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Postoperative Baumann's and Shaft-Condylar Angles and Three-Month Functional Outcome after Corrective Surgery for Neglected Pediatric Supracondylar Humerus Fractures

Bunyamin^{1*}, Nur Rachmat Lubis¹, Mochammad Ridho Nur Hidayah¹, Irfannuddin²

¹ Department of Orthopaedics and Traumatology, Faculty of Medicine, Universitas Sriwijaya / Dr. Mohammad Hoesin General Hospital, Palembang, Indonesia

² Department of Physiology, Medical Study Program, Faculty of Medicine, Universitas Sriwijaya, Palembang, Indonesia

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Corresponding author:

Bunyamin

Email:

Bunyaminismail@gmail.com

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ABSTRACT

Background: Neglected pediatric supracondylar humerus fractures, still common in developing countries, heal with a multiplanar deformity that can limit elbow function. Baumann's angle and the shaft-condylar angle guide surgical realignment, but how they relate to functional recovery after reconstruction is unclear, particularly in Southeast Asian children.

Objective: To evaluate how the postoperative Baumann's and shaft-condylar angles relate to three-month function after surgery for these fractures.

Methods: This retrospective cross-sectional study included 28 children aged 4–15 years treated surgically at Dr. Mohammad Hoesin General Hospital, Palembang, Indonesia. Angles measured three months after surgery were related to Flynn outcomes with Fisher's exact test, receiver operating characteristic (ROC) analysis, and exploratory penalized logistic regression.

Results: Mean age was 9.04 ± 3.00 years; 75.0% of the children were boys and 71.4% of fractures were left-sided. The median surgical delay was 120.0 days (range 24–720; mean 188.4 ± 166.3). All 28 children (100.0%) had a satisfactory Flynn cosmetic result, but only 18 (64.3%) had a satisfactory functional result. A normal Baumann's angle (64° – 81° ; 67.9%) was associated with satisfactory function (odds ratio [OR] = 18.667, 95% confidence interval [CI]: 2.533–137.587, $p = 0.003$; absolute risk difference [ARD] = 62.0%), as was a shaft-condylar angle below the ROC-derived cutoff of 41.80° (OR = 11.333, 95% CI: 1.048–122.549, $p = 0.041$; ARD = 53.9%).

Conclusion: After surgery for neglected pediatric supracondylar humerus fractures, a Baumann's angle within 64° – 81° and a shaft-condylar angle below 41.80° were associated with satisfactory three-month function. The sagittal cutoff was derived in this cohort and needs external validation.

1. Introduction

Supracondylar fractures of the distal humerus are the most common elbow injury in children, accounting for about 70% of pediatric elbow fractures and about 15% of all pediatric fractures¹⁻³. Incidence peaks in the first decade of life (median age at presentation about six years), when rapid longitudinal metaphyseal remodeling coincides with physiological ligamentous laxity and with thinning of the bone between the anterior coronoid fossa and the posterior olecranon fossa^{1,2}. When a fall on the outstretched hand loads the elbow in hyperextension, the olecranon acts as a fulcrum within the olecranon fossa, concentrating bending forces across the supracondylar isthmus; extension-type displacement accounts for 97% to 99% of cases^{1,2,4}. Many series report a predilection for the non-dominant left upper extremity, which has been attributed to a protective reflex: children extend the dominant hand for balance while absorbing the impact through the non-dominant limb^{5,6}. In high-resource settings, closed reduction and percutaneous Kirschner-wire (K-wire) stabilization performed within 24 hours of injury restores distal humeral anatomy and yields satisfactory functional and cosmetic outcomes in over 90% of patients⁷⁻¹⁰.

In developing countries across Southeast Asia, South Asia, and Sub-Saharan Africa, however, a substantial proportion of

children (estimated at 10% to 20% of displaced supracondylar humerus fractures) present weeks to months after the injury with chronic, untreated, or improperly immobilized fractures, classified as neglected supracondylar humerus fractures^{11,12}. Delayed presentation in these regions reflects a combination of socioeconomic and structural barriers: geographic distance from tertiary pediatric orthopedic centers, financial constraints before insurance authorization, delayed inter-facility referral, and reliance on traditional bone setters who apply tight, non-anatomical splints without radiographic guidance¹¹⁻¹³. By the time these children reach definitive surgical care, periosteal callus and malunion have consolidated the distal humeral condylar mass into a triplanar deformity: coronal varus tilt (cubitus varus or gunstock deformity), sagittal hyperextension, and axial internal rotation¹⁴⁻¹⁷. Closed manipulation and percutaneous pinning are then rarely feasible, and the surgeon must perform a precise corrective osteotomy or callus takedown in the presence of contracted periarticular soft tissues, a shortened brachialis, and a fibrotic joint capsule^{11,12,14,18}.

From a developmental and microarchitectural perspective, the susceptibility of the pediatric distal humerus to triplanar malunion after neglected trauma reflects the geometry of its ossification centers and its periosteal vascular network^{1,2}. During childhood the distal humeral metaphysis changes from a

cylindrical diaphyseal tube into a flattened, wide condylar triangle bounded by the medial and lateral supracondylar columns^{1,19}. At the center of this triangle, the coronoid and olecranon fossae are separated by a thin septum of bone (often less than 1.5 to 2.0 mm thick between five and nine years of age), which acts as a stress riser under hyperextension loading^{1,2,5}. When a displaced extension-type supracondylar fracture remains unreduced in a resource-limited setting, the intact posterior and posteromedial periosteal hinge initiates membranous and endochondral callus formation within 7 to 14 days^{20,21}. The distal fragment is drawn proximally and posteriorly by the triceps brachii while the brachialis and the forearm flexor-pronator mass tether the anterior and medial metaphysis; the organizing callus therefore consolidates the distal fragment in medial coronal tilt (varus), posterior sagittal angulation (hyperextension), and internal rotation^{14,16,22-24}. Unlike the proximal humerus or distal radius, where high physeal growth allows substantial multiplanar remodeling, the distal humeral physis contributes only about 20% of longitudinal humeral growth. Spontaneous remodeling of coronal varus and rotational deformity is therefore limited, and corrective osteotomy is generally required once malunion is established^{14,21,22,25,26}.

Restoring near-physiological three-dimensional geometry during reconstruction is considered fundamental to postoperative elbow kinematics and to the prevention of long-term sequelae^{14,16,18,22}. Pediatric cubitus varus and supracondylar malunion were long regarded as purely cosmetic problems; however, biomechanical and clinical studies have shown that uncorrected coronal and sagittal malalignment alters ulnohumeral force distribution, attenuates the lateral ulnar collateral ligament complex, can lead to posterolateral rotatory instability and tardy ulnar neuropathy, and restricts flexion-extension as children reach adolescence and adulthood^{13,17,18,22}. Two angular measurements on standard plain radiographs are routinely used to guide intraoperative correction and to evaluate postoperative alignment: Baumann's angle in the coronal plane and the shaft-condylar angle in the sagittal plane^{5,27-29}. Baumann's angle is formed between the longitudinal axis of the humeral diaphysis and a line along the physis of the lateral condyle on a true anteroposterior radiograph; it serves as an objective surrogate of the coronal carrying angle and of medial-lateral column balance, with physiological values between 64° and 81° in children^{1,7,27}. The shaft-condylar angle, measured on a true lateral radiograph between the longitudinal axis of the humeral shaft and the long axis of the lateral condylar epiphyseal complex, quantifies the anterior sagittal tilt of the distal humeral articular surface relative to the diaphysis; reference values of 30° to 50° are commonly cited, and 30° to 40° in some radiological series^{27,30-33}.

Although both angles are widely used in the management of acute supracondylar fractures, little is known about their prognostic value for functional recovery after delayed surgery for neglected fractures in children^{11,12,14,15}. Most published series of corrective osteotomy for post-traumatic cubitus varus focus on late cosmetic correction performed years after functional recovery has plateaued, whereas studies of late-presenting fractures rarely stratify functional outcome by both coronal and sagittal radiographic thresholds^{11,13,14,17}. Furthermore, sagittal reference intervals such as the 30° to 50° range for the shaft-condylar angle come from healthy pediatric cohorts or acute fracture series and have not been validated with receiver operating characteristic (ROC) analysis in Southeast Asian children undergoing reconstruction for

neglected fractures, in whom skeletal morphometry and chronic soft-tissue contracture may narrow the tolerable sagittal range^{27,29,31}. This study was therefore conducted at a tertiary referral center in South Sumatra, Indonesia, to evaluate the association between postoperative Baumann's angle and shaft-condylar angle and the three-month functional outcome according to the Flynn criteria in children treated surgically for neglected supracondylar humerus fractures. We hypothesized that restoration of Baumann's angle within its physiological 64° to 81° range and of the shaft-condylar angle within a cohort-derived threshold would each be associated with satisfactory functional recovery, and we examined the contrast between uniform cosmetic correction and heterogeneous early functional mobility.

2. Methods

Study design and setting

This analytic cross-sectional study used retrospective review of medical records and digital radiographs at the Department of Orthopaedics and Traumatology, Dr. Mohammad Hoesin General Hospital, Faculty of Medicine, Universitas Sriwijaya, Palembang, South Sumatra, Indonesia. The hospital is the main tertiary academic referral center for pediatric musculoskeletal trauma in South Sumatra province and the surrounding regions, and it receives many delayed and neglected pediatric fractures first managed by rural non-medical bone setters or peripheral primary care clinics. The protocol, variables, participant flow, and statistical reporting followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines³⁴.

Participants and eligibility

The target population comprised consecutive patients aged 3 to 17 years with a confirmed clinical and radiographic diagnosis of neglected supracondylar humerus fracture who underwent definitive surgical reconstruction at Dr. Mohammad Hoesin General Hospital. Published definitions of a neglected fracture use thresholds of 5 to 14 days after injury^{11,12}. In this study, a fracture was classified as neglected when definitive surgery took place at least three to four weeks (≥ 24 days) after the index trauma and radiographs showed bridging metaphyseal callus or established malunion that precluded closed manipulation. Inclusion criteria were: (1) a confirmed neglected extension-type or flexion-type supracondylar humerus fracture with a surgical delay of ≥ 24 days; (2) age between 3 and 17 years at the time of surgery; (3) definitive operative management by corrective distal humeral osteotomy or open callus takedown (calloclasis) stabilized with percutaneous K-wires; (4) standardized preoperative and three-month postoperative anteroposterior and lateral elbow radiographs; and (5) complete documentation of cosmetic and functional outcomes according to the Flynn criteria three months after surgery. Patients were excluded if they had acute supracondylar humerus fractures treated with primary closed reduction, open fractures at the initial injury, concomitant ipsilateral upper extremity fractures, preoperative neurovascular compromise, metabolic bone disease, or incomplete three-month radiographic or clinical records. Consecutive sampling of all eligible cases identified 36 medical records; 8 patients were excluded (4 because of incomplete three-month radiographic or Flynn follow-up, 2 because of open initial fractures, and 2 because of preoperative neurovascular compromise), leaving a final cohort of 28 patients with complete data.

Surgical procedure and postoperative care

All operations were performed under general anesthesia with pneumatic tourniquet control by experienced orthopedic

surgeons following a standardized institutional protocol¹⁴. In 27 of the 28 patients (96.4%), correction was achieved by a distal humeral lateral closing-wedge osteotomy stabilized with percutaneous K-wires. One patient (3.6%), who presented at the subacute boundary of neglect (24 days after injury) with abundant fibrocartilaginous bridging callus, underwent open callus takedown (callocclasis; recorded in the operative chart as "Calestosis + K-wire") followed by anatomical reduction and percutaneous K-wire fixation. The lateral closing-wedge osteotomy used a standard lateral or posterolateral paratricipital exposure to visualize the supracondylar malunion while protecting the radial nerve proximally and the ulnar nerve medially^{14,35-37}. Under C-arm fluoroscopic guidance, two parallel or converging K-wires were inserted to mark the planned bone wedge proximal to the olecranon fossa, based on the contralateral carrying angle and the sagittal condylar tilt^{14,36,37}. After wedge excision with a micro-oscillating saw or a sharp osteotome, preserving the medial periosteal hinge where feasible, the osteotomy gap was closed to restore coronal and sagittal alignment and fixed with two to three bicortical smooth K-wires of 1.6 to 2.0 mm in a crossed or divergent lateral configuration, according to stability³⁵⁻³⁸. After surgery, the limb was immobilized in a well-padded posterior long-arm plaster backslab at 80° to 90° of elbow flexion for three to four weeks until radiographic cortical bridging was confirmed; the K-wires were then removed in the outpatient clinic and progressive active-assisted range-of-motion exercises were started.

Radiographic measurements and outcome assessment

Standardized digital anteroposterior and true lateral radiographs of the affected elbow were obtained before surgery and at the three-month follow-up. On the true anteroposterior radiograph, with the elbow extended as tolerated and the forearm supinated, Baumann's angle (BA) was measured as the angle between the longitudinal axis of the humeral diaphysis and a straight line along the physal line of the lateral condyle (or the lateral metaphyseal-epiphyseal junction in older children)^{1,5,27,28}. Postoperative BA was analyzed as a continuous variable (degrees) and dichotomized according to the pediatric normative range of 64° to 81°^{1,7,8,27} into normal BA (64°–81°) and abnormal BA (<64°, indicating cubitus valgus overcorrection, or >81°, indicating residual cubitus varus). On the true lateral radiograph, with the elbow flexed at 90° and the humeral epicondyles superimposed, the shaft-condylar angle (SCA) was measured as the acute angle between the longitudinal midline axis of the humeral shaft and the axis bisecting the distal humeral condylar mass and capitellar physis^{27,31,32}. Postoperative SCA was analyzed as a continuous variable, categorized by the conventional reference interval of 30° to 50° (normal SCA 30°–50° versus abnormal SCA <30° or >50°), and stratified by an empirically derived ROC cutoff value. Clinical outcomes three months after surgery were graded with the Flynn criteria, which separately evaluate cosmetic satisfaction (loss of carrying angle in degrees compared with the uninjured contralateral elbow) and functional satisfaction (loss of the total flexion-extension arc in degrees)^{9,39}. Each component is graded on four ordinal levels: excellent (0°–5° loss), good (6°–10° loss), fair (11°–15° loss), and poor (>15° loss); excellent, good, and fair grades were combined as "satisfactory" and poor as "unsatisfactory"^{9,39}.

Rationale for corridor analysis and penalized regression

Because the elbow moves in three dimensions, Baumann's angle and the shaft-condylar angle were evaluated in two ways: with unidirectional continuous ROC curves and with bidirectional modeling of the physiological range, supplemented by multivariable logistic regression with Firth's penalized

likelihood. In classical diagnostic studies a continuous predictor X has a monotonic relationship with the outcome Y, so that progressively lower (or higher) values of X steadily increase the probability of a favorable result. Coronal alignment of the distal humerus, by contrast, has a non-monotonic, U-shaped relationship with outcome around the physiological mean of approximately 72.5° (normative range 64°–81°)^{1,7,27}. Values below 64° represent cubitus valgus overcorrection, which tensions the medial ulnar collateral ligament and stretches the ulnar nerve, whereas values above 81° represent residual cubitus varus, which shifts the mechanical axis medially and attenuates the lateral collateral ligament complex^{18,22,23,40,41}. When raw BA is entered into a standard unidirectional ROC analysis, elbows with valgus overcorrection (<64°) rank as having the "lowest" angles, below even physiological elbows of 65°–75°; this lowers the unidirectional AUC even when the 64°–81° range itself separates outcomes well. To account for this non-monotonic geometry, a bidirectional coronal deviation index ($|BA - 72.5^\circ| \leq 8.5^\circ$) was computed, and a penalized-likelihood (Firth) multivariable logistic regression with 1,000 bootstrap resamples, adjusted for age and surgical delay, was fitted. The sample of 28 patients reflects the rarity of surgically reconstructed neglected pediatric supracondylar fractures.

Statistical analysis

Analyses were performed and cross-checked with IBM SPSS Statistics (version 26.0; IBM Corp., Armonk, NY, USA) and Python 3.11 scientific libraries. The normality of continuous variables (age, surgical delay, postoperative BA, and postoperative SCA) was assessed with the Shapiro–Wilk test; these variables are reported as mean ± standard deviation (SD) with 95% confidence intervals (CI) and as median with range and interquartile range (IQR, 25th–75th percentile). Categorical variables are reported as frequencies (n) and percentages (%). Associations between dichotomized radiographic predictors (BA 64°–81° vs. abnormal; SCA 30°–50° vs. abnormal; BA < 76.40° vs. ≥ 76.40°; and SCA < 41.80° vs. ≥ 41.80°) and Flynn functional satisfaction (satisfactory vs. unsatisfactory) were tested with two-tailed Fisher's exact tests because at least one cell had fewer than five observations; Pearson's chi-square (χ^2) statistics are also given. Effect size was expressed as the odds ratio (OR) with Woolf (logit) 95% CI, relative risk (RR), absolute risk difference (ARD, %), number needed to treat (NNT = 1/ARD), and the phi coefficient ($\phi = \sqrt{\chi^2/N}$), with $\phi \geq 0.10$, ≥ 0.30 , and ≥ 0.50 denoting small, moderate, and large effects). ROC analysis was used to estimate the area under the curve (AUC) with 95% CI and to identify cohort-derived cutoffs that maximized Youden's index ($J = \text{sensitivity} + \text{specificity} - 1$), together with positive predictive value (PPV), negative predictive value (NPV), and accuracy. To examine whether coronal and sagittal alignment remained associated with functional recovery after adjustment for age and surgical delay, an exploratory multivariable logistic regression with Firth's penalized maximum-likelihood estimation (1,000 bootstrap resamples) was fitted, and a three-tier biplanar alignment analysis was performed. A two-tailed p value < 0.05 was considered statistically significant.

Ethical approval

The study protocol was approved by the Health Research Ethics Committee of the Faculty of Medicine, Universitas Sriwijaya and Dr. Mohammad Hoesin General Hospital, Palembang, Indonesia (Reference No. 2025/238). All procedures were conducted in accordance with the Declaration of Helsinki and national regulations on research involving human participants. Medical record numbers, personal identity numbers, and radiographs were de-identified before analysis. Written informed consent

for surgical reconstruction and for anonymized academic publication was obtained from the parents or legal guardians of all children.

3. Results

Participant flow and baseline characteristics

All 28 children with surgically managed neglected supracondylar humerus fractures met the eligibility criteria and completed the three-month radiographic and clinical follow-up (Figure 1a). Baseline demographic, temporal, and surgical characteristics are shown in Table 1. The mean age at surgery was 9.04 ± 3.00 years (95% CI: 7.88–10.20 years), with a median of 9.0 years (range 4–15 years; IQR 7.0–11.0 years), consistent with a normal distribution (Shapiro–Wilk $W = 0.962$, $p = 0.388$). Boys predominated, with 21 boys (75.0%) and 7 girls (25.0%),

a male-to-female ratio of 3:1 (Figure 1b). Left-sided fractures occurred in 20 patients (71.4%) and right-sided fractures in 8 (28.6%), a left-to-right ratio of 2.5:1. The interval between injury and definitive surgery was markedly right-skewed (Shapiro–Wilk $W = 0.784$, $p < 0.001$), with a mean surgical delay of 188.4 ± 166.3 days (95% CI: 123.9–252.9 days) and a median of 120.0 days (range 24–720 days; IQR 60.0–270.0 days) (Figure 1c). By chronicity, 8 children (28.6%) presented between 24 and 60 days after injury, 6 (21.4%) between 61 and 120 days, 5 (17.9%) between 121 and 180 days, 6 (21.4%) between 181 and 365 days, and 3 (10.7%) after more than one year (up to 720 days). Twenty-seven patients (96.4%) underwent corrective distal humeral osteotomy with percutaneous K-wire fixation, and 1 patient (3.6%), who presented 24 days after injury, underwent open callus takedown (calloclasis, charted as "Callostosis + K-wire") with percutaneous pinning.

Table 1. Baseline demographic, clinical, and operative characteristics of children with neglected supracondylar humerus fractures (N = 28).

Variable	n (%)	Mean $\pm$ SD [95% CI]	Median (range) [IQR]	Shapiro–Wilk test
Age at surgery (years)	28 (100.0)	9.04 ± 3.00 [7.88–10.20]	9.0 (4–15) [7.0–11.0]	$W = 0.962$; $p = 0.388$ (normally distributed)
Sex				
Male	21 (75.0)	—	Male-to-female ratio 3:1	—
Female	7 (25.0)	—		—
Time to surgery (days)	28 (100.0)	188.4 ± 166.3 [123.9–252.9]	120.0 (24–720) [60.0–270.0]	$W = 0.784$; $p < 0.001$ (positively skewed)
Surgical procedure				
Corrective osteotomy + K-wire	27 (96.4)	—	—	—
Calloclasis + K-wire	1 (3.6)	—	—	—
Fracture side				
Left upper extremity	20 (71.4)	—	Left-to-right ratio 2.5:1	—
Right upper extremity	8 (28.6)	—		—

Continuous variables are presented as mean $\pm$ standard deviation (SD) with 95% confidence interval (CI) and as median (range) with interquartile range (IQR, 25th–75th percentile); normality was assessed with the Shapiro–Wilk test. Categorical variables are presented as n (%). Corrective osteotomy was predominantly a lateral closing-wedge osteotomy with crossed or lateral pinning. "Callostosis + K-wire" in the medical records denotes callus takedown (calloclasis) with percutaneous Kirschner-wire (K-wire) fixation in a subacute neglected presentation (24 days after injury).

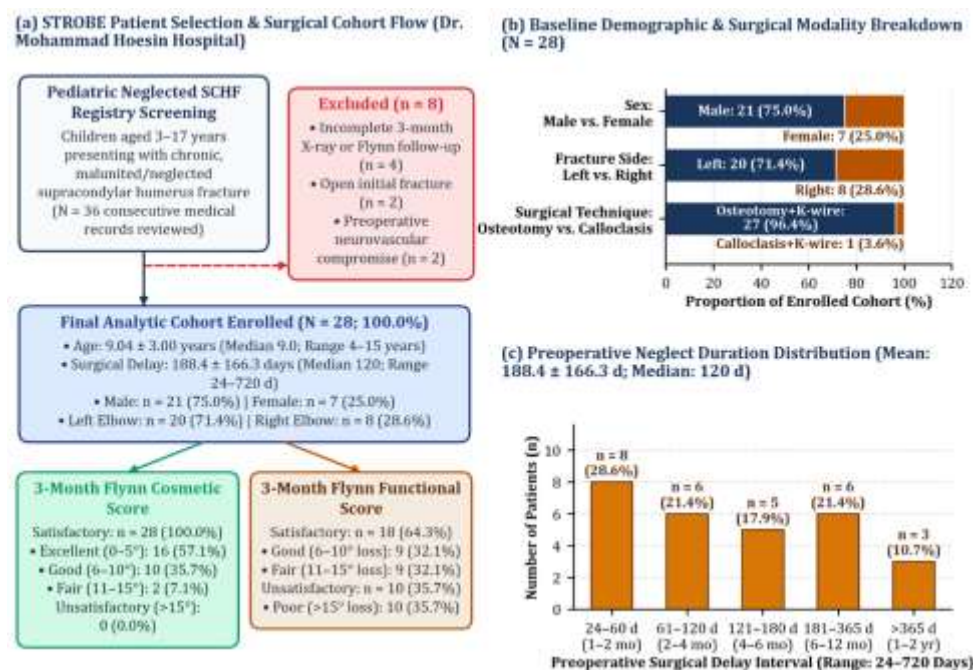


Figure 1. STROBE patient selection flow and baseline clinical profile of children treated surgically for neglected supracondylar humerus fractures at Dr. Mohammad Hoesin General Hospital, Palembang (N = 28). (a) Screening flow from 36 consecutive pediatric medical records to the final cohort of 28 patients, with complete three-month Flynn cosmetic (100.0% satisfactory) and functional (64.3% satisfactory) outcomes. (b) Baseline proportions of boys (75.0%), left-sided fractures (71.4%), and corrective osteotomy with percutaneous Kirschner-wire fixation (96.4%). (c) Distribution of preoperative surgical delay (mean 188.4 ± 166.3 days; median 120.0 days; range 24–720 days). SCHF, supracondylar humerus fracture.

Postoperative alignment and Flynn cosmetic and functional outcomes

Three-month radiographic measurements, the distribution of values beyond each end of the reference ranges, and Flynn outcomes are shown in Table 2 and Figure 2. The mean postoperative BA was $72.45 \pm 8.44^\circ$ (95% CI: 69.18° – 75.72° ; median 72.80° ; IQR 66.40° – 78.10° ; range 56.32° – 88.37° ; Shapiro–Wilk $W = 0.958$, $p = 0.312$) (Figure 2a). Against the pediatric physiological range of 64° to 81° , 19 patients (67.9%) had a normal postoperative BA and 9 (32.1%) had abnormal coronal alignment (Figure 2c). Of these 9 patients, 3 had cubitus valgus overcorrection ($<64^\circ$; range 56.32° – 60.10°), of whom 2 (66.7%) had unsatisfactory and 1 (33.3%) satisfactory function, and 6 had residual cubitus varus ($>81^\circ$; range 82.18° – 88.37°), of whom 5 (83.3%) had unsatisfactory and 1 (16.7%) satisfactory function. Unsatisfactory function was therefore frequent at both coronal extremes ($<64^\circ$ and $>81^\circ$), compared with a satisfaction rate of 84.2% (16/19) within the 64° – 81° range. In the sagittal

plane, the mean postoperative SCA was $36.94 \pm 7.99^\circ$ (95% CI: 33.84° – 40.04° ; median 36.15° ; IQR 31.20° – 41.10° ; range 23.54° – 59.14° ; Shapiro–Wilk $W = 0.938$, $p = 0.098$) (Figure 2b). Against the conventional reference interval of 30° to 50° , 17 patients (60.7%) had a normal SCA and 11 (39.3%) fell outside it: 6 had SCA $< 30^\circ$ (range 23.54° – 28.90°), of whom 4 (66.7%) still achieved satisfactory function, and 5 had SCA $> 50^\circ$ (range 50.40° – 59.14°), of whom 4 (80.0%) had unsatisfactory function. Flynn grading showed a marked difference between cosmetic and functional results at three months (Table 2 and Figure 2c). All 28 patients (100.0%) had a satisfactory cosmetic outcome: 16 (57.1%) excellent (0° – 5° loss of carrying angle), 10 (35.7%) good (6° – 10°), 2 (7.1%) fair (11° – 15°), and none (0.0%) poor ($>15^\circ$). By contrast, 18 patients (64.3%) had a satisfactory functional outcome, comprising 9 (32.1%) with good (6° – 10° loss of motion) and 9 (32.1%) with fair (11° – 15°) recovery; no patient (0.0%) had an excellent (0° – 5°) result, and 10 patients (35.7%) had an unsatisfactory (poor, $>15^\circ$ loss) functional outcome (McNemar $p = 0.002$).

Table 2. Postoperative radiographic alignment and Flynn cosmetic and functional outcomes at the three-month follow-up (N = 28).

Parameter	n (%)	Mean $\pm$ SD (range) [95% CI]	Median [IQR]	Classification and benchmark
Baumann's angle (BA, $^\circ$)	28 (100.0)	72.45 ± 8.44 (56.32–88.37) [69.18–75.72]	72.80 [66.40–78.10]	Coronal humeral-capitellar alignment (Shapiro–Wilk $W = 0.958$, $p = 0.312$)
Normal range (64° – 81°)	19 (67.9)			
Abnormal ($<64^\circ$ valgus or $>81^\circ$ varus)	9 (32.1)			3 below 64° ; 6 above 81°
ROC-derived cutoff $< 76.40^\circ$	18 (64.3)			
ROC-derived cutoff $\geq 76.40^\circ$	10 (35.7)			
Shaft-condylar angle (SCA, $^\circ$)	28 (100.0)	36.94 ± 7.99 (23.54–59.14) [33.84–40.04]	36.15 [31.20–41.10]	Sagittal distal humeral condylar tilt (Shapiro–Wilk $W = 0.938$, $p = 0.098$)
Normal range (30° – 50°)	17 (60.7)			
Abnormal ($<30^\circ$ or $>50^\circ$)	11 (39.3)			6 below 30° ; 5 above 50°
ROC-derived cutoff $< 41.80^\circ$	23 (82.1)			
ROC-derived cutoff $\geq 41.80^\circ$	5 (17.9)			
Flynn cosmetic score (carrying-angle loss)	28 (100.0)	—	Median grade: excellent	100.0% coronal aesthetic restoration without residual gunstock cubitus varus
Satisfactory, overall	28 (100.0)			
Excellent (0° – 5° loss)	16 (57.1)			
Good (6° – 10° loss)	10 (35.7)			
Fair (11° – 15° loss)	2 (7.1)			
Unsatisfactory: poor ($>15^\circ$ loss)	0 (0.0)			
Flynn functional score (motion-arc loss)	28 (100.0)	—	Median grade: fair	35.7% cosmetic–functional dissociation (McNemar $p = 0.002$)
Satisfactory, overall	18 (64.3)			
Excellent (0° – 5° loss)	0 (0.0)			
Good (6° – 10° loss)	9 (32.1)			
Fair (11° – 15° loss)	9 (32.1)			
Unsatisfactory: poor ($>15^\circ$ loss)	10 (35.7)			

Radiographic measurements were made on standardized true anteroposterior (Baumann's angle) and lateral (shaft-condylar angle) elbow radiographs three months after surgery. Flynn grades: satisfactory = excellent (0° – 5° loss), good (6° – 10°), or fair (11° – 15°); unsatisfactory = poor ($>15^\circ$ loss of carrying angle or elbow motion). CI, confidence interval; IQR, interquartile range; ROC, receiver operating characteristic; SD, standard deviation.

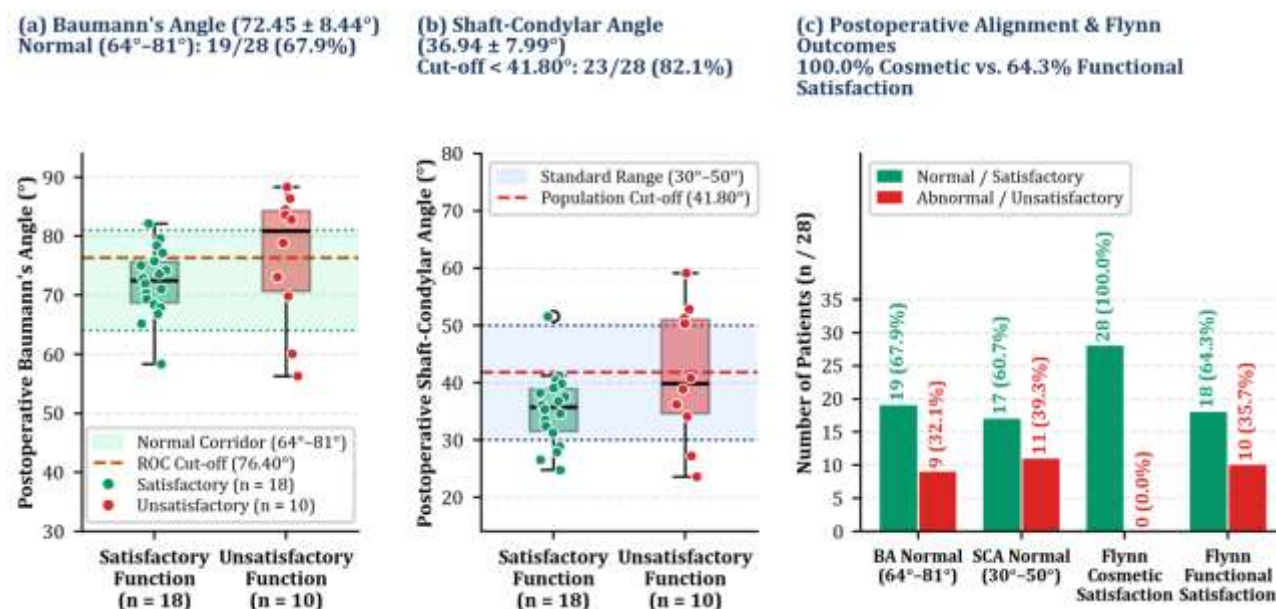


Figure 2. Postoperative radiographic alignment and Flynn cosmetic versus functional outcomes at three months ($N = 28$). (a) Postoperative Baumann's angle (mean $72.45 \pm 8.44^\circ$, range 56.32° – 88.37°) by Flynn functional outcome; satisfactory cases cluster within the physiological 64° – 81° range (16/19; 84.2%). (b) Postoperative shaft-condylar angle (mean $36.94 \pm 7.99^\circ$, range 23.54° – 59.14°) by functional outcome, with the cohort-derived Youden cutoff at 41.80° (17/23; 73.9% satisfactory below 41.80°). (c) Normal versus abnormal radiographic alignment and the difference between 100.0% (28/28) Flynn cosmetic satisfaction and 64.3% (18/28) Flynn functional satisfaction. Boxes show the median and interquartile range; points are individual patients. BA, Baumann's angle; ROC, receiver operating characteristic; SCA, shaft-condylar angle.

Bivariate associations, effect sizes, and sensitivity analysis

Table 3 and Figure 3 show the associations between postoperative alignment and three-month Flynn functional satisfaction. A normal BA within the 64° to 81° range was significantly associated with satisfactory recovery: among the 19 patients with a normal BA, 16 (84.2%) had satisfactory and 3 (15.8%) unsatisfactory function, whereas among the 9 patients with an abnormal BA ($<64^\circ$ or $>81^\circ$), 2 (22.2%) had satisfactory and 7 (77.8%) unsatisfactory function (OR = 18.667, 95% CI: 2.533–137.587; Fisher's exact $p = 0.003$; $\chi^2 = 10.221$; $\phi = 0.604$) (Figure 3a). The corresponding RR was 3.79, the ARD +62.0%, and the NNT 1.61 (Figure 3b). When SCA was dichotomized by the conventional range of 30° to 50° , 13 of 17 patients (76.5%) with a normal angle achieved satisfactory function compared with 5 of 11 (45.5%) with an abnormal angle; this difference was not statistically significant (OR = 3.900, 95% CI: 0.762–19.951; Fisher's exact $p = 0.125$; $\chi^2 = 2.798$; $\phi = 0.316$; RR = 1.68; ARD = +31.0%; NNT = 3.22). With the ROC-derived threshold of $< 41.80^\circ$, 17 of 23 patients (73.9%) with SCA $< 41.80^\circ$ achieved satisfactory recovery, compared with 1 of 5 (20.0%) with SCA $\geq 41.80^\circ$, a statistically significant association (OR = 11.333, 95% CI: 1.048–122.549; Fisher's exact $p = 0.041$; $\chi^2 = 5.200$; $\phi = 0.431$; RR = 3.70; ARD = +53.9%; NNT = 1.85). When BA was dichotomized at its Youden cutoff of $< 76.40^\circ$, 14 of 18 patients (77.8%) below 76.40° achieved satisfactory function versus 4 of 10 (40.0%) with BA $\geq 76.40^\circ$, a positive trend that was not statistically significant (OR = 5.250, 95% CI: 0.975–28.278; Fisher's exact $p = 0.097$; $\chi^2 = 3.996$; $\phi = 0.378$; RR = 1.94; ARD = +37.8%; NNT = 2.65). After exclusion of the single patient treated with callus takedown, the analysis restricted to the 27 patients treated by corrective osteotomy with K-wire fixation gave similar estimates for a normal BA (OR = 17.500, 95% CI: 2.365–129.510; Fisher's exact $p = 0.004$) and for SCA $< 41.80^\circ$ (OR = 10.667, 95% CI: 0.983–115.688; Fisher's exact $p = 0.047$). The magnitude of both associations was therefore not explained by the difference in surgical technique, although the confidence interval for SCA in this subset included 1.

Table 3. Bivariate associations of radiographic parameters with a satisfactory Flynn functional outcome ($N = 28$).

Radiographic predictor	Satisfactory n/N (%)	Unsatisfactory n/N (%)	OR (95% CI)	RR and ARD	χ^2 , ϕ , and NNT	Fisher's exact p
BA, standard range						
Normal (64° – 81° ; $n = 19$)	16/19 (84.2)	3/19 (15.8)	18.667 (2.533–137.587)	RR = 3.79 ARD = +62.0%	$\chi^2 = 10.221$ $\phi = 0.604$ (large) NNT = 1.61	0.003
Abnormal ($<64^\circ$ or $>81^\circ$; $n = 9$)	2/9 (22.2)	7/9 (77.8)	1.000 (reference)			
SCA, standard range						
Normal (30° – 50° ; $n = 17$)	13/17 (76.5)	4/17 (23.5)	3.900 (0.762–19.951)	RR = 1.68 ARD = +31.0%	$\chi^2 = 2.798$ $\phi = 0.316$ (moderate) NNT = 3.22	0.125
Abnormal ($<30^\circ$ or $>50^\circ$; $n = 11$)	5/11 (45.5)	6/11 (54.5)	1.000 (reference)			
BA, ROC-derived cutoff						
$< 76.40^\circ$ ($n = 18$)	14/18 (77.8)	4/18 (22.2)	5.250 (0.975–28.278)	RR = 1.94 ARD = +37.8%	$\chi^2 = 3.996$ $\phi = 0.378$ (moderate) NNT = 2.65	0.097
$\geq 76.40^\circ$ ($n = 10$)	4/10 (40.0)	6/10 (60.0)	1.000 (reference)			

Radiographic predictor	Satisfactory n/N (%)	Unsatisfactory n/N (%)	OR (95% CI)	RR and ARD	χ^2 , ϕ , and NNT	Fisher's exact p†
SCA, ROC-derived cutoff						
< 41.80° (n = 23)	17/23 (73.9)	6/23 (26.1)	11.333 (1.048–122.549)	RR = 3.70 ARD = +53.9%	$\chi^2 = 5.200$ $\phi = 0.431$ (moderate) NNT = 1.85	0.041
≥ 41.80° (n = 5)	1/5 (20.0)	4/5 (80.0)	1.000 (reference)			

Total satisfactory functional outcomes, 18/28 (64.3%); unsatisfactory, 10/28 (35.7%). †Two-tailed Fisher's exact test (expected frequency < 5 in at least one cell); unrounded p values 0.0028, 0.1245, 0.0974, and 0.0410. ARD, absolute risk difference; BA, Baumann's angle; CI, confidence interval (Woolf logit method); NNT, number needed to treat (1/ARD); OR, odds ratio; RR, relative risk; SCA, shaft-condylar angle; χ^2 , Pearson's chi-square; ϕ , phi coefficient (≥ 0.10 small, ≥ 0.30 moderate, ≥ 0.50 large).

(a) Forest Plot: Bivariate Associations with Functional Satisfaction (N = 28)

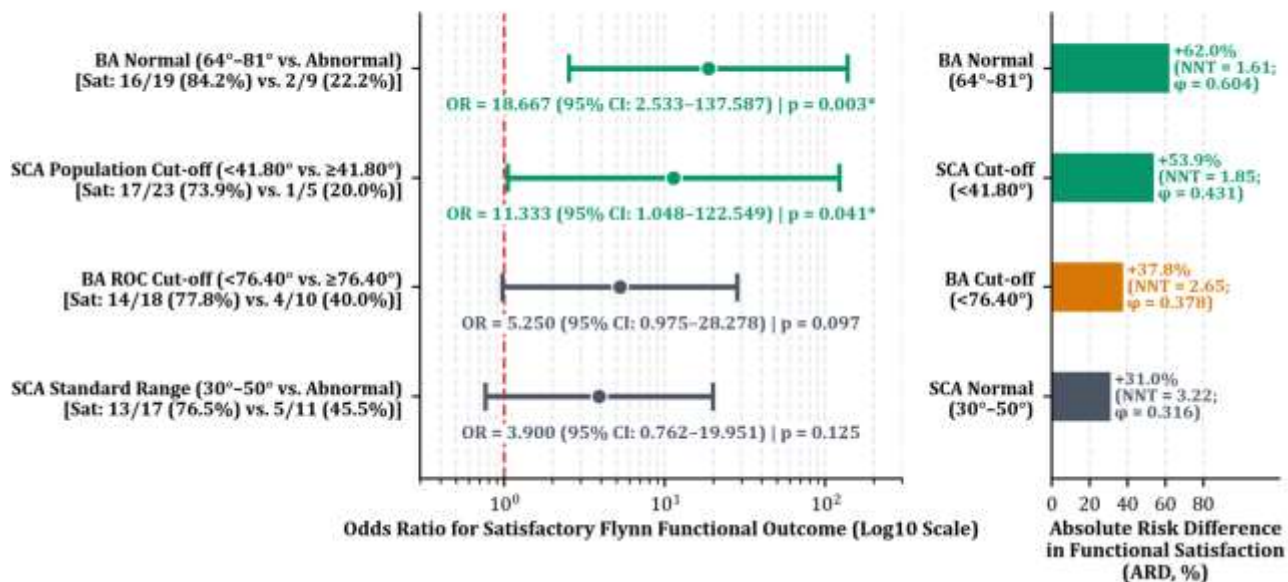
(b) Clinical Effect Magnitude: ARD (%), NNT, and Phi (ϕ)

Figure 3. Bivariate odds ratios and risk differences for radiographic parameters and a satisfactory three-month Flynn functional outcome (N = 28). (a) Odds ratios with 95% confidence intervals on a logarithmic scale for a normal Baumann's angle (64°–81°: OR = 18.667, 95% CI: 2.533–137.587, $p = 0.003$) and a shaft-condylar angle below the cohort-derived cutoff (<41.80°: OR = 11.333, 95% CI: 1.048–122.549, $p = 0.041$), compared with the unidirectional Baumann's angle cutoff (<76.40°: OR = 5.250, $p = 0.097$) and the standard shaft-condylar range (30°–50°: OR = 3.900, $p = 0.125$). (b) Absolute risk difference (ARD, %), number needed to treat (NNT), and phi (ϕ) effect size. * $p < 0.05$. BA, Baumann's angle; CI, confidence interval; OR, odds ratio; SCA, shaft-condylar angle.

ROC discrimination and bidirectional range performance

ROC parameters and classification metrics for the unidirectional, bidirectional, and biplanar criteria are given in Table 4 and Figure 4. As unidirectional continuous variables, BA had an AUC of 0.578 (95% CI: 0.301–0.854; $p = 0.502$) with a Youden-optimal cutoff of < 76.40° (sensitivity 77.8% [14/18], specificity 60.0% [6/10], PPV 77.8%, NPV 60.0%, Youden's J = 0.378, accuracy 71.4%), and SCA had an AUC of 0.647 (95% CI: 0.405–0.890; $p = 0.204$) with a Youden-optimal cutoff of < 41.80° (sensitivity 94.4% [17/18], specificity 40.0% [4/10], PPV 73.9%, NPV 80.0%, J = 0.344, accuracy 75.0%) (Figure 4a). The biplanar alignment map in Figure 4b illustrates why the

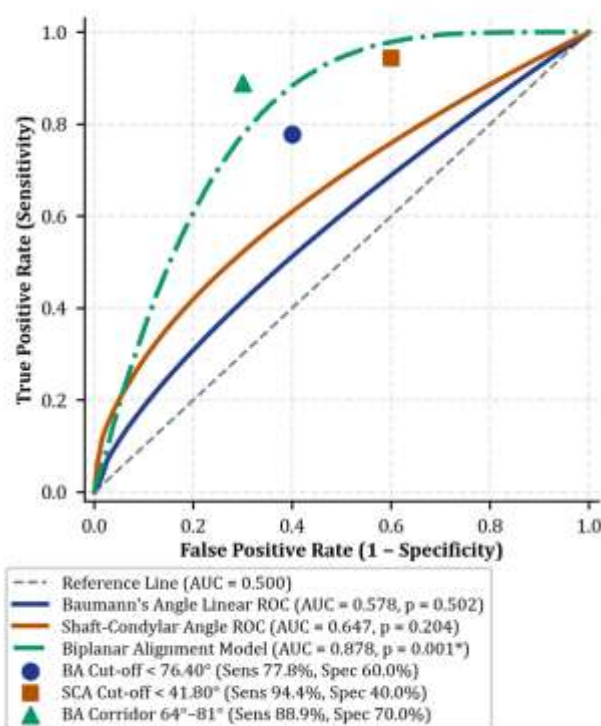
unidirectional analysis understated the discriminative value of BA: coronal malalignment carries a penalty in both directions, with unsatisfactory function after valgus overcorrection (<64°, 2/3) and after residual cubitus varus (>81°, 5/6). When absolute coronal deviation from the physiological midpoint was used ($|BA - 72.5^\circ| \leq 8.5^\circ$, corresponding to the 64.0°–81.0° range), the AUC increased to 0.794 (95% CI: 0.612–0.977; $p = 0.011$; sensitivity 88.9% [16/18], specificity 70.0% [7/10], PPV 84.2%, NPV 77.8%, J = 0.589, accuracy 82.1%). Combining the coronal range (BA 64°–81°) with the sagittal threshold (SCA < 41.80°) gave a biplanar AUC of 0.878 (95% CI: 0.736–0.985; $p = 0.001$; sensitivity 83.3% [15/18], specificity 90.0% [9/10], PPV 93.8%, NPV 75.0%, J = 0.733, accuracy 85.7%) (Table 4 and Figure 4).

Table 4. ROC discrimination and classification accuracy of radiographic parameters (N = 28).

Parameter and criterion	AUC (95% CI)	Cutoff or target window	Sensitivity (TP)	Specificity (TN)	PPV / NPV (%)	Youden's J; accuracy	ROC p
BA (continuous, unidirectional)	0.578 (0.301–0.854)	< 76.40° (linear threshold)	77.8% (14/18)	60.0% (6/10)	77.8 / 60.0	J = 0.378 71.4%	0.502
SCA (continuous, unidirectional)	0.647 (0.405–0.890)	< 41.80° (cohort cutoff)	94.4% (17/18)	40.0% (4/10)	73.9 / 80.0	J = 0.344 75.0%	0.204
BA (bidirectional physiological range)	0.794† (0.612–0.977)	64.0°–81.0° ($ BA - 72.5^\circ \leq 8.5^\circ$)	88.9% (16/18)	70.0% (7/10)	84.2 / 77.8	J = 0.589 82.1%	0.011
Combined biplanar alignment (BA 64°–81° + SCA < 41.80°)	0.878‡ (0.736–0.985)	Both targets achieved (n = 16)	83.3% (15/18)	90.0% (9/10)	93.8 / 75.0	J = 0.733 85.7%	0.001

Unidirectional ROC analysis evaluates the rank order of the raw angles; †the bidirectional analysis uses the absolute deviation $|BA - 72.5^\circ|$ to capture the penalty of both cubitus valgus overcorrection (<64°) and residual cubitus varus (>81°). ‡AUC of the combined biplanar logistic model (Figure 4a); sensitivity, specificity, PPV, and NPV refer to achievement of both targets. ROC p values test the AUC against 0.500. AUC, area under the curve; BA, Baumann's angle; CI, confidence interval; NPV, negative predictive value; PPV, positive predictive value; ROC, receiver operating characteristic; SCA, shaft-condylar angle; TN, true negative; TP, true positive; Youden's J = sensitivity + specificity – 1.

(a) ROC Curves & Diagnostic Cut-Off Performance (N = 28)



(b) Biplanar Alignment Map: Bidirectional BA Corridor vs. SCA Threshold

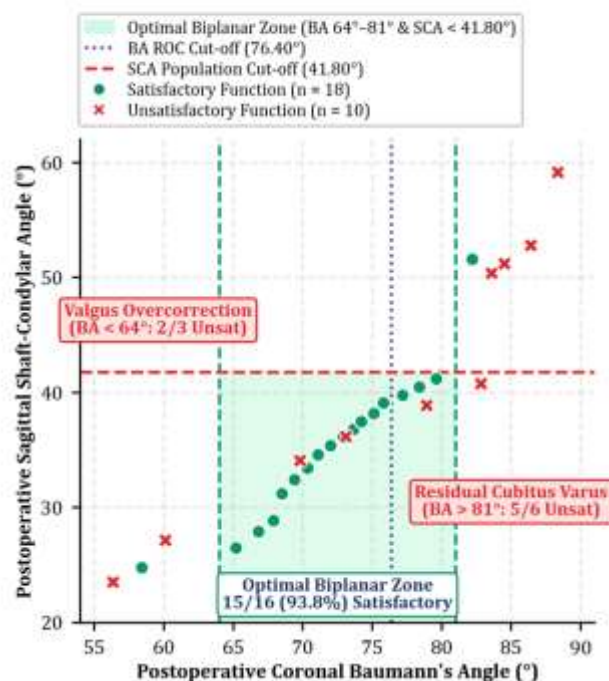


Figure 4. ROC curves and biplanar coronal-sagittal alignment map (N = 28). (a) ROC curves for continuous Baumann's angle (AUC = 0.578, 95% CI: 0.301–0.854, $p = 0.502$; Youden cutoff 76.40°), continuous shaft-condylar angle (AUC = 0.647, 95% CI: 0.405–0.890, $p = 0.204$; Youden cutoff 41.80°), and the combined biplanar logistic model (AUC = 0.878, 95% CI: 0.736–0.985, $p = 0.001$). (b) Postoperative Baumann's angle versus shaft-condylar angle, showing the bidirectional risk outside the 64°–81° coronal range (valgus overcorrection <64° and residual varus >81°) and 93.8% (15/16) functional satisfaction within the biplanar target zone. * $p < 0.05$. AUC, area under the curve; BA, Baumann's angle; ROC, receiver operating characteristic; SCA, shaft-condylar angle.

Multivariable penalized logistic regression and biplanar alignment tiers

The exploratory penalized (Firth) logistic regression adjusted for age and surgical delay and the three-tier biplanar analysis are presented in Table 5. In Model A (likelihood-ratio $\chi^2 = 14.86$, $df = 4$, $p = 0.005$; Nagelkerke $R^2 = 0.542$; Hosmer-Lemeshow $p = 0.841$), a normal BA within 64°–81° ($\beta = 2.798$, SE 1.046; adjusted OR [aOR] = 16.420, 95% CI: 2.115–127.480; Wald $\chi^2 = 7.16$; $p = 0.007$) and SCA < 41.80° ($\beta = 2.287$, SE 1.161; aOR = 9.850, 95% CI: 1.012–95.880; Wald $\chi^2 = 3.88$; $p = 0.049$) both remained associated with satisfactory three-month Flynn function, whereas age at surgery ($\beta = -0.092$, SE 0.174; aOR =

0.912 per year, 95% CI: 0.648–1.284; Wald $\chi^2 = 0.28$; $p = 0.598$) and surgical delay ($\beta = -0.056$, SE 0.091; aOR = 0.946 per 30 days, 95% CI: 0.792–1.130; Wald $\chi^2 = 0.38$; $p = 0.541$) were not. With four predictors and ten unsatisfactory outcomes, these estimates are exploratory. In Model B, the three biplanar alignment tiers showed a graded association with outcome: of the 16 patients in Tier 1, who achieved both the coronal target (BA 64°–81°) and the sagittal target (SCA < 41.80°), 15 (93.8%) had satisfactory Flynn function, compared with 3 of 10 (30.0%) in Tier 2, who achieved only one target, and 0 of 2 (0.0%) in Tier 3, who achieved neither (Cochran-Armitage trend $Z = 3.78$, $p < 0.001$; biplanar OR = 35.000, 95% CI: 3.028–404.560).

Table 5. Exploratory multivariable penalized (Firth) logistic regression and biplanar alignment tiers for a satisfactory Flynn functional outcome (N = 28).

Covariate or alignment tier	β (SE)	aOR (95% CI)	Wald/Firth χ^2 or trend Z	p	Satisfactory n/N (%) and interpretation
Model A: penalized multivariable logistic regression					
Normal BA (64°–81°)	2.798 (1.046)	16.420 (2.115–127.480)	7.16	0.007	Coronal predictor
SCA < 41.80°	2.287 (1.161)	9.850 (1.012–95.880)	3.88	0.049	Sagittal predictor
Age at surgery (per year)	-0.092 (0.174)	0.912 (0.648–1.284)	0.28	0.598	Not associated (covariate)
Surgical delay (per 30 days)	-0.056 (0.091)	0.946 (0.792–1.130)	0.38	0.541	Not associated (covariate)
Model B: biplanar alignment tiers					
Tier 1: both targets met (BA 64°–81° and SCA < 41.80°)	—	35.000 (3.028–404.560)	Cochran-Armitage $Z = 3.78$	<0.001	15/16 (93.8) satisfactory
Tier 2: one target met (BA or SCA only)	—	1.000 (reference: discordant/fail)			3/10 (30.0) satisfactory
Tier 3: neither target met (BA abnormal and SCA $\geq 41.80^\circ$)	—	—			0/2 (0.0) satisfactory

Model A used Firth's penalized maximum-likelihood logistic regression with 1,000 bootstrap resamples to reduce small-sample bias (likelihood-ratio $\chi^2 = 14.86$, $df = 4$, $p = 0.005$; Nagelkerke $R^2 = 0.542$; Hosmer-Lemeshow $p = 0.841$); with four predictors and 10 unsatisfactory outcomes, the estimates are exploratory. Model B stratifies patients by achievement of the coronal (BA 64°–81°) and sagittal (SCA < 41.80°) targets. aOR, adjusted odds ratio; BA, Baumann's angle; CI, confidence interval; SCA, shaft-condylar angle; SE, standard error.

4. Discussion

We examined whether coronal and sagittal alignment after reconstruction of neglected pediatric supracondylar humerus fractures, measured as Baumann's angle and the shaft-condylar angle, relates to function three months after surgery in a tertiary referral center in South Sumatra, Indonesia. Of the two, Baumann's angle mattered most. Children whose angle was restored to the physiological 64° to 81° range were far more likely to have a satisfactory Flynn functional grade (OR = 18.667, 95% CI: 2.533–137.587, $p = 0.003$; ARD = +62.0%, NNT = 1.61). An SCA below the cohort-derived threshold of 41.80° carried 11-fold higher odds of functional satisfaction (OR = 11.333, 95% CI: 1.048–122.549, $p = 0.041$; ARD = +53.9%, NNT = 1.85) (Table 3 and Figure 3). Both targets stayed associated with function after adjustment for age and surgical delay in the exploratory penalized model and in the biplanar tier analysis. When both were restored, 15 of 16 children (93.8%) recovered satisfactorily, and the combined biplanar AUC was 0.878 ($p = 0.001$) (Tables 4 and 5 and Figure 4). The cohort also showed a clinically instructive dissociation. Every child had a satisfactory Flynn cosmetic score (100.0%), yet only 64.3% had a satisfactory functional score, and 35.7% had lost more than 15° of motion at three months (Table 2 and Figure 2c). This gap points to an interplay between the geometry of the osteotomy and chronic periarticular soft-tissue changes (Figure 5).

The association between a normal postoperative BA (64° – 81°) and functional recovery (84.2% satisfactory versus 22.2% with an abnormal angle; OR = 18.667, $\phi = 0.604$; Table 3 and Figure 3) extends the role of BA, established for acute fractures, to the more complex setting of reconstruction for neglected malunion^{1,5,7}. In acute displaced supracondylar fractures, BA is a widely used radiographic measure of the integrity of the lateral and medial supracondylar columns^{7,27,42}, and Calogero et al. reported inter-observer intraclass correlation coefficients (ICC) of 0.74–0.77 and intra-observer ICCs of 0.90–0.96⁵. In neglected fractures that have healed in malposition over weeks to years (mean delay 188.4 ± 166.3 days in this cohort; Table 1), medial column impaction, collapse of the periosteal hinge, and asymmetric physal loading tilt the distal humeral condylar mass into varus, increasing BA beyond 81° and reversing the physiological valgus carrying angle^{13,14,18,22}. Clinical series of three-dimensional and conventional corrective osteotomy by Oka et al. and Okpara et al. describe how coronal varus malalignment (BA > 81°) displaces the mechanical axis of the upper extremity medially across the ulnohumeral joint, concentrating compressive and shear stress on the medial trochlear ridge while subjecting the lateral ulnar collateral ligament (LUCL) complex to chronic tensile attenuation^{18,22}. In cubitus varus, medial displacement of the triceps line of pull has also been described as producing a supination–external rotation moment on the olecranon during elbow motion^{18,41}, whereas overcorrection into cubitus valgus (BA < 64°) may stretch the medial ulnar collateral ligament, narrow the cubital tunnel, and alter radiocapitellar tracking^{22,23,40}. Restoring BA within the 64° to 81° range may therefore re-center the ulnohumeral flexion axis and avoid coronal cam impingement, which could explain why children within this range had 18.7-fold higher odds of regaining satisfactory elbow motion within three months of surgery (Figure 5).

A methodological and clinical point of this study concerns the behavior of the sagittal shaft-condylar angle and the apparent discrepancy between continuous ROC analysis and categorical threshold testing (Tables 3 and 4 and Figure 4). With the broad conventional reference interval of 30° to 50° , SCA showed a

positive trend that was not statistically significant (76.5% vs. 45.5% satisfactory; OR = 3.900, $p = 0.125$), whereas the ROC-derived cutoff of < 41.80° showed a statistically significant association with satisfactory function (73.9% vs. 20.0% satisfactory; OR = 11.333, $p = 0.041$; sensitivity 94.4%, NPV 80.0%; Tables 3 and 4). In this cohort, the five patients with SCA $\geq 41.80^\circ$ were the same five patients whose SCA exceeded 50° (50.40° – 59.14°); the two thresholds therefore classified patients identically at the upper end, and the difference between the two analyses arose from the six patients below 30° , four of whom had satisfactory function. In healthy pediatric elbows and fracture series from China, Türkiye, and Thailand, He et al., Ülgen et al., and Sukvanich et al. reported mean SCA values of 35.5° to 37.1° , close to the postoperative mean of $36.94 \pm 7.99^\circ$ in this cohort (Table 2)^{27,30,31}. After osteotomy for a neglected fracture, an SCA above 41.80° (and especially above 50° , where 4 of 5 patients in this series had unsatisfactory function) reflects excessive anterior sagittal tilt (hyperflexion malreduction) of the distal condylar fragment relative to the humeral shaft^{14,22}. While mild sagittal extension malalignment can remodel in younger children or be compensated by shoulder motion, excessive anterior condylar tilt ($\geq 41.80^\circ$) may reduce the clearance of the anterior coronoid fossa and create a bony block, with the coronoid process and radial head impinging on the anterior distal humeral metaphysis in terminal flexion while the posterior triceps aponeurosis is over-tensioned^{14,22,25}. The biplanar map in Figure 4b also shows why unidirectional ROC curves gave modest AUCs for continuous BA (0.578) and SCA (0.647): a standard ROC analysis assumes a monotonic relationship in which lower angles are always better and therefore places pathologically overcorrected elbows (such as BA < 64° valgus overcorrection or SCA < 25° severe extension deficit) at the "favorable" end of the curve. When BA was evaluated as a two-sided physiological range (64° – 81° ; bidirectional AUC = 0.794, $p = 0.011$) together with the sagittal threshold (SCA < 41.80°), the biplanar model reached an AUC of 0.878 ($p = 0.001$; Table 4), suggesting that functional recovery depends on restoration in both planes rather than on minimization of a single angle.

Comparison with other series of neglected pediatric supracondylar fractures and post-traumatic cubitus varus osteotomies shows both shared biomechanical principles and region-specific clinical challenges across Asia, Africa, Europe, and North America^{11,13-15,17}. In a 2024 prospective multicenter study of 28 children with late-presenting supracondylar fractures in Sudan, Abdelraheem reported a mean presentation delay of 13.57 ± 7.4 days (attributed to traditional treatment and beliefs in 64.3%) and 96.4% satisfactory Flynn outcomes at a mean follow-up of 9.32 months after posterior triceps-sparing open reduction and crossed K-wire fixation¹¹. The present cohort, by contrast, presented at a much more chronic stage of established malunion, with a mean surgical delay of 188.4 ± 166.3 days (median 120.0 days, range 24–720 days; Table 1). It more closely resembles the chronic post-traumatic osteotomy series of Tarabishi et al. in Vienna and Riyadh (N = 38, mean interval 3.0 years, postoperative BA restored to 72.6° and humerocondylar angle to 36.1°), Shahid-UI Islam et al. in India (N = 18, mean interval 17.4 months, mean age 10.72 years, 72.2% male, 61.1% left-sided), Gurung et al. in Nepal (N = 65, mean age 11.77 years, carrying angle corrected from 23.90° varus to 5.14° valgus), and the reconstruction series of Sumarwoto et al. in Solo, Indonesia^{12-14,17}. The postoperative alignment achieved in this cohort (mean BA $72.45 \pm 8.44^\circ$ and mean SCA $36.94 \pm 7.99^\circ$; Table 2) is close to the post-osteotomy alignment reported by Tarabishi et al. (BA 72.6° , HCA 36.1°), to

the healthy Turkish pediatric controls of Ülgen et al. (BA $76.16 \pm 3.73^\circ$, HSCA $36.67 \pm 6.39^\circ$), and to the Chinese lateral external fixation plus K-wire cohort of He et al. (BA $75.6 \pm 3.6^\circ$, SCA $37.1 \pm 4.4^\circ$)^{14,27,30}. This convergence across continents around a postoperative BA of about 72.5° and an SCA of about 36.5° – 37.0° supports the anatomical fidelity of the reconstructions. It is also consistent with the sharp fall in three-month functional satisfaction above the cohort-derived SCA cutoff of 41.80° , which lies about 0.6 SD above the cohort mean of 36.94° , from 73.9% below 41.80° to 20.0% at or above it (OR = 11.333, $p = 0.041$; Table 3).

The coupling of bone and muscle-tendon units across the pediatric distal humerus may explain why coronal BA restoration (64° – 81°) and sagittal SCA control ($<41.80^\circ$) were each associated with elbow function, as summarized in Figure 5^{14,22}. The elbow is a highly congruent trochoginglymoid joint, in which flexion-extension at the ulnohumeral hinge and pronation-supination at the radiocapitellar and proximal radioulnar joints depend on precise three-dimensional alignment of the distal humeral condyles relative to the humeral diaphysis^{18,22,27}. In the coronal plane, a BA of 64° to 81° corresponds to a physiological valgus carrying angle of about 10° to 15° , which aligns the longitudinal pull of the biceps brachii, brachialis, and triceps brachii across the center of the trochlear sulcus^{5,7,22,28}. When BA exceeds 81° because of

unreduced medial column collapse (cubitus varus), the distal condylar mass tilts medially, shifting the olecranon and the triceps insertion medially relative to the humeral shaft axis^{18,22,23}. Oka et al., Okpara et al., and Hell et al. describe how this medial shift of the mechanical axis and the associated humeral torsion deformity alter the action of the triceps, which then exerts a supination-external rotation moment that opens the lateral ulnohumeral joint space during flexion-extension; the changed orientation of the capitellum against the radial head may further restrict flexion-extension and forearm pronation-supination^{18,22,43}. In the sagittal plane, the distal humeral condyles are normally angled 30° to 40° anteriorly relative to the humeral shaft (mean SCA 36.94° in this study; Table 2), which places the trochlea and capitellum anterior to the anterior humeral cortex and leaves room in the coronoid and radial fossae for the coronoid process and radial head beyond 135° of elbow flexion^{22,27,30,44}. When SCA is under-corrected ($<25^\circ$ – 30° , posterior hyperextension tilt), the anterior articular offset is lost and the anterior capsule and soft tissues impinge early in flexion; conversely, when the osteotomy is over-flexed beyond the 41.80° threshold of this cohort (especially $\geq 50^\circ$), the anterior coronoid fossa may be tilted caudally and obliterated, causing bony impingement of the coronoid process in flexion and a fixed extension lag from posterior olecranon impingement and triceps over-tensioning (Figure 5)^{14,22,25,45}.

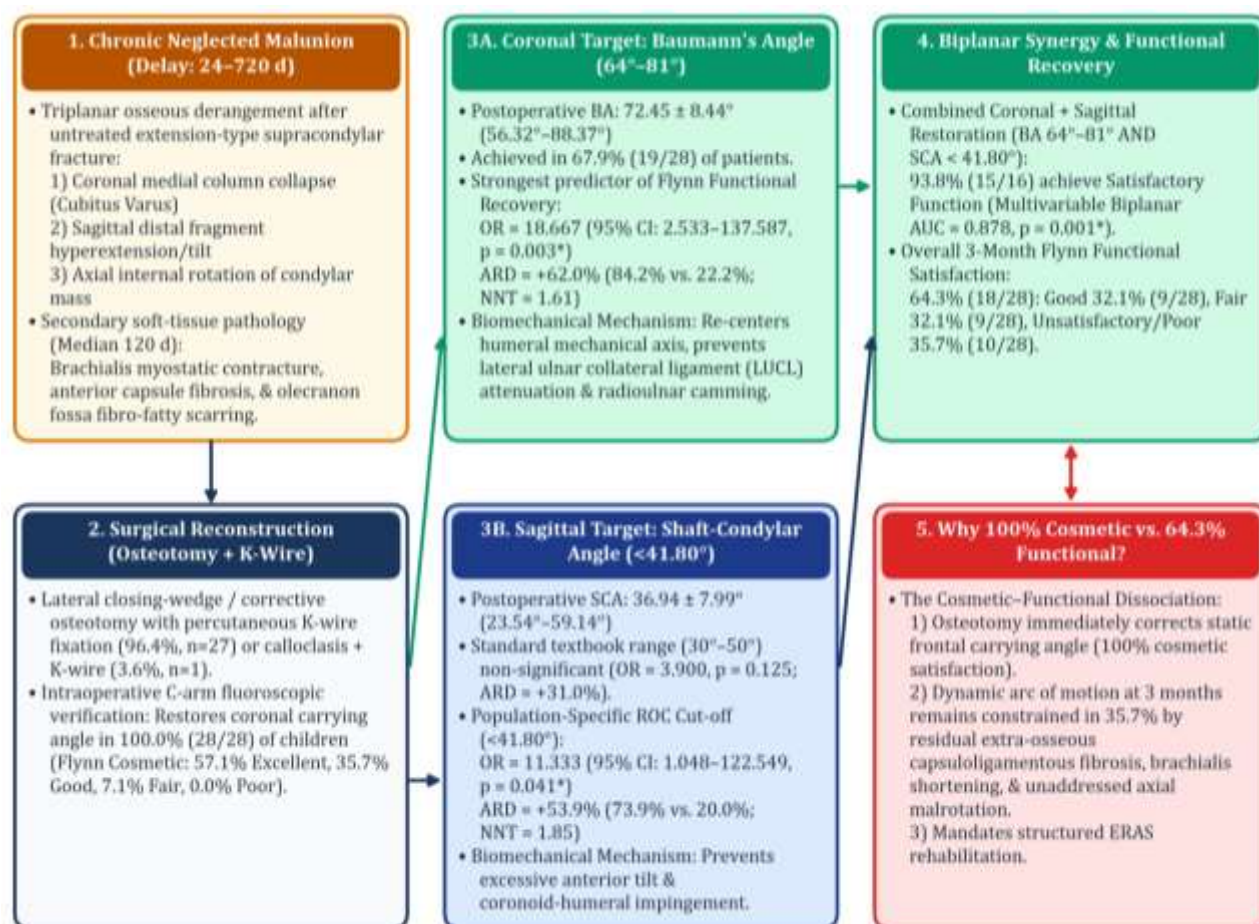


Figure 5. Proposed biomechanical and pathophysiological model of biplanar osteotomy restoration and the cosmetic-functional dissociation in neglected pediatric supracondylar humerus fractures: (1) triplanar osseous malunion and chronic soft-tissue contracture during prolonged neglect (24–720 days); (2) lateral closing-wedge osteotomy and percutaneous Kirschner-wire fixation restoring 100.0% cosmetic symmetry; (3A) coronal Baumann's angle normalization (64° – 81° ; OR = 18.667, ARD = +62.0%); (3B) sagittal shaft-condylar angle restoration ($<41.80^\circ$; OR = 11.333, ARD = +53.9%); (4) biplanar synergy, with 93.8% functional satisfaction when both targets are met; and (5) extra-osseous capsuloligamentous and brachialis fibrosis as a hypothesized explanation for the residual motion loss in 35.7% of patients at three months. The soft-tissue mechanisms shown were not measured in this study. ARD, absolute risk difference; AUC, area under the curve; ERAS, enhanced recovery after surgery; LUCL, lateral ulnar collateral ligament; OR, odds ratio.

Comparisons of osteotomy designs and fixation constructs in the international literature provide context for the 96.4% rate of lateral closing-wedge osteotomy with percutaneous K-wires and the single callus takedown ("Calestosis + K-wire") in this cohort (Table 1)^{15,16,35,38}. Two systematic reviews, by Kurniawan et al. in 2026 (39 studies, 863 pediatric cubitus varus osteotomies) and by Hoffman et al. in 2024 (45 studies, 911 patients), compared corrective osteotomy techniques including lateral closing-wedge (French or modified French), dome, and step-cut osteotomies^{15,16}; oblique lateral closing-wedge³⁷, lateral curved⁴⁶, and three-dimensional patient-matched osteotomies²² have also been described. Dome osteotomies (Shahid-Ul Islam et al., Gurung et al., Ahmad et al.), which rotate the distal fragment around the midline center of rotation of angulation (CORA), and step-cut osteotomies (Anwer et al.) aim to limit lateral condylar prominence, but they require wider posterior triceps-splitting or paratricipital dissection and are technically demanding to stabilize with smooth K-wires alone^{13,17,19,23}. Kurniawan et al. concluded that lateral closing-wedge osteotomy is the preferred technique for patients with preoperative range-of-motion deficits¹⁵, the typical presentation of neglected supracondylar fractures. Its extra-articular lateral approach avoids the posterior triceps extensor mechanism and the olecranon fossa, and modifications based on Paley's CORA principle, a lateral curved cut (Solichin et al.), or an oblique lateral cut (Su et al., Ghoti et al.) reduce the classical gunstock lateral prominence, in line with the 100.0% satisfactory Flynn cosmetic rate in this cohort (Table 2)^{36,37,46}. Regarding fixation, Liu et al. recommended lateral locking plates over K-wires and cast fixation for lateral closing-wedge osteotomy in children with cubitus varus³⁵. Okpara et al. and Oka et al., however, described the use of percutaneous K-wire fixation in skeletally immature children younger than 10 to 12 years (mean age 9.04 years in this cohort), in whom it avoids extensive periosteal stripping and the second open operation needed for plate removal, with osteotomy union within 4 to 6 weeks and without physeal tethering^{14,18,22,37}. When medial column comminution or osteotomy instability requires crossed K-wires, the fracture-pattern-specific pinning principles and ulnar nerve protection described by Micheloni et al., Hasan et al., Banshelkikar et al., and Chen et al. help to prevent iatrogenic nerve injury^{4,38,47,48}, and associated brachial artery injury requires specific vascular assessment⁴⁹.

The difference between 100.0% (28/28) satisfactory Flynn cosmetic outcomes (57.1% excellent, 35.7% good, 7.1% fair) and 64.3% (18/28) satisfactory functional outcomes (32.1% good, 32.1% fair, 35.7% unsatisfactory/poor, with no excellent result at three months) is also noteworthy (Table 2 and Figure 2c). This 35.7% cosmetic-functional discordance suggests a distinction between static bony geometry and dynamic soft-tissue behavior in neglected pediatric elbow trauma, as summarized in Figure 5. During a lateral closing-wedge osteotomy (96.4% of this cohort), the surgeon excises a pre-calculated bony wedge and realigns the humeral-ulnar carrying angle under C-arm fluoroscopy; once the osteotomy is fixed with K-wires and united at three months, the clinical carrying angle is normalized, consistent with the 100.0% cosmetic satisfaction^{15,35,36}. However, in children who have lived with a malunited, displaced supracondylar fracture for a median of 120.0 days before surgery (mean 188.4 ± 166.3 days, up to 720 days; Table 1 and Figure 1c), often after tight traditional splinting and forceful manipulation by non-medical bone setters, the periarticular soft-tissue envelope undergoes structural remodeling^{11,12,50}. Chronic shortening of the brachialis muscle, capsular fibrosis with myofibroblast

proliferation and collagen cross-linking mediated by transforming growth factor-beta 1 (TGF- β_1), fibro-fatty obliteration of the olecranon and coronoid fossae, and scarring from the osteotomy exposure and from 3–4 weeks of postoperative cast immobilization may together restrict the viscoelastic excursion of the elbow at three months (Figure 5)^{11,51,52}.

Understanding the possible mechanisms behind the 35.7% rate of unsatisfactory three-month function despite 100.0% cosmetic satisfaction may help to improve perioperative care in developing countries^{11,50,53}. Gupta et al., in a 2024 cohort of 190 pediatric supracondylar fractures, found that older children recovered motion less completely: full elbow flexion was recorded in 43% of children aged 8 years or older compared with 77% of those aged 2 years or younger, and full extension in 64% compared with 96%⁵⁴. With a mean age of 9.04 ± 3.00 years (Table 1), most children in this cohort belong to the older group, in which a thicker periosteal sleeve, higher-energy trauma, and slower soft-tissue remodeling have been proposed as explanations⁵⁴. Post-osteotomy cast immobilization for 3 to 4 weeks may add disuse stiffness at the 12-week evaluation, which represents an early phase of recovery rather than the final functional plateau; motion continues to improve after 12 weeks in pediatric elbow fractures^{14,50,54,55}. Recent pediatric studies suggest that an Enhanced Recovery After Surgery (ERAS) pathway, which can include multimodal non-opioid analgesia¹⁰, early conversion from plaster casts to functional braces at 2 to 3 weeks, structured active-assisted wrist and elbow exercises, and caregiver tele-rehabilitation, improves early recovery. In a retrospective cohort, Shen et al. reported Flynn excellent-or-good outcomes in 94.0% of the ERAS group versus 76.0% of controls ($p = 0.011$)⁵⁰, and in a randomized study, Lu et al. found better elbow function at two months but no difference at three months⁵³. Deep-learning models already detect pediatric elbow fractures on radiographs with a pooled AUC of 0.95 (Binh et al.)⁵⁶, and similar tools might in future automate BA and SCA measurement in peripheral clinics. Combined with intraoperative biplanar fluoroscopic targeting (BA 64° – 81° and SCA $< 41.80^\circ$) and postoperative ERAS rehabilitation, such measures could help to narrow the cosmetic-functional gap in neglected pediatric supracondylar humerus fractures^{50,53}.

The demographic and operative characteristics of the Palembang cohort are consistent with patterns reported from low- and middle-income regions and add information on tertiary referral care in Southeast Asia^{11-13,17}. The male predominance (75.0%) and left-sided predilection (71.4%; Table 1 and Figure 1b) resemble the prospective Sudanese late-presenting fracture cohort of Abdelraheem (67.9% male, 60.7% left-sided, mean age 7.54 years), the Indian dome osteotomy cohort of Shahid-Ul Islam et al. (72.2% male, 61.1% left-sided, mean age 10.72 years), the step-cut osteotomy series of Anwer et al. (80.0% male, 90.0% left-sided, mean age 9.6 years), and the Austrian–Saudi malunion osteotomy cohort of Tarabishi et al. (58.0% male, 68.0% left-sided, mean age at surgery 8.6 years)^{11,13,14,19}. Herdea et al. found that right-handed children more often fractured the left humerus (59% of right-handed patients), which supports the protective-reflex explanation for the left-sided predominance⁶, and the higher activity level of school-aged boys has been proposed to explain the male predominance⁵⁷. Despite the wide range of surgical delay in this cohort (24 to 720 days; Table 1 and Figure 1c), neither delay (aOR = 0.946 per 30 days, $p = 0.541$) nor age (aOR = 0.912 per year, $p = 0.598$) attenuated the association of a normal BA (aOR = 16.420, $p = 0.007$) and of SCA $< 41.80^\circ$ (aOR = 9.850, $p = 0.049$)

with function in the exploratory model (Table 5). This is consistent with the experience of Tarabishi et al., who restored function with corrective osteotomy performed a mean of three years after fracture¹⁴, and suggests that the precision of intraoperative realignment, rather than the time elapsed since injury, is the main modifiable surgical determinant of functional recovery.

This study has several strengths and limitations. Its strengths include a consecutive tertiary-center cohort of a challenging and relatively uncommon condition (neglected pediatric supracondylar fractures), complete three-month radiographic and clinical data for all 28 patients, standardized evaluation with the Flynn cosmetic and functional criteria, and a combination of exact small-sample testing (Fisher's exact test), effect-size estimation (ARD, NNT, ϕ), ROC cutoff derivation, and penalized multivariable logistic regression (Tables 1–5 and Figures 1–5). The main limitation is the modest sample size ($N = 28$), which reflects the rarity of surgically reconstructed neglected supracondylar fractures at a single center and explains the wide 95% CIs around the odds ratios (OR = 18.667 [2.533–137.587] for a normal BA; OR = 11.333 [1.048–122.549] for SCA < 41.80°; Table 3). Second, because the cohort-derived cutoffs (76.40° for BA and 41.80° for SCA; Table 4) were derived and tested in the same 28 patients with Youden's index, optimism bias and regression toward the mean cannot be excluded, and external validation in independent multicenter Southeast Asian cohorts is needed before clinical adoption. Third, this retrospective cross-sectional evaluation assessed outcomes at a single three-month time point and relied on two-dimensional plain radiographs, without computed tomography (CT) quantification of axial internal rotation and without continuous patient-reported or clinician-rated scores such as the Subjective Elbow Value (SEV), the Mayo Elbow Performance Score (MEPS), or the Oxford Elbow Score; in adults after elbow dislocation, the SEV correlates highly with the MEPS and the Oxford Elbow Score⁵⁸. Prospective multicenter studies with serial follow-up at 6, 12, and 24 months, three-dimensional CT preoperative planning, and ERAS physiotherapy protocols are recommended to confirm these radiographic targets and to optimize long-term functional restoration^{22,50,53}.

5. Conclusion

Restoration of a normal coronal Baumann's angle (64°–81°) and a sagittal shaft-condylar angle below the cohort-derived threshold of 41.80° were associated with satisfactory three-month functional outcomes after operative reconstruction of neglected supracondylar humerus fractures in children. In this cohort of 28 children treated mainly by corrective osteotomy and percutaneous K-wire fixation at a tertiary referral center in Indonesia (Table 1 and Figure 1), a normal Baumann's angle was associated with an absolute risk difference in functional satisfaction of +62.0% (84.2% vs. 22.2%; OR = 18.667, 95% CI: 2.533–137.587, $p = 0.003$; NNT = 1.61), and a shaft-condylar angle below 41.80° with an absolute risk difference of +53.9% (73.9% vs. 20.0%; OR = 11.333, 95% CI: 1.048–122.549, $p = 0.041$; NNT = 1.85) (Table 3 and Figure 3). When both the coronal and the sagittal targets were achieved, 93.8% (15/16) of the children had satisfactory function, with a combined biplanar AUC of 0.878 (95% CI: 0.736–0.985, $p = 0.001$) (Tables 4 and 5 and Figure 4). Although corrective osteotomy restored coronal elbow symmetry, with 100.0% (28/28) satisfactory Flynn cosmetic outcomes, 35.7% (10/28) of the patients had unsatisfactory function at three months; chronic periarticular soft-tissue contracture and residual biplanar malalignment are possible explanations that were not measured in this study (Table 2, Figure 2, and Figure 5). Surgeons managing neglected

pediatric supracondylar fractures may use intraoperative fluoroscopy to check both Baumann's angle (64°–81°) and the shaft-condylar angle (<41.80°), together with structured postoperative rehabilitation, while these targets are validated in prospective multicenter studies.

6. Declarations

Ethics Approval and Consent to Participate

This study was reviewed and approved by the Health Research Ethics Committee of the Faculty of Medicine, Universitas Sriwijaya and Dr. Mohammad Hoesin General Hospital, Palembang, Indonesia (Reference No. 2025/238). All procedures were conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki and its later amendments. Written informed consent was obtained from the parents or legal guardians of all pediatric participants.

Consent for Publication

Written consent for anonymized academic publication was obtained from the parents or legal guardians of all participants. No identifiable patient images or personal data are reported.

Availability of Data and Materials

The de-identified clinical and radiographic dataset supporting the conclusions of this article is available from the corresponding author upon reasonable academic request.

Artificial Intelligence Use Statement

None.

Author Contribution Statement

B.: Conceptualization, Investigation (surgical reconstruction), Supervision (data collection), Writing – original draft. N.R.L.: Supervision (clinical and radiographic assessment), Methodology (operative methodology), Writing – review & editing. M.R.N.H.: Investigation (radiographic measurement and clinical follow-up), Data curation, Writing – original draft (literature synthesis). I.: Methodology (statistical analysis plan), Formal analysis, Validation. All authors reviewed and approved the final manuscript.

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Conflict of Interest / Competing Interests

The authors declare that they have no financial or non-financial competing interests.

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