RESEARCH ARTICLE

Internal Rotation Measurements: Correlation between Vertebral Body Level and Goniometer Measurements on Functional Outcome Scores

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Abstract

Objectives: Reverse total shoulder arthroplasty (rTSA) has shown success in the treatment of end-stage glenohumeral pathology. However, one major shortcoming has been the lack of internal rotation (IR), which can have significant functional consequences. Much research has been conducted to maximize IR after rTSA, but the literature is unclear which measurement of IR represents the "gold standard" between vertebral level and goniometer-based measurements.

Methods: Patients were prospectively enrolled into one of three groups: postoperative from rTSA, subacromial pain (SA), and normal. IR measurements were obtained either by the vertebral body level, by which radiographic markers indicated the highest level that the patient was able to reach on the body midline; or by using a goniometer while the shoulder was in 90-degree abduction as the patient stood upright.

Results: Comparisons between the radiographic vertebral level and goniometer IR measurements showed significant correlations within the normal (r = - 0.43, P = 0.02) and SA pain groups (r = - 0.44, P = 0.02). The rTSA group did not quite reach statistical significance (P = 0.11), but had a moderate correlation coefficient (r = - 0.33). Accuracy of visual IR measurements was also significant. All rTSA group vertebral level measurements were within two vertebral levels, while only 84.6% of IR measurements by goniometer were within 15 degrees. Visual vertebral level measurements were found to be more accurate for the SA pain group (86.2 vs 66.7%).

Conclusion: A comparison of the two primary IR measurement methods for shoulders was shown to have a correlation. This would allow for direct comparison of different literature using only one measurement method. While the correlation is not yet strong enough to allow for conversion between the two measurement types, creating a matched cohort taking into account other factors may lead to the correlation reaching this point.

Level of evidence: III

Keywords: Internal rotation, Range of motion, Rotator cuff, Shoulder arthroplasty, Shoulder pain

Introduction

Reverse total shoulder arthroplasty (rTSA) has quickly grown in popularity as a surgical option for patients with shoulder conditions that were previously viewed as difficult to treat. From 2012 to 2017, the incidence of rTSA increased from 7.3 to 19.5 per 100,000.[1] While many surgeons view the rTSA as a viable option for numerous shoulder pathologies, the procedure has some disadvantages. One major concern is the creation of an internal rotation (IR) deficit for the operative extremity, which leads to difficulties with activities of daily living (ADLs) such as maintaining hygiene.[2-7]

Range of motion (ROM) is one assessment tool used to

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gauge a patient's outcome after rTSA. While viewed as arm dominance and evaluator experience. Additionally, there are three recognized methods of measuring IR, and very few correlations have been made between them. The most used measurement method evaluates the most cranial vertebral level reached behind the back. While up to 90% of investigations use this method, inexperienced examiners can be off by up to two vertebral levels.[8] Due to concern for reliability, validity, and accuracy, some investigations attempt to use a goniometer for measurement; this can either be done in a standing position with the shoulder abducted and elbow flexed, leaving the scapula unstabilized, or a similar arm position while lying down to stabilize the scapula.[9,10,4] Even though some researchers view goniometer measurements as more objective, there has been little success showing any correlation between goniometer and vertebral level measurements, and no studies have directly compared their accuracy.[11,12]

Several biomechanical studies have investigated surgical techniques and implants that would improve rTSA IR results, including the use of a lateralized glenoid design and subscapularis repair.[2,13-18] Other investigators have focused on body mass index (BMI), age, and preoperative function that exhibit some effect on the final outcome, but IR appears to be the overarching driving force.[10,19,20,6,21,22] To quantify IR effects on function, patient-reported outcome measurements (PROMs) are the most commonly used method. The primary purpose of this study was to determine if vertebral level and goniometer measurements of IR had a correlation, thus allowing investigations using either measurement method to be more easily compared and extrapolated. Secondary purposes included determining if either IR measurement was objectively more accurate by direct comparison, and to investigate IR objective, the measurement is affected by patient age, sex, measurements and their effect on PROMs. We hypothesized that a correlation would be present between vertebral level and goniometer measurements throughout ROM, and patients with higher IR measurements would have improved PROMs compared with those with lower IR measurements.

Materials and Methods

Patient Selection

A retrospective cohort study was performed following institutional review board approval (21-08238-FB). Three cohorts of patients were created, all of which included patients from 18 to 80 years old, beginning in 2015 to 2023. Those who underwent rTSA were required to have at least 12 months of follow-up, only one shoulder with pathology, and to have suffered a unilateral rotator cuff injury. Patients who underwent revision shoulder arthroplasty, bilateral rTSA, and arthroplasty for trauma were excluded. A second cohort was composed of patients who suffered from subacromial pain (SA) for at least six months without undergoing invasive intervention. The final cohort contained individuals with "normal" shoulders who denied any preceding shoulder pain or pathology. Informed consent was obtained from each patient for an additional anteroposterior spinopelvic radiograph (aside from standard shoulder radiographs).

A total of 87 patients were studied, equally allocated across the three groups. Patient demographics were largely found to be similar across the groups, except for age which was significantly younger in the "normal" shoulder cohort and oldest in the rTSA group [Table 1].

Table 1. Descriptive summary of baseline characteristics

		Internal Rotation			
Covariate	**Statistics**	**Normal (N=29)**	**SA Pain (N=29)**	**RTSA (N=29)**	**P-value<0.0001**
Age	Mean Std Deviation	54.3 12.3	64.5 11.6	69.8 6.5	<0.0001
Sex	Male Female	16 (55%) 13 (45%)	17 (59%) 12 (41%)	12 (41%) 17 (59%)	0.79
Extremity	Right Left	13 (45%) 16 (55%)	16 (55%) 13 (45%)	16 (55%) 13 (45%)	0.60
Race	White Black	22 (76) 7 (24%)	24 (83%) 5 (17%)	24 (83%) 5 (17%)	0.52

* The P-value is calculated by ANOVA
RTSA, Reverse total shoulder arthroplasty; SA, subacromial

Operative Description and Post-operative Protocol

For patients who underwent rTSA, both medial glenoid, lateral humeral and lateral glenoid, medial humeral designs were used per investigator preference. All patients underwent a standard deltopectoral approach from a shoulder and elbow fellowship-trained surgeon. Subscapularis peel was performed if applicable and the subscapularis was repaired in all cases if the tendon was in good enough condition to facilitate a repair. At return clinic visits, radiographs were reviewed by the operative surgeon to ensure there were no signs of scapular notching or loosening. All patients then underwent a standardized physical-therapy program beginning at two weeks after surgery.

Patient Cohort Design

Patients were evaluated for ROM and PROMs. Each patient First, the patient would complete a maximal effort reach behind his/her back to obtain a vertebral level measurement; a radiographic marker was placed at the most cranial thumb position on the back after the maneuver. The treating physician would then provide a visual vertebral level measurement that was recorded before obtaining an x-ray to show the radiographic vertebral level. The radiographic vertebral level was determined by the attending surgeon, then confirmed by a second provider through radiographs. The most cranial vertebral level measurement (T5) was given a value of 1, and the most cephalad vertebral level underwent ROM testing, and IR was measured in two ways.

measurement (buttock) was given a value of 15. A second IR measurement was obtained via goniometer. The patient remained in an upright position with his/her shoulder abducted to 90 degrees and elbow flexed to 90 degrees. From this neutral position, an IR movement was completed with maximal effort, and a provider used a goniometer to measure the degree of IR achieved. Before leaving the clinic, the patient completed three PROM questionnaires: Visual Analog Scale (VAS), American Shoulder and Elbow Surgeons (ASES) score, and Single Assessment Numeric Evaluation (SANE) score.

Statistical Analysis

Statistical analysis was completed through the study organization's Biostatistics, Epidemiology, and Research Design (BERD) Clinic. A power analysis showed that a minimum of 25 patients were required in each study group, and after using the inclusion/exclusion criteria 29 patients were found for each cohort. Quantitative data were analyzed using either ANOVA, t-tests or Pearson correlation coefficients. Categorical data were analyzed using either chi-squared or Fisher exact tests. Statistical significance was set at $P < 0.05$.

Results

The IR measurements used for comparison within each study group included a radiographic vertebral level and a goniometer-based value. The treating physicians provided a visual vertebral level measurement before learning the radiographic vertebral level. All three study groups showed no significant difference in visual vertebral level and radiographic vertebral level, and this lack of a difference continued when examining the entire cohort of 87 patients ($P = 0.197$). While the visual and radiographic vertebral levels showed a global similarity, multiple patients (8/87) had a visual level of 3 or more different from the radiographic level. Four of these patients were in the "normal" group and three were part of the SA pain group. Comparisons between the radiographic vertebral level and goniometer IR measurements showed significant correlations within the normal ($r = -0.43$, $P = 0.02$) and SA pain groups ($r = -0.44$, $P = 0.02$) [Table 2, Figure 1]. While the rTSA group did not reach statistical significance ($r = -0.33$, $P = 0.11$), it appeared to be approaching significance since the r-value suggested a moderate correlation could be found.

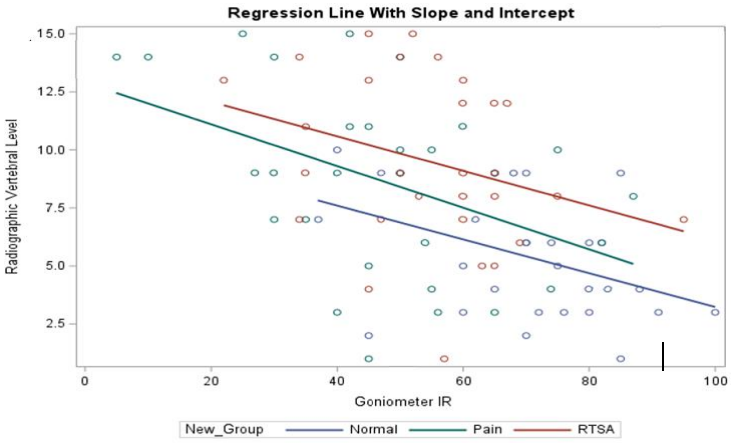

Figure 1. Correlation of the Goniometer vs. Radiographic Vertebral Measurement between the study groups

Table 2. Comparison of measurement methods: goniometer vs. radiographic vertebral level

Cohorts	Statistics	Goniometer_IR	Radiographic_VL	P-value	R-value
Normal	Mean Std Deviation	70.0 15.3	5.9 3.0	0.27	-0.43
SA pain	Mean Std Deviation	47.2 19.5	8.1 4.1	0.15	-0.44

	Mean	54.8	9.5	0.32	-0.33
RTSA	Std Deviation	14.8	3.6		

IR, internal rotation; RTSA, Reverse total shoulder arthroplasty; SA, subacromial; VL, vertebral level

Accuracy of visual IR measurements was investigated; some measurements were noted to be significant. All of the rTSA group vertebral level measurements were within two vertebral levels, while only 84.6% of IR measurements by goniometer were within 15 degrees. A Student *t*-test of the rTSA group values showed that the measured and estimated vertebral levels were so close that the *P-value* was 0.88. The goniometer measurements were also noted to be similar, creating a $P = 0.16$. Visual vertebral level measurements were found to be more accurate for the SA pain group as well when using the same parameters (86.2 vs 66.7%). The SA pain group did not have as close of a match among each measured versus estimated vertebral level measurement as the *t*-test produced a *P-value* of 0.0002, but the goniometer measurements actually produced an insignificant *P-value* of 0.29.

All three patient groups showed statistically significant differences in all but one of the PROMs investigated. [Table 3] VAS scores for the "normal" group were the lowest of the three groups at 0.52 ± 1.3; the SA pain group was the highest at 4.8 ± 2.2; and the rTSA group was between the others at 1.4 ± 2.4. The SA pain group was significantly higher in comparison with the normal group ($P < 0.001$) and the rTSA group ($P < 0.001$), but the normal and rTSA groups showed no significant difference ($P = 0.097$). The ASES and SANE scores showed significant differences across all groups. Those scores followed the trend of normal>rTSA>subacromial pain groups from highest to lowest score values.

Table 3. Summary of patient-reported outcome measurements by shoulder cohort

Covariate	Statistics	Normal (N=29)	SA Pain (N=29)	RTSA (N=29)	P-value
	Mean	92.6	54	81.8	
ASES score	Std Deviation	14.9	19.6	16.5	**<0.0001**
	Mean	0.52	4.8	1.4	
VAS score	Std Deviation	1.3	2.2	2.4	**<0.0001**
	Mean	95.3	58.4	82	
SANE score	Std Deviation	12.7	20.8	17.1	**<0.0001**

IR, internal rotation; RTSA, reverse total shoulder arthroplasty; SA, subacromial; VL, vertebral level. Boldface denotes statistical significance

ASES subscores involving IR were analyzed; no significant correlations were found for the rTSA group with either vertebral level measurements ($P = 0.42$) or goniometer measurements ($P = 0.53$) [Figures 2-6]. The "normal" group also failed to show any significant correlations in IR-related ASES subscores when compared with vertebral level measurements ($P = 0.44$). The SA pain group did exhibit a significant correlation: a negative correlation was found, suggesting lower vertebral level measurements result in lower IR subscores ($r = -0.50$, $P = 0.005$). This correlation was not replicated when analyzing the SA pain group using goniometer measurements ($P = 0.09$).

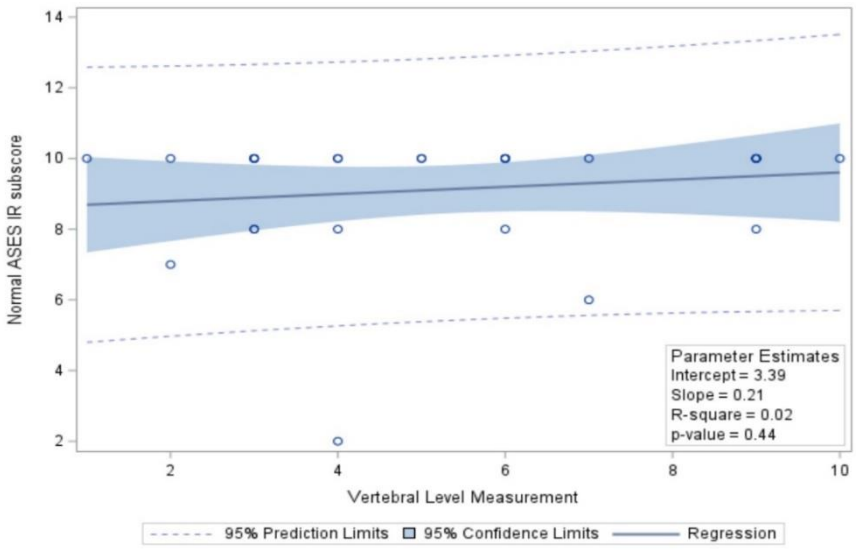

Figure 2. Regression for Normal group with VL measurements and their ASES IR sub scores

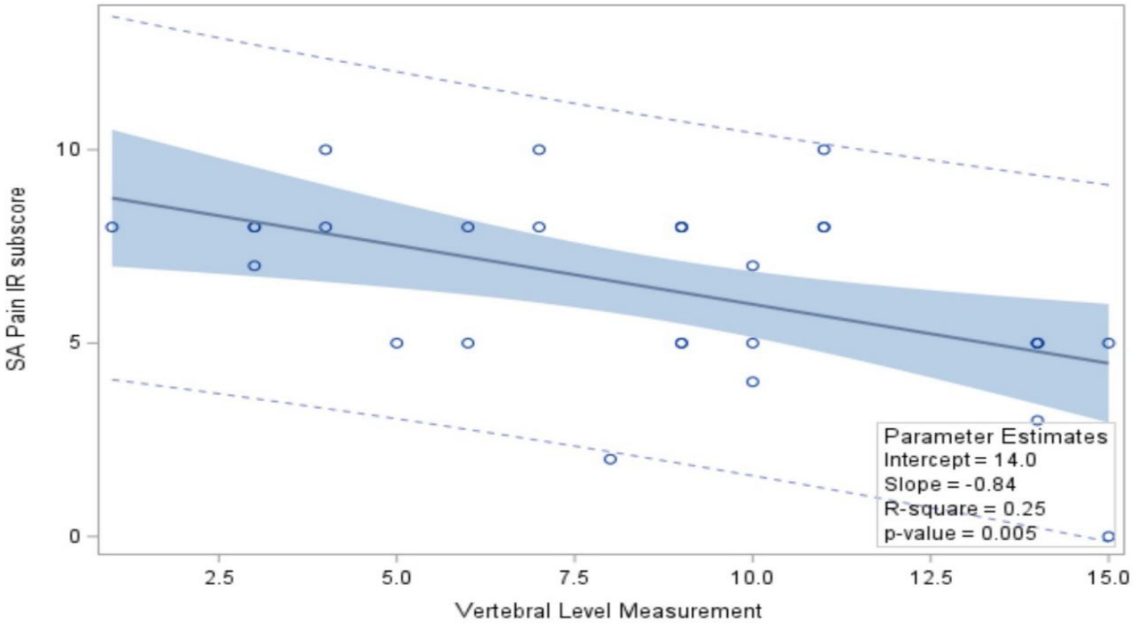

Figure 3. Regression for Subacromial Pain group with vertebral level measurements and their ASES IR sub scores.

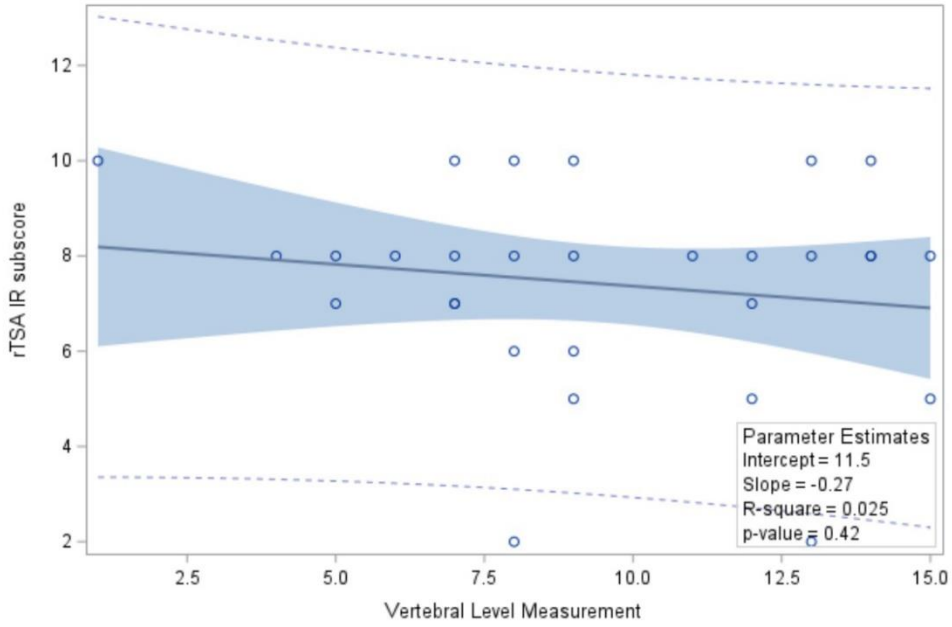

Figure 4. Regression for rTSA group with vertebral level measurements and their ASES IR sub scores

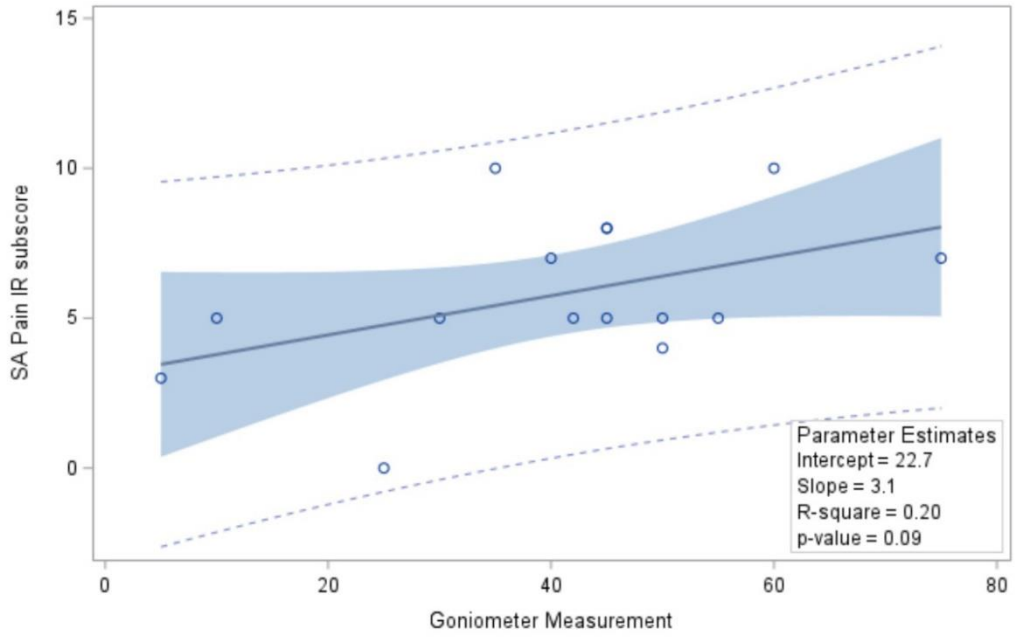

Figure 5. Regression for Subacromial Pain group with goniometer measurements and their ASES IR sub scores

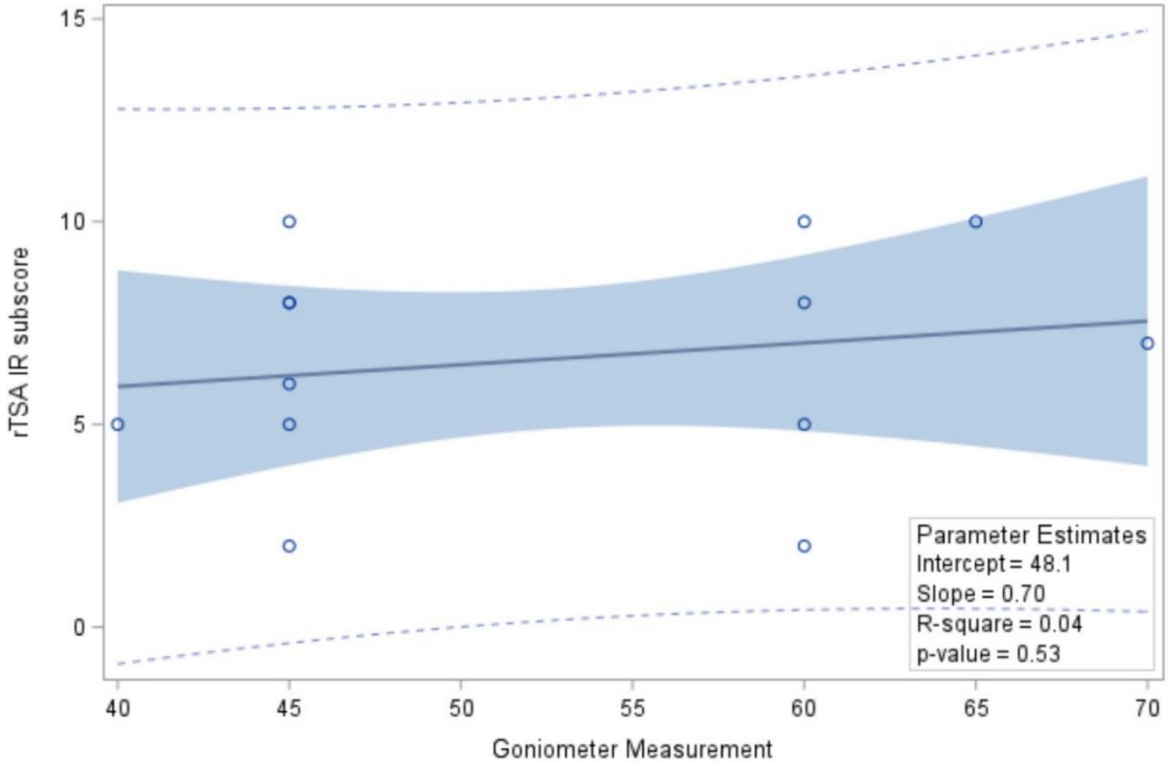

Figure 6. Regression for rTSA group with goniometer measurements and their ASES IR sub scores

Discussion

Optimizing IR has been a primary focus for rTSA as the procedure is becoming more widely indicated. As literature investigating the importance of IR and how to maximize it becomes more prevalent, the ability to have a consistent, reproducible measurement method is required. Unfortunately, literature has shown a lack of consistency and correlation between various IR measurement methods. The goal of this investigation was to determine if there was any correlation between the two most commonly used methods. Additionally, the relationship between IR and ASES IR subscores was investigated to further elucidate IR's importance for a patient's function and ADL.

The most commonly utilized IR measurement method for papers investigating shoulder arthroplasty is vertebral body level. While the method is used frequently, multiple papers recognize the inaccuracy commonly associated with visual vertebral body level measurements, and most recognize the average error for this method is one to two vertebral levels.[8,11,12] Interestingly, our data showed no significant differences when comparing the patient's visual vertebral level measurement with the radiographically confirmed vertebral level (P = 0.197). In fact, 100% of estimated vertebral levels were within two of the radiographically measured vertebral levels for the rTSA group. This indicated that vertebral level measurements are an accurate, replicable way of determining an rTSA patient's IR. The average difference between visual and radiographic measurements was 0.8 levels, a higher level of accuracy than previously published data. Each primary operating surgeon had nearly identical rates of visual vertebral level accuracy when comparing measured with estimated levels (69 vs 67%). These findings suggest that intraobserver reliability may be higher than the literature reports if the surgeon frequently uses the visual vertebral level IR measurement method.

Wanting to ensure the highest level of accuracy possible, we compared the radiographic vertebral level measurements with the goniometer measurements for each patient's IR. The "normal" (r = -0.43, P = 0.02) and SA pain (r = -0.44, P = 0.02) cohorts showed a moderate correlation with statistical significance, while the rTSA group (r = -0.33, P = 0.11) had a moderate correlation that did not reach significance. Using the linear regressions created for each comparison between the three patient groups, a conversion from radiographic vertebral level to goniometer measurement was attempted. [Figure 1] Unfortunately, the goniometer measurements created through conversion from their respective radiographic vertebral levels were significantly greater than the values obtained in our study cohorts, indicating the correlations were not strong enough for direct conversion from one IR measurement method to the other.

Examining the correlation present for the "normal" shoulder cohort provides evidence that without any pathology present, a patient with a higher goniometer measurement will subsequently have a larger amount of IR observed through a vertebral level movement. The SA pain group exhibited a similar correlation, but as can be seen in Figure 1, that group had an overall lower IR ROM at baseline compared with the "normal" group. The primary demographic difference between these groups is age. Based on literature, if two populations of patients were examined, with the only difference being age, ROM in each plane would decrease with age.[23] Since the SA pain group was significantly younger than the "normal" group, it would be expected to have a higher level of internal ROM if all else were equal. However, the opposite was true for our cohorts, so it can be assumed that pain was a significant driving factor in a patient's ability to generate internal ROM for both measurements.

While the normal and SA pain groups showed significant correlations between goniometer and vertebral level measurements, the rTSA group exhibited a moderate correlation (r = -0.33), but it did not reach statistical significance (P = 0.11). Even though the correlation had not yet reached significance, it appeared to be trending in that direction. As has been described in other literature, patients with rTSA have decreased IR compared with the general population, which was seen in our data as well. Additionally, it has been suggested that vertebral level measurement for IR can be significantly affected by a patient's BMI and shoulder extension.[14,20] Plus, our data suggested that pain was an important driver of motion, or lack thereof, and the rTSA group had significantly higher scores than the "normal" patient cohort. These factors seemed to play enough of a role to limit the correlation strength and keep it from being significant.

We then investigated how IR measurements would affect the IR subscores of our PROMs, primarily involving the "wash back/hook bra" and "manage toileting" aspects. Neither method produced statistically significant correlations with the two IR-related subscore PROMs: vertebral level measurement had a P-value of 0.42, and goniometer measurement had a P-value of 0.53. Interestingly, there were significant correlations for the SA pain group, with a negative correlation suggesting lower vertebral level measurements result in lower IR subscores (r =-0.50, P = 0.005). Goniometer failed to show a significant correlation, with a P-value of 0.09, suggesting that it was possibly approaching significance. This would suggest that IR was not the key driver in IR-related movements after a rTSA, but that pain was a bigger deterrent.

Looking at the PROM values more broadly, the only three correlations reaching significance were the "normal" group's goniometer measurements compared with its SANE scores (r = 0.37, P = 0.045), and the SA pain group's goniometer measurements compared with its VAS scores (r = 0.049, P = 0.007) and ASES scores (r = 0.42, P = 0.025). The two strongest correlations between ROM and subjective/functional outcome scores involved those experiencing the most pain (i.e. the SA pain group). Even

though the goniometer to SANE score did not reach significance, it appeared to be moving in that direction (r = 0.29, P = 0.130); these correlations continued to suggest pain significance. Previous literature proposed that 100 degrees of IR was required for a functional level of IR.[6] Our data refuted this proposal as three-fourths of the rTSA patients had an ASES or SANE score greater than 80, yet none had 100+ degrees of IR measurements by goniometer. Newer literature has recommended transitioning from strict IR measurements to measuring a patient's ease of completing multiple tasks requiring shoulder IR. Much of this literature has viewed the necessary IR reached somewhere between L1 and L4 by vertebral level measurement method.[13,4,5] Our data does not show a specific level of IR associated with a significantly improved functional level for the rTSA group, as patients with both higher and lower internal ROM exhibited high PROM scores examining functionality. While no significant trend was observable, rTSA patients with higher VAS scores clustered more frequently in the lower ASES and SANE score ranges, thus further suggesting that pain was a primary variable affecting a patient's ability to perform IR.

Our study had several limitations. It was not age matched, which affected the generalizability and interpretation of the results. There was also a lack of preoperative data for the rTSA group; while this couldn't be used for comparison with the other cohorts, other literature has suggested that preoperative function affects postoperative outcomes; additionally, the extent of the rotator cuff injury before surgery also had an effect, and neither of those variables were taken into account.[21,7] Lastly, BMI was not measured or matched; it has been shown to affect a patient's ability to abduct an arm, thus changing the amount of IR that can be obtained through a vertebral level measurement.[10] One way to possibly combat the difference in body habitus of patients would be to use an IR measurement that stabilizes the scapula, thus isolating IR through the shoulder. This can be accomplished by obtaining a goniometer measurement while the patient is supine on a table with his/her scapula stabilized, leaving the arm in a space with freedom of motion for greater than 90 degrees of IR.

Conclusion

A comparison of the two primary IR measurement methods for shoulders, vertebral level and goniometer, was shown to have a correlation from our data set. This would allow for direct comparison of different literature using only one measurement method. While the correlation was not yet strong enough to allow for conversion between the two measurement types, creating a matched cohort taking into account other important factors, such as BMI and shoulder extension, may lead to the correlation reaching this point. Additionally, visual vertebral level measurements appeared to be slightly more accurate than visual goniometer measurements for in-office use when the surgeon was well versed in obtaining IR measurements. Finally, the IR-related subscores of the PROMs did not have any significant correlation with a patient's overall IR ROM, thus suggesting other factors affect a patient's ability to perform these movements primarily involving IR.

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Authors Contribution:

Eric West: Conceived, designed, and performed analysis; collected data, wrote paper.
Derek T. Dixon: Collected data, contributed data or analysis tools, performed analysis.
Thomas W. Throckmorton: Supervised study, reviewed final draft of manuscript.
David L. Bernholt: Wrote paper
Frederick M. Azar: Supervised study, reviewed final draft of manuscript.
Tyler J. Brolin: Conceived and designed analysis, supervised study, reviewed final draft of manuscript.

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Not required for retrospective cohort study

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