75). For cases where MRI was the assigned AIM, US was deemed adequate for only 13% of orthopedic cases but 61% of nonorthopedic cases ($P = .011$; OR = 7.9, 95% CI = 1.62-38.69).

When US and radiograph were deemed inadequate, the potentially US-occult destabilizing glenoid labral injuries (6/31) and tumors (1/31) were found on examinations ordered by nonorthopedic providers. Superior labrum anterior to posterior tears (17 of 31 cases) comprised the most common reason for US inadequacy. Concomitant rotator cuff tears were present in 77% of cases where US was deemed inadequate, calling to question the source of the patient's symptoms.

We also assessed the financial impact of unnecessary imaging by using relative value units published by CMS

for shoulder US and MRI in 2013, and made modifications with internal VA cost multipliers for diagnostic services. This resulted in estimated costs of a shoulder MRI ranging from $474.06 to $764.23, depending on the use of contrast material. Similarly estimating upper extremity US at $152.45 resulted in a conservative differential of $321.59 per substituted examination. Assuming 5% of substituted US examinations would require MRI follow-up imaging, we conservatively estimate that providing shoulder US with an appropriate preceding radiograph could have supplanted or eliminated up to 178 (75%) of shoulder MRI examinations where either US or no AIM were indicated, with annual savings of $57,243 and an approximately 6% (178/3075) reduction in associated MRI scheduling delays at our facility.

A total of 79 providers representing 7 specialties ordered an average of 3.0 patient MRI examinations per year (median = 2, min = 1, max = 18). There was no difference in median number of orders per provider across

Table 3. Estimated adequacy of ultrasound in characterizing MRI imaging findings by advanced imaging modality assignment and ordering specialty

	All Specialties	Orthopedics	Emergency Medicine	Primary Care	Rheumatology	Medical Specialists	Neurology	General Surgery
MRI indicated	49	8	0	37	2	1	0	1
US adequate	26	1		24	0	1		0
% Adequate	53.06%	12.5%		64.86%	0.00%	100.00%		0.00%
US indicated	157	13	9	121	13	1	0	0
US adequate	133	9	7	105	12	0		
% Adequate	84.71%	69.23%	77.78%	86.78%	92.31%	0%		
Neither indicated	31	3	1	22	4	0	1	0
US adequate	24	2	1	16	4		1	
% Adequate	77.42%	66.67%	100.00%	72.73%	100.00%		100.00%	

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specialty groups ($P = .152$), though subgroup analysis demonstrated a significantly higher number of studies ordered by primary care providers (mean = 3.53, median = 2) than non-primary care providers (mean = 2.04, median =1) ($P = .01$). There was no difference in median number of studies ordered between physician and nonphysician providers across specialties ($P = .192$) or within primary care ($P = .713$).

DISCUSSION

On retrospective evaluation, we found that advanced shoulder imaging is often not ordered according to published appropriateness criteria. Within the study year, nonorthopedic providers ordered more than 90% of shoulder MRI orders, with 75% attributable to primary care. Nonorthopedic providers also demonstrated more inappropriate ordering, usually for absent preceding radiograph (nearly 45% of cases), similar to prior studies [37,38]. Our data suggest that efforts to improve ordering practices targeting both primary care and other nonorthopedic providers would yield the highest returns toward ordering appropriateness, though orthopedic providers would also benefit from such interventions.

Even though ultrasound was not available to our providers, our imaging algorithm offers a strong methodology for selection of AIM. Prior studies have shown that orthopedic specialty providers tend to order shoulder imaging more appropriately than nonspecialists [37], with considerable potential cost savings of ultrasound substitution for MRI [39]. However, prior studies evaluating US substitution adequacy only designated a "primary" diagnosis for evaluation without confirming that it was responsible for the patient's symptoms. As multiple pathologies often coexist, any proposed imaging modality substitution should assess the performance of competing modalities to assess *all* potential pathologies to better identify the relevant symptom generator. Rotator cuff and biceps tendon injuries were the most common pathologies within our study population, with 72% of patients found to have tearing of one or more of these structures, though these injuries rarely existed in isolation. Given the high prevalence of pathologies such as rotator cuff tears in the asymptomatic population [9], clinically identifying the most likely etiology of the patient's symptoms is critical to guiding imaging and treatment decisions. Prior studies disadvantaging shoulder US against MRI fail to account for the information provided by the indicated preceding radiograph or utilize US imaging

algorithms to inform the choice of AIM, with resultant low estimated adequacy of US substitution at 38% [39]. By utilizing all relevant clinical information and radiograph findings to assign the AIM, we estimate that US could diagnose all relevant pathologies for nearly 85% of patients when indicated. In cases where US was deemed inadequate, previous studies have shown that only approximately 5% of patients may require follow-up MRI after US, and only 10% of these had intra-articular pathology that altered the treatment approach [17].

US would have been less adequate for diagnosis in examinations ordered by orthopedic providers, possibly reflecting more complex pathologies referred for orthopedic evaluation, or suggesting that orthopedic specialists apply more rigorous internal clinical criteria for AIM appropriateness than is evident in retrospective EHR review. Orthopedic specialists may make diagnoses with clinical and radiographic examination more confidently, obviating advanced imaging for all but the most complex or clinically ambiguous cases. Our data suggest that efforts to facilitate US substitution would be best targeted toward nonorthopedic providers.

Clinical decision support (CDS) can decrease imaging overutilization when implemented as part of a computerized physician order entry (CPOE) system [40-43]. Such systems can improve communication and examination appropriateness by providing study-specific templates for examination ordering, ensuring that the most relevant clinical questions have been addressed before consideration of advanced imaging [44]. These tools can also be targeted toward specific providers or clinical settings where overutilization is more prevalent, and can be designed to minimize their obtrusiveness to ordering providers [45-47]. Potential causes of inappropriate ordering may include patient preference for advanced imaging, logistics of consolidating clinical and imaging appointments, or ingrained practice patterns favoring advanced imaging in pursuit of diagnoses [48,49]. Significant rates of inappropriate imaging can persist within capitated systems despite the lack of specific financial incentives, with most instances of inappropriateness in other studies similarly attributed to a select provider subset [50]. However, CDS within CPOE systems has been shown to improve appropriateness of MRI utilization among primary care providers, by providing real-time instruction on imaging guidelines at the time of order entry [40,51]. Similar results with CDS/CPOE systems were reported among emergency medicine providers, with one recent study

showing decreased imaging volume and concomitant increased yield of CT angiography for exclusion of pulmonary emboli [52]. Our data suggest that CDS targeted toward nonorthopedic providers should prompt them to both order a preceding radiograph and provide the most relevant clinical findings, affording the most appropriate AIM selection. Our most common MRI indication was "nonspecific pain, weakness" (51%), without additional relevant clinical history provided. Capturing more relevant patient history through CPOE could improve both imaging appropriateness and communication of critical clinical findings.

The potential cost savings of substituting musculoskeletal US for MRI are substantial [37,39]. Our estimated cost differential of $321.59 per substituted examination is similar to values reported in the literature [39]. This differential would be reduced if the reported 5% rate of follow-up MRI after US were realized [17]. Though it is unclear that VA patients would require similar rates of repeat imaging, decreased MRI resource utilization should decrease waiting times for indicated MRI examinations.

Study limitations include the use of retrospective review and imaging analysis to determine outcomes. Despite the rigorous EHR review, important clinical context may have been lost in determining ordering appropriateness, potentially affecting our estimates of the value of US. Some of the patients for whom no prior radiograph was available may have undergone imaging at another institution, although EHR review showed no evidence of radiograph review by clinicians. Regardless, future prospective studies might elucidate MRI ordering once US is available and highlight why there are differences in ordering appropriateness between provider specialties. Finally, because shoulder US is not yet widely offered at our center, an accurate assessment of cost savings or impact of increase in ultrasound imaging utilization is not currently feasible.

In summary, 45% of shoulder MRI examinations in our study did not meet ordering appropriateness criteria. Inappropriate ordering was more common among primary care and other nonorthopedic provider—originated examinations, although both orthopedic and nonorthopedic providers could benefit from interventions to modify ordering practices. The combination of ultrasound and radiograph substitution for MRI could provide accurate shoulder pathology characterization for a high percentage of cases originated by nonorthopedic providers, with highest diagnostic performance demonstrated when specifically indicated by imaging guidelines. We conservatively estimate that if musculoskeletal ultrasound had been available within our center in 2013, we could have saved $57,243, with an associated 6% reduction in scheduling delays for all MRI examinations. These annual savings should be magnified if musculoskeletal ultrasound were similarly instituted at additional VA health care facilities.

TAKE-HOME POINTS

- Approximately 45% of shoulder MRI examinations are ordered inappropriately based on established criteria, most commonly due to the absence of a preceding radiograph.
- While inappropriate ordering was more common among nonorthopedic providers, both orthopedic and nonorthopedic providers could benefit from interventions to modify ordering practices to improve appropriateness.
- Based on clinical and radiograph criteria, ultrasound would be indicated as a cost-effective substitution for 66% of MRI orders, and the combination of US and radiograph could accurately diagnose approximately 85% of all shoulder pathologies present in those cases.
- Adequacy of ultrasound for diagnosis was highest among primary care and other nonorthopedic provider—originated examinations, so that interventions to modify ordering practices to incorporate shoulder ultrasound should target these provider groups.

REFERENCES

1. Hendee WR, Becker GJ, Borgstede JP, et al. Addressing overutilization in medical imaging. Radiology 2010;257:240-5.
2. Rao VM, Levin DC. The Choosing Wisely initiative of the American Board of Internal Medicine Foundation: what will its impact be on radiology practice? AJR Am J Roentgenol 2014;202:358-61.
3. Nazarian LN, Jacobson JA, Benson CB, et al. Imaging algorithms for evaluating suspected rotator cuff disease: Society of Radiologists in Ultrasound consensus conference statement. Radiology 2013;267: 589-95.
4. Wise JN, Daffner RH, Weissman BN, et al. ACR Appropriateness Criteria(R) on acute shoulder pain. J Am Coll Radiol 2011;8:602-9.
5. Burbank KM, Stevenson JH, Czarnecki GR, Dorfman J. Chronic shoulder pain: part I. Evaluation and diagnosis. Am Fam Physician 2008;77:453-60.
6. Hanchard NC, Lenza M, Handoll HH, Takwoingi Y. Physical tests for shoulder impingements and local lesions of bursa, tendon or labrum that may accompany impingement. Cochrane Database Syst Rev 2013;4:CD007427.
7. Hegedus EJ, Goode AP, Cook CE, et al. Which physical examination tests provide clinicians with the most value when examining the shoulder? Update of a systematic review with meta-analysis of individual tests. Br J Sports Med 2012;46:964-78.

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Health Services Research and Policy ■ Sheehan et al ■ Reducing Unnecessay Shoulder MRI in Capitated Health Care

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8. Dean Deyle G. The role of MRI in musculoskeletal practice: a clinical perspective. J Man Manip Ther 2011;19:152-61.

9. Tashjian RZ. Epidemiology, natural history, and indications for treatment of rotator cuff tears. Clin Sports Med 2012;31:589-604.

10. Armstrong A, Teefey SA, Wu T, et al. The efficacy of ultrasound in the diagnosis of long head of the biceps tendon pathology. J Shoulder Elbow Surg 2006;15:7-11.

11. de Jesus JO, Parker L, Frangos AJ, Nazarian LN. Accuracy of MRI, MR arthrography, and ultrasound in the diagnosis of rotator cuff tears: a meta-analysis. AJR Am J Roentgenol 2009;192:1701-7.

12. Dinnes J, Loveman E, McIntyre L, Waugh N. The effectiveness of diagnostic tests for the assessment of shoulder pain due to soft tissue disorders: a systematic review. Health Technol Assess 2003;7: iii, 1-166.

13. Fotiadou AN, Vlychou M, Papadopoulos P, Karataglis DS, Palladas P, Fezoulidis IV. Ultrasonography of symptomatic rotator cuff tears compared with MR imaging and surgery. Eur J Radiol 2008;68:174-9.

14. Lenza M, Buchbinder R, Takwoingi Y, Johnston RV, Hanchard NC, Faloppa F. Magnetic resonance imaging, magnetic resonance arthrography and ultrasonography for assessing rotator cuff tears in people with shoulder pain for whom surgery is being considered. Cochrane Database Syst Rev 2014;9:CD009020.

15. Skendzel JG, Jacobson JA, Carpenter JE, Miller BS. Long head of biceps brachii tendon evaluation: accuracy of preoperative ultrasound. AJR Am J Roentgenol 2011;197:942-8.

16. Teefey SA. Shoulder sonography: why we do it. J Ultrasound Med 2012;31:1325-31.

17. Rutten MJ, Spaargaren GJ, van Loon T, de Waal Malefijt MC, Kiemeney LA, Jager GJ. Detection of rotator cuff tears: the value of MRI following ultrasound. Eur Radiol 2010;20:450-7.

18. Lewis JS. Rotator cuff tendinopathy/subacromial impingement syndrome: is it time for a new method of assessment? Br J Sports Med 2009;43:259-64.

19. Roy JS, Braen C, Leblond J, et al. Diagnostic accuracy of ultrasonography, MRI and MR arthrography in the characterisation of rotator cuff disorders: a systematic review and meta-analysis. Br J Sports Med 2015;49:1316-28.

20. Sansone V, Consonni O, Maiorano E, Meroni R, Goddi A. Calcific tendinopathy of the rotator cuff: the correlation between pain and imaging features in symptomatic and asymptomatic female shoulders. Skeletal Radiol 2016;45:49-55.

21. Wall LB, Teefey SA, Middleton WD, et al. Diagnostic performance and reliability of ultrasonography for fatty degeneration of the rotator cuff muscles. J Bone Joint Surg 2012;94:e83.

22. Longo UG, Loppini M, Marineo G, Khan WS, Maffulli N, Denaro V. Tendinopathy of the tendon of the long head of the biceps. Sports Med Arthrosc 2011;19:321-32.

23. Green A, Norris TR. Imaging techniques for glenohumeral arthritis and glenohumeral arthroplasty. Clinical orthopaedics and related research 1994:7-17.

24. Menashe L, Hirko K, Losina E, et al. The diagnostic performance of MRI in osteoarthritis: a systematic review and meta-analysis. Osteoarthritis Cartilage 2012;20:13-21.

25. Hayes ML, Collins MS, Morgan JA, Wenger DE, Dahm DL. Efficacy of diagnostic magnetic resonance imaging for articular cartilage lesions of the glenohumeral joint in patients with instability. Skeletal Radiol 2010;39:1199-204.

26. Bruyn GA, Pineda C, Hernandez-Diaz C, et al. Validity of ultrasonography and measures of adult shoulder function and reliability of ultrasonography in detecting shoulder synovitis in patients with rheumatoid arthritis using magnetic resonance imaging as a gold standard. Arthritis Care Research (Hoboken) 2010;62:1079-86.

27. Manske RC, Prohaska D. Diagnosis and management of adhesive capsulitis. Curr Revi Musculoskelet Med 2008;1:180-9.

28. Smith TO, Drew BT, Toms AP. A meta-analysis of the diagnostic test accuracy of MRA and MRI for the detection of glenoid labral injury. Arch Orthop Trauma Surg 2012;132:905-19.

29. Zawadsky M, Marra G, Wiater JM, et al. Osteolysis of the distal clavicle: long-term results of arthroscopic resection. Arthroscopy 2000;16:600-5.

30. Kurtz CA, Humble BJ, Rodosky MW, Sekiya JK. Symptomatic os acromiale. J Am Acad Orthop Surg 2006;14:12-9.

31. de Abreu MR, Chung CB, Wessely M, Jin-Kim H, Resnick D. Acromioclavicular joint osteoarthritis: comparison of findings derived from MR imaging and conventional radiography. Clin Imaging 2005;29:273-7.

32. Nemec U, Oberleitner G, Nemec SF, et al. MRI versus radiography of acromioclavicular joint dislocation. AJR Am J Roentgenol 2011;197: 968-73.

33. Bureau NJ, Dussault RG, Keats TE. Imaging of bursae around the shoulder joint. Skeletal Radiol 1996;25:513-7.

34. Feldman F, Staron R, Zwass A, Rubin S, Haramati N. MR imaging: its role in detecting occult fractures. Skeletal Radiol 1994;23:439-44.

35. Sundaram M, McLeod RA. MR imaging of tumor and tumorlike lesions of bone and soft tissue. AJR Am J Roentgenol 1990;155:817-24.

36. Lew DP, Waldvogel FA. Osteomyelitis. Lancet 2004;364:369-79.

37. Freeman R, Khanna S, Ricketts D. Inappropriate requests for magnetic resonance scans of the shoulder. Int Orthop 2013;37:2181-4.

38. Sher JS, Iannotti JP, Williams GR, et al. The effect of shoulder magnetic resonance imaging on clinical decision making. J Shoulder Elbow Surg 1998;7:205-9.

39. Parker L, Nazarian LN, Carrino JA, et al. Musculoskeletal imaging: medicare use, costs, and potential for cost substitution. J Am Coll Radiol 2008;5:182-8.

40. Blackmore CC, Mecklenburg RS, Kaplan GS. Effectiveness of clinical decision support in controlling inappropriate imaging. J Am Coll Radiol 2011;8:19-25.

41. Bright TJ, Wong A, Dhurjati R, et al. Effect of clinical decision-support systems: a systematic review. Ann Intern Med 2012;157: 29-43.

42. Duszak R Jr, Berlin JW. Utilization management in radiology, part 1: rationale, history, and current status. J Am Coll Radiol 2012;9:694-9.

43. Ip IK, Schneider LI, Hanson R, et al. Adoption and meaningful use of computerized physician order entry with an integrated clinical decision support system for radiology: ten-year analysis in an urban teaching hospital. J Am Coll Radiol 2012;9:129-36.

44. Pevnick JM, Herzik AJ, Li X, et al. Effect of computerized physician order entry on imaging study indication. J Am Coll Radiol 2015;12: 70-4.

45. Duszak R Jr, Berlin JW. Utilization management in radiology, part 2: perspectives and future directions. J Am Coll Radiol 2012;9: 700-3.

46. Levick DL, Stern G, Meyerhoefer CD, Levick A, Pucklavage D. Reducing unnecessary testing in a CPOE system through implementation of a targeted CDS intervention. BMC Med Inform Decis Mak 2013;13:43.

47. Sittig DF, Krall MA, Dykstra RH, Russell A, Chin HL. A survey of factors affecting clinician acceptance of clinical decision support. BMC Med Inform Decis Mak 2006;6:6.

48. Covinsky KE, Redberg RF. An intervention to reduce use of low-value imaging tests. JAMA Intern Med 2015;1.

49. Fenton JJ, Kravitz RL, Jerant A, et al. Promoting patient-centered counseling to reduce use of low-value diagnostic tests: a randomized clinical trial. JAMA Intern Med 2015:1-7.

50. Gidwani R, Sinnott P, Avoundjian T, Lo J, Asch SM, Barnett PG. Inappropriate ordering of lumbar spine magnetic resonance imaging: are providers choosing wisely? Am J Manag Care 2016;22:e68-76.

51. Ip IK, Gershanik EF, Schneider LI, et al. Impact of IT-enabled intervention on MRI use for back pain. Am J Med 2014;127: 512-518 e1.

52. Raja AS, Ip IK, Prevedello LM, et al. Effect of computerized clinical decision support on the use and yield of CT pulmonary angiography in the emergency department. Radiology 2012;262:468-74.