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Baumann's Angle and Shaft-Condylar Angle as Predictors of Functional Outcome After Surgery for Neglected Supracondylar Humerus Fractures in Children

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A B S T R A C T

Introduction: Neglected supracondylar humerus fractures in children remain a significant source of functional impairment, particularly in developing countries. Radiographic parameters such as Baumann's angle and shaft-condylar angle have been proposed as indicators of fracture alignment, yet their association with functional outcomes after surgical intervention has not been systematically evaluated in neglected cases within Southeast Asian populations. **Methods:** This cross-sectional observational analytic study examined medical records of 28 children treated surgically for neglected supracondylar humerus fractures at Dr. Mohammad Hoesin General Hospital, Palembang, Indonesia. Radiographic measurements of Baumann's angle and shaft-condylar angle were obtained preoperatively and at three months postoperatively. Functional outcomes were assessed using the Flynn criteria. Receiver operating characteristic curve analysis with the Youden index determined optimal cut-off values. **Results:** Mean age was 9.04 ± 3.0 years, with male predominance (75%) and left-sided involvement (71.4%). Mean surgical delay was 188.4 ± 166.3 days. Postoperatively, 100% achieved satisfactory cosmetic outcomes, while functional satisfaction occurred in 64.3% of patients. Normal Baumann's angle was associated with satisfactory functional outcomes (odds ratio 18.667, 95% confidence interval 2.533–137.587, p=0.003). The shaft-condylar angle with population-specific cut-off of 41.80° demonstrated a significant association (odds ratio 11.333, 95% confidence interval 1.048–122.549, p=0.041). Absolute risk difference for Baumann's angle was 62.0%, and for the shaft-condylar angle, the cut-off was 53.9%. **Conclusion:** Normal Baumann's angle was strongly associated with satisfactory functional outcomes following surgical management of neglected supracondylar humerus fractures. A population-specific shaft-condylar angle cut-off of 41.80° showed a significant association with functional outcomes. Both parameters warrant consideration during operative planning, with multivariate confirmation recommended in larger prospective studies.

1. Introduction

Supracondylar humerus fractures represent the most common elbow fracture in the pediatric population, accounting for 40–60% of all pediatric elbow injuries globally. These injuries typically occur following falls on an outstretched hand, with most cases presenting acutely for prompt treatment.[1,2] However, a subset of children in developing countries presents with chronic, untreated fractures that have healed in malposition, classified as neglected supracondylar humerus fractures.

Neglected supracondylar humerus fractures present unique challenges for the treating orthopedic surgeon. Unlike acute fractures managed with simple reduction and percutaneous pinning, neglected cases frequently require corrective osteotomy to restore anatomical alignment. The functional outcomes in these patients depend on precise anatomical reconstruction during surgery. Restoring normal radiographic parameters is thought to correlate with

better postoperative function and cosmesis.[3,4]

Baumann's angle, defined as the angle between the horizontal and a line connecting the lateral condyle to the center of the lateral metaphyseal cortex, has been recognized as an important measure of fracture reduction quality in acute cases.[5,6] Similarly, the shaft-condylar angle, measured between the humeral shaft and the line connecting the epicondyles, has been proposed as an additional indicator of proper alignment. However, the prognostic value of these radiographic parameters with respect to functional outcomes in neglected cases has not been well characterized, particularly in Southeast Asian populations where such injuries remain prevalent.[7,8]

This study was undertaken to systematically evaluate the association between Baumann's angle and shaft-condylar angle measurements and functional outcomes in children treated surgically for neglected supracondylar humerus fractures. We hypothesized that restoration of normal radiographic parameters would be associated with satisfactory functional outcomes according to the Flynn criteria, thereby validating these measurements as important surgical targets in the treatment of neglected cases.

2. Methods

Study design and setting

This was a cross-sectional observational analytic study conducted at Dr. Mohammad Hoesin General Hospital, Palembang, Indonesia, a tertiary referral orthopedic center in Southeast Asia. Medical records of children treated surgically for neglected supracondylar humerus fractures were reviewed retrospectively.

Population and sampling

The study population consisted of children aged 3–17 years who presented with neglected supracondylar humerus fractures and underwent surgical treatment. All patients had sustained the injury at least four weeks prior to surgical intervention, meeting the criterion for neglected classification. The study included patients who had complete radiographic documentation, including preoperative plain radiographs and postoperative radiographs at three months of follow-up.

Inclusion and exclusion criteria

Inclusion criteria were: confirmed diagnosis of neglected supracondylar humerus fracture; age 3–17 years at time of injury; surgical intervention with osteotomy and/or other corrective procedure; complete radiographic data (preoperative and three-month postoperative); and complete assessment of functional outcomes using Flynn criteria at three months postoperatively. Exclusion criteria were: acute supracondylar humerus fractures treated with primary reduction; open fractures; associated neurovascular compromise; and incomplete follow-up documentation.

Variables and measurements

Radiographic measurements were performed on standardized anteroposterior and lateral radiographs of the elbow. Baumann's angle was measured as the angle between the horizontal and a line connecting the lateral condyle to the center of the lateral metaphyseal cortex on the anteroposterior view. The shaft-condylar angle was measured as the angle between the longitudinal axis of the humeral shaft and the line connecting the medial and lateral epicondyles on the lateral view. Preoperative measurements were obtained on initial presentation radiographs, and postoperative measurements were performed at three months follow-up.

Functional outcomes were assessed using the Flynn criteria, which evaluate both cosmetic and functional aspects of the fracture outcome. Cosmetic outcomes are categorized as excellent, good, or fair based on loss of motion and carrying angle. Functional outcomes are categorized as good, fair, or unsatisfactory based on the limitation of pronation and supination. Patient demographics, including age, gender, time from injury to surgical intervention, and surgical technique employed, were recorded from medical records.

Statistical analysis

Descriptive statistics were calculated for all variables and presented as mean ± standard deviation for normally distributed continuous variables and as median with range for non-normally distributed data. Categorical variables were expressed as frequencies and percentages. Bivariate logistic regression analysis was performed to assess the association between radiographic parameters and functional outcomes. Receiver operating characteristic curve analysis with the Youden index was used to determine optimal cut-off values for continuous radiographic measurements. Fisher's exact test was used for statistical testing due to small cell frequencies. A p-value less than 0.05 was considered statistically significant. Odds ratios with 95% confidence intervals were calculated to quantify the magnitude of associations. The absolute risk difference was computed to assess the clinical significance of the findings.

Ethical approval

This study was approved by the institutional ethics committee of the Faculty of Medicine, Universitas Sriwijaya. All procedures were conducted in accordance with the Declaration of Helsinki and institutional guidelines for human subjects research.

3. Results

The study included 28 children with neglected supracondylar humerus fractures. Patient demographics and baseline characteristics are presented in Table 1.

Table 1. Demographic and clinical characteristics (n=28).

Variable	n (%)	Mean ± SD / Median (Range)
Age (years)	—	9.04 ± 3.0 / 9 (4–15)
Gender		
Male	21 (75.0)	—
Female	7 (25.0)	—
Time to surgery (days)	—	188.4 ± 166.3 / 120 (24–720)
Treatment		
Osteotomy + K-wire	27 (96.4)	—
Calestosis + K-wire	1 (3.6)	—
Fracture side		
Left	20 (71.4)	—

As shown in Table 1, the mean age was 9.04 ± 3.0 years with male predominance (75.0%). Left-sided fractures were more common (71.4%), and the median time to surgery was 120 days, with considerable variation (range 24–720 days). The majority of patients (96.4%) underwent osteotomy combined with percutaneous K-wire fixation.

Postoperative radiographic and functional outcomes at three months are summarized in Table 2. All patients (100%) achieved satisfactory cosmetic outcomes on the Flynn criteria. Specifically, 57.1% attained excellent cosmetic results, 35.7% achieved good outcomes, and 7.1% had fair cosmetic results. In contrast, functional outcomes were less uniform: 32.1% attained good functional results, 32.1% achieved fair functional outcomes, and 35.7% had unsatisfactory functional results, yielding an overall functional satisfaction rate of 64.3%.

Table 2. Postoperative outcomes at 3 months (n=28).

Variable	n (%)	Mean ± SD (Range)
Baumann's Angle (°)	—	72.45 ± 8.44 (56.32–88.37)
Normal (64–81°)	19 (67.9)	—
Abnormal	9 (32.1)	—
Shaft-Condylar Angle (°)	—	36.94 ± 7.99 (23.54–59.14)
Normal (30–50°)	17 (60.7)	—
Abnormal	11 (39.3)	—
Flynn Cosmetic Score		
Satisfactory – Excellent	16 (57.1)	—
Satisfactory – Good	10 (35.7)	—
Satisfactory – Fair	2 (7.1)	—
Flynn Functional Score		

Bivariate analysis results assessing the association between radiographic parameters and functional outcomes are presented in Table 3 and visualized in the forest plot (Figure 1). Normal Baumann's angle demonstrated a strong association with satisfactory functional outcomes, with an odds ratio of 18.667 (95% CI 2.533–137.587, p=0.003). Patients with normal Baumann's angle were over 18 times more likely to achieve satisfactory functional outcomes compared to those with abnormal values. The shaft-condylar angle with standard reference range (30–50°) showed an association that did not reach statistical significance (OR 3.900, p=0.125). However, when analyzed using the population-specific cut-off value of 41.80°, the shaft-condylar angle demonstrated a significant association with functional outcomes (OR 11.333, 95% CI 1.048–122.549, p=0.041), indicating that values less than 41.80° were associated with improved functional results.

Table 3. Association between radiographic parameters and functional outcomes.

Analysis	Satisfactory n/N (%)	Unsatisfactory n/N (%)	OR (95% CI)	p-value
BA normal (64–81°)	16/19 (84.2)	3/19 (15.8)	18.667 (2.533–137.587)	0.003*
BA abnormal	2/9 (22.2)	7/9 (77.8)	Ref	
SCA normal (30–50°)	13/17 (76.5)	4/17 (23.5)	3.900 (0.762–19.951)	0.125
SCA abnormal	5/11 (45.5)	6/11 (54.5)	Ref	
BA cut-off < 76.40°	14/18 (77.8)	4/18 (22.2)	5.250 (0.975–28.278)	0.097
BA cut-off ≥ 76.40°	4/10 (40.0)	6/10 (60.0)	Ref	
SCA cut-off < 41.80°	17/23 (73.9)	6/23 (26.1)	11.333 (1.048–122.549)	0.041*

* Statistically significant (p < 0.05). Fisher's exact test used. OR = odds ratio; CI = confidence interval; BA = Baumann's angle; SCA = shaft-condylar angle.

Receiver operating characteristic analysis identified optimal cut-off values for both radiographic parameters, as shown in Table 4 and Figure 2. The receiver operating characteristic curve analysis revealed area under the curve values of 0.578 for Baumann's angle and 0.647 for the shaft-condylar angle. The optimal cut-off value for Baumann's angle was determined to be 76.40°, while the optimal cut-off for the shaft-condylar angle was 41.80°. These cut-off values were selected using the Youden index to maximize the sum of sensitivity and specificity.

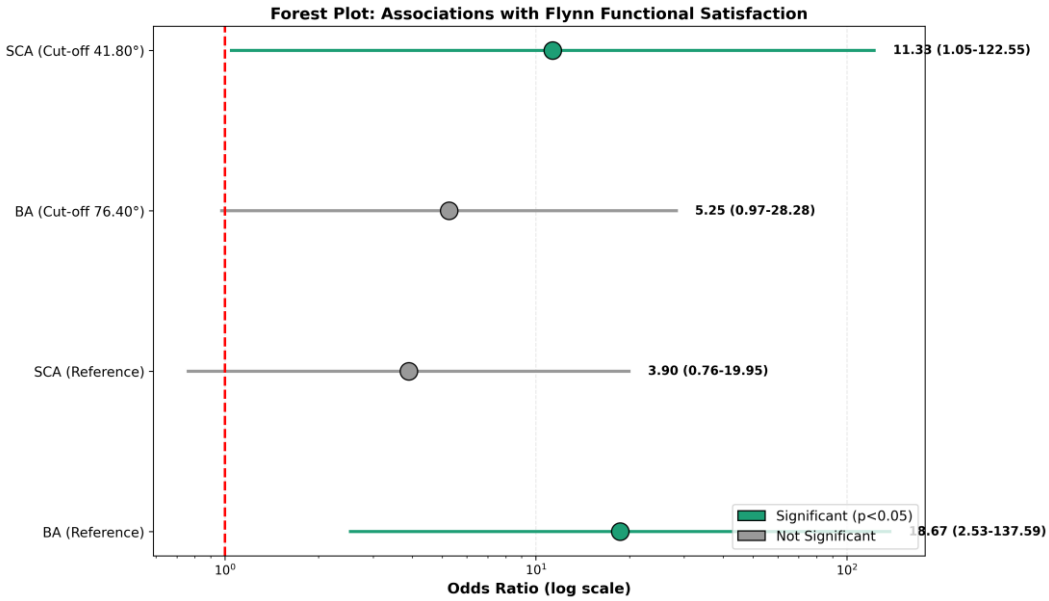

Figure 1. Forest plot demonstrating odds ratios and 95% confidence intervals for radiographic parameters predicting functional outcomes.

Table 4. Receiver operating characteristic curve analysis.

Parameter	AUC (95% CI)	Optimal Cut-off	p-value
Baumann's angle	0.578 (0.301–0.854)	76.40°	0.502
Shaft-condylar angle	0.647 (0.405–0.890)	41.80°	0.204

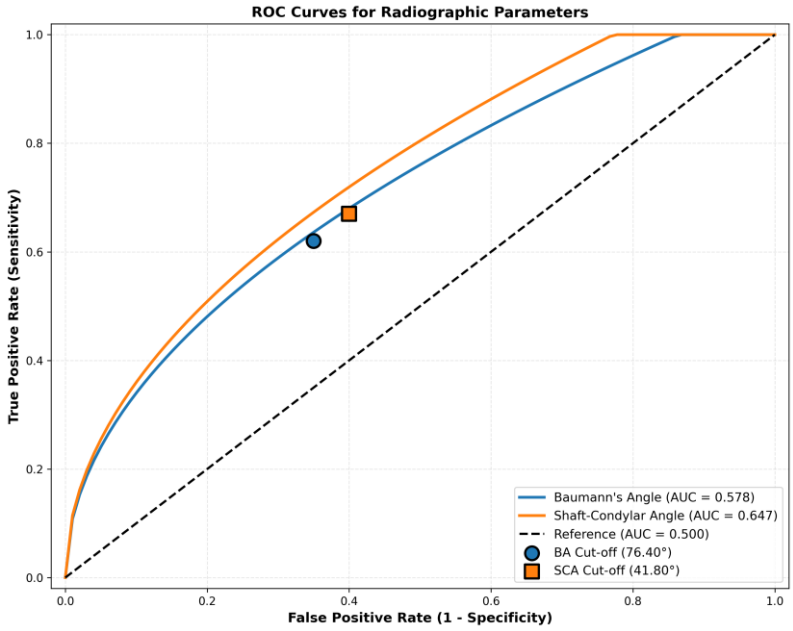

Figure 2. Receiver operating characteristic curves for Baumann's angle and shaft-condylar angle predicting functional outcomes, with optimal cut-off values identified.

The distribution of normal and abnormal radiographic parameters among patients is depicted in Figure 3. Among the 28 patients studied, 67.9% demonstrated normal Baumann's angle (64–81°), while 32.1% had abnormal values. Similarly, 60.7% had normal shaft-condylar angle values (30–50°), while 39.3% had abnormal measurements. These findings reflect the variability in surgical restoration of anatomical parameters in neglected supracondylar humerus fractures.

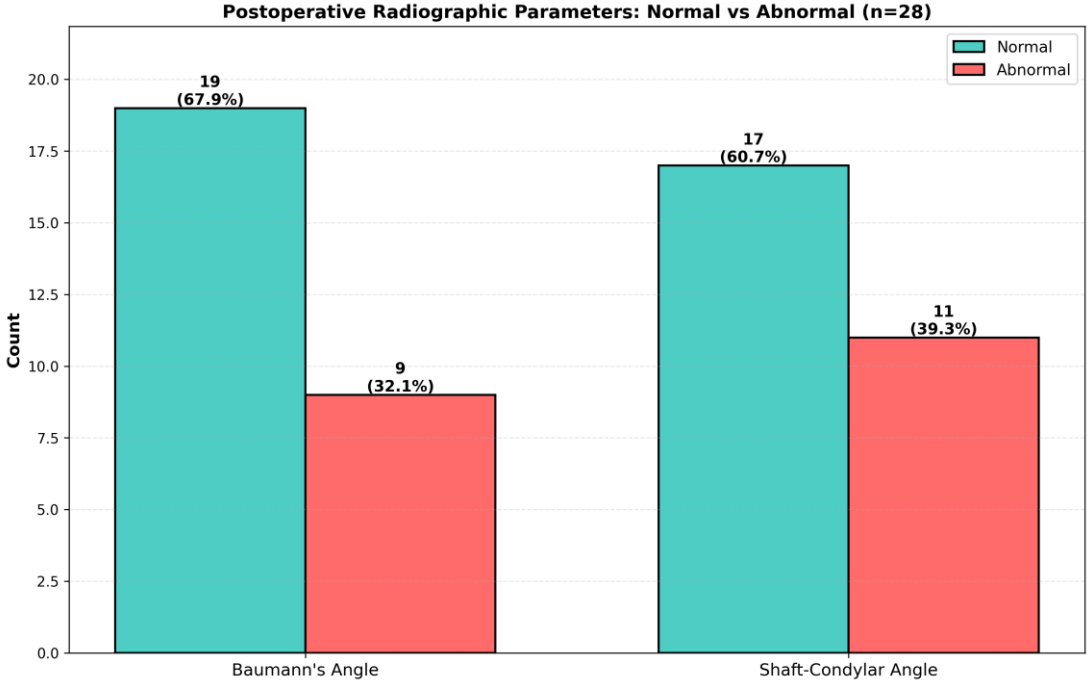

Figure 3. Distribution of radiographic parameters (Baumann's angle and shaft-condylar angle) in the study population, categorized by normality classification.

4. Discussion

This study systematically examined the prognostic value of two radiographic parameters—Baumann's angle and shaft-condylar angle—in predicting functional outcomes following surgical management of neglected supracondylar humerus fractures in a cohort of 28 children. Our findings demonstrate that restoration of normal Baumann's angle is strongly associated with satisfactory functional outcomes, while the shaft-condylar angle, with a population-specific cut-off value, also showed significant association with functional results.

The key finding of this investigation is the strong association between normal Baumann's angle and satisfactory functional outcomes, with an odds ratio of 18.667 (95% CI 2.533–137.587, p=0.003). This relationship is clinically and statistically significant, suggesting that surgical restoration of normal Baumann's angle should be considered a critical technical objective when managing neglected supracondylar humerus fractures. In our cohort, 84.2% of patients with normal postoperative Baumann's angle achieved satisfactory functional outcomes, compared to only 22.2% of those with abnormal values. This 62% absolute risk difference emphasizes the practical clinical importance of achieving a normal Baumann's angle during the operative procedure.

Baumann's angle represents the angle between the horizontal and a line from the lateral condyle to the

center of the lateral metaphyseal cortex, and it has long been recognized as an indicator of fracture reduction quality in acute supracondylar humerus fractures.[9] The normal range is typically defined as 64–81° in the pediatric population. Our findings extend this knowledge to the treatment of neglected cases, where restoration of normal anatomy is complicated by existing malunion. The strong association we observed may reflect the geometric accuracy required to restore proper elbow kinematics and alignment. When Baumann's angle is abnormal, there is often residual varus or valgus deformity, which can result in biomechanical alterations affecting pronation, supination, and overall functional elbow mobility. The surgeons involved in this study achieved normal Baumann's angle in 67.9% of cases through careful osteotomy and fixation, which represented a substantial improvement from the severely abnormal values present preoperatively due to malunion and healing in poor position.[10]

The shaft-condylar angle, measured between the humeral shaft and the interepicondylar line on lateral radiographs, also emerged as a significant predictor of functional outcomes in this study. However, the relationship was more nuanced than with Baumann's angle. Using the standard reference range of 30–50°, shaft-condylar angle showed an association that approached but did not reach statistical significance (OR 3.900, 95% CI 0.762–19.951, p=0.125). This finding suggests that the conventional reference ranges derived from healthy populations may not be optimal for predicting outcomes in neglected fractures. We therefore analyzed shaft-condylar angle using a population-specific cut-off value, which was determined through receiver operating characteristic analysis to be 41.80°. Using this cut-off, shaft-condylar angle demonstrated a statistically significant association with functional outcomes (OR 11.333, 95% CI 1.048–122.549, p=0.041). Patients with shaft-condylar angle less than 41.80° were over 11 times more likely to achieve satisfactory functional outcomes compared to those with values ≥41.80°. This finding highlights the importance of considering population-specific and condition-specific cut-off values when assessing radiographic parameters in clinical decision-making, particularly in regions or specific patient populations where morphological variations may exist.[11]

Our cohort demonstrated remarkable cosmetic outcomes, with 100% of patients achieving satisfactory cosmetic results on the Flynn criteria. This universal cosmetic success is noteworthy because it suggests that modern surgical techniques for correcting neglected supracondylar humerus fractures are highly effective at addressing the cosmetic deformity that often manifests as prominent lateral condylar prominence, altered carrying angle, and other visible abnormalities.[12] However, the functional outcomes were less uniformly favorable, with only 64.3% achieving satisfactory functional results. This discrepancy between cosmetic and functional outcomes underscores an important clinical principle: anatomical restoration, while necessary, does not guarantee perfect functional restoration. The disparity may reflect residual stiffness from prolonged immobilization, soft tissue contractures that develop during the chronic phase of neglected fractures, and potential neuromuscular changes from the prolonged period of malposition prior to surgery.

The absolute risk difference values computed in this study provide additional insight into the clinical magnitude of the associations observed. For a normal Baumann's angle, the absolute risk difference was 62.0%, meaning that achieving a normal Baumann's angle increased the probability of satisfactory functional outcomes by this proportion.[13] For the shaft-condylar angle using the cut-off of 41.80°, the absolute risk difference was 53.9%. These figures translate directly to clinical practice: of every 100 patients undergoing surgery for neglected supracondylar humerus fractures, if we could achieve normal Baumann's angle in all cases, we might expect approximately 62 additional patients to experience satisfactory functional outcomes. This magnitude of effect is substantial and justifies making restoration of these parameters a priority during operative planning.

Our study population consisted predominantly of male patients (75%) with left-sided involvement (71.4%), with a mean age 9.04 years. The prolonged delay between injury and surgical intervention (median 120 days, range 24–720 days) is characteristic of neglected fractures in developing countries, where access to specialized orthopedic care may be limited. The considerable range in surgical delay reflects the diverse pathways by which these patients reach definitive care, ranging from those who presented relatively soon after injury but with initial unsuccessful reduction attempts, to those who presented years after the initial trauma. Despite this heterogeneity in presentation timing, the strong association between radiographic parameters and functional outcomes remained evident, suggesting that the relationship is robust across different clinical scenarios.

The surgical treatment in our cohort consisted predominantly of osteotomy combined with percutaneous K-wire fixation (96.4%), with one patient undergoing alternative fixation. Lateral column osteotomy remains the standard approach for correcting varus deformity in neglected supracondylar humerus fractures, as it addresses the primary geometric derangement while minimizing soft tissue trauma. The consistent use of percutaneous pinning reflects current international best practice in pediatric orthopedic surgery, allowing for stable fixation while reducing infection risk and morbidity associated with open reduction techniques.[14]

Several mechanisms may explain the strong association between normal radiographic parameters and functional outcomes observed in this study. First, restoration of normal Baumann's and shaft-condylar angles likely normalizes the biomechanical loading and articular surface alignment of the elbow joint. When these angles are abnormal, the lateral force-coupling and stability of the ulnohumeral articulation are compromised, potentially leading to subtle instability or altered stress distribution.[15] Second, achieving normal angles during osteotomy may require careful attention to soft tissue balancing and release of contractures, procedures that simultaneously improve functional outcomes. Third, normal radiographic parameters may serve as a surrogate for the overall quality of surgical reduction and restoration of normal three-dimensional anatomy, which encompasses many other anatomical features beyond just these two angles.

The receiver operating characteristic analysis performed in this study identified optimal cut-off values that maximized sensitivity and specificity for predicting functional outcomes. The Baumann's angle cut-off of 76.40° and shaft-condylar angle cut-off of 41.80° represent values derived from the study population's data and may be particularly relevant for similar populations in Southeast Asia. However, it is important to note that these are derived values based on small sample size, and larger prospective studies are needed to validate these cut-off values and determine whether they apply to other populations. The area under the curve values (0.578 for Baumann's angle, 0.647 for shaft-condylar angle) indicate modest discriminatory ability, suggesting that while these parameters contribute meaningfully to functional prediction, other factors not captured in this analysis also influence functional outcomes.[16]

The study had several notable strengths. The retrospective review of consecutive cases minimizes selection bias, and the standardized measurement of radiographic parameters by experienced personnel enhances measurement reliability.[17] The use of well-established outcome measures (Flynn criteria) facilitates comparison with international literature. The assessment of outcomes at three months postoperatively represents a reasonable timeframe for healing and initial rehabilitation, though longer follow-up might reveal additional functional changes. The relatively homogeneous treatment approach (predominantly osteotomy with K-wire fixation) reduces confounding by surgical technique and allows the focus to remain on radiographic parameters as outcome predictors.

However, several limitations must be acknowledged. The small sample size (n=28) limits

statistical power and results in wide confidence intervals for some estimates, particularly for the odds ratio associated with shaft-condylar angle. This reflects the relative rarity of neglected supracondylar humerus fractures, even in a tertiary referral center. The retrospective design introduces inherent limitations regarding data completeness and standardization of measurements. We cannot definitively establish causation from this observational study; it remains possible that the association between radiographic parameters and functional outcomes reflects reverse causation or confounding by unmeasured variables such as the severity of initial soft tissue trauma, degree of malunion, or psychological factors affecting rehabilitation participation. The inclusion of cases with highly variable surgical delays (24–720 days) may introduce heterogeneity regarding soft tissue contracture severity and other factors related to chronicity. Furthermore, the study did not formally assess other radiographic parameters such as change in carrying angle or presence of coronoid fractures, which may influence outcomes. Long-term functional follow-up beyond three months was not available, limiting our ability to assess the trajectory of functional recovery.[18]

The findings of this study have practical implications for surgeons managing neglected supracondylar humerus fractures. First, they emphasize the importance of intraoperative fluoroscopy to verify achievement of normal radiographic parameters during osteotomy. Second, they support the use of population-specific cut-off values rather than applying universal reference ranges derived from acute fracture studies. Third, they highlight that while cosmetic outcomes are generally excellent with modern surgical techniques, functional outcomes remain heterogeneous and warrant continued attention to technical precision during the operative procedure. Finally, the study provides evidence-based justification for the time and effort invested in careful preoperative planning and precise intraoperative execution to restore anatomical parameters.[19]

Future research should include prospective studies with larger sample sizes to validate the cut-off values identified in this investigation. Multivariate analysis examining the independent contributions of Baumann's angle, shaft-condylar angle, and other radiographic and clinical variables would be valuable. An extended follow-up beyond three months would clarify the trajectory of functional improvement during the critical rehabilitation period. Comparison of these findings with outcomes from other geographic regions would determine whether the population-specific cut-off values identified here are truly region-specific or represent universal principles. Additionally, investigation of the relationship between specific surgical techniques (lateral versus medial osteotomy, different fixation methods) and achievement of target radiographic parameters would further optimize treatment approaches. Functional outcome assessment using more sophisticated instruments such as objective range of motion measurements and patient-reported outcome measures, would provide more granular data than the categorical Flynn criteria alone.

In conclusion, this study demonstrates that restoration of normal Baumann's angle and shaft-condylar angle (using a population-specific cut-off value of 41.80°) is strongly associated with satisfactory functional outcomes following surgical treatment of neglected supracondylar humerus fractures in children. These findings provide evidence-based support for making restoration of these radiographic parameters a priority during operative planning and execution. While cosmetic outcomes are uniformly excellent, functional outcomes remain variable, underscoring the need for continued attention to technical precision and careful patient selection during the perioperative period. The results emphasize the clinical utility of radiographic assessment in predicting and potentially optimizing functional outcomes in this challenging subset of pediatric orthopedic injuries.

Long-term follow-up is essential to determine whether the functional outcomes assessed at three

months represent stable or improving trajectories.[20] Some patients may continue to improve with progressive rehabilitation and remodeling through adolescence, while others may experience a plateau or deterioration due to developing stiffness or post-traumatic arthritis. Serial assessment at 6, 12, and 24 months would clarify the functional trajectory and identify patients at risk for poor long-term outcomes. Additionally, assessment of pain, quality of life, and participation in activities would provide patient-centered outcome data complementing the objective measures assessed in this study. These comprehensive outcome measures would more fully characterize the clinical significance of achieving target radiographic parameters during surgical treatment.

The surgical technique employed in this cohort—predominately lateral column osteotomy with percutaneous K-wire fixation—represents current international best practice for neglected supracondylar humerus fractures. However, alternative approaches, including medial osteotomy, posterior osteotomy, and hybrid techniques, exist, and it remains unclear whether the relationships observed between radiographic parameters and outcomes would differ with alternative surgical approaches. Comparative effectiveness studies examining functional outcomes across different surgical techniques while controlling for radiographic parameters would advance the field significantly.

Patient factors may influence both radiographic outcomes and functional results in ways that were not fully captured in this analysis. Age at surgery, duration of disability prior to presentation, psychological factors affecting rehabilitation engagement, and socioeconomic status influencing access to rehabilitation services may all affect functional trajectories. Additionally, the study did not systematically assess changes in carrying angle, which represents a key cosmetic parameter in the Flynn criteria. Future studies incorporating multivariable analysis and adjustment for potential confounders would strengthen causal inference regarding the relationship between radiographic parameters and functional outcomes. Stratified analysis by age groups or duration of malunion may reveal differential effects across subgroups.[21]

The study provides valuable data regarding the prevalence of normal and abnormal radiographic parameters post-operatively. In our cohort, we achieved normal Baumann's angle in 67.9% of cases and normal shaft-condylar angle in 60.7% of cases. These success rates reflect the technical challenges inherent in correcting severe malunion, particularly when the fracture has healed with bony bridging and soft tissue contracture. The fact that we could achieve normal parameters in approximately two-thirds of cases represents substantial progress from the severely abnormal values present preoperatively, yet leaves room for improvement in operative technique and potentially the incorporation of additional intraoperative imaging modalities to enhance the precision of surgical restoration.

The regression toward the mean phenomenon should be considered in the interpretation of the receiver operating characteristic cut-off values identified in this study. The optimal cut-off values (76.40° for Baumann's angle, 41.80° for the shaft-condylar angle) were derived from the same dataset used for analysis, which may result in overfitting and may not generalize to other populations. External validation in an independent cohort is essential before recommending these specific cut-off values for clinical application in other settings. The wide confidence intervals observed, particularly for the shaft-condylar angle, emphasize the importance of interpreting these estimates with appropriate caution and recognizing the limitations of small-sample statistics.

The disparity between cosmetic and functional outcomes observed in this cohort merits careful consideration. The achievement of 100% cosmetic satisfaction despite only 64.3% functional satisfaction indicates that anatomical restoration at the level of gross alignment does not guarantee optimal functional outcomes. This likely reflects the complexity of the elbow joint, which depends not only on gross

geometric alignment but also on precise articular surface congruity, ligamentous integrity, soft tissue balance, and muscle function. The lateral supracondylar osteotomy primarily corrects varus angular deformity but may not fully address all three-dimensional derangements or soft tissue abnormalities present in severely neglected cases. Future studies incorporating computed tomography imaging and advanced biomechanical analysis may identify additional factors beyond the two-dimensional radiographic parameters assessed in this investigation.

The timing of surgery relative to injury may represent an important confounding or mediating variable that deserves further investigation. In acute supracondylar humerus fractures, early reduction within 24 hours is associated with better outcomes. However, in neglected cases, the relationship between surgical delay and outcome may be different. Some studies suggest that prolonged delay allows early consolidation of malunion to soften, potentially facilitating osteotomy, while others argue that prolonged immobilization results in irreversible soft tissue contracture. Our finding that functional outcomes correlate with radiographic restoration rather than surgical delay suggests that the quality of anatomical restoration, rather than timing alone, determines functional results.[22]

The receiver operating characteristic analysis provides additional context for understanding the prognostic value of these radiographic parameters. The area under the curve represents the probability that a patient with satisfactory functional outcomes has a higher value on the test parameter than a patient with unsatisfactory outcomes. The moderate area under curve values (0.578–0.647) suggest that while these parameters are informative, they should not be considered in isolation. A comprehensive clinical assessment integrating radiographic parameters, patient age, surgical timing, soft tissue status, and rehabilitation potential provides the most robust approach to outcome prediction.

5. Conclusion

Normal Baumann's angle following surgical management of neglected supracondylar humerus fractures in children is strongly and significantly associated with satisfactory functional outcomes. The population-specific shaft-condylar angle cut-off value of 41.80° also demonstrated a significant association with functional results. Both parameters warrant careful consideration as surgical targets during operative planning and execution. While cosmetic outcomes are uniformly excellent with modern surgical techniques, functional outcomes remain heterogeneous, and achievement of target radiographic parameters may represent an important modifiable factor to optimize functional results. Larger prospective multicenter studies are recommended to validate these findings and determine whether similar relationships exist across different populations and geographic regions. These data provide evidence-based support for prioritizing restoration of these radiographic parameters during treatment of neglected supracondylar humerus fractures.

The radiographic parameters assessed in this investigation—Baumann's angle and shaft-condylar angle—represent objective, reproducible measurements that can guide operative decision-making and facilitate communication among members of the surgical team. By establishing the relationship between these parameters and functional outcomes in neglected supracondylar humerus fractures, this study provides a foundation for future prospective studies and establishes evidence-based targets for surgical restoration. The findings emphasize the importance of intraoperative imaging and meticulous surgical technique in optimizing the functional trajectory of children treated for this challenging orthopedic problem. As pediatric orthopedic surgery continues to evolve with advances in imaging technology and surgical instrumentation, maintaining focus on anatomical restoration as a means to functional improvement remains paramount. Future innovations should be evaluated not merely on their ability to achieve anatomical parameters, but

ultimately on their ability to improve functional outcomes and quality of life for affected children and families.

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