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The value of lateral glenohumeral offset in predicting construct failure in proximal humerus fractures following internal fixation

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Background: Proximal humerus fractures are the third most common osteoporosis defining injury in the United States, yet operative fixation of these injuries remains technically challenging. Although several modifiable and nonmodifiable risk factors are correlated with failure of proximal humerus fixation, no study has investigated whether failure to restore glenohumeral offset plays a part in fixation failure. The goals of this study are: (1) to determine if lateral glenohumeral offset (LGHO) and humeral head diameter (HHD) can be measured radiographically with accuracy between observers, (2) to observe whether there is a correlation between failure to operatively restore an anatomic LGHO:HHD ratio and failure of fixation, and (3) if there is a correlation, can any recommendations be made in regard to the ideal LGHO:HHD ratio.
Methods: Retrospective review found 183 patients meeting inclusion criteria who underwent operative fixation for proximal humerus fractures between 2005 and 2018. Patients suffering construct failure requiring reoperation were compared with clinically successful surgeries on the basis of age, sex, fracture morphology, head-shaft angle, smoking history, presence or absence of a calcar screw, and LGHO:HHD ratio. The groups were compared using a combination of Student *t*-tests, χ^2, and bivariate and multivariate logistic regression analyses where appropriate. The Student *t*-test and intraclass correlation coefficient were both used to assess interobserver reliability.
Results: We found that LGHO and HHD can be measured by independent observers accurately (intraclass correlation coefficient = 0.80, 95% confidence interval: 0.65-0.89). Patients suffering implant failure had a significantly lower LGHO:HHD ratios compared with those who did not (0.94 vs. 1.03, $P \leq .001$). The LGHO:HHD ratio was an independent predictor of implant failure even after controlling for other potential risk factors. Patients with an LGHO:HHD of 1.0 or above have a <10% chance of failure compared with a 20% risk with a ratio of 0.9 and a 40% risk at 0.8.
Conclusion: We found the LGHO:HHD ratio to be an independent predictor for construct failure after plate and screw fixation of proximal humerus fractures. Efforts should be made to restore an anatomic ratio of at least 1.0 to minimize the risk of failure.
Level of evidence: Level III; Retrospective Cohort Comparison; Treatment Study

Keywords: Proximal humerus fractures; osteoporosis; open reduction and internal fixation; outcomes; glenohumeral offset; humeral head diameter; radiograph

Proximal humerus fractures are the third most common osteoporosis defining injury in the United States comprising 4%-5% of fractures in the elderly with rates increasing as the US population ages.[2,14] Data suggest that widely

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displaced fractures or those with more complex morphologies benefit from operative fixation to reduce complications and improve functional outcomes.[17,25] Although no ‘‘gold standard’’ surgical treatment exists for displaced proximal humerus fractures, open reduction and internal fixation (ORIF) can provide superior functional outcomes compared with primary hemiarthroplasty or reverse total shoulder arthroplasty.[14,29,34] Nevertheless, multiple factors have been shown to affect functional outcomes after fracture fixation including varus malposition, greater tuberosity malunion, and more complex fracture morphologies.[3,24,25,30] Successfully treating proximal humerus fractures during the index procedure is imperative as revision surgery has poorer functional outcomes.[9,19,26]

Assessing the adequacy of one’s intraoperative reduction during ORIF can be difficult. Clinical judgment often serves as the substitute to measuring various angles that can be cumbersome or unreliable. Several studies have explored the normal radiographic and anatomic relationships in the shoulder and the importance of maintaining these relationships after arthroplasty.[6,18,20,33] In shoulder arthroplasty, lateral glenohumeral offset (LGHO) is a major contributor in restoring functional range of motion and reducing pain.[20,32,35] Capsular tension, resting length of rotator cuff muscles, and deltoid moment arm are all dependent on appropriate restoration of LGHO. Given the importance of LGHO in shoulder biomechanics, especially as it relates to arthroplasty, we speculate that LGHO may also play a role in clinical outcomes after ORIF of proximal humerus fractures where this anatomic relationship is frequently disrupted. Not only may the altered biomechanics place the patient at risk for posttraumatic arthrofibrosis due to altered preload of shoulder girdle musculature, but it may also create an environment where the construct is under more stress leading to failure.

The challenge remains that accurately measuring LGHO radiographically can be technically difficult as magnification, projection angle, and software calibration can vary from patient to patient. Radiographic and cadaveric studies have found that a strong linear, 1:1 correlation exists between humeral head diameter (HHD) and LGHO.[18,20,33] In proximal humerus fractures, HHD remains constant, whereas LHGO is typically disrupted. By creating a ratio between LGHO and HHD, we can assess whether anatomic reduction and fixation was achieved and determine if LGHO:HHD correlates with construct failure.

In this study, we hypothesize that failure to restore LGHO may predispose patients to construct failure after internal fixation of proximal humerus fractures.

Patients and methods

This is an institutional review board approved, retrospective comparative study comprising patients who underwent operative fixation of proximal humerus fractures between 2005 and 2018. Operations were carried out at multiple level I and level II hospitals by multiple surgeons. The primary outcome measure was whether or not a patient required return to the operating theatre as a result of construct failure. This was defined as (1) screw cut-out resulting in failure of fixation, (2) symptomatic implant resulting from screw penetration into the glenohumeral joint, or (3) development of posttraumatic arthrofibrosis requiring manipulation under anesthesia. If any of the above occurred, but did not require a secondary procedure, it was not considered a construct failure. Secondary outcome measurements included time from index surgery to the second procedure and the type of revision surgery performed.

Patients selected for this study underwent ORIF with a plate and screw construct for proximal humerus fractures as categorized by *Current Procedural Terminology* codes 23615 or 23630. A priori power analysis assuming a 10% failure rate, a 10% difference in LGHO:HHD, a standard deviation of 0.1, and a power ($1 - \beta$) of 0.80 yielded a sample size of 90 patients. Our inclusion criteria also required that the patients have adequate postoperative X-rays to assess glenohumeral offset (see the next paragraph for a description of radiographic analysis) as well as >120 days of postoperative follow-up. Patients were excluded from the study if they fulfilled any of the following criteria: (1) any fixation method other than a plate and screw construct such as percutaneously placed cannulated screws or intramedullary rods, (2) open physes, (3) inadequate postoperative radiographs, (4) lost to follow-up, or (5) revision secondary to infection.

True anterior-posterior (AP) radiographs of the shoulder (Grashey view) were used to make radiographic measurements. These radiographs were obtained either intraoperatively via image intensifier or during the first postoperative visit (ie, some patients did not have Grashey views taken intraoperatively but did have Grashey views obtained during their first postoperative visit and vice versa). Radiographs were deemed appropriate if the anterior and posterior rims of the glenoid were superimposed and the humerus was adducted in neutral as is the institutional protocol. These views were used to measure LGHO and HHD in accordance with the method described by Takase et al.[33] HHD is represented by the distance between (1) a point at the humeral head-greater tuberosity junction and (2) a point just medial to the anatomic neck. LGHO is obtained by measuring the distance between (1) a parallel line in the most medial arc of the glenoid cavity (ie, joint line) and (2) the lateral most aspect of the greater tuberosity. Fig. 1a is a schematic representation of these measurements, and Fig. 1b depicts the measurement being obtained on one of the study patients. The LGHO:HHD ratio was tabulated for each patient.

Head-shaft alignment was also calculated for each patient. This was done according to the method described by Schnetzke et al,[30] where (1) a line is drawn coincident with the anatomic neck, (2) a second line was made perpendicular to the line drawn in (1), and (3) a third line is drawn bisecting the humeral shaft. The angle subtended between lines (2) and (3) is the head-shaft angle (Fig. 2).[30]

All patients meeting the inclusion criteria had the following parameters recorded: (1) age at time of surgery, (2) sex, (3) fracture morphology as described by Neer et al,[25] (4) presence or absence of a calcar screw, (5) smoking history within a year of surgery, (6) head-shaft angle, and (7) LGHO:HHD ratio. A calcar screw was defined as a screw positioned <12 mm from the apex of the arch of the calcar or within the inferior 25% of the humeral head.[28] Fracture morphology was determined by each observer

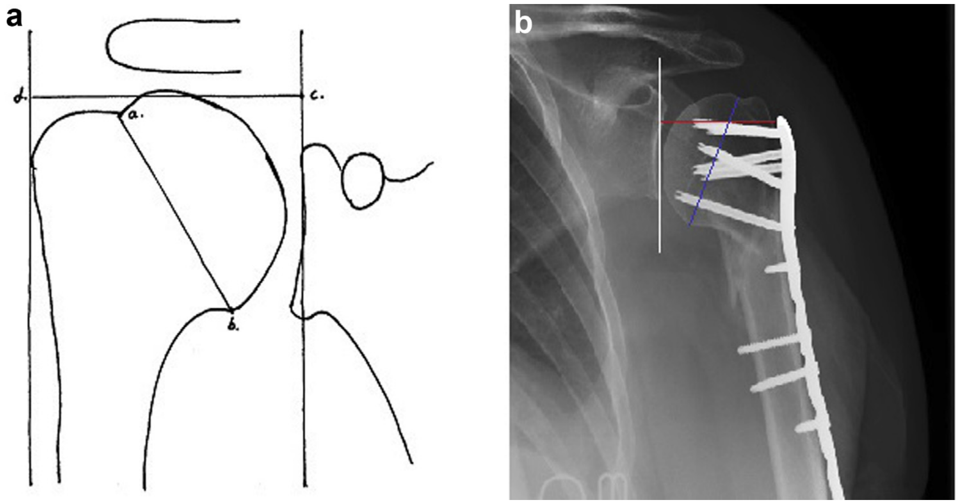

Figure 1 (**a**) A schematic representation of how humeral head diameter (HHD) and lateral glenohumeral offset (LGHO) were measured radiographically. HHD was measured from points a to b. LGHO was measured from points c to d. (**b**) Radiographic example of HHD and LGHO being measured in a patient radiograph. Lines represent the glenoid joint line (white), LGHO (red), and HHD (blue).

independently. In cases where disagreement existed, the case was discussed between the observers and a consensus was reached. In order to assess interobserver reliability, LGHO:HHD was measured in 50 contiguously selected patients by 2 separate observers.

Of the 308 patients undergoing operative intervention for proximal humerus fractures, 183 met the inclusion criteria outlined above (Fig. 3). A total of 18 patients (9.83%) suffered construct failure requiring further operative intervention. Women composed the majority of the study population at 134 (74%). The average overall age at the time of index surgery was 64.7 ± 15.7 years (range, 15-92 years). The average length of time from the index surgery to time of revision was 33 ± 52 weeks. The most common secondary procedure performed was removal of hardware without further instrumentation (44.4%). This was followed by revision ORIF and conversion to hemiarthroplasty, each representing 16.7% of revision procedures (Table I).

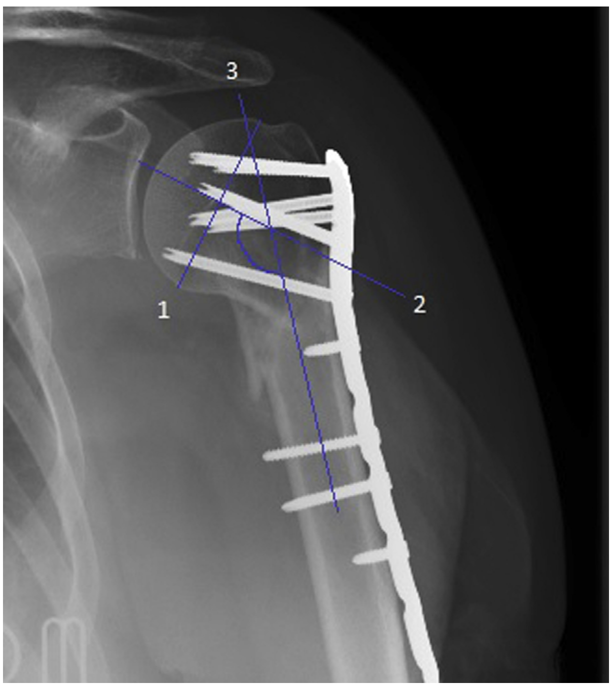

Figure 2 Radiograph depicting the humeral head-shaft angle. Line 1 is the anatomic neck; line 2 is perpendicular to the anatomic neck coincident with line 3 bisecting the humeral shaft. The angle subtended between lines 2 and 3 represents the head-shaft angle.

Statistical analysis

Once all data had been collected, 2 groups were created: (1) patients who had successful primary proximal humeral ORIF not requiring further intervention and (2) patients whose index ORIF failed and required further operative intervention. The LGHO:HHD ratio was tabulated for each patient, and the mean LGHO:HHD ratio was calculated for each group.

In order to test interrater reliability for LGHO:HHD, 50 contiguous patients were evaluated by 2 separate observers. This population included patients in both study groups. The average LGHO:HHD ratio was tabulated for each observer, and a nondirectional 2-sample unpaired Student *t*-test assuming unequal variance was performed to detect any difference in the means. Further comparison was carried out using intraclass correlation coefficient with a (3, κ) modeling scheme.

Categorical variables (age, sex, presence/absence of calcar screw, smoking history, and fracture morphology) were analyzed using χ^2 and multiple contingency tables where appropriate. Discrete and continuous data were analyzed via nondirectional 2-sample unpaired Student *t*-test assuming unequal variance. In order to control for confounding variables, binomial logistic regression was employed to determine the significance of LGHO:HHD in the context of sex, age, fracture morphology, presence/absence of calcar screw, and head-shaft angle. All calculations were performed using Excel (Microsoft, Redmond, WA, USA) with a P value of $<.05$, indicating significance.

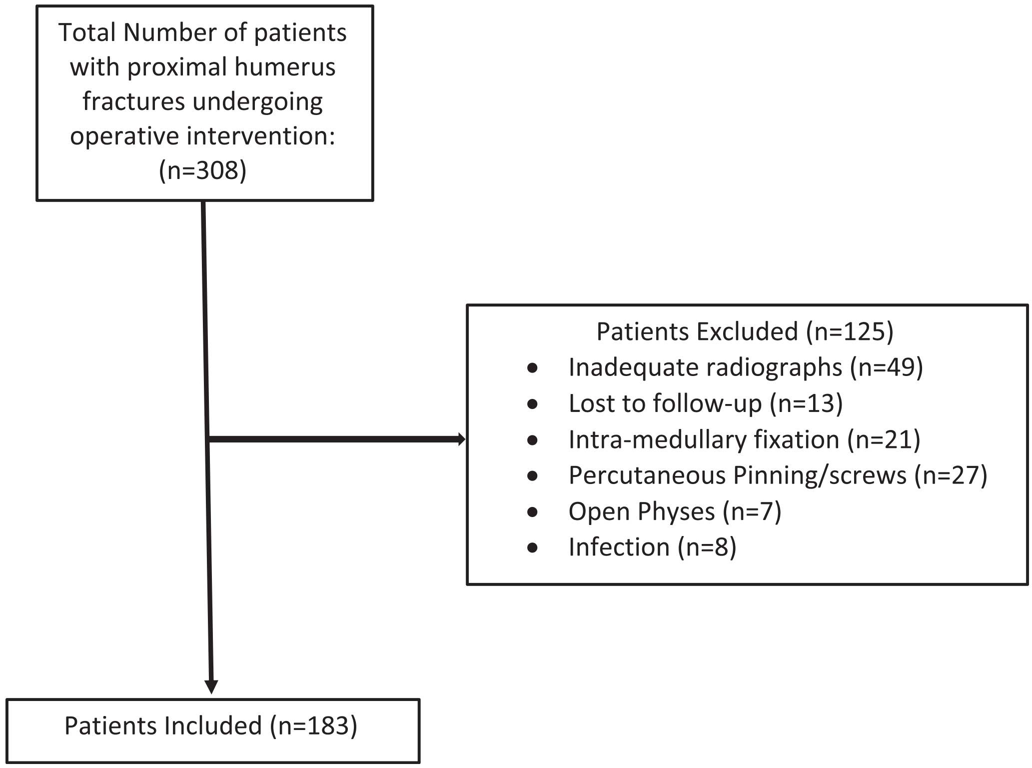

Figure 3 A PRISMA flow diagram showing the study population.

Results

The average intraclass correlation coefficient for LGHO:HHD was 0.80, with a 95% confidence interval ranging from 0.65 to 0.89. This indicates "good" interobserver reliability according to the work of Koo and Li.[22] Further characterization of this data found an average difference in LGHO:HHD calculation of 6.47%. The comparison of means found no significant difference between observers (observer 1 average: 0.98 ± 0.12, observer 2 average: 0.99 ± 0.09; Student *t*-test $P = .65$).

Table I Patient demographics

	Number	Percentage of total
Sex		
Men	48	26.4
Women	135	74.2
Age	64.7 ± 15.7 yr	
Time of revision	33 ± 52 weeks	
Revision procedure		
ORIF	3	16.7
TSA	1	5.6
RTSA	2	11.1
Hemiarthroplasty	3	16.7
ROH	8	44.4
MUA	1	5.6
IMN	1	5.6

ORIF, open reduction and internal fixation; *TSA*, total shoulder arthroplasty; *RTSA*, reverse total shoulder arthroplasty; *ROH*, removal of hardware; *MUA*, manipulation under anesthesia; *IMN*, intramedullary nail.

The mean LGHO:HHD in patients requiring revision surgery for implant failure was 0.94 ± 0.05. This was significantly lower than the LGHO:HHD ratio for patients not requiring revision surgery (1.03 ± 0.08, Student *t*-test $P < .001$).

The χ^2 analysis of all categorical variables including sex ($P = .33$), presence or absence of a calcar screw ($P = .44$), smoking history ($P = .51$), or fracture morphology ($P = .42$) failed to show a significant difference between patients experiencing failed index procedures and those whose index procedures were successful. Likewise, Student *t*-tests comparing means for both age and head-shaft angle failed to show a significant difference in the 2 study populations ($P = .14$ and $.60$, respectively). To further confirm these results, simple logistic regression was performed with each variable independently. None had a *P* value approaching significance except for LGHO:HHD ($P < .001$). Lastly, multivariate logistic regression was used to compare all variables simultaneously to determine the possible confounding effect, if any, on the relationship between LGHO:HHD and implant failure. The difference in LGHO:HHD between study groups remained significant ($P < .001$), whereas all other variables failed to approach significance (Table II).

Table II *P* values for each potential risk factor

	Bivariate logistic regression, *P* value
LGHO:HHD	<**.001**
Head-shaft angle	.55
Age	.18
Sex	.33
Calcar screw	.44
Smoking history	.51
Fracture morphology	.2
	Multivariate logistic regression, *P* value
LGHO:HHD	<**.001**
Head-shaft angle	.56
Age	.08
Sex	.12
Calcar screw	.19
Smoking history	.65
Fracture morphology	.87

LGHO:HHD, lateral glenohumeral offset to humeral head diameter ratio. Bolded values represent variables with significant P values.

Logistic regression was employed to plot LGHO:HHD vs. probability of implant failure (Fig. 4). The graph suggests that maintaining an LGHO:HDD of 1.0 or greater confers a <10% chance of implant failure, whereas a ratio of 0.9 approaches a failure rate of 20% and 0.8 roughly 40%.

Discussion

Proximal humerus fractures in the elderly continue to be a significant health care burden in the United States. Since the advent of locking plates for the management of fractures in the context of poor bone stock, more proximal humerus fractures have been treated with ORIF. Unfortunately, this increase in ORIF rate has also seen an increase in the rate of revision surgery.[2] Developing a quick, reliable, and repeatable way to radiographically evaluate the quality of proximal humerus reduction in both the intraoperative and postoperative settings can give surgeons insight as to the expected clinical outcomes and risk of construct failure. The goal of this study was to determine if measuring LGHO relative to HHD can be a surrogate to predicting implant failure after proximal humeral ORIF.

Several factors have been linked to poor functional outcome after ORIF of the proximal humerus with plate and screw constructs including age, smoking history, varus malunion, complex fracture morphology, and failure to place a calcar screw.[1,3,10,16,27,31] Until now, little exploration of the relationship of LGHO and construct failure after operative fixation of the proximal humerus has been performed. The topic has been well studied in relation to shoulder arthroplasty especially as it relates to preserving the moment arm of the deltoid and rotator cuff musculature.[18] A biomechanical study by Greiner et al[13] in 2012 confirmed that lateral offset preserves the preload of the subscapularis and teres minor, thereby preserving their rotational moment arms. Recently, in a study correlating lateral offset with clinical outcomes, Camus et al[4] found that patients had a significantly better range of motion when overall lateral offset was >10 mm after TSA with humeral resurfacing. Here, we found that failure to restore the LGHO:HDD ratio is an independent risk factor for construct failure requiring revision surgery after plate and screw fixation of proximal humerus fractures. Further graphic extrapolation of the data appears to suggest that efforts should be made to restore this relationship to the anatomic 1:1 ratio, as failure to do so will expose the patient to risk of failure. This method of radiographic evaluation is a simple and repeatable method for measuring LGHO that surgeons may use intraoperatively to define adequacy of reduction.

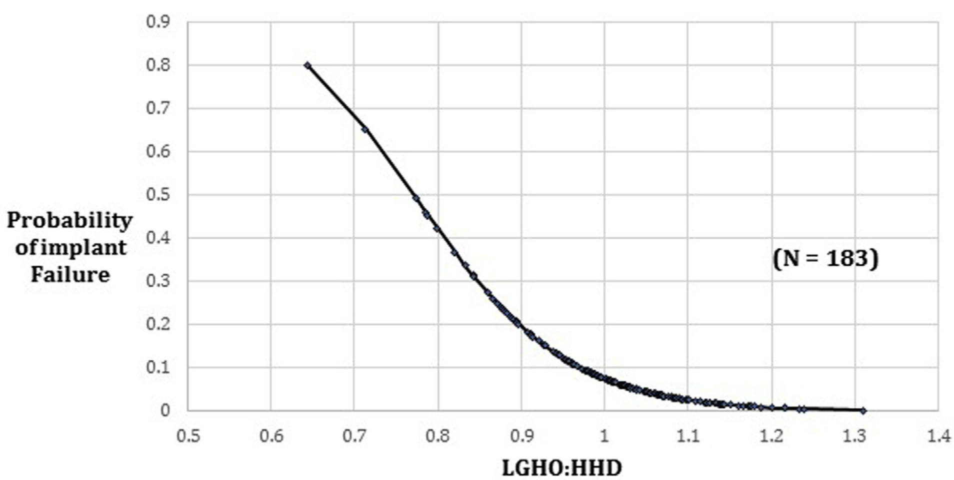

Figure 4 Bivariate logistic regression graph plotting the LGHO:HHD ratio against probability of implant failure. *LGHO*, lateral glenohumeral offset; *HHD*, humeral head diameter.

Author recommendations for intraoperative implementation of LGHO:HHD is as follows: after obtaining reduction and provisional fixation of the proximal humerus fracture, a "true" AP radiograph of the operative shoulder should be obtained. Using transparency film on the image intensifier screen, the HHD can be marked with a ruler and pen. The transparency film can then be placed between the glenoid and lateral aspect of the humerus to assess LGHO. Adjustments to the fracture reduction can be made accordingly to achieve an LGHO, which is roughly equal to the HHD.

The rate of construct failure requiring operative intervention in this study was 9.83%, which is consistent with other studies reporting fixation failures including Lee et al[24] (11.4%), Krappinger et al[23] (19.4%), and Agudelo et al[1] (13.7%). Several second procedures were performed to address the clinical failures in primary operative fixation, the most common of which was the removal of the symptomatic implant. In a series of 121 patients who had failed primary osteosynthesis, Jost et al[19] found that 41 (33.9%) required total implant removal with another 16 (13.2%) patients opting for partial implant removal. Primary and secondary screw cutout was the primary reason cited for implant removal.[19] This rate of removal was similar to the rate demonstrated in our study (47.1% vs. 56.5%) though the loss of fixation was the most commonly cited reason for revision in our study. Screw penetration into the glenohumeral joint is also a frequently seen complication in proximal humerus fracture repair. In a large meta-analysis of 191 studies, Kavuri et al[21] reported that primary and secondary screw penetration was the most common complication related to proximal humerus ORIF with an overall rate of 9.5%. Our data are dissimilar in that we had an overall screw penetration incidence of 1.6%.[21] It should be noted that a small subset of radiographs did show screw penetration into the glenohumeral joint in patients who did not undergo revision surgery. Lastly, reoperation secondary to the development of posttraumatic arthrofibrosis was seen in 1.1% of all patients and 11.1% of those requiring repeat operative intervention. This is lower than reported rates of posttraumatic arthrofibrosis in the literature, which tends to hover around 4%-6%.[5,7,24] We suspect that more patients suffer from clinically significant arthrofibrosis than those reported to have undergone surgical manipulation.

This study has several limitations. It is designed as a retrospective level III therapeutic study and therefore assumes all the limitations according to the American Academy of Orthopaedic Surgeons (AAOS) evidence-based practice committee guidelines including lack of a control group and nonrandomized design.[36] Other limitations include the absence of a standard postoperative rehabilitation protocol and the wide array of surgeons of various skill levels performing the operations. Importantly, this study had a number of patients who did not have technically adequate postoperative radiographs to be included. Of the 125 patients who were excluded from the study, 49 had removed secondary radiographs insufficient to accurately measure LGHO. Six of these patients required a return trip to the operating room for a failed primary fixation. Although this matches the rate of repeat operation for the patients included in the study, it is unclear whether the LGHO/HDD ratio correlated in the same manner. One other limitation related to this study is the lack of objective clinical observations of shoulder function after operative fixation. Several well-validated scores and ratings have been developed to assess functional status of the shoulder including the Constant-Murley score, UCLA rating, American Shoulder and Elbow Surgeons score, and others.[8,15] Although the primary endpoint of this study was the requirement for a return trip to the operating theatre, we believe that many patients live with functional debilitations about the shoulder and may not seek surgical corrective intervention. Lastly, this study does not take into account the effect bone mineral density has on the risk for construct failure. It is well established that osteoporosis has several implications, as it relates to fracture fixation and has been shown to be a factor in construct failure.[11,12] Unfortunately, many patients in our study population did not have quantifiable data in regard to osteoporosis or osteopenia (eg, dual energy x-ray absorptiometry [DEXA] scan). Nevertheless, the vast majority of our study population sustained proximal humerus fractures via low-energy mechanisms, thus categorizing them as osteoporotic by virtue that these are osteoporosis defining injuries.

Conclusion

This is the first study of its kind to correlate the LGHO:HDD ratio to failure of proximal humerus fixation after ORIF with a plate-and-screw construct. Surgical management of complex proximal humerus fractures continues to be technically challenging even with modern day instrumentation. Here, we demonstrate that restoration of an LGHO/HDD ratio of at least 1.0 can serve as a positive prognostic indicator for surgical success. By using this simple and reproducible radiographic parameter, surgeons may be able to better characterize the quality of their reduction intraoperatively and improve the potential for satisfactory clinical outcomes.

Disclaimer

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Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jse.2020.07.029.

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