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Preoperative planning with three-dimensional CT vs. three-dimensional magnetic resonance imaging does not change surgical management for shoulder instability

Alexandra V. Paul, MD[a,*], Imoh Udoh, BS[a], Ananyaa Bharadwaj, BS[a], Steven Bokshan, MD[a], Brett D. Owens, MD[b], William N. Levine, MD[c], Grant E. Garrigues, MD[d], Jeffrey S. Abrams, MD[e], Patrick J. McMahon, MD[f], Anthony Miniaci, MD[g], Sameer Nagda, MD[h], Jonathan P. Braman, MD[i], Peter MacDonald, MD[j], Jonathan C. Riboh, MD[k], Scott Kaar, MD[l], Brian Lau, MD[a]

[a]Department of Orthopedic Surgery, Duke University Medical Center, Durham, NC, USA
[b]Department of Orthopaedic Surgery, Warren Alpert Medical School, Brown University, Providence, RI, USA
[c]Department of Orthopaedic Surgery, Columbia University Medical Center, New York, NY, USA
[d]Midwest Orthopaedics at RUSH, Rush University Medical Center, Chicago, IL, USA
[e]University Medical Center at Princeton, Princeton, NJ, USA
[f]University of Pittsburgh Medical Center, Pittsburgh, PA, USA
[g]Department of Orthopaedic Surgery, The Cleveland Clinic Foundation, Cleveland, OH, USA
[h]Anderson Orthopaedic Clinic, Arlington, VA, USA
[i]Department of Orthopedic Surgery, University of Minnesota, Minneapolis, MN, USA
[j]Orthopaedic Surgery, Pan Am Clinic, University of Manitoba, Winnipeg, MB, Canada
[k]Atrium Health Musculoskeletal Institute, Charlotte, NC, USA
[l]Department of Orthopaedic Surgery, Saint Louis University, St. Louis, MO, USA

A R T I C L E I N F O

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Level of evidence: Survey Study; Experts

Background: This study aims to determine the effect of time and imaging modality (three-dimensional (3D) CT vs. 3D magnetic resonance imaging (MRI)) on the surgical procedure indicated for shoulder instability. The hypothesis is there will be no clinical difference in procedure selection between time and imaging modality.

Methods: Eleven shoulder surgeons were surveyed with the same ten shoulder instability clinical scenarios at three time points. All time points included history of present illness, musculoskeletal exam, radiographs, and standard two-dimensional MRI. To assess the effect of imaging modality, survey 1 included 3D MRI while survey 2 included a two-dimensional and 3D CT scan. To assess the effect of time, a retest was performed with survey 3 which was identical to survey 2. The outcome measured was whether surgeons made a “major” or “minor” surgical change between surveys.

Results: The average major change rate was 14.1% (standard deviation: 7.6%). The average minor change rate was 12.6% (standard deviation: 7.5%). Between survey 1 to the survey 2, the major change rate was 15.2%, compared to 13.1% when going from the second to the third survey ($P = .68$). The minior change rate between the first and second surveys was 12.1% and between the second to third interview was 13.1% ($P = .8$).

Discussion: The findings suggest that the major factor related to procedural changes was time between reviewing patient information. Furthermore, this study demonstrates that there remains significant intrasurgeon variability in selecting surgical procedures for shoulder instability. Lastly, the findings in this study suggest that 3D MRI is clinically equivalent to 3D CT in guiding shoulder instability surgical management.

Conclusion: This study demonstrates that there is significant variability in surgical procedure selection driven by time alone in shoulder instability. Surgical decision making with 3D MRI was similar to 3D CT scans and may be used by surgeons for preoperative planning.

Duke University Institutional Review Board approved this study (protocol no. 00106844; expiration date: 01/01/2100).

*Corresponding author: Alexandra V. Paul, MD, Duke University Medical Center, DUMC Box 3000, Durham, NC 27710, USA.

E-mail address: alexandra.paul@duke.edu (A.V. Paul).

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Shoulder dislocations and glenohumeral instability are common problems within the general population. In North America, estimates have shown the rate of shoulder dislocation to be around 23 per 100,000 person-years.[14,30] The rate and proportion of glenoid bone loss (GBL) has been shown to have a significant impact on outcomes and recurrent instability after operative intervention.[2] After arthroscopic Bankart repair, >15% GBL is associated with a significant increase in postsurgical complications and continued instability.[2,7,29] Additionally, worse outcomes have been found with "subcritical" bone loss of just 13.5%.[8,21] In patients with a concomitant Hill-Sachs lesion, failure rates after capsulolabral repair procedures can be even higher, with >20% humeral head bone loss being a significant risk factor.[6,22] Evaluating glenoid and humeral head bone loss are important factors that surgeons consider when indicating patients for surgical procedures, and furthermore, which type of procedure to utilize. A study using conjoint analysis determined that bone loss was the greatest factor in how surgeons determined their surgical procedure.[13] Even so, there is evidence that in the presence of significant glenoid bone loss, surgeons do not consistently make the decisions for surgical procedure, such as glenoid augmentation.[3] There is large variety in the types of procedures surgeons will choose, even based on similar presentations of shoulder instability and GBL, but there is limited data demonstrating why surgeons may make different decisions in these instances.[5]

Among techniques to evaluate bone loss, CT is largely considered the gold standard.[24,25] Some studies have suggested that CT compared to magnetic resonance imaging (MRI) is more accurate in assessing bony defects specifically.[19,28] MRI, however, is the most commonly used modality to assess extent of soft tissue injury. Three-dimensional (3D) MRI technology may be able to serve as an ideal modality to allow accurate bony and soft tissue assessment.[10,26] Although there may be conflicting data as to the superiority of CT vs. MRI in preoperative evaluation, little is known about the impact the imaging modality makes on surgeon decision making and the type of procedure surgeons choose for each patients with shoulder instability.

This study aims to determine the effect of time and imaging modality (3D CT vs. 3D MRI) on the surgical procedure plan by surgeons during intial patient evaluation. The hypothesis of this study is that there will be no clinical difference in procedure selection between time and imaging modality for shoulder instability.

Methods

Upon obtaining institutional review board approval, a total of 11 senior shoulder orthopedic surgeons were surveyed with ten clinical scenarios involving patients undergoing differing degrees of anterior shoulder instability (Table I). These surgeons were identified through the American Shoulder and Elbow Surgeons Shoulder Instability Bone Loss Committee. All surgeons that were members of this community were considered experts in the field, and thus appropriate for the study. Emails were sent to each member asking for willingness to participate in the study. We defined shoulder instability surgeon experts as having at least 40 shoulder instability surgeries per year, as well serving on an academic committee, such as the American Shoulder and Elbow Surgeons Shoulder Instability Bone Loss Committee, which demonstrates commitment to education and staying up to date on the latest research and advances in the field. Those that responded were included. The surveyed surgeons were not medical providers for the patients included in the scenarios and did not have any prior knowledge of patient case or imaging. Each surgeon was individually interviewed three times with the identical 10 clinical scenarios with a minimum of 7 days in-between all interviews in order to minimize recall bias (Fig. 1). Each interview lasted 30 minutes and was conducted in an identical manner by the same interviewer over zoom.

During all 3 survey sessions, each surgeon was shown a presentation of 10 patient cases which included patient demographics, number of prior instability events, hand dominance, injury mechanism, goals for return to sports and activity. The musculoskeletal shoulder exam, and plain radiographs were included (AP-greyshey, axillary lateral, and scapular Y images and two-dimensional (2D) MRI were also included in all patient scenarios during all 3 interviews.

Differences between each survey session were in which advanced imaging reformations were provided. During survey 1, surgeons were also provided 3D MRI reformations. During the survey 2 and survey 3, a 2D CT and 3D CT replaced the 3D MRI. Survey 2 and 3 had identical imaging with CT scans. For each patient scenario, surgeons were asked to list their surgical treatment plan as an open-ended questions. Surgeons could select any surgical treatment or combination of treatments they wished. Additionally, surgeons were able to request glenoid and humeral bone loss measurements, on- and off- track, glenoid version at any time for all scenarios.

These patients' 3D MRIs were performed utilizing a Siemens Skyra (3-tesla magnets) MRI scanner. We utilized a standard protocol for patients with glenohumeral shoulder instability. To create 3D MRI osseous reformats, we also performed a 3D isotropic volumetric interpolated breath-hold examination (VIBE), in addition to the previously mentioned standard protocol. Each patient also received CT performed with a 64-multidetector-row CT and helical imaging, followed by 3D postprocessing. We used the MRI and CT parameters derived from Lander et al.[11]

GBL measurements utilized a best fit circle, drawn to fit the inferior glenoid.[9] This can then be compared to the width or surface

Table I
List of instability patient scenarios stratified by patient demographics and number of prior dislocation events.

Scenario number	Bone loss glenoid (%)	Bone loss humeral (%)	On-track (y/n)	Patient age	Patient sex	Patient hand dominance	Number of previous dislocations
1	24	7	y	19	M	Right	>10
2	17	5.6	n	23	M	NP	>10
3	0	15.9	y	49	F	Right	1
4	10	13	y	23	M	NP	7
5	13.5	6.6	y	29	F	NP	>10
6	5.2	6.3	y	26	M	NP	6
7	13.6	9.8	n	30	M	Right	>10
8	37.5	13.	n	56	F	NP	1
9	28.9	0	n	40	M	Right	>10
10	20.0	18.2	N	33	M	Left	6

NP, Not provided for the scenario.

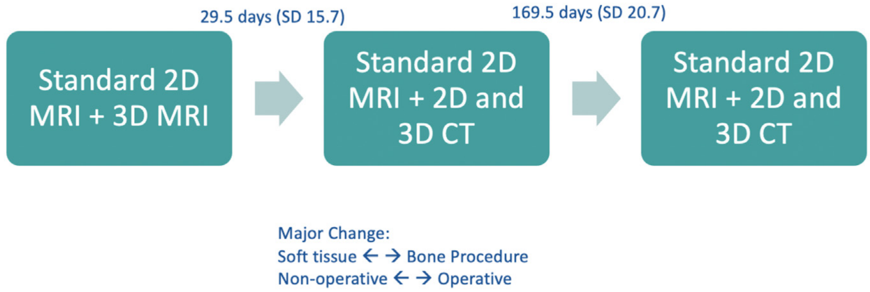

Figure 1 Pictorial representation of 3 individual interviews over time among 11 senior shoulder surgeons. *2D*, two-dimensional; *3D*, three-dimensional; *MRI*, magnetic resonance imaging; *CT*, computed tomography.

area of GBL within the circle relative to the diameter or surface area of the whole circle respectively.[9] Humeral bone loss was measured on axial views with percent of bone loss. Glenoid track (GT) was evaluated through Yamamoto et al concept of GT. A more recent study utilized motion analysis and determined GT to be 83% of the width and is the number utilized in GT equation (18). GT, therefore, was calculated utilizing the diameter (D) of the glenoid as determined on the en face projection, as well as the width of the anterior GBL (d). GT = 0.83 × D−d.

The primary outcome was the surgical management of each identical scenario between all three survey sessions, Two main comparisons were made 1) between 3D MRI, and 3D CT, 2) between 3D CT and 3D CT (Figs. 2 and 3). Specifically, surgeons were graded in terms of making a "major", a "minor" surgical change, or no change for each individual scenario between the three different interview sessions. Major changes were defined as a switch from a soft tissue procedure to a procedure utilizing bone block augmentation (either autograft or allograft) or vice versa, or from a nonoperative physical therapy based treatment to an operative treatment or vice versa. Minor changes were defined as the addition or subtraction of a remplissage procedure. Finally, the change rate between types of bone block augmentation were also calculated separatedly. Significant change rates were calculated utilizing a two sample *Z*-test. A *P*-value of .05 was used to determine significance for all tests (SPSS, version 21.0; IBM Corp., Armonk, NY, USA).

Results

A total of 11 senior orthopedic shoulder surgeons were interviewed (Table II). The average age among all surgeons was 50.6 years old (standard deviation (SD): 8.4 years). The average number of surgical cases performed annually was 400.9 (SD: 121.6 surgical cases). Of these, the average number of arthroscopic shoulder cases performed was 189.5 (SD: 53.9 surgical cases) and the average number of open shoulder surgeries performed was 93.8 (SD: 76.5 surgical cases). For all surgeons, the average number of glenohumeral instability patients treated annually was 119.3 (SD: 47.9 patients) and of these the average number of annual shoulder instability operations performed was 60.0 (SD: 21.6 surgical cases). The average number of days elapsed between the first and second interviews was 29.5 (range: 9-60 days, SD: 15.7 days) (Fig. 1). The average number of days elapsed between the second and third interviews was 169.5 (range: 113-183 days, SD: 20.7 days) (Fig. 1).

As shown in Table I, a total of 5 cases were presented with on-track bony instability and 5 cases were provide with off-track bony lesions. For all scenarios, only 1 surgeon did not make at least one major change throughout the 3 interview sessions. The average major change rate among all surgeons for all scenarios was 14.1% (SD: 7.6%, range 0%-27.8%). The average minor change rate among all surgeons was 12.6% (SD: 7.5%, range 0%-22.2%). When going from survey 1 to survey 2 (addition of 3D CT information), the major change rate was 15.2% compared to 13.1% when going from survey 2 to survey 3 (no change in any interview information), with no statistically significant difference between the two proportions, $P = .68$. As shown in Table III, there was no significant difference in the distribution or type of major surgical change (ie, bone block to soft tissue repair vs. soft tissue repair to bone block) made between the scenarios. When comparing minor changes, the change rate between survey 1 and survey 2 was 12.1% and between survey 2 and 3 was 13.1%, again with no statistically significant difference between these two change rates, $P = .8$.

After intial review of the patient scenarios, one scenario (Table I, Scenario 10) was ultimately included in a separate anlsyis as it was deemed by a majority of the participating surgeons that shoulder arthroplasty was indicated and, as such, was not representative of routine instability surgical management. For this scenario, 8 out of 11 (72%) surgeons made a major change when the additional 3D CT scan was provided between scenario 1 and 2, with 7 surgeons ultimately converting to a shoulder arthroplasty. Between the second and third scenario, only 1 major change was made back to a non-arthroplasty (9.1%) which resulted in a significantly increased major change rate ($P = .002$) to an arthroplasty when a 3D CT scan was provided for large humeral bone loss.

Finally, there was no significant difference in the change rate of type of bone block augmentaiton type from scenario 1 to 2 and between scenario 2 and 3, $P = .52$. Specifically the change rate from scenario 1 to 2 was 5.5% and 3.6% between 2 and 3.

Discussion

This study demonstrates that when expert shoulder instability surgeons are presented with the same clinical scenario and advanced imaging (3D CT) that they make major changes to their surgical treatment plan 13.1% of the time. There was not a statistically significant difference between in the percent of change when presented with 3D MRI vs. 3D CT scan. There was no significant difference in major or minor changes when presented with 3D MRI or 3D CT. The findings suggest the leading factor to a change in procedure was time between reviews and not any patient demographic, injury mechanism, return to sport goals, examination findings, or imaging. The findings suggest that there remains significant intrasurgeon variability in selecting surgical procedures for shoulder instability even amongst experts and that our understanding of appropriate surgical treatments in the setting of bone loss requires continued work and evaluation. Lastly, the findings in

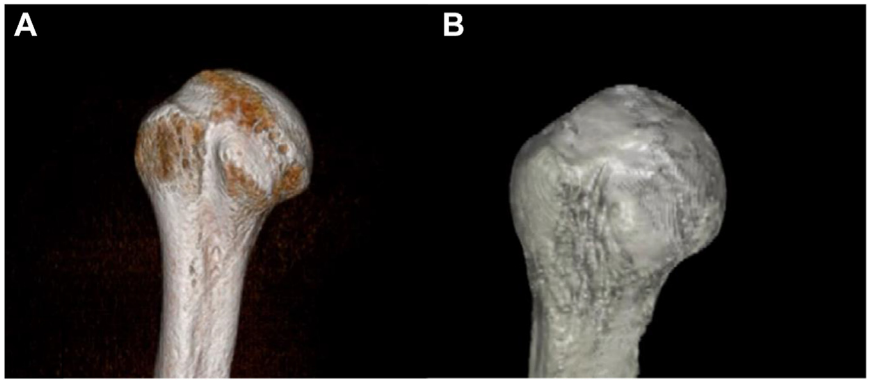

Figure 2 Examples of the (**A**) 3D CT and (**B**) 3D MRI of the humerus utilized by the 11 senior shoulder surgeons. *3D*, three-dimensional; *MRI*, magnetic resonance imaging; *CT*, computed tomography.

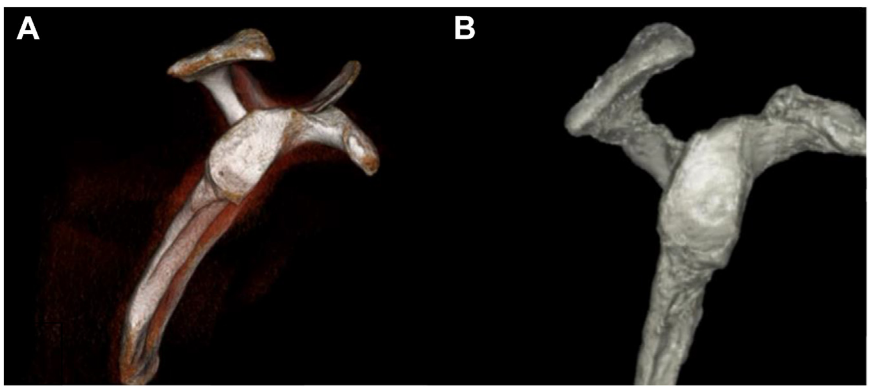

Figure 3 Examples of the (**A**) 3D CT and (**B**) 3D MRI of the glenoid utilized by the 11 senior shoulder surgeons. *3D*, three-dimensional; *MRI*, magnetic resonance imaging; *CT*, computed tomography.

Table II
Anonymized list of surgeons broken down by surgeon demographic, surgical procedures performed annually, and glenohumeral instability surgical cases performed annually.

Surgeon	Age	Sex	Annual total cases	Annual open shoulder cases	Annual arthroscopic shoulder cases	Total shoulder instability patients treated	Annual shoulder instability cases
1	44	Male	475	50	250	150	60
2	59	Male	150	40	110	200	25
3	63	Male	375	75-100	125	75-100	NR
4	48	Male	250	50	200	100	50
5	48	Male	550	200	150-200	75	50
6	42	Male	500	250	250	100	75
7	37	Male	400	20	200	70	50
8	49	Male	360	100	260	80	40
9	62	Male	550	75	150	100	75
10	56	Male	400	150	200	200	75
11	49	Male	400	10	150	150	100

NR, not reported by surgeon.

this study suggest that 3D MRI can serve as equally as well as a 3D CT to help surgeons plan their treatments.

Data from this study additionally suggests that the amount of time that passed in between evaluation and decision making was the largest contributor to changing surgical plans. There are multiple possible explanations for this. Surgeons may be more heavily influenced extraneous factors such as recency bias related to the outcomes of previous patients with similar procedures. New and conflicting data may have been released during that time period. Conversations with fellow shoulder surgeons may sway their decision making at one time or another. Some of the variability may be related to the wide variety of surgical options that exist for treatment shoulder instability. For instability, without significant GBL, a variety of soft tissue procedures exist including open Bankart repair, arthroscopic Bankart repair, reimplissage.[1,4,17] In cases where significant GBL exisits, surgeons can perform a Laterjet, autograft bone reconstruction, or allograft bone reocnstruction.[1,4,17] Common autografts used include distal clavicle, iliac crest or distal tibial.[1] Common allografts include distal tibia, glenoid, or humeral head.[20] There is some literature demonstrating that even in cases with similar patient presentations, different surgeons may make extremely different choices. For example, Balke et al demonstrated

Table III

Individual breakdown of the distribution of major surgical changes made between the first and second interview and the second and third interview.

Major surgical change made	Survey 1 – Survey 2 (3D MRI to 3D CT)	Survey 2 – Survey 3 (no change)	*P* value
Average Major Change per Surgeon	15.2%	13.1%	.68
Change from Soft Tissue Repair to Bone Block (% of all major changes)	7 (46.7%)	5 (41.7%)	.79
Change from Bone Block to Soft Tissue Repair (% of all major changes)	5 (33.3%)	5 (41.7%)	.65
Change from Operative to Nonoperative (% of all major changes)	3 (20%)	2 (16.6%)	.83

3D, three-dimensional; *MRI*, magnetic resonance imaging; *CT*, computed tomography.

that among patients with greater than 25% GBL, only 46% of surgeons performed some type of glenoid bone augmentation.[3] It is unclear from this study, what factors specifically made surgeons switch surgical procedures at different time points, but it demonstrates that there is significant intrasurgeon variability based soley on time alone and not any patient factors, demographics, or imaging findings.

This intrasurgeon variability is reported elsewhere in the literature as well. Robitaille et al demonstrated that spine surgeons differed in their surgical plan for treating adolescent idiopathic scoliosis when asked about the same case one year apart. They found that 71% of surgeons changed their proximal level for hardware placement, and 35% changed their distal fusion levels.[18] In the shoulder literature, a study by Parsons et al looked at augment use for anatomic total shoulder arthroplasty, and they found that not only did surgeons differ from one another in whether to use augments and what size augments to use for the same case, but the same surgeon differed in their own choice when asked about the same scenario at two different time points.[16] They repeated this study in reverse total shoulder arthroplasty as well with similar results.[15] There is a lack of data both demonstrating this intrasurgeon variability in the shoulder instability population, and more research is needed to determine why this is the case.

There is conflicting data in the literature as to whether CT provides more reliable data necessary for shoulder instability evaluation and surgical planning. Much of the current literature suggests that CT is the gold standard for evaluating bone loss, and thus should be used over MRI.[19,24,25,28] For example, Weber et al looked at measurements of glenoid height and width on 3D CT vs. 2D MRI among 2 blinded raters. They found that the mean height measured on both imaging studies was significantly different (p .032), measuring 39.09 ± 2.93 mm on 2D MRI, compared to 38.71 ± 2.89 mm on 3D CT. They had similar results looking at measurements of glenoid with ($P < .001$). This study, as well as many of the others that argue for superiority of CT use 2D MRI as a comparison. This study differs from those in that it utilized 2D and 3D MRI with VIBE sequence protocol, which allows for more accurate analysis of bony and three-dimensional structures.[19,24,25,28] A recent study found that there was no difference in GBL, humeral bone loss, GT, or glenoid version measurements between 3D MRI with VIBE vs. 3D CT.[10]

Neverthless there is data to support the equal use of 3D CT and 3D MRI in preoperative evaluation of shoulder instability.[23,26,27] Prospectively collected data has shown that GBL and glenoid bone surface area (GBSA) measurements are equal between the two imaging modalities.[23,26] Additionally, intrauser and interuser reliability has been shown to be equivalent between the two study modalities when assessing GBL.[10,12]

Landsdown et al looked at bone loss measurements in patients with anterior shoulder instability with 3D CT and 3D MRI.[12] They demonstrated excellent intrarater and interrater reliability. Differences in bone loss measurements between the two groups ranged from 0% to 6%. There was less than 2% difference in 88% of all measurements.[12] Another study by Vopat et al similarly compared measurements of GBSA and GBL between 3D CT and 3D MRI. They found no significant difference in GBL measurements ($P = .852$). The average GBL for 3D CT was 41 mm^2 (6.6%), and the average for 3D MRI was 40 mm^2 (6.5%) The averages for GBSA differed by only 4 mm^2 ($P = .482$).[26] These studies, that also compared 3D MRI to 3D CT, corroborate our findings that 3D MRI is equivalent in terms of preoperative evaluation and surgical planning.[10,12,23] Downsides to the use of CT include additional radiation exposure, as well as poor evaluation of the soft tissues including labral and rotator cuff pathology, which may be important factors in surgical decision making as well.[19,28]

This study additionally demonstrates that the type of surgical procedure indicated does not change when given 3D CT vs. 3D MRI information. The proportion of those who made major changes who switched from a soft tissue procedure to a bone block procedure (46.7%) was similar to those who made changes in the reverse direction (33.3%). When no change was made between survey 2 and 3, there was the same number of participants who switched from soft tissue to bone block, as those who made the reverse decision, 5 in each group. There both does not appear to be a difference in the rate of change between the those provided with 3D CT vs. 3D MRI, nor the type of procedure indicated.

There are limitations to this study. This was a relatively small sample size of surgeons with 11 participating in the study. Although the number of participants was small, they performed a high volume of shoulder surgeries a year, representing a large number of surgeries done for shoulder instability. Additionally, the time frame between surgeon response was not standardized as this factor was limited by surgeons' responsiveness via email. Finally, this data is limited in generalizability without the possibility of outcome data. It is unable to evaluate whether the changes in management would have resulted in any changes in patient outcome.

Conclusion

This study demonstrates that there is signicant variability in surgical procedure selection driven by time alone in shoulder instability. Surgical decision making with 3D MRI was similar to 3D CT scans and may be used by surgeons for preoperative planning.

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