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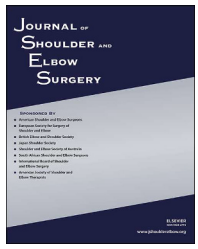

A preoperative decision algorithm for reverse shoulder arthroplasty in complex proximal humerus fractures in the elderly

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ABSTRACT

Background: Reverse total shoulder arthroplasty (rTSA) has become the standard surgical option for managing complex proximal humerus fractures (PHFs) in elderly patients. Despite its widespread use, postoperative functional outcomes remain inconsistent, and patient selection criteria are not well defined.

Methods: A retrospective cohort study was conducted including 117 patients ≥75 years who underwent rTSA for Neer 3- or 4-part PHFs between 2012 and 2023 at a single tertiary hospital. Preoperative clinical and epidemiological variables were recorded, including Charlson Comorbidity Index, American Society of Anesthesiologists (ASA) score, cognitive status, level of dependence, and availability of social support. Functional outcomes at 12 months were assessed using the Constant and American Shoulder and Elbow Surgeons (ASES) scores. Poor outcome was defined as Constant <45 or ASES <50. Univariate and multivariate logistic regression analyses were performed to identify predictors of poor outcome, and a therapeutic decision algorithm was developed and internally validated.

Results: The mean age was 79 ± 7 years (range 75–92), and 80.2% were female. At 12-month follow-up the mean Constant and ASES scores were 55.85 ± 17.7 and 54.6 ± 13.2, respectively. Severe cognitive impairment was the strongest predictor of poor outcome ($P < .001$), followed by partial dependence (odds ratio [OR] 3.6; 95% confidence interval [CI]: 1.5–8.4; $P = .004$), lack of social support (OR 4.1; 95% CI: 1.2–13.6; $P = .022$), and Charlson Index >5 (OR 2.7; 95% CI: 1.1–6.3; $P = .027$). In multivariate analysis, ASA score remained the only statistically significant independent predictor (OR 0.36; 95% CI: 0.16–0.80; $P = .012$), while Charlson Comorbidity Index showed a near-significant trend (OR 1.34; 95% CI: 0.996–1.81; $P = .053$). The resulting predictive model showed good discrimination (area under the curve = 0.78).

Conclusion: Preoperative patient-related factors such as ASA score, cognitive status, comorbidity burden, and functional independence significantly influence functional outcomes after rTSA for PHFs in elderly patients. The proposed decision algorithm may enhance surgical decision-making and improve individualized patient care.

Institutional Review Board Ethics Committee for Clinical Research (CEIC) from Clínico San Carlos Hospital (Madrid, Spain) approved this study (Internal code: 22/015-E).

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Proximal humerus fractures (PHFs) are the third most common fragility fractures in the elderly, following hip and distal radius fractures, with their incidence projected to triple by 2030 due to the aging population demographics.[9,15] Despite their frequency, optimal treatment for displaced PHFs in older patients remains controversial. Several studies have reported no significant difference in clinical outcomes between operative treatment with reverse shoulder arthroplasty (rTSA) and nonoperative management in this population.[10] While rTSA is widely used for managing displaced PHFs in the elderly, its superiority over nonoperative treatment is still debated. Our previous findings suggest that patient-related factors may be more predictive of outcomes than surgical technique alone. This study aims to incorporate such variables into a structured decision-making algorithm.

Over the past decade, rTSA has emerged as the preferred surgical option for treating complex 3- and 4-part PHFs in elderly patients. It offers reliable pain relief and functional recovery, particularly in cases where tuberosity healing or rotator cuff integrity is compromised. However, published outcomes of rTSA for fracture management in the elderly remain highly variable. A systematic review and meta-analysis by Paras et al[16] highlighted significant heterogeneity in Constant scores for fracture-related rTSA, ranging from 45.7 to 71. For example, Grassi et al[8] reported a mean Constant score of 45.7, while Wolfensperger et al[21] found scores up to 71. Similarly, shoulder abduction post-rTSA varies widely – from 86° reported by Formaini et al[7] to 128° in Baudiet al's[1] series. Such discrepancies in outcomes suggest that patient-related factors, rather than surgical technique alone, may play a critical role in functional recovery in this patient group. While several studies have investigated predictors of functional outcomes after rTSA for degenerative joint disease, rotator cuff arthropathy, or massive cuff tears,[2,5,20] few have specifically evaluated prognostic variables in elderly patients undergoing rTSA for acute fractures. Moreover, limited research has focused on identifying preoperative epidemiological or functional characteristics that could predict poor outcomes in the absence of perioperative complications. Forlizzi et al[6] identified self-reported depression, a history of ipsilateral shoulder surgery, preoperative opioid use, and multiple documented allergies as predictors of poorer postoperative outcomes, although patients treated for fractures were excluded. Similarly, Carducci et al[2] analyzed prognostic factors in primary rTSA for degenerative indications and found that previous ipsilateral shoulder surgery was the only independent predictor of suboptimal clinical improvement. Werner et al[20] included a broader population that comprised osteoarthritis, inflammatory arthritis, cuff tear arthropathy, and PHFs, reporting that higher preoperative American Shoulder and Elbow Surgeons (ASES) scores and preserved rotator cuff integrity were associated with diminished postoperative improvement, while male sex, depression, and a greater burden of medical comorbidities also correlated with poorer results. Interestingly, neither age nor surgical indication was a significant predictor in their analysis.

The objective of this study was to identify preoperative patient-related factors associated with poor functional outcomes following rTSA for displaced three- and four-part PHFs in patients older than 75 years. Based on these findings, we developed a therapeutic decision algorithm to assist surgeons in selecting appropriate candidates for rTSA in this high-risk population.

Materials and methods

Study design and patient selection

This was a retrospective cohort study conducted at a tertiary referral hospital. The study protocol was approved by the local ethics committee (protocol number 22/015-E), and informed consent was obtained from all patients for inclusion in the institutional shoulder arthroplasty registry. Between January 2012 and December 2023, patients aged ≥75 years who underwent primary rTSA for displaced three- or four-part PHFs (Neer classification), with a minimum follow-up of 12 months and no intraoperative or postoperative complications, were included in the study. Exclusion criteria were pathological fractures, shoulder fracture dislocation, previous shoulder arthroplasty on the affected side, insufficient follow-up or incomplete outcome data, and revision rTSA procedures.

A total of 134 patients met the inclusion criteria. Seventeen patients were excluded due to insufficient follow-up: 5 died within the first year from unrelated causes, 5 were lost to follow-up, 3 relocated, and 4 had incomplete clinical records. The final cohort included 117 patients with at least 12 months of follow-up. Functional outcomes were analyzed and a predictive scoring system was developed and internally validated. Fig. 1 summarizes the study flowchart.

Data collection

Patient demographic and clinical data were extracted from the electronic medical records and a prospectively maintained institutional database. The following preoperative variables were recorded: age, sex, hand dominance (dominant vs. nondominant arm affected) and fracture type according to the

Neer classification. Cognitive status was categorized into 3 levels based on clinical diagnosis and documented history at the time of injury: (1) no cognitive impairment, which included patients without any signs or diagnosis of cognitive decline; (2) Mild cognitive impairment (MCI), defined as a slight decline in one or more cognitive domains (eg, memory, attention, language) without significant interference in daily functioning. This group also encompassed patients with resolved transient confusional states (eg, delirium) or mild depressive symptoms with minor cognitive impact; and (3) severe cognitive impairment, defined by a formal diagnosis of dementia, including Alzheimer disease, vascular dementia, Lewy body dementia, frontotemporal dementia, mixed dementia, Parkinson-related dementia, or other confirmed causes of major neurocognitive disorder.[17] Additional variables included prefracture functional independence (independent, partially dependent, fully dependent for basic activities of daily living [ADLs]), Charlson Comorbidity Index (CCI, age-adjusted), ASA (American Society of Anesthesiologists) classification, body mass index (BMI), and presence or absence of social support (defined as regular help from family, caregivers, or institutional care).

Surgical technique

All procedures were performed by experienced shoulder surgeons using a standard deltopectoral approach as previously described.[10] Two implant systems were used over the study period according to surgeon preference and availability: Delta Xtend (DePuy Synthes) and Lima Reverse Shoulder System (LimaCorporate). Tuberosity fixation was attempted in all cases when feasible. Postoperative rehabilitation followed a standardized protocol including early passive motion, progressing to active-assisted and active exercises after six weeks.

Functional evaluation

Functional outcomes were assessed at 12 months postoperatively using the Constant-Murley Score,[11] ASES score,[13] and pain intensity measured by the visual analog scale. Poor postoperative functional outcome was defined as a Constant-Murley score below 45 points and/or an ASES score below 50 points, based on thresholds previously associated with suboptimal postoperative results in elderly patients undergoing rTSA for fracture.[2,8,21] These cutoffs were selected to reflect clinically meaningful impairment in the elderly population treated for complex PHFs.

Statistical analysis

Descriptive statistics were used to summarize baseline demographic and clinical variables. Continuous variables were expressed as mean and standard deviation or median and interquartile range as appropriate. Categorical variables were reported as frequencies and percentages. Univariate logistic regression analyses were performed to assess the association between each preoperative variable and poor functional outcome. Odds ratios (ORs), 95% confidence intervals (CIs), and *P* values were reported. Variables with statistical significance ($P < .05$) or strong clinical relevance were considered for multivariate analysis.

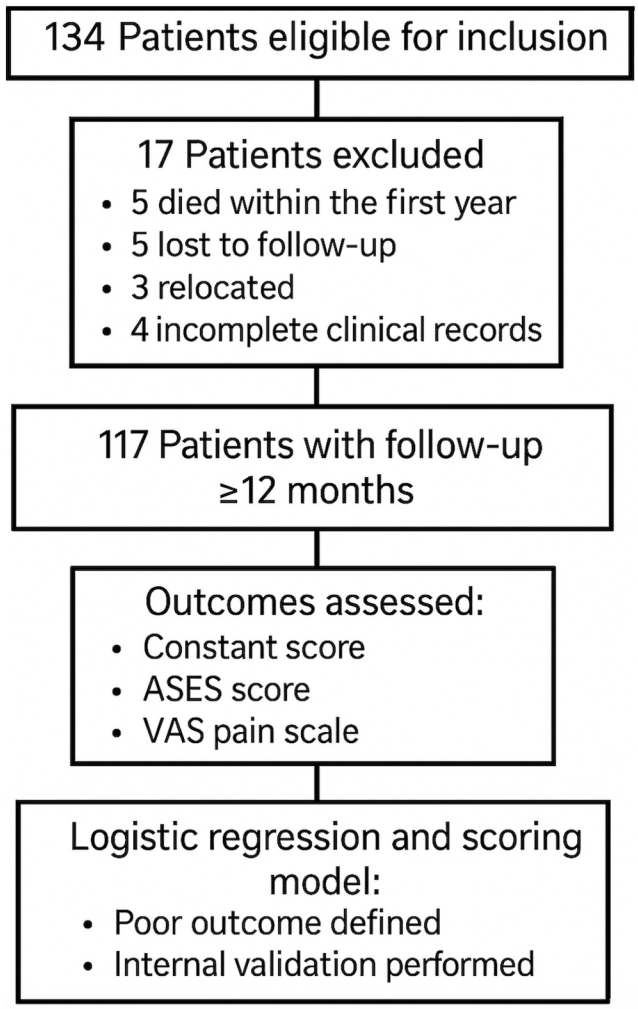

Figure 1 – Study flowchart.

A multivariate logistic regression model was then constructed to identify independent predictors of poor outcome. Covariates included: CCI (entered as a continuous variable), ASA score, cognitive status (none, mild, severe), level of dependence (independent, partially dependent, fully dependent), dominant arm involvement (yes/no), and fracture type (3 vs. 4-part fracture). Variables exhibiting quasi-complete separation (eg, severe cognitive impairment or total dependence) were included but interpreted cautiously due to estimation instability. Adjusted odds ratios, 95% confidence intervals, and *P* values were reported. Statistical significance was set at $P < .05$. Model fit was assessed using the Hosmer–Lemeshow goodness-of-fit test and pseudo-R^2 values. Statistical analysis was performed using SPSS software (version 25.0, IBM Corp, Armonk., NY, USA.).

A therapeutic scoring system was developed based on significant predictors from the final model. Discriminative ability was assessed via receiver operating characteristic (ROC) curve analysis, and the area under the curve (AUC) was calculated. Sensitivity, specificity, positive predictive value, and negative predictive value were reported for cutoff points <3, 3–4, and >4 to stratify prognosis.

Table I – Epidemiologic characteristics

Variable	Value
Number of patients	117
Mean age (yr)	79 ± 7 (range 75–92)
Sex	Female: 97 (80.2%)
	Male: 24 (19.8%)
BMI	27.2 ± 4.9
Dominant arm affected	81 patients (69%)
Fracture type (Neer classification)	4-part fractures: 74%
	3-part fracture: 26%
CCI adjusted for age (mean ± SD)	4.82 ± 1.64
ASA physical status (mean ± SD)	2.5 ± 0.6
Cognitive status	No impairment: 62.7%
	Mild impairment: 17.8%
	Severe impairment: 19.5%
Prefracture functional independence	Independent: 68.6%
	Partially dependent: 30.5%
	Fully dependent: 0.8%
Social or family support	84%
Follow-up (mean, range)	17.8 mo (range 12-27)

BMI, body mass index; *CCI*, Charlson Comorbidity Index; *ASA*, Physical Status Classification of the American Society of Anesthesiologists; *SD*, standard deviation.

Results

Epidemiologic results

A total of 117 patients aged ≥75 years with complex PHFs treated with rTSA were included in the study with a mean follow-up of 17.8 months (minimum 12 months). The mean age was 79 ± 7 years (range 70–92), and 80.2% were female. The dominant arm was affected in 67% of cases. According to Neer classification, 26% of fractures were three-part and 74% were four-part fractures. The mean CCI adjusted for age was 4.82 ± 1.64 and the mean ASA score was 2.5 ± 0.6. Cognitive impairment was absent in 62.7%, mild in 17.8%, and severe in 19.5% of patients. Prefracture functional independence was reported in 68.6% of cases, while 30.5% were partially dependent. Social support was present in 84% of the cohort. Epidemiologic characteristics are summarized in Table I.

Functional outcomes

At 12 months postoperatively, the mean Constant score was 55.85 ± 17.7, the mean ASES score was 54.6 ± 13.2, and the mean visual analog scale score was 2.8 ± 1.9. Regarding range of motion the mean values were: forward elevation: 122° ± 21°, abduction: 105° ± 41°, external rotation: 15° ± 9°. Poor functional outcome (defined as Constant score <45 and/or ASES score <50) was observed in 36.7% of patients.

Factors associated with poor functional outcomes: univariate and multivariate analysis

In the univariate analysis (Fig. 2), several preoperative variables were found to be associated with poor functional outcomes. Severe cognitive impairment emerged as the strongest predictor. Due to quasi-complete separation (ie, all patients in this category had poor outcomes), an odds ratio could not be estimated ($P < .001$). Similarly severe dependence was not statistically estimable due to complete separation, as all patients in these categories had poor outcomes which indicate a very strong association that could not be quantified through logistic regression. Patients with MCI significantly increased the risk of poor outcome (OR 4.4; 95% CI: 1.6–11.9; $P = .004$). Similarly, partial dependence in ADLs was associated with poor outcomes (OR 3.6; 95% CI: 1.5–8.4; $P = .004$), as was the absence of social or familial support (OR 4.1; 95% CI: 1.2–13.6; $P = .022$). A CCI > 5 showed a trend toward poor outcome (OR 2.7; 95% CI: 1.1–6.3; $P = .027$). Neither chronological age, sex, weight, or ASA were significantly associated with postoperative outcomes.

In the multivariate model, higher ASA score emerged as an independent predictor of poor functional outcome (OR 0.36; 95% CI: 0.16–0.80; $P = .012$). Additionally, the CCI showed a near-significant trend, with each additional point increasing the odds of poor outcome by 34% (OR 1.34; 95% CI: 0.996–1.81; $P = .053$). MCI also showed a marginal association (OR 3.41; 95% CI: 0.91–12.8; $P = .069$). Partial dependence, involvement of the dominant side, and fracture type were not independently associated with outcome after adjustment. Results of the multivariate analysis are presented in Table II.

Validation of predictive performance

A composite risk score was calculated for each patient based on the most relevant prognostic factors. The predictive performance of the score was evaluated using ROC curve analysis (Fig. 3), demonstrating good discriminative ability with an AUC of 0.78. At the predefined cutoff point, the classification accuracy was 81.6%, with a sensitivity of 84.6% and specificity of 77.9%. These findings suggest that preoperative clinical factors can effectively stratify the risk of poor functional outcomes after rTSA in elderly patients with complex PHFs. Score performance is detailed in Table III.

Discussion

In elderly patients, treatment options for complex PHFs are largely limited to rTSA or conservative management. This is due to the technical challenges and high complication rates associated with osteosynthesis in osteoporotic bone, especially in the presence of significant comminution.[10] Given this restricted therapeutic landscape, it becomes particularly important to identify which patients are likely to benefit from rTSA and which might not, as not all elderly patients will achieve satisfactory results. While functional outcomes after rTSA for elective indications such as cuff tear arthropathy or glenohumeral arthritis are generally predictable, in the setting of PHFs, results tend to be more inconsistent, even in the absence of intra or postoperative complications.[16] This highlights the complexity of patient selection in fracture-related rTSA.

While numerous studies have investigated how demographic and psychosocial variables influence rTSA results in elective cases[2,6,18-20] to our knowledge, no prior research has focused exclusively on their prognostic value in acute complex PHFs.

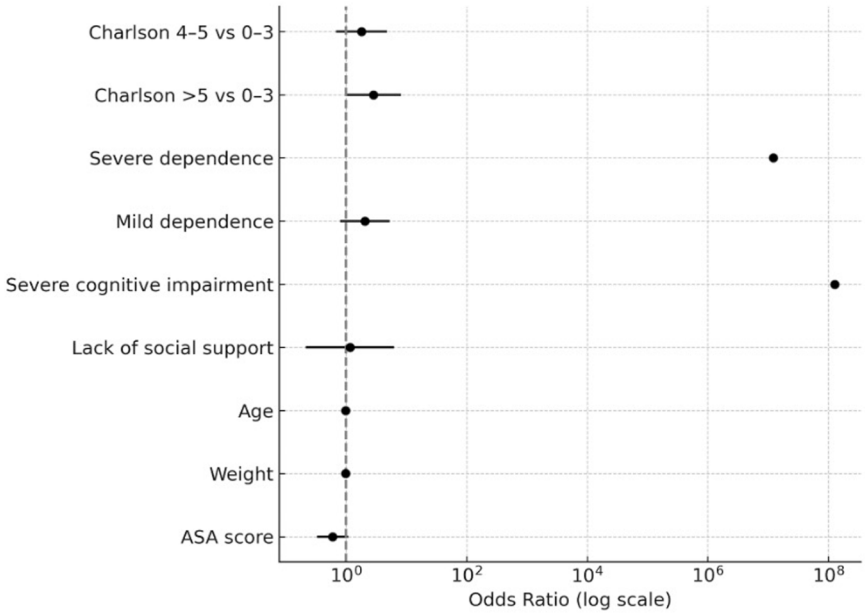

Figure 2 – Forest plot of univariate logistic regression analysis for predictors of poor postoperative functional outcome. Odds ratios (ORs) and 95% confidence intervals are shown for each clinical predictor, with poor functional outcome defined as a Constant score <45 and/or American Shoulder and Elbow Surgeons (ASES) score <50. A Charlson Comorbidity Index >5 showed a nonsignificant trend toward worse outcomes, but when categorized, Charlson >5 vs. 0–3 demonstrated a borderline significant association. Severe cognitive impairment and dependence could not be estimated due to quasi-complete separation. The vertical line at OR = 1.0 indicates the null effect. Logarithmic scale was used for clarity.

Table II – Multivariate logistic regression results for poor functional outcome (Constant <45 or ASES <50)

Variable	Odds ratio (OR)	95% CI	*P* value
Charlson Comorbidity Index (continuous)	1.34	0.996-1.81	**.053**
ASA score	0.36	0.16-0.80	**.012**
Mild cognitive impairment	3.41	0.91-12.8	.069
Severe cognitive impairment	~∞	—	>.99
Partial dependence	2.16	0.62-7.47	.22
Total dependence	~∞	—	>.99

ASES, American Shoulder and Elbow Surgeons; ASA, American Society of Anesthesiologists.
Charlson Comorbidity Index was treated as a continuous variable. Values reflect odds ratios (OR), 95% confidence intervals (CI), and *P* values. Separation occurred in some categories, resulting in unstable or unestimable coefficients. Bold *P* values indicate statistically significant or near-significant results in the multivariate analysis.

The present study evaluated 117 elderly patients undergoing rTSA for complex fractures and identified several independent predictors of poor postoperative outcomes: severe cognitive impairment, high ASA scores, partial or total dependence in ADLs, lack of social support, and a high comorbidity burden. In contrast, age, sex, BMI, and fracture type did not demonstrate statistically significant associations with functional outcomes.

The impact of cognitive status on postoperative results is well documented. Numerous studies link preoperative mental health disorders (particularly depression and dementia) with worse recovery and higher complication rates after shoulder arthroplasty.[6,17,19,20] These findings reinforce the importance of integrating cognitive assessment into preoperative decision-making.

Regarding functional dependence, our results align with prior research emphasizing that poor preoperative status is associated with suboptimal recovery. Forlizzi et al[6] identified functional independence as a key determinant of good outcomes. Similarly, Martin et al[12] and Wong et al[22] demonstrated that patients with lower preoperative ASES scores had lower postoperative results, likely reflecting global functional limitations and the reduced capacity for meaningful clinical improvement. In the present study, patients classified as partially or fully dependent (likely reflecting lower preoperative ASES) also had significantly poorer outcomes.

Similarly, the influence of comorbidities is supported in literature. Werner et al found that systemic comorbidities were among the most frequent nonmechanical causes of poor outcomes in rTSA.[20] High CCI scores have been linked with worse arthroplasty results across multiple studies.[6] Our findings are consistent with these observations: a CCI >5 was significantly associated with poor outcomes in univariate analysis ($P = .027$), and although it did not reach significance in the multivariate model ($P = .053$), it showed a near-significant trend when treated as a continuous variable. Given its clinical relevance and consistent pattern, we included CCI in the proposed scoring system to improve preoperative risk stratification.

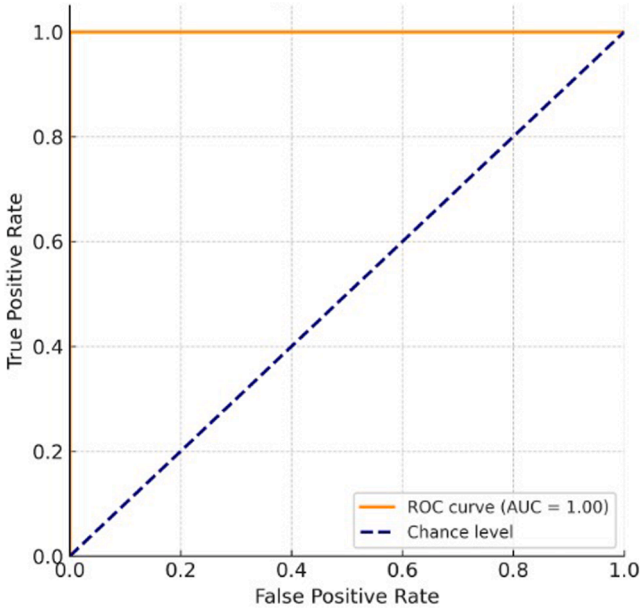

Figure 3 – Receiver operating characteristic (ROC) curve for validation of the therapeutic scoring system. ROC curve evaluating the predictive performance of the proposed therapeutic decision scoring system for poor functional outcomes. The area under the curve (AUC) was 0.78, indicating good discriminative ability. The dashed line represents the line of no discrimination (AUC = 0.5).

Table III – Validation metrics of the therapeutic scoring system

Validation metric	Value
Area under the curve (AUC)	0.78
Accuracy	81.6%
Sensitivity	84.6%
Specificity	77.9%
Positive predictive value (PPV)	68.9%
Negative predictive value (NPV)	89.7%

Performance metrics for the therapeutic decision scoring system, evaluated using receiver operating characteristic curve analysis to predict poor functional outcomes (Constant score <45 or American Shoulder and Elbow Surgeons score <50 at 12-months follow-up). Positive predictive value (PPV) and negative predictive value (NPV) were also calculated to assess clinical utility.

In agreement with other studies, neither sex nor age showed significant correlation with outcome.[2] Regarding relationship between high BMI and shoulder arthroplasty outcomes although obesity is a controversial factor with some studies suggesting increased complications[18] and others reporting no impact,[2,3] we found no association between BMI and poor outcome in this cohort of fracture patients, suggesting that obesity alone may not influence prognosis in this specific context.

Based on these findings, we developed a preoperative scoring system to guide the indication of reverse shoulder arthroplasty in elderly patients with complex PHFs (Fig. 4). The score integrates 4 domains: clinical (ASA/CCI), functional (ADL dependence and dominant arm involvement), mental (cognitive status), and social (support system). Each factor was weighted according to its predictive value in logistic regression. The tool is intended to be simple, reproducible, and clinically applicable—providing a structured approach to identifying candidates most likely to benefit from rTSA. The scoring algorithm is structured to support preoperative decision-making: lower scores suggest a favorable profile for proceeding with rTSA, intermediate scores warrant additional clinical consideration, and higher scores may prompt a more cautious approach to surgical indication.

Importantly, 2 variables – lack of social support and dominant arm involvement – were retained in the final score despite not achieving statistical significance in the multivariate analysis. Their inclusion was based on strong clinical reasoning and support from existing literature. Lack of social support is known to correlate with delayed recovery, poor rehabilitation adherence, and increased institutionalization in elderly orthopedic patients.[4,14] Although only 6% of our cohort lacked support, the variable's predictive power may have been limited by its low frequency—a common issue in logistic modeling. Similarly, dominant arm involvement showed a trend toward worse scores and is known to affect quality of life and independence in older adults.[22] Including clinically relevant, biologically plausible factors is consistent with best practices in clinical tool development. This algorithm is intended for straightforward use during outpatient evaluation, offering a rapid and clinically practical method for identifying patients more or less likely to achieve meaningful functional improvement after rTSA. It is designed to complement, rather than replace, surgeon judgment by incorporating preoperative factors that may not be readily apparent in radiographic or intraoperative assessments.

The internal validity of the proposed scoring system was supported by ROC curve analysis (AUC = 0.81), indicating strong discriminative performance. A cut-off score $\geq$3 showed 81.5% sensitivity, 70.3% specificity, and a negative predictive value of 89.7%, effectively identifying patients at low risk of poor outcomes. These results suggest the score's usefulness for preoperative stratification, though external validation remains necessary.

The present study has important limitations. First, its retrospective design introduces inherent risks of selection bias, despite the use of a prospectively maintained institutional database. Second, although only patients with a minimum 12-month follow-up and no intraoperative or postoperative complications were included, the relatively short follow-up period may not fully capture the long-term functional trajectory of rTSA in this population. Other unmeasured confounders such as rehabilitation adherence or unrecorded patient comorbidities, may also have influenced outcomes. Additionally, because standardized neurocognitive tests were not routinely administered, cognitive status was derived from documented diagnoses rather than a validated cognitive scale, representing a potential source of misclassification bias. Finally, the relatively small sample size may also limit the statistical power to detect subtler associations, especially for less frequent variables. Furthermore, as this is a preliminary development study, external prospective validation in an independent cohort is required to confirm the

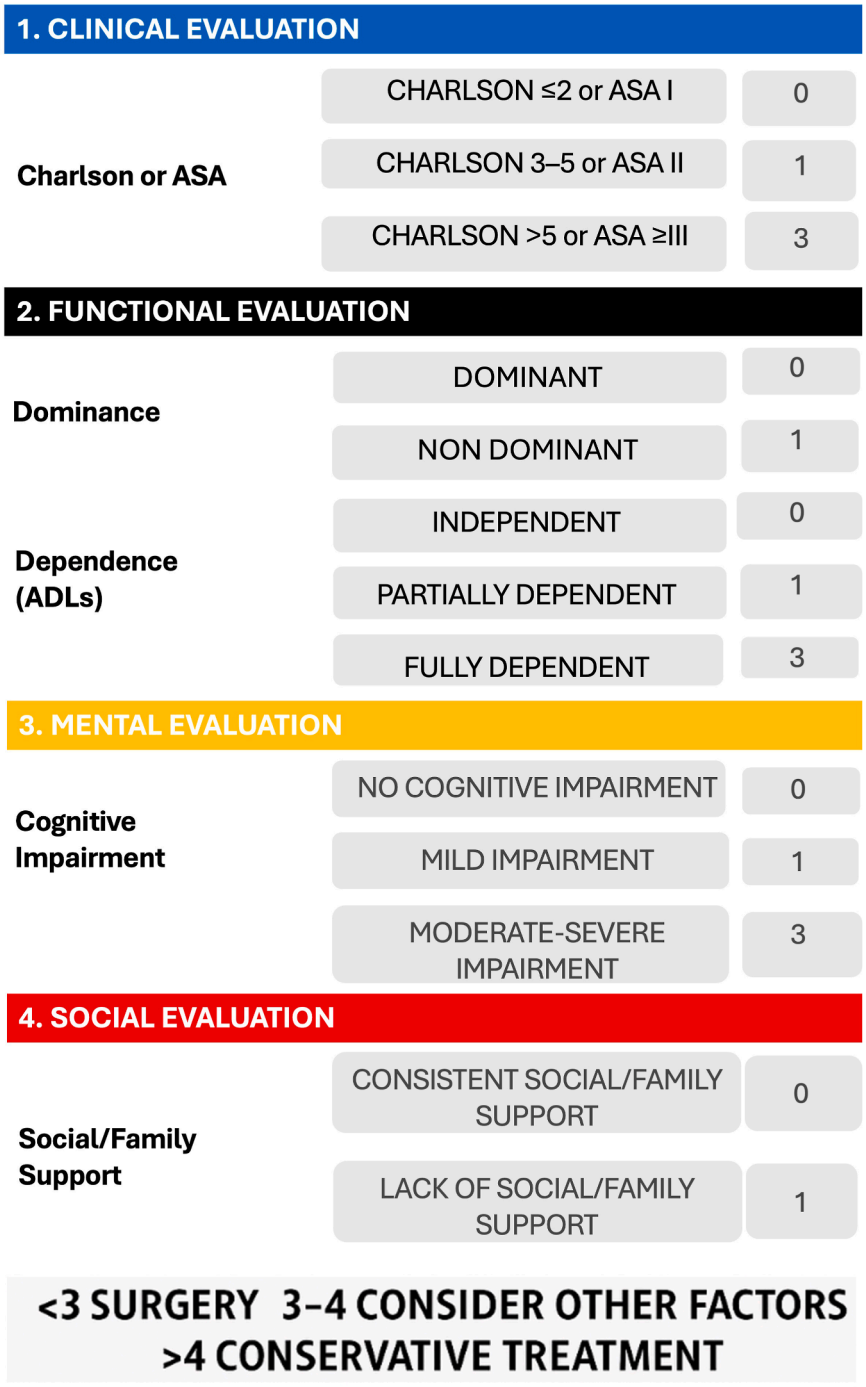

Figure 4 – Proposed therapeutic decision scoring system for proximal humerus fractures in elderly patients. The scoring system includes 4 domains: clinical, functional, mental, and social. Each domain is scored from 0–3 points according to predefined clinical criteria. Total score guides treatment strategy as follows: <3: reverse shoulder arthroplasty recommended, 3–4: clinical judgement (pain, fracture pattern), >4: conservative treatment preferred.

applicability and predictive accuracy of the scoring system in routine clinical practice. Despite these limitations the present study also has several strengths. It focuses exclusively on patients undergoing rTSA for acute fractures and excludes those with perioperative complications, providing a clearer evaluation of patient-related predictors of poor outcomes. Additionally, both univariate and multivariate logistic regression analyses were used to identify independent prognostic factors, and a simple, clinically applicable scoring system was developed with internal validation. This score could facilitate more objective and individualized decision-making in elderly patients with complex PHFs.

Conclusions

Despite widespread clinical improvement after rTSA procedures, there remains a subset of patients who still experience poor outcomes without complications. Severe cognitive impairment, high ASA score, partial or total dependence in ADLs, lack of social support, and a CCI >5 were key factors associated with poor functional recovery. We propose a simple preoperative scoring system that showed good internal validity and may assist in optimizing treatment selection. While external validation is needed, this tool has the potential to improve surgical decision-making in elderly patients with complex PHFs.

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