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Appropriateness of the Use of MRI in the Diagnosis and Treatment of Wrist Ligamentous Injury

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Abstract

Background—When diagnosing wrist ligamentous injury, we hypothesize that MRI is used injudiciously and is associated with unnecessary cost.

Methods—A retrospective review was conducted of patients, ages 20–60 years, who underwent an MRI for possible wrist ligamentous injury at a tertiary care center between 2009 and 2014. Treatment recommendation was classified as non-operative, operative, or equivocal. If the MRI-directed treatment recommendation differed from the pre-MRI treatment recommendation, we noted that the MRI influenced patient care (impact study). The cost estimate of an impact study was calculated by dividing the total studies performed by the number of studies that impacted the treatment recommendation and multiplying this value by the institutional wrist MRI cost (USD \$2,246, 2016).

Results—140 patients were included. MRI affected treatment recommendation in 28% of patients. Independent predictors of MRI impact on treatment recommendation were: “question specific injury,” or “question scapholunate injury.” (OR 9.46 (3.18 – 28.16), $P < 0.001$), OR 2.88 (1.21–6.88), $P = 0.02$). The only independent predictor of surgery was ordering physician (hand surgeon) (OR 3.69 (1.34–10.13), $P = 0.01$). The cost of an impact study ordered by a non-hand surgeon vs. hand surgeon was \$13,359 versus \$6,491.

Conclusions—The provider must carefully consider the pre-test probability of ordering a study that will affect treatment recommendation. Injudicious screening with MRI (\$15,565) incurred a cost nearly seven times the cost of the one MRI (\$2,246) before impacting one treatment recommendation. In the current era of cost containment and bundled payment, diagnostic test probability must be appreciated to guide physician ordering practices.

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The authors have no conflicts of interest

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Keywords

Magnetic resonance imaging; wrist ligamentous injury; healthcare resource utilization

The United States spends more money on health care than any other nation in the world.¹ Per capita expenditures have continued to increase from \$4,703 in 2009, to \$9,146 in 2013.¹ Spending on medical imaging has become an important area of concern, with costs approaching \$100 billion annually.² Compared to other imaging modalities, magnetic resonance imaging (MRI) accounts for the highest expenditures.² Despite the increased use of MRI, this imaging modality may not improve patient outcomes, contributing substantial unnecessary costs.^{3,4} As a result, the American College of Radiology (ACR) developed an Appropriateness Criteria for ordering advanced diagnostic imaging; however, studies have demonstrated that these guidelines are not impacting ordering practices.⁵ Bautista et al. found that only 2.4% of the physicians had correctly followed the criterion established by the ACR.⁵ This may be owing to medico-legal fears, patient demand, economically-motivated self-referral, and lack of physician training and education with respect to appropriate ordering indications.^{2,6}

Many studies have detailed the use of MRI in patients with musculoskeletal complaints.^{7–11} These studies highlight differences in the ordering process as it impacts diagnosis and treatment recommendations. Researchers demonstrated that MRI studies that were ordered by orthopedic surgeons versus non-orthopedic physicians were more likely to be associated with a specific diagnosis, impact patient treatment, and result in surgery that was of benefit to the patient.^{9,10,12} Additionally, when used as a screening tool for non-specific hip pain, Keeney et al. calculated a cumulative institutional cost for obtaining a single study that impacted a patient's treatment of \$59,296. When the study cost was compared between providers, they found that the cost of obtaining a study that impacted a patient's treatment was three-times greater when the ordering physician was a non-orthopedic provider (\$7,804 versus \$2,834) suggesting that education of referring physicians is paramount to reducing healthcare costs.⁹

The "Choose Wisely" campaign, a partnership between Consumer Reports and the American Board of Internal Medicine, has been adopted by many medical and surgical societies. The objective of this campaign is to promote effective use of healthcare resources by identifying areas of injudicious use and by educating physicians and patients. By their estimates, eliminating unnecessary tests could save \$5 billion.^{13–16}

The goal of this study was to examine the appropriateness of MRI ordering in the diagnosis and treatment of wrist ligamentous injury. Specific aims of the study were to evaluate the ordering practices of hand surgeons and non-hand surgeons and to highlight the increased costs associated with inappropriate ordering of MRI.

We hypothesized that hand surgeons would more commonly order a wrist MRI for a specific indication and would be more likely to order an MRI that impacted treatment. Therefore, the cost of obtaining a study that had impact on a patient's treatment would be less. Finally, we

use two commonly encountered clinical scenarios to illustrate the concept of test probability and discuss its impact on changing a treatment recommendation.

Methods

After obtaining institutional review board approval, we conducted a retrospective review of the electronic medical record of all patients, ages 20 to 60 years, who visited a tertiary care facility between June 2009 and June 2014. We utilized ICD-9 codes to identify the following wrist ligament injuries: scapholunate ligament injury (SL), triangular fibrocartilage complex injury (TFCC), and lunotriquetral ligament injury (LT). We also collected information from patients who had non-specific wrist pain with possible ligamentous injury, distal radioulnar joint (DRUJ) instability, or ulnocarpal abutment.

Patients were included in the study cohort if they underwent at least one wrist MRI investigating one of the aforementioned diagnoses and had at least one documented clinical examination and standard radiographic assessment of the wrist prior to the MRI study. Patients who had additional confirmed or suspected pathology were excluded from the study (concern for fracture, infection, inflammatory or crystalline arthropathy, neoplasm, compression neuropathy, or severe degenerative arthritis).

Patient age, sex, and existing comorbidities were recorded. Relevant clinical history and physical examination provided by the ordering physician, context of the diagnosis, and the explanation of the patient's treatment plan were collected. We identified the indication for the MRI, ordering clinician, and MRI diagnosis from the original MRI report. 3 Tesla MRI scans were excluded to control for the sensitivity with which different MRI scanners may identify soft tissue changes.

Blinded to the MRI report and ordering physician, the pre-MRI history, physical examination, and x-ray images were reviewed by a fellowship-trained hand surgeon to determine both diagnosis and treatment plan. Treatment recommendation was classified as non-operative, operative, or equivocal. If, following the MRI, the treatment recommendation changed, we noted that the MRI scan influenced the patient's treatment recommendation (impact study). In order to be considered an impact study one of the following criteria was met: 1) a clear treatment recommendation was made prior to the wrist MRI and that recommendation was different from the treatment recommendation after the MRI, 2) a directed physical exam had been performed and a conclusive diagnosis could not be determined, therefore, the decision to proceed with non-operative versus operative management was said to be "equivocal." In this scenario, an MRI study was of benefit if either non-operative or operative management could be recommended based on the study findings. An MRI was considered unnecessary if: 1) the treatment recommendation prior to the wrist MRI was the same as the treatment recommendation after the MRI or 2) the MRI was normal when the study indication was "wrist pain," i.e. a screening MRI. Post-MRI diagnosis was determined to be different from pre-MRI diagnosis if the MRI identified clinically unapparent pathology within the wrist. Additional post-MRI diagnoses, owing to the high-sensitivity of MRI for detecting soft tissue changes, were only determined to be clinically significant if acted upon by the treating physician.

Patients were categorized by MRI study indication (question specific injury vs. wrist pain), ordering provider (hand surgeon vs. non-hand surgeon), and timing (≤6 weeks or >6 weeks). Patients were also separated into more specific study indication groups. These included: question ligamentous injury, question SL ligament injury, question TFCC injury, question DRUJ instability, question ulnocarpal abutment, or wrist pain. Data were pooled from all studies in which a specific indication was recorded and termed “question specific injury.” Multiple diagnoses were studied individually.

We analyzed four outcome variables of interest, including: 1) MRI impact on treatment recommendation, 2) MRI diagnosis, 3) MRI-directed treatment, 4) surgery. In our analysis of these dependent outcomes variables, we included age, gender, number of comorbidities, ordering physician (hand surgeon versus non-hand surgeon), study indication, and MRI-timing ≤6 weeks as independent variables. Univariate analysis was used to examine the association between independent variables and each of the four outcomes. Chi-square test was used for categorical variables and Wilcoxon Rank Sum test was used for continuous variables. All independent variables found to be statistically significant in univariate analysis were then applied to a multivariable model. The stepwise selection method was used to select proper variables for the final model. The four outcomes were binary variables so logistic regression models were used for all outcomes.

Lastly, the additional cost incurred by unnecessary MRIs over the study period was calculated. We used our institution’s fixed unit cost for an upper extremity MRI (USD \$2,246, 2016) to calculate the total cost of all wrist MRIs performed before one study impacted the treatment plan for a patient. To calculate this cost, we identified the total number of studies performed and divided this by the number of MRI studies that impacted the treatment recommendation. This value was then multiplied by the institutional MRI unit cost.

$$\text{Cost} = \text{Institutional MRI unit Cost} \times \frac{\text{number of total studies performed}}{\text{number of impact studies}}$$

Results

A total of 140 patients were included. The most common indication for ordering an MRI was wrist pain (n=70, 50%), followed by MRIs ordered to question a SL ligament injury (n=25, 18%). Thirty-four percent of the MRI studies were performed within 6 weeks of when the patient first started experiencing symptoms. Following an MRI, surgery could be recommended in 29% of patients (n=41), non-operative management could be recommended in 67% of the cohort (n=94), and in 5 patients (4%) the MRI could not be used to discern between operative and non-operative recommendations. Overall, the post-MRI treatment recommendation was different from the pre-MRI recommendation, and was therefore said to have influenced the treatment recommendation, in 28% of the patients (n=39) studied.

Pre-MRI and post-MRI wrist diagnoses were also noted. Post-MRI diagnoses were found to be different in 61% of patients (n=85). In other words, MRI often detected additional

pathology, such as degenerative changes or cysts, within the wrist. These incidental diagnoses were usually not acted upon by the ordering physician. (Table 1)

In univariate analysis, younger age (32.6 yrs vs 38.4 yrs, $P=0.007$) was an independent predictor of MRI impact on treatment recommendation. Hand surgeons were more likely to obtain an MRI that impacted a treatment recommendation (38% vs. 18%, $P=0.01$). Additionally, MRI more frequently changed the patient's treatment recommendation if ordered to "question a specific injury" rather than to screen patients with wrist pain (40% vs 16%, $P=0.001$). Lastly, MRIs ordered less than 6-weeks after the onset of symptoms were associated with a greater likelihood of impacting the treatment recommendation (40% vs. 22%, $P=0.002$), demonstrating that patients with chronic injuries were less likely to be influenced by an MRI. (Table 2)

Of the 39 patients found to have impact MRI studies, the post-MRI treatment was selected by only 26 patients ($n=67\%$). A study indication of "question scapholunate ligament injury" was the only predictor of a post-MRI treatment recommendation being selected by the patient. (Table 3)

Twenty-four patients (17%) proceeded with the recommendation to have surgery. The only predictor of surgery following the MRI was if the study was ordered by a hand surgeon (26% vs. 8%, $P=0.006$). This is likely because an MRI ordered by a hand surgeon was more often ordered to confirm a diagnosis in the setting of a suspected surgical injury. In other words, the hand surgeon is more likely to narrow a differential diagnosis with physical examination and use an MRI as adjunct to confirm a surgical problem, as opposed to using an MRI for screening purposes.

There were no independent predictors of a difference in diagnosis following the MRI. In other words, pre-imaging variables could not be used to predict whether or not an MRI would reveal additional clinically significant diagnoses. (Table 4)

Multivariable analysis was performed based on the variables that were statistically significant in univariate analysis. Compared to a study indication of "wrist pain", an MRI scan ordered to "question a specific injury" was predictive of MRI influence on treatment recommendation (OR 2.88(1.21–6.88), $P=0.02$). Specific wrist ligament injuries were then analyzed, and a study indication of "question scapholunate injury" was found as the only independent predictor of MRI influence on treatment recommendation (OR 9.46 (3.18 – 28.16), $P<0.001$). (Table 5) MRI studies ordered by hand surgeons were more likely to result in surgery (OR 3.69 (1.34–10.13), $P=0.01$). (Table 6)

The cumulative institutional cost of obtaining an MRI study that impacted a treatment recommendation was calculated for the entire cohort and for each study indication. Over the entire cohort, the estimated cost of obtaining an impact MRI study was \$8,781, meaning our institution ordered roughly 4 wrist MRIs before one impacted a treatment recommendation. The highest impact study cost was found for a study indication of "wrist pain" (\$15,565), whereas, the most cost-effective MRIs were ordered for study indication: "question scapholunate ligament injury" (\$3,597). Estimated cost for each study indication is presented in Table 7.

The overall cost of obtaining an impact MRI study when ordered by a non-hand surgeon as compared to a hand surgeon was \$13,359 versus \$6,491. These data demonstrate that non-hand surgeons ordered roughly 6 wrist MRI studies before 1 impacted a treatment recommendation, compared to an estimate of 3 MRIs per 1 impact study for hand surgeons. (Table 8)

Discussion

Ligamentous injury exists among the spectrum of pain-generating pathology within the wrist.¹⁷ Few studies have been conducted to investigate the appropriate use of MRI for diagnosing the etiology of wrist pain. In a study performed by Ruston et al., the authors retrospectively compared the diagnostic accuracy of clinical examination and MRI for TFCC, LT, and SL injuries. Using arthroscopy as the reference standard, researchers found a high specificity associated with clinical examination for TFCC and LT injuries, 92.7% and 92.3%, respectively, but not for SL injury.¹⁸ Other data suggest that examination and clenched-fist x-ray views have a high enough sensitivity and specificity to diagnose scapholunate pathology.¹⁹

The results from this study further demonstrate the injudicious ordering of MRI and are consistent with previously published data. Following an MRI study, surgery was recommended in 29% of patients. Prior to the wrist MRI, operative treatment was recommended in 15% of patients suggesting that the MRI findings led to a change from non-operative to operative treatment in only 14% of patients. Additionally, of the patients for whom surgery was recommended, approximately half decided not to proceed with the operation.

In the scenario where more information is needed to rule out surgery, a negative MRI is a useful study. Prior to MRI in 24% of patients in our cohort, neither an operative or non-operative treatment recommendation could be determined. Following MRI, 85% of patients in this subgroup could be given a treatment recommendation. In this scenario, a negative MRI avoids the cost incurred with unnecessary surgery.

Physical examination using specific provocative wrist maneuvers may permit physicians to confidently diagnose patients with wrist pain and curtail unnecessary ordering of MRI. However, several studies have highlighted the lack of training and understanding of the musculoskeletal system in non-specialist providers, which may influence the overuse of MRI in clinical practice.^{20–23} In a study by Harzell et al., the authors examined the impact of the gatekeeper model in hand surgery. They concluded that advanced imaging, such as CT or MRI, was used unnecessarily in 22% of patients.²⁴ Our study is consistent with previous musculoskeletal studies that have questioned the utility of MRI scans ordered prior to referral to a specialist.^{25–27} Hand surgeons were more likely compared to non-hand surgeons to obtain an MRI that impacted a treatment recommendation (38% vs. 18%). This may be because hand surgeons more frequently ordered MRI scans for a specific study indication, whereas, non-hand surgeons ordered MRIs to investigate wrist pain. Furthermore, the overall cost of obtaining an impact MRI study was doubled when the scan was ordered by a non-hand surgeon compared to a hand surgeon (\$13,359 vs. \$6,491).

Another important consideration is the concept of pre-test probability (PTP). In the wrist injury population, several factors may influence the probability that an MRI may impact the treatment recommendation such as: timing of injury (acute vs. chronic), employment status (self-employed vs. worker's compensation), prior treatment (strict immobilization, OT), patient motivation, and provocative exam maneuvers.

If used for screening purposes, the MRI pre-test probability is low and the test is not cost-effective. When the pre-test probability is high such that a surgical injury exists, MRI is also not cost effective because the patient will likely require surgery despite the test results.²⁸

Let us consider two common clinical scenarios to better understand the impact of pre-test probability on treatment recommendation.

Case 1: 38-year-old, manual laborer who fell onto his outstretched dominant left wrist 6 months prior to presentation. He complains of dorsal wrist pain, primarily with loading and extension. On physical examination, he is tender over the scapholunate interval. Watson shift test generates mild pain. X-rays were normal at the time of injury. Clenched-fist x-rays during this visit demonstrate dynamic scapholunate instability. He has failed a trial of strict immobilization.

Case 2: 46-year-old, manual laborer who injured his non-dominant left wrist after falling from a stepladder 6 weeks prior to presentation. The patient reports that his wrist hurts with all activity but especially during loading. On examination, he is tender along the dorsal aspect of the radiocarpal joint, but most tender over the scapholunate interval. X-rays were negative for acute bony or ligamentous injury at the time of presentation. Stress views are negative during your visit. He has worn a splint since the injury without relief.

In the first scenario, the patient presents with a focused history and physical examination consistent with scapholunate injury. There are no warning signs and he has completed a period of strict immobilization. An MRI in this scenario has a low probability of changing the treatment recommendation in favor of avoiding surgery and, therefore, is not indicated. Our recommendation would be to proceed with arthroscopy to systematically evaluate the wrist, better characterize the injury, and further develop a treatment plan. It would also be acceptable to bypass arthroscopy and proceed directly with scapholunate reconstruction.

In the second scenario, the patient presents similarly but the history and exam is equivocal for scapholunate injury. The probability of finding an operative indication on MRI is much lower in this scenario but a negative MRI is useful to rule out operative pathology.

Each case should be carefully scrutinized and individualized. A personal algorithm should be developed for determining when a patient can be safely treated operatively or non-operatively. An MRI should be ordered only when it is likely to impact treatment recommendation, rule out a specific injury, and potentially limit the costs associated with unnecessary surgery.

One limitation of this study is its retrospective nature, specifically our ability to determine pre-MRI treatment plan based on the medical record. Another limitation is the referral and

practice patterns of a tertiary care facility. The pre-test probability of obtaining an MRI that will impact the treatment recommendation is likely to be higher when ordered by a hand surgeon. Due to narrow scope of practice, hand surgeons are more familiar with provocative physical exam maneuvers, careful interpretation of x-ray studies, and/or proceeded to arthroscopy prior to, or in place of, MRI in certain clinical scenarios.

Our criteria for determining that a history and exam was “equivocal” included a focused yet comprehensive physical examination. Primary care doctors often did not document a focused exam. If a diagnosis was not obvious, (i.e. greater than 4 mm SL gapping on x-ray), we classified the study as a screening MRI. Where conservative treatment had not been attempted in this scenario, (i.e. splint immobilization and NSAIDs), non-operative treatment was recommended. In our study, when an MRI was ordered for wrist pain, independent of ordering physician, it was less likely to influence the treatment decision. We identified this group of studies as an area where costs could be reduced in the future with education and/or proper timing of referrals.

Cost of the MRI (bill versus collection) will vary across institutions. We used the fixed institutional cost of an upper extremity MRI (\$2246) for our calculations, though a survey of community MRI costs returned values of \$525–\$3800. From the information obtained, it is unclear if these values reflect bills versus collections and if the numbers vary depending on the extent of the extremity that is imaged. If the absolute cost of an MRI study is at the lower end of this range, the cost of a screening MRI might be equivocal or less than the costs associated with time spent waiting to see a hand surgeon and lost wages.

Another contentious issue is how to effectively evaluate the worker’s compensation patient where the history and physical examination do not correlate with the patient’s perceived level of pain or impairment. We did not consider how a normal MRI, in this scenario, may be useful in encouraging the patient to return to work or resume a regular routine.

Although MRI is associated with a high sensitivity to detect soft tissue pathology, clinical examination with standard and special x-ray views may provide a similar treatment recommendation at a lower cost. In order to limit unnecessary ordering of advanced imaging such as MRI, further musculoskeletal education may be needed in the primary care setting. Additionally, the probability of an MRI study to change the treatment recommendation must be carefully considered to limit the costs associated with these expensive diagnostic tests.

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Table 1

Overall Summary for Continuous Variables and Categorical Variables

N of patients=140				
Age	Mean	Median	SD	Range
	36.8	36	11.2	17–59
Comorbidity	0.32	0	0.60	0–2
N of patients=140				
Gender		Frequency	Percent (%)	
Female		86	61	
Male		54	39	
Surgery				
Yes		24	17	
No		116	83	
Ordering physician				
Hand physician		69	49	
Non-hand physician		71	51	
Outpatient Primary Care Provider		52	73	
Rheumatologist		7	10	
Internal Medicine Hospitalist		5	7	
Physiatrist		5	7	
Emergency Medicine		2	3	
Study indication (Multi)				
Question Distal radial ulnar joint (DRUD) instability		3	2	
Question ligamentous injury		21	15	
Question scapholunate ligament injury		25	18	
Question TFCC injury		15	11	
Question ulnocarpal abutment		6	4	
Wrist pain		70	50	
Study indication (Two)				
Question specific injury		70	50	

N of patients=140				Frequency	Percent (%)			
<hr/>								
Wrist pain								
<hr/>								
MRI-timing (6 weeks)								
<hr/>								
Yes	48				34			
No	92				66			
<hr/>								
Pre-MRI recommendation								
<hr/>								
Operation	21				15			
No operation	85				61			
Equivocal	34				24			
<hr/>								
Post-MRI recommendation								
<hr/>								
Operation	41				29			
No operation	94				67			
Equivocal	5				4			
<hr/>								
MRI diagnosis different than pre-MRI diagnosis								
<hr/>								
Yes	85				61			
No	55				39			
<hr/>								
Hand Surgeon Group (N=69)			Non-Hand Surgeon Group (N=71)					
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	Mean	Median	SD	Range	Mean	Median	SD	Range
Age	35.5	32	11.7	20-57	38.1	39	10.7	17-59
Comorbidity	0.30	0	0.58	0-2	0.34	0	0.63	0-2
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Hand Surgeon Group (N=69)			Non-Hand Surgeon Group (N=71)					
<hr/>								
Frequency								
<hr/>								
Percent (%)								
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Gender								
<hr/>								
Female	46				67			
Male	23				33			
<hr/>								
Surgery								
<hr/>								
Yes	18				26			
No	51				74			

Hand Surgeon Group (N=69)				Non-Hand Surgeon Group (N=71)			
	Frequency	Percent (%)		Frequency	Percent (%)		
Study indication (Multi)							
Question Distal radial ulnar joint (DRUJ) instability	3	4		0		0	
Question ligamentous injury	7	10		14		20	
Question scapholunate ligament injury	22	32		3		4	
Question TFCC injury	7	10		8		11	
Question ulnocarpal abutment	6	9		0		0	
Wrist pain	24	35		46		65	
Study indication (Two)							
Question specific injury	45	65		25		35	
Wrist pain	24	35		46		65	
MRI-timing (6 weeks)							
Yes	22	32		26		37	
No	47	68		45		63	
Pre-MRI recommendation							
Operation	16	23		5		7	
No operation	26	38		59		83	
Equivocal	27	39		7		10	
Post-MRI recommendation							
Operation	27	39		14		20	
No operation	37	54		57		80	
Equivocal	5	7		0		0	
MRI diagnosis different than pre-MRI diagnosis							
Yes	39	57		46		65	
No	30	43		25		35	

Table 2

Did MRI findings impact treatment recommendation?

Variables	Yes n=39, 28%	No n=101, 72%	P values*
Age	32.6 (11.46)	38.4 (10.83)	0.007
Sex			0.10
Female	24 (28%)	62 (72%)	
Male	15 (28%)	39 (72%)	
Comorbidity	0.21 (0.47)	0.37 (0.64)	0.20
Ordered physician			0.01
Hand physician	26 (38%)	43 (62%)	
Non-hand physician	13 (18%)	58 (82%)	
Study indication			
Question Distal radial ulnar joint (DRUJ) instability	2 (67%)	1 (33%)	
Question scapholunate ligament injury	17 (68%)	8 (32%)	
Question TFCC injury	3 (20%)	12 (80%)	
Question ligamentous injury	6 (29%)	15 (71%)	
Question ulnocarpal abutment	0 (0%)	6 (100%)	
Wrist pain	11 (16%)	59 (84%)	
Study indication			0.001
Question specific injury	28 (40%)	42 (60%)	
Wrist pain	11 (16%)	59 (84%)	
MRI-timing 6 weeks			0.002
Yes	19 (40%)	29 (60%)	
No	20 (22%)	72 (78%)	

Table 3

If the pre-MRI and post-MRI recommendations are different, was MRI-directed treatment selected?

Variables	Yes (selected) N=26, 67%	No (not selected) N=13, 33%	P values*
Age	31.3 (10.84)	35.3 (12.63)	0.323
Sex			0.485
Female	17 (71%)	7 (29%)	
Male	9 (60%)	6 (40%)	
Comorbidity	0.23 (0.51)	0.15 (0.38)	0.739
Ordered physician			0.055
Hand physician	20 (77%)	6 (23%)	
Non-hand physician	6 (46%)	7 (54%)	
Study indication			0.044
Question Distal radial ulnar joint (DRUJ) instability	2 (100%)	0 (0%)	
Question scapholunate ligament injury	15 (88%)	2 (12%)	
Question TFCC injury	2 (67%)	1 (33%)	
Question ligamentous injury	2 (33%)	4 (67%)	
Question ulnocarpal abutment	0 (0%)	0 (0%)	
Wrist pain	5 (45%)	6 (55%)	
Study indication			0.078
Question specific injury	21 (75%)	7 (25%)	
Wrist pain	5 (45%)	6 (55%)	
MRI-timing < 6 weeks			0.365
Yes	12 (60%)	8 (40%)	
No	14 (74%)	5 (26%)	

Table 4

Is post- MRI diagnosis different than pre-MRI diagnosis?

Variables	Yes (different) N=85, 61%	No (the same) N=55, 39%	P values*
Age	37.7 (11.35)	35.5 (11.15)	0.288
Sex			0.322
Female	55 (64%)	31 (36%)	
Male	30 (56%)	24 (44%)	
Comorbidity	0.31 (0.60)	0.35 (0.62)	0.642
Ordered physician			0.317
Hand physician	39 (57%)	30 (43%)	
Non-hand physician	46 (65%)	25 (35%)	
Study indication			
Question Distal radial ulnar joint (DRUJ) instability	3 (100%)	0 (0%)	
Question scapholunate ligament injury	13 (52%)	12 (48%)	
Question TFCC injury	7 (47%)	8 (53%)	
Question ligamentous injury	12 (57%)	9 (43%)	
Question ulnocarpal abutment	3 (50%)	3 (50%)	
Wrist pain	47 (67%)	23 (33%)	
Study indication			0.119
Question specific injury	38 (54%)	32 (46%)	
Wrist pain	47 (67%)	23 (33%)	
MRI-timing 6 weeks			0.755
Yes	30 (63%)	18 (38%)	
No	55 (60%)	37 (40%)	

Table 5

Multivariable analysis of MRI influence

Parameter	OR (95% CI)	P-value
Age	0.97 (0.93–1.01)	0.128
Study Indication		
Wrist pain (ref)		
Question specific injury	2.88 (1.21–6.88)	0.017
Hand physician		
No (ref)		
Yes	2.33 (0.99–5.48)	0.052
MRI timing 6 weeks		
No (ref)		
Study Indication		
Wrist pain (ref)		
Question distal radial ulnar joint (DRUJ) instability	6.09 (0.45–82.24)	0.174
Question scapholunate ligament injury	9.46 (3.18–28.16)	<.001
Question TFCC injury	1.21 (0.28–5.20)	0.798
Question ligamentous injury	1.93 (0.61–6.14)	0.267

Table 6

Multivariable analysis of surgery

Parameter	OR (95% CI)	P-value
Hand physician		
No (ref)		
Yes	3.69 (1.34–10.13)	0.011

Table 7

Overall impact MRI costs

Study Indication	Wrists (N=140, 100%)	Impact cases (N=39, 28%)	Impact study cost (USD)
Question Distal radial ulnar joint (DRUJ) instability	3 (2%)	2 (1%)	3/2*2446=3669
Question scapholunate ligament injury	25 (18%)	17 (12%)	25/17*2446=3597
Question TFCC injury	15 (11%)	3 (2%)	15/3*2446=12230
Question ligamentous injury	21 (15%)	6 (4%)	21/6*2446=8561
Question ulnocarpal abutment	6 (4%)	0 (0%)	6/0*2446=∞
Wrist pain	70 (50%)	11 (8%)	70/11*2446=15565
Total	140 (100%)	39 (28%)	140/39*2446=8781

Study Indication	Wrists (N=140, 100%)	Impact cases (N=39, 28%)	Impact study cost (USD)
Question specific injury	69 (49%)	28 (20%)	69/28*2446=6028
Wrist pain	71 (51%)	11 (8%)	71/11*2446=15788
Total	140 (100%)	39 (28%)	140/39*2446=8781

MRI institutional unit cost \$2246.00, 2016

Table 8

Costs associated with impact studies: Hand surgeon vs. non-hand surgeon

Study Indication	Impact Study Non-Hand Surgeon (n=13)	Impact Study Hand Surgeon (n=26)	Impact Study Cost (Non-Hand Surgeon) (USD)	Impact Study Cost (Hand Surgeon) (USD)
Question specific injury	8	20	25/8*2446=7644	45/20*2446=5504
Wrist pain	5	6	46/5*2446=22503	24/6*2446=9784
Total	13	26	71/13*2446=13359	69/26*2446=6491

Question Distal radial ulnar joint (DRUJ) instability	0	2	0/0*2446=0	3/2*2446=3669
Question scapholunate ligament injury	2	15	3/2*2446=3669	22/15*2446=3587
Question TFCC injury	2	1	8/2*2446=9784	7/1*2446=17122
Question ligamentous injury	4	2	14/4*2446=8561	7/2*2446=8561
Question ulnocarpal abutment	0	0	0/0*2446=0	6/0*2446=∞
Wrist pain	5	6	46/5*2446=22503	24/6*2446=9784
Total	13	26	71/13*2446=13359	69/26*2446=6491

MRI institutional unit cost \$2246.00 USD, 2016