ACCSCIENCE PUBLISHING

Journal of Clinical and Translational Research

ORIGINAL ARTICLE

Humeral shaft coverage: A preliminary radiographic measurement of displacement in surgical neck humerus fractures

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Abstract

Background: Fracture displacement and bony contact in proximal humeral fractures can affect healing and patient outcomes. The eccentric head index, currently used to measure displacement, is relatively complex and not ideal for all fracture types. **Aim:** This study proposes and evaluates the reproducibility of an exploratory measurement, the humeral shaft coverage, to quantify the degree of bony contact between fracture ends in surgical neck humeral fractures. **Methods:** All patients with surgical neck humeral fractures who had undergone closed reduction in our electronic medical records were identified using the diagnostic terms, and their full series of follow-up radiographs were reviewed for measurement by two observers. The estimated total humeral shaft coverage (THSC) was calculated by multiplying the proportion of metaphyseal width covered by the humeral head on both anteroposterior (AP) and scapular Y views. Total uncoverage was determined using the formula: 1 – THSC. **Results:** Two observers evaluated 22 shoulder AP and Y radiographs, resulting in 44 measurements, and each repeated their measurements to assess intra-observer reliability. The mean HSC values for observers 1 and 2 were 0.36 ± 0.32 and 0.44 ± 0.31, with no significant difference (p = 0.098). Inter-observer reliability was good to excellent (intraclass correlation coefficient [ICC] = 0.88, 95% confidence interval: 0.67–0.97). Intra-observer reliability was excellent for both observers (ICC = 0.99). **Conclusion:** Humeral shaft coverage is a consistent measurement that may help quantify fracture displacement in surgical neck humeral fractures. **Relevance for patients:** A simple method for quantifying fracture displacement may help predict prognosis and guide management of proximal humeral fractures.

Keywords: Humeral fractures; Radiography; Fracture displacement; Shoulder joint; Prognosis; Emergency treatment

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Citation: Mahmoud AN, Ozdag Y, Bernate JD, *et al*. Humeral shaft coverage: A preliminary radiographic measurement of displacement in surgical neck humerus fractures. *J Clin Transl Res*. 2026;12(3):025490091. doi: 10.36922/JCTR025490091

Received: December 1, 2025

Revised: February 19, 2026

Accepted: May 11, 2026

Published online: June 5, 2026

1. Introduction

Proximal humeral fractures represent about 4–10% of all fractures in adults[1] and are one of the most common geriatric nonvertebral fragility fractures, ranking third after proximal femoral and distal radius fractures.[2,3] They are often associated with a significant functional disability, morbidity, and an all-cause one-year mortality reaching 17.4%.[2,4]

Proximal humerus fractures occur when a strong force or fall disrupts the upper part of the arm bone, most commonly at the surgical neck, where the bone transitions from the humeral head to the shaft. In older adults, these fractures commonly result from lowenergy falls and are strongly linked to osteoporosis, while highenergy trauma is a more frequent cause in younger patients. Because these injuries often impair shoulder movement and independence, they place a significant burden on modern healthcare systems through emergency visits, imaging needs, prolonged rehabilitation, and the risk of complications such as nonunion and functional decline. As populations age, the incidence and healthcare impact of proximal humerus fractures continue to rise, making accurate assessment and appropriate management increasingly important.[1–4]

Common proximal humerus fracture classifications include the Neer (displacement-based) and Arbeitsgemeinschaft für Osteosynthesefragen/ Orthopaedic Trauma Association (AO/OTA classification, location-based) systems, while the Codman–Hertel system offers the highest inter-observer reliability using a twelve-type "Lego-block" model.[5-7] Still controversial, fractures of the proximal humerus can be treated conservatively or surgically, depending on several factors, including fracture displacement, patient age and functional status, soft tissue condition, neurovascular injury, bone quality, dominance, patient's decision, and surgeon preference.[8,9] Conservative treatment is generally utilized in non-displaced and minimally displaced fractures where there is bony contact between the humeral head and shaft, no humeral head dislocation, minimal displacement of the greater tuberosity (<5 mm), minimal varus/valgus angulation, and minimal or no articular involvement.[10,11] Surgical management is usually utilized in displaced fractures, 3–4-part fractures, articular fractures, and fracture dislocations.[11]

The presence of head/shaft bony contact is recognized as a significant parameter that predicts fracture healing in proximal humerus, and particularly surgical neck humeral fractures. Studies have shown that 33–100% displacement of the humeral shaft relative to the humeral head has been associated with an increased risk of nonunion and poor functional outcomes in surgical neck humeral fractures treated nonoperatively.[12,13] The term "disengaged neck" refers to a grossly unstable humeral neck with no contact between the humeral neck and shaft and carries a high risk of fracture nonunion, which may handicap patients in their routine daily activities.[12]

Few studies have described measurement techniques for translations in proximal humerus fractures. Foruria *et al.*[14] described the measurement of mediolateral and anteroposterior (AP) translations of the humeral shaft relative to the humeral neck in coronal computed tomography (CT)/AP radiograph and sagittal CT/ lateral radiographs of the shoulder, respectively. Frank *et al.*[15] described the eccentric head index (EHI), which is measured in the shoulder AP and the scapular Y (Neer) view. The translation measurement[14], despite being easy, describes humeral shaft translation in millimeters in each plane but does not quantify bony contact or necessarily reflect fracture severity, given variation in anatomical size between individuals. The EHI is a more complex measurement (Figure 1A) that quantifies the extent of humeral head displacement relative to the humeral shaft and accounts for the actual displacement. Despite this, the measurement is not easy, is affected by the precise identification of the humeral shaft axis[15], depends on the direction of shaft displacement, and may not be applicable in certain fracture configurations (Figure 1C).

While current classification systems[5-7] have limited ability to determine whether operative or conservative treatment is indicated, a simple radiographic technique for measuring the extent of fracture displacement could aid in assessing fracture severity and prognosis. Given the role of bony contact in determining the likelihood of union, among other factors, this study aims to describe an easy radiographic method for calculating fracture displacement in surgical neck proximal humeral fractures, accounting for both the degree of bony contact and fracture displacement. Many surgeons may be using this method; however, to our knowledge, it has not been described in detail.

2. Materials and methods

2.1. Study cohort

After Institutional Review Board approval, we searched our electronic medical database (Geisinger Database) using diagnostic terminology to extract all patients with surgical neck humerus fractures who underwent closed reduction, to track their serial follow-up radiographs, and perform the necessary measurements. Cases of proximal humerus fractures, admitted between November 2019 and November 2024, had their radiographs reviewed by four orthopedic surgeons to select adequate quality radiographs that allow for the execution of the measurements.

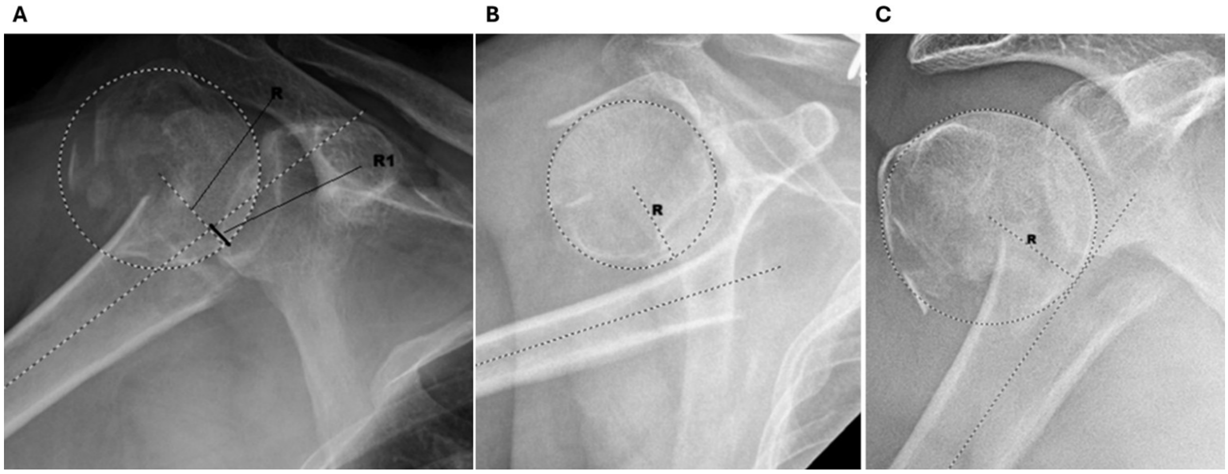

Figure 1. The eccentric head index (EHI) in anteroposterior (AP) shoulder radiographs. The EHI describes the offset of the humeral head center in relation to the diaphyseal axis[15] (A) EHI = 1 – (R1/R), where R represents the diameter of a circle around the humeral head, and R1 represents the eccentric portion of the humeral head outside the humeral shaft axis. In this case, there is humeral head contact with the shaft, and EHI would be typically < 1. (B) In this case, R1 is 0 since the humeral head is completely displaced from the shaft; hence, EHI = 1, indicating complete displacement. (C) In this case, R1 = 0, and EHI is also =1, despite fair contact between the humeral head and the shaft, underscoring the limitations of EHI as a measurement method. Images are original, de-identified radiographs provided by the authors.

2.2. Inclusion criteria

The inclusion criteria were: (i) cases that were diagnosed with surgical neck proximal humeral fractures, and (ii) cases that underwent fracture closed reduction in the emergency setting (traction and gentle manipulation for displaced fractures).

2.3. Exclusion criteria

The exclusion criteria were: (i) cases with poor-quality radiographs hindering the two-rater assessment, or cases with incomplete serial (emergency, postreduction, and last follow-up) radiographic assessment, (ii) cases that underwent early surgical intervention (to avoid the hardware artifacts), (iii) cases with missing AP or Y views, and (iv) cases with isolated proximal humerus fractures not involving the surgical neck (isolated shaft, anatomical neck, greater or lesser tuberosity fractures).

2.4. Radiographic assessment

The radiographs were assessed to quantify the humeral head displacement and bony contact. Traditionally, displacement is evaluated using AP and lateral X-ray views, which provide orthogonal projections of the humeral head and shaft. However, quantifying the total displacement in a clinically meaningful way can be challenging due to the three-dimensional nature of these fractures. Given the limitations encountered with the EHI (Figure 1) and the lack of ability of the translation measurements in describing fracture displacement or the amount of bony coverage, a simpler technique (the humeral shaft coverage [HSC]) has been proposed for identifying, quantifying, and monitoring fracture displacement by combining the translation and bony contact parameters.

2.5. Humeral shaft coverage

The relative HSC was calculated separately on the AP (rHSC_AP) and scapular Y (rHSC_Y) radiographs. Each is estimated by dividing the width of the metaphyseal portion covered by the humeral head (or its spherical contour) at the most proximal (metaphyseal) border of the fracture by the total width of the proximal metaphysis. The total HSC (THSC) was then calculated by multiplying the rHSC_AP by rHSC-Y (Figure 2). From the AP view, the fraction of the shaft's mediolateral width covered by the head was calculated (e.g., 20/30 = 0.75). From the scapular Y view, the fraction of the shaft's AP depth covered by the head was calculated (e.g., 14/28 = 0.50). The two fractions were multiplied to find the combined (total) coverage: 0.75 × 0.50 = 0.375. This means 37.5% of the metaphyseal surface remains in contact with the humeral head fragment.

2.6. Fundamental geometric principle

The core principle of this methodology is the treatment of the humeral head's contact surface with the shaft as a two-dimensional projection onto a plane perpendicular to the long axis of the humerus. This concept of projecting complex three-dimensional anatomy onto two-dimensional planes for measurement is well-established in orthopedic radiology.[16] For this calculation, this contact surface was modeled as a rectangle, where:

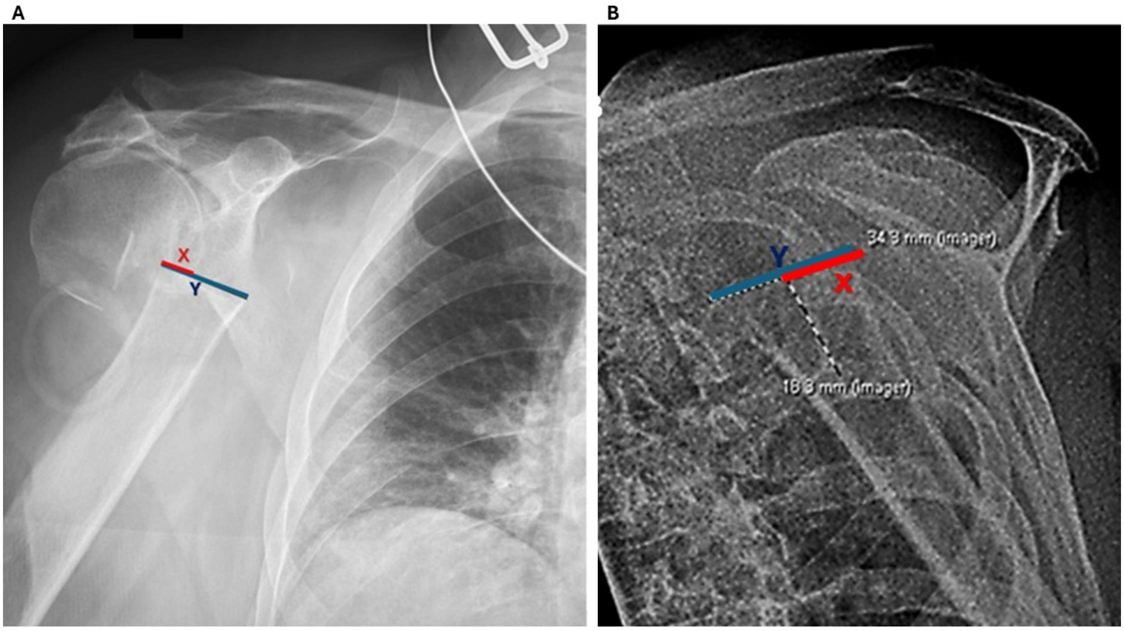

Figure 2. Humeral shaft coverage in anteroposterior (AP) and scapular Y shoulder radiographs. (A) The rHSC_AP (AP view) is calculated by dividing the metaphyseal width covered by the humeral head (X, red line) by the total width of the humeral metaphysis (Y, blue line). (B) The rHSC_Y is calculated similarly (X/Y). The total HSC will be HSC_AP X HSC_Y. In this example, rHSC_Y = 18.3/34.3 = 53.35%. Images are original, de-identified radiographs provided by the authors.

(i) The AP view provides a measure of displacement along the mediolateral axis. It quantifies the portion of the shaft's width that is covered by the head.
(ii) The scapular Y (Lateral) view provides a measure of displacement along the AP axis. It quantifies the portion of the shaft's depth that is covered by the head.

These two views are orthogonal, meaning they assess displacement in perpendicular planes. The true "coverage" potentially exists only where contact occurs in both planes simultaneously.[17] A point on the humeral shaft's surface is considered "covered" by the humeral head only if it lies beneath the head's projection in the AP view and in the scapular Y view.

2.7. The estimated total humeral shaft uncoverage

Total humeral shaft uncoverage can be defined as the approximate total area fraction that is not covered and is simply the complement of the total coverage fraction. A point on the shaft is "uncovered" if the head is displaced in the AP view, the scapular Y view, or in both views. The total uncoverage is the union of these sets, calculated using **Equation 1**:

$$\begin{aligned}\text{Total humeral shaft uncoverage} &= 1 - \text{THSC} \\ &= 1 - 0.375 \\ &= 0.625\end{aligned} \tag{1}$$

This indicates that 62.5% of the shaft's surface is uncovered, representing the degree of fracture displacement. It is important to note that multiplying the uncovered area in the AP and Y views, as in THSC, would only yield the area uncovered in both views simultaneously. It completely misses the areas that are uncovered in only one view (e.g., the head is off to the side but aligned front-to-back, or vice versa). For an approximate direct calculation of the THSC, the vector-sum methodology may be utilized.[18-20]

2.8. Statistical analysis

The HSC measurements were plotted on an Excel sheet, and the averages, medians, and ranges were calculated. The interobserver reliability was assessed using the intraclass correlation coefficient (ICC), with values below 0.4 indicating poor reliability, 0.4 to 0.59 indicating moderate reliability, 0.59 to 0.75 indicating good reliability, and values above 0.75 indicating excellent reliability.[21] The paired t-test was used to compare the means, and a $p \leq 0.05$ was considered statistically significant. Statistical analysis was performed using Microsoft Excel version 2205 (Microsoft Corporation, Redmond, USA).

3. Results

A total of 22 shoulder radiographs from patients with surgical neck humeral fractures met the selection criteria and were measured by the two raters, yielding 44 measurements. All cases underwent closed reductions in the emergency settings and had their serial shoulder AP and Neer radiographs assessed by the raters. Humeral metaphyseal width measured on AP and scapular Y views ranged from 19 mm to 44.8 mm. The mean and SD of HSC for raters 1 and 2 were 0.36 ± 0.32 and 0.44 ± 0.31, respectively (p = 0.098) (Figure 3). Inter-rater reliability between the two raters was good, with ICC = 0.884 (95% confidence interval [CI]: 0.679–0.973). Intra-rater reliability was excellent for both raters: ICCs were 0.995 (95% CI: 0.982–0.999) for Rater 1 and 0.997 (95% CI: 0.987–0.999) for Rater 2.

4. Discussion

This study presents a simple and reproducible method for assessing the fracture displacement and bony contact in surgical neck humeral fractures. Our measurement technique demonstrated high inter-rater agreement and provided a straightforward measure to describe the fracture and potentially predict the likelihood of fracture healing. Using a standardized approach to describe displacement can help improve decision-making, documentation, and communication among the care teams.

4.1. Radiographic assessment of proximal humerus fractures

Radiographic assessment of proximal humerus fractures relies on X-rays and CT scans. The trauma shoulder X-ray series consists of a true AP view, an axillary lateral view, and a scapular Y view. At least two perpendicular X-rays (true AP and a scapular Y view) are necessary to identify the fracture type.[22-24] A "true AP X-ray" of the shoulder is made with the central ray tangential to the glenoid surface, while the scapular Y view is made with the central ray perpendicular to the glenoid[14] (Figures 1 and 2). On the other hand, while shoulder CT scans can be very helpful for assessing complex injuries, particularly involving the humeral head or those with sagittal comminution, they are not necessary for all fracture patterns, especially if minimally displaced. CT scans are particularly helpful for the assessment of fracture morphology, bone stock, degree of comminution, size of fixable fragments, and the extent of posteromedial metaphyseal fracture.[25] Given that CTs may not be available in all settings, our study focused on measurements from shoulder radiographs.

Presenting a method for radiographic measurement of fracture displacement is not only helpful for describing the fracture but also for predicting healing potential, since bony contact has been deemed an important factor in predicting fracture healing. In a prospective study by Court-Brown *et al.*[13], the authors studied 126 translated two-part fractures of the proximal humerus and found that surgical neck translation was directly associated with poorer functional outcomes, as measured by the Neer score at 52 weeks postoperatively, particularly in elderly patients. Most (80%) of the nonunion cases in their series had an initial fracture displacement of >34%. The authors defined translation as "the percentage of the diameter of the surgical neck of the proximal humerus." The authors, however, did not describe their measurement technique, assess bony coverage, or rely solely on AP radiographs. In another study, partially by the same authors, the authors assessed the risk factors of proximal humerus fracture nonunion in 1,027 proximal humeral fracture cases and found an overall prevalence of proximal humeral nonunion of 1.1%, rising to about 8% if metaphyseal comminution is present and 10% if there is between 33% and 100% translation of the surgical neck.[12] The authors found that the effect of nonunion on function is considerable, even as early as six weeks after fracture, and recommended against delaying surgical treatment for >six months due to its significant impact on functional status.

4.2. Factors affecting healing in proximal humerus fractures

Several factors could contribute to nonunion in the proximal humerus, particularly humeral neck fractures. It has been suggested that severe displacement, soft tissue interposition, patient age, early mobilization, and poor surgical technique may be implicated.[12,25] However, fracture displacement is likely a significant factor associated with an increased incidence of nonunion, as borne out by applying Neer's criteria of 1 cm of displacement and 45 degrees of angulation.[18] Fracture displacement, however, does not solely predict nonunion. Court-Brown and McQueen[12] reported nonunion prevalence of 2.6%, 10%, and 8.1% in patients presenting with less than 33%, 33–66%, and 66–100% translation, respectively. Interestingly, none of the patients with more than 100% translation in their series developed a nonunion.

Bone healing is strongly influenced not only by mechanical stability but also by a wide range of biological factors that regulate inflammation, angiogenesis, and new bone formation. After a fracture, the early inflammatory phase triggers the release of cytokines and growth factors that recruit immune cells and mesenchymal progenitor cells, which are essential for callus formation and remodeling. Recent reviews highlight the key roles of mediators, such as transforming growth factor beta, receptor activator of nuclear factor kappa B–receptor activator of nuclear factor kappa B ligand–osteoprotegerin, and parathyroid hormone, which coordinate osteoblastic and osteoclastic activity throughout the healing phases.[26] Experimental and clinical studies also emphasize how

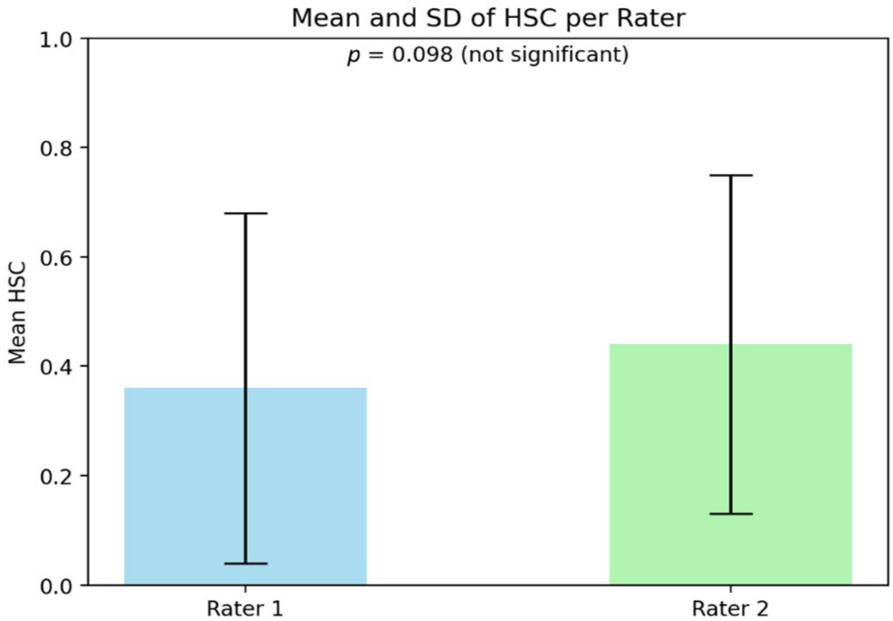

Figure 3. Comparison of mean humeral shaft coverage (HSC; ±standard deviation) between Rater 1 and Rater 2. The *p*-value (0.098) indicates no statistically significant difference (paired *t*-test).

immune-driven processes and molecular cross-talk guide angiogenesis, cartilage formation, and woven bone deposition during the repair phase.[27] In addition to these classical pathways, newer research has shown that naturally occurring compounds such as rosavin and salidroside may modulate osteogenic signaling and support bone metabolism, underscoring the expanding understanding of biological contributors to fracture healing.[28,29]

4.3. Clinical application of the humeral shaft coverage measurement

Neer's original classification defines a bone fragment as displaced when there is more than 1 cm of separation or 45° of angulation, and these criteria have traditionally guided surgical decision-making for proximal humerus fractures, with minimally displaced fractures managed nonoperatively.[5] However, recent evidence emphasizes that displacement alone is not the sole determinant of treatment; factors such as fragment involvement and medial hinge integrity, as highlighted by Hertel's predictors, are critical for assessing vascularity and healing potential.[30] In our series, the humeral metaphyseal width measured on AP and scapular Y views ranged from 19 mm to 44.8 mm, underscoring the variability in applying Neer's 1 cm threshold. For example, a 10 mm displacement represents 52% loss of contact in a 19 mm metaphysis but only 22.7% in a 44 mm metaphysis.

Given this variability and the limitations of a fixed displacement threshold, expressing displacement as a percentage of metaphyseal coverage may provide a more proportional and clinically meaningful assessment. Based on our observations and acknowledging the absence of clinical validation, we propose that coverage of less than 50% may serve as a conservative descriptive threshold and, in conjunction with Hertel's parameters[31,32], such as medial hinge integrity and calcar length, may indicate the need for surgical intervention. This threshold, however, should be considered exploratory and requires further clinical validation before adoption as a standard criterion.

Recent studies have further underscored the critical importance of specific displacement patterns in predicting outcomes for proximal humerus fractures, reinforcing the need for a comprehensive measurement system like the HSC. Shahien *et al.*[33] demonstrated that anterior translation of the humeral shaft relative to the head is a significant predictor of the need for subsequent surgical intervention. While their work valuably identifies a specific high-risk displacement vector, their assessment of translation was uniplanar and measured in absolute millimeters, which, as our study notes, can be confounded by variations in individual patient anatomy. In contrast, our HSC method offers a more realistic, proportional assessment by quantifying the resultant bony contact in two orthogonal planes (AP and scapular Y), thereby capturing the combined effect of both anterior–posterior and medial–lateral displacement. This allows the HSC to account for complex, multiplanar displacements that a single linear measurement might not fully represent.

Similarly, Goudie and Robinson[34] developed a comprehensive nomogram to predict nonunion in nonoperatively treated fractures, identifying factors such as initial displacement (translation and angulation) and posteromedial metaphyseal comminution. Their study robustly confirms the principle that displacement is a key determinant of healing. However, the predictive model relies on categorical and linear assessments of displacement from plain radiographs. The HSC methodology could serve as a more precise, continuous variable to refine such predictive models. Therefore, while existing studies have successfully identified the direction or presence of displacement as critical prognostic factors, the HSC aims to complement these findings by providing a practical tool to quantify the extent of the resulting bony opposition, which is an important biological requirement for uneventful healing.

Although our study did not correlate displacement or bony contact with functional or radiographic outcomes, it may be used in future research to assess clinical or radiographic outcomes in proximal humerus fractures. Given that fracture translation can be difficult to measure accurately on plain radiographs[12], we focused on measuring bony contact as an indicator of translation. While the HSC offers a novel method for combining multiplanar displacement into a single quantitative value, we acknowledge that the clinical relevance of this composite measurement requires further investigation. To our knowledge, this is the first study to propose multiplying the fractional coverage from orthogonal radiographic views to estimate the approximate total bony contact in proximal humerus fractures. Consequently, specific thresholds to distinguish fractures that are likely to heal uneventfully from those at risk of nonunion have not yet been established. It is currently unknown whether a THSC of 0.3 (30% contact) carries a different prognosis than isolated 50% translation in the coronal plane alone, or at what exact percentage the risk of failure begins to rise exponentially. Future studies should aim to correlate HSC values with patient-reported outcomes, nonunion rates, and the need for secondary surgery to establish evidence-based clinical thresholds. Until such validation is available, the HSC should be viewed as a descriptive adjunct to existing classification systems, offering a reproducible measure of displacement, rather than a standalone indicator for operative intervention.[33-35]

4.4. Technical considerations

Radiographs are two-dimensional projections of three-dimensional structures and, as such, are subject to inherent limitations, including overlap and foreshortening.[35-39] Overlapping bone fragments or variations in patient anatomy can obscure the true extent of displacement, leading to inaccuracies in the measurement. To address these projection artifacts, it is important to obtain high-quality radiographs that clearly visualize the humeral head and shaft. The use of multiple radiographic views, including axillary or Velpeau views, can provide additional perspectives to confirm the extent of displacement.[40,41] Furthermore, digital imaging software can be employed to enhance image clarity and measure displacement more precisely. Given the unavoidable rotational components in proximal humeral fractures, we considered the calculated displacement an approximation, and a tolerance margin of ±5–10% may be added to account for projection error.

It is important to acknowledge that the rectangular model underlying the HSC calculation assumes that the humeral head and shaft fragments remain relatively parallel in the coronal and sagittal planes. In the presence of significant varus or valgus angulation, the plane of the metaphyseal surface is no longer perpendicular to the long axis of the shaft, and the simple ratio of covered-to-total width becomes a less accurate representation of true three-dimensional contact. In such cases, the HSC measurement describes the projected coverage but does not capture the angular deformity. Therefore, the HSC is best utilized as a quantitative tool for translational displacement and should be interpreted in conjunction with standard angular measurements (e.g., neck-shaft angle) to fully characterize complex fracture morphology.

4.5. Management of proximal humerus fractures

Clinical decision-making in fracture management is multifaceted, and while fracture displacement provides insight into the potential for healing, it is only one factor among many that influence treatment strategies. Factors such as fracture pattern, bone quality, soft tissue integrity, and patient-specific considerations such as age, activity level, and comorbidities play a significant role in determining the appropriate treatment strategy. A single displacement value, while useful, may not fully capture the complexity of these clinical factors. Therefore, fracture displacement should be integrated into a broader clinical decision-making framework, serving as a quantitative tool to supplement qualitative assessments and guide surgical planning.[42-46]

Proximal humerus fractures, often presenting as surgical neck fractures[3], are among the most common fractures in adults, particularly in the elderly population, and their management remains a subject of ongoing debate due to the diversity of fracture patterns and patient-specific factors involved.[8,47] These injuries often occur following low-energy falls in older adults with osteoporotic bone, while high-energy trauma is more typical in younger individuals.[48] Treatment strategies broadly fall into two categories: nonoperative and operative management. The choice between these approaches depends on multiple considerations, including fracture displacement, bone quality, patient age, comorbidities, and functional demands.[49]

Nonoperative treatment is generally favored for minimally displaced fractures and has been associated with satisfactory outcomes in many cases.[50] This approach typically involves sling immobilization followed by early, progressive rehabilitation to restore range of motion and function. Recent evidence suggests that early mobilization, initiated within one week of injury, may confer short-term functional benefits without increasing complication rates compared to delayed protocols.[51] However, conservative management requires careful monitoring to avoid secondary displacement and stiffness, particularly in complex fracture patterns.

Operative intervention is considered for displaced, unstable, or multi-part fractures, as well as for fracture dislocations and cases with compromised vascularity or soft tissue integrity.[52] Surgical options include open reduction and internal fixation (ORIF) using locking plates or intramedullary nailing, hemiarthroplasty (HA), and reverse shoulder arthroplasty (RSA). ORIF aims to restore anatomical alignment and allow early mobilization, but its success depends on achieving stable fixation, which can be challenging in osteoporotic bone.[53] Locking plates have improved fixation in complex fractures, yet they carry risks of screw cut-out and avascular necrosis, particularly in varus patterns.[54] Intramedullary nails offer a minimally invasive alternative but may be less effective in comminuted fractures.

Arthroplasty options are increasingly utilized for severely comminuted fractures or cases where fixation is unlikely to succeed. HA was historically the standard for complex fractures, but outcomes depend heavily on tuberosity healing, which can be unpredictable.[55] RSA has gained popularity for three- and four-part fractures in elderly patients, as it provides more reliable pain relief and functional recovery, even when tuberosity healing is suboptimal.[56] Systematic reviews indicate that RSA often yields superior functional scores compared to HA and ORIF in older patients, though it is associated with higher costs and potential complications such as instability and scapular notching.[57]

Ultimately, management of surgical neck humeral fractures should be individualized, integrating radiographic findings with patient-specific factors such as age, activity level, and comorbidities. While fracture displacement offers valuable insights, it represents only one component of a multifactorial decision-making process. A comprehensive approach that considers biological, mechanical, and social factors is essential for optimizing outcomes and minimizing complications.[47,50,53]

4.6. Study limitations

Our study has several limitations that necessitate careful interpretation of the results. First, it relies on two-dimensional radiographs and assumes that the metaphysis has a rectangular projection and that the calculated values accurately represent fracture displacement, whereas calculating displacement from three-dimensional CT scans would likely yield different values. This was not performed, however, because not all patients had CT scans performed at each radiographic assessment. Another limitation is the absence of clinical or functional assessment; hence, the study's clinical applicability remains exploratory. Another significant limitation in our study is that the measurements were not blinded, which could create significant bias.

It is important to acknowledge that the reliability of displacement assessment on X-rays is not comparable to that of more advanced imaging modalities such as CT scans. Without validation studies comparing humeral coverage measurements with three-dimensional imaging or intraoperative findings, its accuracy and reliability remain debatable. To address these concerns, future research may focus on comparative studies that evaluate the coverage measurement method against three-dimensional CT reconstructions or intraoperative assessments of displacement. Such studies would provide empirical evidence of the method's accuracy and help establish its role in clinical practice.

Despite these limitations, this methodology provides a consistent, reproducible, and simple quantitative assessment compared to qualitative description or isolated linear measurements, suggesting a potential guide for clinical decision-making and research.

5. Conclusion

We described a simple and reproducible technique for measuring the extent of fracture displacement/bony contact in surgical neck humeral fractures. The HSC showed high inter-observer agreement and could be used to describe fractures. Importantly, while the HSC demonstrates good to excellent reproducibility, its clinical utility, specifically its ability to predict nonunion or guide treatment decisions, has not yet been established. This study provides the foundational data necessary to justify future prospective investigations aimed at correlating HSC values with functional outcomes and healing rates. Until such data are available, the HSC should be considered a descriptive research tool rather than a validated clinical predictor. Future research may further develop this measurement and use it in clinical studies assessing fracture healing and functional outcomes in relation to fracture displacement and bony contact.

Acknowledgments

The authors would like to thank the research coordinator, Abigail Nye, BS, for her great assistance in the administrative work related to the study.

Funding

None.

Conflict of interest

The authors declare no conflict of interest.

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Methodology: Ahmed Nageeb Mahmoud, Yagiz Ozdag, Mahmoud AH Mahmoud, Juan David Bernate, William Mack Malarkey
Writing–original draft: Ahmed Nageeb Mahmoud
Writing–review & editing: All authors

Ethics approval and consent to participate

An Institutional Review Board approval was obtained before commencing this study (IRB# 2019-0102 on 8/2/2019). Consent for participation was not required due to the retrospective nature of the study.

Consent for publication

Waived by the Institutional Review Board, as this is a retrospective study using deidentified clinical data.

Availability of data

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request after fulfilling an institutional data use agreement.

References

1. Launonen AP, Lepola V, Saranko A, Flinkkilä T, Laitinen M, Mattila VM. Epidemiology of proximal humerus fractures. *Arch Osteoporos.* 2015;10(1):209.

   doi: 10.1007/s11657-015-0209-4

2. Curtin PB, Hall RR, Molla VG, Lansbury JN, O'Connor EP, Aaron DL. Morbidity and mortality of fragility proximal humerus fractures: a retrospective cohort study of patients presenting to a level one trauma center. *J Shoulder Elbow Surg.* 2022;31(10):2116-2120.

   doi: 10.1016/j.jse.2022.03.006

3. Court-Brown CM, Caesar B. Epidemiology of adult fractures: A review. *Injury*. 2006;37(8):691-697.

   doi: 10.1016/j.injury.2006.04.130

4. Mastrantonakis K, Karvountzis A, Yiannakopoulos CK, Kalinterakis G. Mechanisms of shoulder trauma: Current concepts. *World J Orthop*. 2024;15(1):11-21.

   doi: 10.5312/wjo.v15.i1.11

5. Neer CS 2nd. Displaced proximal humeral fractures. I. Classification and evaluation. *J Bone Joint Surg Am*. 1970;52(6):1077-1089.

6. Müller ME, Nazarian S, Koch P, Schatzker J. *The comprehensive classification of fractures of long bones*. Berlin Heidelberg Springer; 1990.

   doi: 10.1007/978-3-642-61261-9

7. Hertel R, Hempfing A, Stiehler M, Leunig M. Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. *J Shoulder Elbow Surg.* 2004;13(4):427-433.

   doi: 10.1016/j.jse.2004.01.034

8. Baker HP, Gutbrod J, Strelzow JA, Maassen NH, Shi L. Management of Proximal Humerus Fractures in Adults-A Scoping Review. *J Clin Med*. 2022;11(20):6140.

   doi: 10.3390/jcm11206140

9. Handoll HH, Ollivere BJ, Rollins KE. Interventions for treating proximal humeral fractures in adults. *Cochrane Database Syst Rev.* 2015.

   doi: 10.1002/14651858.CD000434.pub4

10. Robinson CM, Page RS. Severely impacted valgus proximal humeral fractures. Results of operative treatment. *J Bone Joint Surg Am*. 2003;85(9):1647-1655.

    doi: 10.2106/00004623-200309000-00001

11. Robinson CM, Amin AK, Godley KC, Murray IR, White TO. Modern perspectives of open reduction and plate fixation of proximal humerus fractures. *J Orthop Trauma*. 2011;25(10):618-629.

    doi: 10.1097/BOT.0b013e31821c0a2f

12. Court-Brown CM, McQueen MM. Nonunions of the proximal humerus: their prevalence and functional outcome. *J Trauma*. 2008;64(6):1517-1521.

doi: 10.1097/TA.0b013e3181469840

13. Court-Brown CM, Garg A, McQueen MM. The translated two-part fracture of the proximal humerus. Epidemiology and outcome in the older patient. *J Bone Joint Surg Br*. 2001;83-B(6):799-804.

doi: 10.1302/0301-620X.83B6.0830799

14. Foruria AM, de Gracia MM, Larson DR, Munuera L, Sanchez-Sotelo J. The pattern of the fracture and displacement of the fragments predict the outcome in proximal humeral fractures. *J Bone Joint Surg Br*. 2011;93-B(3):378-386.

doi: 10.1302/0301-620X.93B3.25083

15. Frank FA, Niehaus R, Borbas P, Eid K. Risk factors for secondary displacement in conservatively treated proximal humeral fractures. *Bone Joint J*. 2020;102-B(7):881-889.

doi: 10.1302/0301-620X.102B7.BJJ-2020-0045.R1

16. Ku PC, Liu M, Grupp R, *et al*. End-to-end 2D/3D registration from pre-operative MRI to intra-operative fluoroscopy for orthopedic procedures. *Int J Comput Assist Radiol Surg*. 2025;20(11):2355-2366.

doi: 10.1007/s11548-025-03426-w

17. Efrima B, Benady A, Dahmen J, Kerkhoffs GMMJ, Karlsson J, Usuelli FG. Revolutionising orthopaedic imaging: From 2D radiography and computed tomography to 3D volumetric radiography. *J Exp Orthop*. 2025;12(1):e70161.

doi: 10.1002/jeo2.70161

18. Guo M, Li C, Wang S, Yin S, Liu S, Ge X. Vector-Sum Method for 2D Slope Stability Analysis Considering Vector Characteristics of Force. *Int J Geomech*. 2019;19(6).

doi: 10.1061/(asce)gm.1943-5622.0001436

19. Hung WC, Lin YL, Lin CW, Chin WL, Wu CH. Advanced Sampling Technique in Radiology Free-Text Data for Efficiently Building Text Mining Models by Deep Learning in Vertebral Fracture. *Diagnostics*. 2024;14(2):137.

doi: 10.3390/diagnostics14020137

20. North Toronto Collegiate Institute. *Displacement, distance and the addition of vectors*. Toronto NTCI. Available from: https://ntci.on.ca/departments/physics/snc2d/vectoradd.pdf [Last accessed on November 25, 2025].

21. Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J Chiropr Med*. 2016;15(2):155-163.

doi: 10.1016/j.jcm.2016.02.012

22. Helfet DL, Haas NP, Schatzker J, Matter P, Moser R, Hanson B. AO philosophy and principles of fracture management-its evolution and evaluation. *J Bone Joint Surg Am*. 2003;85(6):1156-1160.

doi: 10.2106/00004623-200306000-00029

23. Abdeldayem SM, Mahmoud AN, Diab RA. Humeral Neck Fractures in Association with Traumatic Shoulder Dislocation. *Orthop Rheumatol Open Access J*. 2018;10(1):11-15.

doi: 10.19080/OROAJ.2018.10.555779

24. Orhan SS, Keklikçi K. The Radiographic and Clinical Outcomes of Proximal Humerus Fractures in Patients Over 60 Years of Age. *Arch Basic Clin Res.* 2025;7(2).

doi: 10.5152/abcr.2025.25331

25. Brorson S. Fractures of the proximal humerus. *Acta Orthop Suppl*. 2013;84(351):1-32.

doi: 10.3109/17453674.2013.826083

26. Hedayatzadeh RA, Nafisi N, Velasquez-Hammerle M, *et al.* Advances in computational modeling of cytokine and growth factor dynamics in bone healing: a scoping review. *Biomech Model Mechanobiol*. 2025;24(3):761-778.

doi: 10.1007/s10237-025-01938-7

27. Ganse B. Methods to accelerate fracture healing–a narrative review from a clinical perspective. *Front Immunol.* 2024;15:1384783.

doi: 10.3389/fimmu.2024.1384783

28. Wojdasiewicz P, Turczyn P, Lach-Gruba A, *et al.* The Role of Rosavin in the Pathophysiology of Bone Metabolism. *Int J Mol Sci*. 2024;25(4):2117.

doi: 10.3390/ijms25042117

29. Wojdasiewicz P, Brodacki S, Cieślicka E, *et al.* Salidroside: A Promising Agent in Bone Metabolism Modulation. *Nutrients*. 2024;16(15):2387.

doi: 10.3390/nu16152387

30. Russo R, Guastafierro A, Pietroluongo LR. A morphovolumetric study of head malposition in proximal humeral fractures based on 3-dimensional computed tomography scans: the control volume theory. *J Shoulder Elbow Surg*. 2018;27(5):940-949.

doi: 10.1016/j.jse.2017.12.004

31. Sukthankar AV, Leonello DT, Hertel RW, Ding GS, Sandow MJ. A comprehensive classification of proximal humeral fractures: HGLS system. *J Shoulder Elbow Surg*. 2013;22(7):e1-6.

doi: 10.1016/j.jse.2012.09.018

32. Campochiaro G, Rebuzzi M, Baudi P, Catani F. Complex proximal humerus fractures: Hertel's criteria reliability to predict head necrosis. *Musculoskelet Surg*. 2015;99(S1):S9-15.

doi: 10.1007/s12306-015-0358-z

33. Shahien A, Likine EF, Soles G, *et al.* Not All Proximal Humerus Fractures Do Well Without Surgery: Anterior Translation Predicts the Need for Surgery. *J Orthop Trauma*. 2023;37(7):366-369.

doi: 10.1097/BOT.0000000000002585

34. Goudie EB, Robinson CM. Prediction of Nonunion After Nonoperative Treatment of a Proximal Humeral Fracture. *J Bone Joint Surg Am*. 2021;103(8):668-680.

doi: 10.2106/JBJS.20.01139

35. Schmidt JC, Gutekunst CJ, Dagassan-Berndt D, Schmidlin PR, Walter C. Comparison of Two-Dimensional and Three-Dimensional Radiographs Using Clinically Relevant Parameters. *Dent J*. 2019;7(2):50.

doi: 10.3390/dj7020050

36. Subramanian AK, Chen Y, Almalki A, Sivamurthy G, Kafle D. Cephalometric analysis in orthodontics using artificial intelligence—A comprehensive review. *BioMed Res Int.* 2022;2022(1):1880113.

doi: 10.1155/2022/1880113

37. Nalçaci R, Oztürk F, Sökücü O. A comparison of two-dimensional radiography and three-dimensional computed tomography in angular cephalometric measurements. *Dentomaxillofac Radiol*. 2010;39(2):100-106.

doi: 10.1259/dmfr/82724776

38. Haude AM, Lehmann T, Hennig CL, Jacobs C. Comparison of conventional two-dimensional and digital three-dimensional imaging in orthodontics: A systematic review and meta-analysis. *J Orofac Orthop*. 2026;87(3):288-305.

doi: 10.1007/s00056-024-00574-7

39. Ali A, Chandna AK, Munjal A. Accuracy and reliability of soft tissue landmarks using three-dimensional imaging in comparison with two-dimensional cephalometrics: a systematic review. *J Indian Orthod Soc.* 2020;54(4):289-296.

doi: 10.1177/0301574220963412

40. Cruz SA, Castillo H, Chintapalli RT, *et al.* The clinical utility of additional axillary and Velpeau radiographs in the evaluation of suspected shoulder trauma. *J Orthop Trauma*. 2020;34(8):e261-e265.

doi: 10.1097/BOT.0000000000001760

41. Leung JH, Griffith JF. Current Protocols for Radiographic and CT Evaluation of the Shoulder. In: *The Shoulder: Imaging Diagnosis With Clinical Implications*. Springer International Publishing; 2019:3-21.

doi: 10.1007/978-3-030-06240-8_1

42. Shaharudin NAS, Dunseath O, Azmi NA, Aun NY, Foley A. Strategies for Assessment and Decision Making in Complex Limb Fracture Management: A Review. *Cureus*. 2025;17(11):e97913.

doi: 10.7759/cureus.97913

43. Varathan K, Bakka HSA, Zacken A, *et al.* Critical Evaluation of Assessment and Decision-Making in Complex Limb Fracture Management: A Review of Current Practice and Emerging Trends. *Cureus*. 2025;17(11):e96229.

doi: 10.7759/cureus.96229

44. Bigham-Sadegh A, Oryan A. Basic concepts regarding fracture healing and the current options and future directions in managing bone fractures. *Int Wound J*. 2015;12(3):238-247.

doi: 10.1111/iwj.12231

45. Sullivan PS, Cosgrove CT. Evidence-based Decision-making in Geriatric Proximal Humerus Fractures. *Orthop Clin North Am*. 2026;57(1):31-39.

doi: 10.1016/j.ocl.2025.08.004

46. Koshy DI, Koshy D, Ishaku Z. Assessment and Decision-Making in Complex Limb Fracture Management. *Cureus*. 2025;17(5):e83877.

doi: 10.7759/cureus.83877

47. Iglesias-Rodríguez S, Domínguez-Prado DM, García-Reza A, *et al.* Epidemiology of proximal humerus fractures. *J Orthop Surg Res*. 2021;16(1):402.

doi: 10.1186/s13018-021-02551-x

48. Schumaier A, Grawe B. Proximal Humerus Fractures: Evaluation and Management in the Elderly Patient. *Geriatr Orthop Surg Rehabil*. 2018;9:2151458517750516.

doi: 10.1177/2151458517750516

49. Vachtsevanos L, Hayden L, Desai AS, Dramis A. Management of proximal humerus fractures in adults. *World J Orthop*. 2014;5(5):685-693.

doi: 10.5312/wjo.v5.i5.685

50. Kleinlugtenbelt YV, Bhandari M. Cochrane in CORR (®): Interventions for Treating Proximal Humeral Fractures in Adults (Review). *Clin Orthop Relat Res*. 2015;473(9):2750-2756.

doi: 10.1007/s11999-015-4430-7

51. Challoumas D, Minhas H, Bagni S, Millar N. Early versus delayed mobilisation for non-surgically treated proximal humerus fractures: a systematic review and meta-analysis of randomised trials. *BMC Musculoskelet Disord*. 2025;26(1):203.

doi: 10.1186/s12891-025-08371-y

52. Lapner P, Sheth U, Nam D, Schemitsch E, Guy P, Richards R. Management of Proximal Humeral Fractures in Adults: A Systematic Review and Meta-Analysis. *J Orthop Trauma*. 2023;37(2):e80-e88.

doi: 10.1097/BOT.0000000000002494

53. Gupta AK, Harris JD, Erickson BJ, *et al.* Surgical management of complex proximal humerus fractures-a systematic review of 92 studies including 4500 patients. *J Orthop Trauma*. 2015;29(1):54-59.

doi: 10.1097/BOT.0000000000000229

54. Zheng Y, Tang N, Zhang WJ, Shi W, Zhao WW, Yang K. Comparative efficacy and safety of medical treatments for proximal humerus fractures: a systematic review and network meta-analysis. *BMC Musculoskelet Disord*. 2024;25(1):17.

doi: 10.1186/s12891-023-07053-x

55. Sears BW, Hatzidakis AM, Johnston PS. Intramedullary Fixation for Proximal Humeral Fractures. *J Am Acad Orthop Surg*. 2020;28(9):e374-e383.

doi: 10.5435/JAAOS-D-18-00360

56. Kuechly HA, Perry AK, Grawe BM. Reverse shoulder replacement for the treatment of proximal humerus fractures: a current literature review. *JSES Int*. 2024;9(5):1855-1859.

doi: 10.1016/j.jseint.2024.06.006

57. Beks RB, Ochen Y, Frima H, *et al.* Operative versus nonoperative treatment of proximal humeral fractures: a systematic review, meta-analysis, and comparison of observational studies and randomized controlled trials. *J Shoulder Elbow Surg*. 2018;27(8):1526-1534.

doi: 10.1016/j.jse.2018.03.009