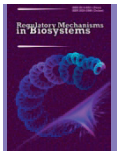

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Effects of fracture type, bone mineral density, and surgical technique on clinical outcomes of proximal humeral fracture surgery

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As the proportion of elderly individuals in Ukraine's population rises, optimizing the treatment of proximal humeral fractures is becoming increasingly important, given their significant impact on quality of life. Surgical treatment was performed using one of three methods in three patient groups (aged 45–78 years, total n = 102) with reduced bone mineral density following a three- or four-fragment proximal humerus fracture: open reduction and internal fixation with a proximal humeral locking plate with angular stability; open reduction and internal fixation with a plate using 3D-printed porous polylactide implants; primary reverse total shoulder arthroplasty using an advanced endoprosthesis or porous elements made from titanium powder via 3D printing and novel friction pairs. The Constant-Murley Score was used to evaluate functional outcomes at 3, 6, and 12 months postoperatively. Functional outcomes were analyzed based on individual preoperative parameters, treatment methods, and the presence of complications to identify risk factors for poor functional outcomes within 12 months postoperatively. At each follow-up period (3, 6, and 12 months), no statistically significant differences in mean Constant-Murley Score values were observed based on sex, age, or time between trauma and surgery. It was established that functional treatment outcomes showed a positive trend across all analyzed subgroups as the postoperative period increased from 3 to 12 months. Fracture type, cortical index value, and the presence of postoperative complications were the primary factors influencing functional outcomes in the studied sample. At all follow-up stages (3, 6, and 12 months), patients with four-fragment fractures had worse functional outcomes than those with three-fragment fractures. Similarly, patients with a cortical index value ≤ 0.36 demonstrated poorer outcomes than those with values of 0.38–0.40, as did patients with postoperative complications compared to those without. The presence of a four-fragment fracture and a cortical index ≤ 0.36 in patients aged 55–78 years in the studied sample may be considered risk factors for an unsatisfactory functional outcome within 12 months postoperatively. To determine both qualitative and quantitative relationships between initial patient conditions and functional outcomes over time, further studies are required in larger patient groups. Specifically, reverse prosthetics may offer a more advanced solution for older individuals with reduced bone density in cases of three- and four-fragment fractures, necessitating a longer follow-up period.

Keywords: arthroplasty; shoulder; bone density; treatment outcome; Constant–Murley score; aged.

Introduction

Proximal humerus fractures represent a significant public health concern due to their prevalence, treatment complexity, and the need for long-term monitoring and rehabilitation. Over the past 15 years, the average incidence of these injuries has nearly doubled. While the exact rate varies depending on geographic region, year, and study population, estimates suggest that these fractures are the second most common upper limb fractures, account for up to 60 cases per 100,000 inhabitants annually and constitute between 9.6% and 14.7% of all upper limb injuries (McLean et al., 2019; Iglesias-Rodríguez et al., 2021; Czarnecki et al., 2024).

Epidemiological studies indicate a significant increase in the incidence of proximal humerus fractures among individuals over 50 years of age, particularly in women (Leino et al., 2022; Relvas Silva et al., 2022). In this population, most fractures are complex and displaced, with their proportion increasing as the average age of the population rises. This trend is primarily attributed to a higher likelihood of falls and progressive mineral bone density deterioration due to aging, which affects an estimated 5.5% of the EU population, contributing to an increased fracture risk (Iglesias-Rodríguez et al., 2021; Patel et al., 2021).

A study conducted in Australia (McLean et al., 2019) reported that while the incidence of proximal humerus fractures has increased, surgical treatment rates have significantly declined over the past decade, particularly among patients aged 65 and older. Consensus on the optimal treatment strategies for these fractures remains lacking, especially in elderly patients.

A significant decline in the proportion of hemiarthroplasty (from 19.3% to 3.0%), a decrease in open reduction – internal fixation (ORIF) procedures (from 76.6% to 72.6%), and a substantial increase in the use of reverse total shoulder arthroplasty (RTSA) (from 4.1% to 24.5%) indicate advancements in surgical techniques (McLean et al., 2019; Lin et al., 2022; Zheng et al., 2024). Statistical data suggest that RTSA has become a favorable choice for treating three- and four-part displaced fractures in elderly patients, resulting in superior clinical outcomes and a lower rate of revision surgery compared to other techniques used for similar indications (Du et al., 2017; Larose et al., 2022; Samborski et al., 2022). Reverse shoulder arthroplasty is now widely accepted for specific proximal humerus fractures, demonstrating long-term benefits, broader indications for traumatic injuries, and high patient satisfaction rates (Yang et al., 2024). However, the overall increase in surgical management of complex humeral fractures does not fully correspond to the rising incidence of such injuries (Iglesias-Rodríguez et al., 2021).

Surgical treatment of proximal humerus fractures is a complex intervention that is determined by many indicators and requires long-term follow-up and rehabilitation, with functional status assessments playing a crucial role in evaluating patient recovery and return to activity. Clinical outcomes are seldom determined by a single metric. Various measurement tools have been developed to critically assess surgical outcomes and functional status, including patient-reported outcome measures, which provide subjective evaluations of care quality from the patient's perspective. These standardized, condition-specific questionnaires capture unique aspects of different musculoskeletal

disorders and provide insight into patient responses to treatment. In the field of orthopedic shoulder disorders, three widely used patient-reported outcome measures for evaluating surgical outcomes are the Oxford Shoulder Instability Score (OSIS), Constant-Murley Score (CMS), and University of California, Los Angeles (UCLA) Shoulder Score (Yang et al., 2024). Additionally, the Disabilities of the Arm, Shoulder, and Hand (DASH) Score is commonly applied in this context (Louwerens et al., 2020). These scoring systems have been widely and successfully implemented in international studies and clinical settings; however, discussions on their limitations and future applications persist in the literature.

Comparative analyses have demonstrated their validity for different clinical conditions and their correlation with each other: UCLA Shoulder Score and CMS show high to very high correlation across all post-operative evaluations of rotator cuff repair and proximal humerus fracture treatment (Malavolta et al., 2018); OSIS, CMS, and UCLA Shoulder Score are strong predictors of treatment success following arthroscopic Bankart repair (Xu et al., 2020); CMS, UCLA Shoulder Score, and OSIS demonstrated nearly identical ratings at 3, 6, and 12 months after reverse shoulder arthroplasty (Yang et al., 2024).

Although these scoring systems differ in their scale ranges, their primary distinction lies in the type of information they collect. OSIS and DASH are exclusively based on patient-reported data, whereas CMS and UCLA combine clinician- and patient-reported components, allowing for both subjective and objective shoulder function assessment (Malavolta et al., 2018; Chelli et al., 2019; Louwerens et al., 2020).

CMS is a multi-point functional scale with a maximum total score of 100, representing optimal shoulder function (Vrotsou et al., 2018). It is sensitive to even minor functional changes, easy to administer, and requires minimal time. Notably, CMS is considered one of the most widely used clinician-reported tools for evaluating shoulder injuries (Pires Rodrigues et al., 2018). In Ukraine, CMS has recently become the predominant tool for assessing functional outcomes following shoulder surgery.

Based on the CMS, the Auto-Constant questionnaire was developed as an original tool for automated remote functional assessment. This self-administered tool utilizes photographs of different arm positions according to CMS guidelines (Chelli et al., 2019). It was considered more user-friendly for patients, demonstrating high correlations across major shoulder pathologies and proving valuable for daily clinical practice.

Recently, the development and implementation of modern technologies and solutions in medicine, particularly in orthopedics, have accelerated, aiming to enhance patient satisfaction and restore previous levels of daily functioning. The application of artificial intelligence in orthopedic surgery, including shoulder surgery, is being actively explored (Gupta et al., 2023).

In 2021, a new machine-learning-based tool for quantitative assessment of clinical outcomes after shoulder arthroplasty was introduced – the Shoulder Arthroplasty Smart score – along with a smartphone application providing visual instructions and automatic score calculation (Roche et al., 2021). The Shoulder Arthroplasty Smart score comprises only six input variables and improves efficiency by at least 50% compared to other shoulder function assessment tools (Roche et al., 2021). Based on the results of the analysis of the proposed assessment and its comparison with five other scales, including CMS and UCLA, conducted on clinical data from 3,667 patients undergoing shoulder joint arthroplasty with 8,104 postoperative follow-up reports, it was established that the new assessment tool has equivalent or superior validity, sensitivity, and clinical interpretability for quantifying shoulder arthroplasty outcomes compared to other scales. However, each of the analyzed assessments exhibited equally high standardized mean response and sensitivity to effect size, while the threshold values of the Shoulder Arthroplasty Smart assessment were most similar in magnitude to the CMS assessment (Roche et al., 2021). In recent years, clinical decision support tools based on machine learning and artificial intelligence have been developed. Algorithms based on the identification of the most significant characteristics enable precise determination of which patients will achieve clinical improvement , exceeding patient satisfaction threshold values, and which will not (Kumar et al., 2020, 2021; Kumar et al., 2022).

A systematic review conducted in 2024 (Karimi et al., 2024) indicates that, overall, models built using machine learning can predict 30-day postoperative complications with 90% accuracy, postoperative range of motion with over 85% accuracy, and clinical improvement in patient-reported outcomes exceeding the minimal clinically important differences with an accuracy of 93–99%. Additionally, these models can predict the duration of hospitalization, the optimal timing of surgical intervention when necessary, and hospitalization costs.

With the increasing proportion of elderly individuals in the demographic structure of Ukraine, the importance of measures for identifying and preventing risk factors for proximal humeral fractures is growing. These fractures are increasingly becoming a cause of functional limitations and reduced quality of life in older adults.

The European Society of Trauma and Emergency Surgery guidelines for proximal humeral fracture in the elderly indicate a clear trend towards reverse shoulder arthroplasty, especially in patients over 75 years of age, but evidence-based recommendations are still lacking (Wendt et al., 2021). RTSA is considered the gold standard for surgical treatment of displaced three- and four-part fractures in the elderly (Vall et al., 2022). RTSA has been shown to be associated with a lower risk of needing re-surgery (Zheng et al., 2024). At the same time, several authors believe that due to the complexity of the RTSA technique, the surgeon should have full knowledge of the fracture characteristics, available surgical treatment options, and possible complications that may arise, which may enhance patient safety and contribute to satisfactory clinical outcomes (Czarnecki et al., 2024).

To plan preventive measures, optimize treatment tailored to individual patient conditions, and establish economic models in this field, extensive epidemiological data are required, alongside objective and subjective indicators of treatment effectiveness and recovery quality. These indicators must be evaluated from the perspectives of clinicians, the healthcare system, and patient expectations, Under these circumstances, defining assessment tools capable of capturing longitudinal changes while minimizing random errors is crucial for evaluating the functional status of patients following surgical treatment for proximal humerus fractures. These tools should serve as a basis for the development of automated digital and computational systems for analyzing and predicting treatment effectiveness, as well as for designing rehabilitation strategies for the upper limb and shoulder joint.

The presented analysis of the literature data justifies selecting the CMS as the foundational tool for assessing the success of surgical treatment outcomes for proximal humeral fractures. This choice is based on expert evaluations that recognize the CMS as an objective, comprehensive, and integrative scale. It is independent of the diagnostic specifics of the disease or injury, reliable, sensitive even to minor functional changes, methodologically simple to apply, and requires minimal time investment. In the context of Ukraine, where digitalization remains limited, the CMS offers advantages as a classical model with a small number of parameters, which can be retrieved from medical records. Additionally, it holds potential for remote application within modern digital and artificial intelligence-based systems.

The objectives of the study are to assess the effectiveness of treatment for proximal humeral fractures in patients with reduced bone mineral density, depending on individual preoperative parameters, and to identify risk factors for a negative functional outcome within 12 months after surgical treatment.

Material and methods

Patients and data collection. The study performed a retrospective analysis of the outcomes of proximal humeral factures for 102 patients. This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and the Good Clinical Practice guidelines. Ethical approval was obtained from the Ethics Committee at the Sytenko Institute of Spine and Joint Pathology (Academy of Medical Science, Ukraine), approval number 191-dated 22.04.2019 and number 229-dated 20.02.2023. Prior to participation,

all patients provided written informed consent, acknowledging their voluntary participation and understanding of the study procedures, potential risks, and benefits. To ensure patient confidentiality, all personal data were anonymized and securely stored in compliance with ethical guidelines. The study complied with General Data Protection Regulation to safeguard patient privacy and medical records. For all participants, standard preoperative and postoperative protocols were followed to minimize risks, and no experimental surgical techniques were employed beyond those approved by institutional guidelines. Intraoperative and postoperative complications were recorded and managed according to established clinical protocols. No conflicts of interest were identified concerning the ethical conduct of this study.

Patients with three- or four-fragment proximal humeral fractures in the context of reduced bone mineral density underwent treatment between 2009 and 2023 at the State Institution "Specialized Multidisciplinary Hospital №1 of the Ministry of Health of Ukraine" and the Municipal Non-Profit Enterprise "State City Hospital No. 16" (Dnipro, Ukraine).

All patients underwent standard clinical and radiographic examinations. In addition to demographic data, the following preoperative parameters were recorded for each patient: affected side, time from trauma to surgery, fracture type (11-B or 11-C) according to the AO/OTA classification (Müller et al., 2012; Marongiu et al., 2020), and cortical index to assess the severity of bone density loss (den Teuling et al., 2017).

The treatment method was determined individually based on fracture type, bone density loss severity, and the general condition of the patient. Based on the treatment method, patients were divided into three groups:

– open reduction and internal fixation with a proximal humeral locking plate with angular stability (PHILOS^{TM}) (Group 1, n = 50);

– open reduction and internal fixation with a PHILOS^{TM} plate using 3D-printed porous polylactide implants (Group 2, n = 44);

– primary reverse total shoulder arthroplasty using an advanced endoprosthesis or porous elements made from titanium powder via 3D printing and novel friction pairs (Group 3, n = 8).

All surgeries were performed by the same surgeon, and the surgical techniques and procedural details are described in detail in the study (Korzh et al., 2023).

Functional outcomes were evaluated using the Constant-Murley Score (Constant & Murley, 1987; Vrotsou et al., 2018) at 3, 6, and 12 months postoperatively. Since a significant proportion of patients (81 individuals, 79.4%) underwent surgery within the first three days after injury, accurate preoperative CMS assessment was not feasible due to pain syndrome. Therefore, preoperative CMS values were not included in the subsequent analysis.

Postoperative complications, when present, were considered in the analysis; however, specific complication types were not specified. The analysis of functional outcomes based on complication type was not performed due to the small number of cases for each complication.

Statistical analysis. Categorical variables were presented as percentages, demographic data were reported as means and ranges, and quantitative assessments were expressed as mean (x) ± standard error (SE). Differences between functional outcomes assessed by the Constant-Murley Score were evaluated using Tukey's test at a significance level of $P < 0.05$, based on the results of the one-way analysis of variance (ANOVA).

Results

The primary analysis of demographic and baseline clinical data of 102 patients (Table 1) was conducted to identify variables that may influence treatment outcomes for inclusion in further analysis. Analysis was conducted to identify the relationships between functional outcomes of proximal humeral fracture treatment, assessed using the CMS, and the patient's initial data: sex, age, time between injury and surgery, affected side, cortical index, fracture type, treatment method, and presence of postoperative complications. No statistically significant differences in CMS values at 3, 6, and 12 months postoperatively were found based on sex, affected side, or time intervals between injury and surgery.

Table 1
Demographic characteristics and initial clinical data

Indicator	x ± SE, range
Age, years	61.1 ± 8.1 (45–78)
Time between injury and surgery, days	5.9 ± 13.1 (1–90)
Cortical index	0.383 ± 0.022 (0.29–0.40)
Indicator	**Number (percentage)**
Sex: female / male	78 (76.5%) / 24 (23.5%)
Affected side: right / left	78 (76.5%) / 24 (23.5%)
AO/OTA type: 11-B / 11-C	71 (69.6%) / 31 (30.4%)

To analyze the effect of age, patients were categorized into subgroups with 10-year intervals: 45–54, 55–64, and 65–78 years. The last subgroup was extended to 78 years, as there were only six patients older than 75, making it impractical to allocate them into a separate subgroup. The number of women exceeded the number of men both in the overall group and in each age subgroup (Fig. 1).

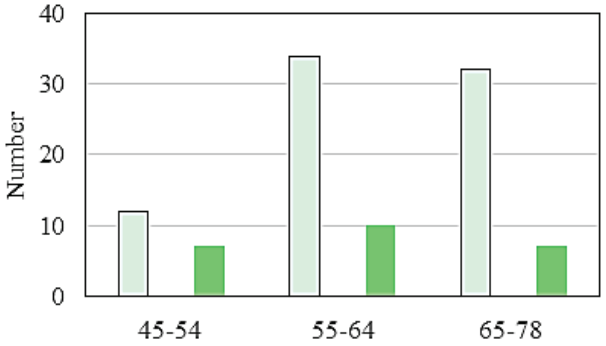

Fig. 1. Distribution of patients of different sexes by age subgroups: axis X – age range (years), axis Y – number of patients in each subgroup; light green –women, dark green – men

Functional outcomes progressively improved from 3 to 12 months postoperatively, demonstrating a consistent positive trend across all age subgroups (Fig. 2). However, for each specific time point (3, 6, and 12 months), no statistically significant differences in CMS values were found between age subgroups.

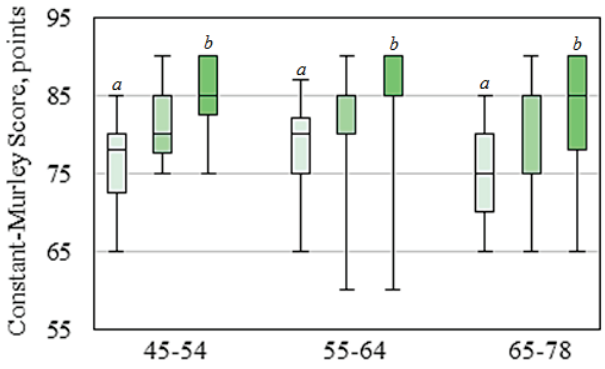

Fig. 2. Dynamics of changes in functional outcomes in patients from different age subgroups: axis X – age range (years), axis Y – Constant-Murley score; upper and lower borders of the rectangle – 25% and 75% quartiles; horizontal line within the rectangle – median; vertical line – minimum and maximum values; results at 3, 6, and 12 months post-surgery are indicated in light green, green, and dark green, respectively; different letters indicate values that were significantly different from each other within one subgroup

A statistically significant overall increase in mean CMS was observed in all subgroups as time after surgery increased from 3 to 12 months, when comparing functional treatment outcomes across subgroups with different cortical index values (Fig. 3) and fracture types according to the AO/OTA classification (Fig. 4).

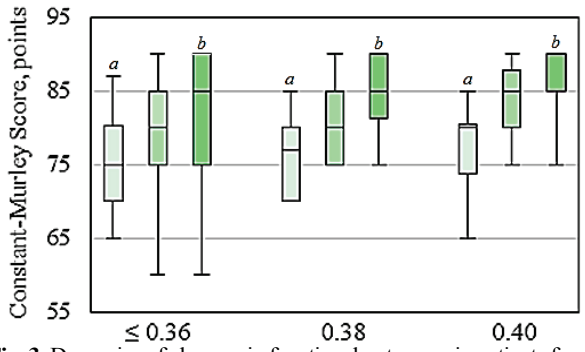

Fig. 3. Dynamics of changes in functional outcomes in patients from different cortical index subgroups; axis X– cortical index; axis Y – Constant–Murley score; upper and lower borders of the rectangle – 25% and 75% quartiles; horizontal line within the rectangle – median; vertical line – minimum and maximum values; results at 3, 6, and 12 months post-surgery are indicated in light green, green, and dark green, respectively; different letters indicate values that were significantly different from each other within one subgroup

At none of the three individual time points after injury were differences found in the mean CMS values for subgroups with similar cortical index values (0.40 and 0.38; 0.38 and ≤ 0.36). Patients with 11-B fractures according to the AO/OTA classification had significantly better mean CMS values throughout the observation period (3, 6, and 12 months) compared to patients with 11-C fractures.

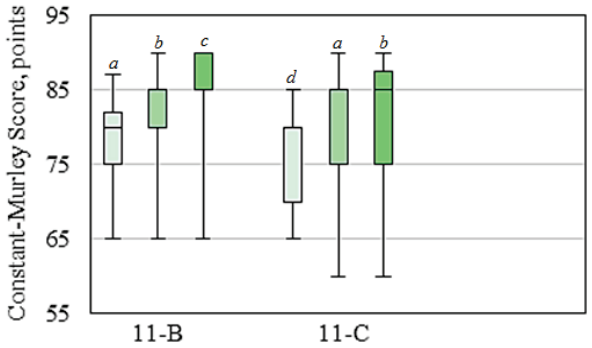

Fig. 4. Dynamics of changes in functional outcomes in patients from subgroups with two types of fracture according to the AO/OTA classification; axis X – type of fracture; axis Y – Constant-Murley score; upper and lower borders of the rectangle – 25% and 75% quartiles; horizontal line within the rectangle – median; vertical line – minimum and maximum values; results at 3, 6, and 12 months post-surgery are indicated in light green, green, and dark green, respectively; different letters indicate values that were significantly different from each other

Comparison of functional outcomes among patient groups undergoing different treatment methods for shoulder injuries (Fig. 5) revealed a significant increase in mean CMS from 3 to 12 months postoperatively. However, at each specific time point (3, 6, and 12 months), no statistically significant differences in mean CMS values were found between groups.

In the study population, 30 (29.4%) cases of various postoperative complications were recorded, including superficial infection (8 cases), secondary displacement (7 cases), varus displacement of fragments (7 cases), avascular necrosis of the humeral head (4 cases), endoprosthesis dislocation (2 cases), and screw perforation of the humeral head fragment (2 cases). All patients with avascular necrosis (all in treatment group 1) underwent metal structure removal and RTSA between 6 and 12 months after the primary surgery.

When comparing the functional outcomes of patients in subgroups with and without postoperative complications (Fig. 6), all subgroups demonstrated a significant increase in mean CMS as time after surgery progressed from 3 to 12 months. However, the subgroup of patients with complications showed significantly worse mean functional outcomes at time points 3 and 12 months.

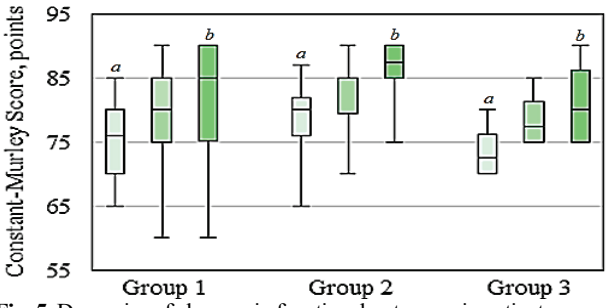

Fig. 5. Dynamics of changes in functional outcomes in patient groups undergoing different surgical treatments for proximal humerus injuries; axis X– group number; axis Y – Constant-Murley score; upper and lower borders of the rectangle – 25% and 75% quartiles; horizontal line within the rectangle – median; vertical line – minimum and maximum values; results at 3, 6, and 12 months post-surgery are indicated in light green, green, and dark green, respectively; different letters indicate values that were significantly different from each other within one group

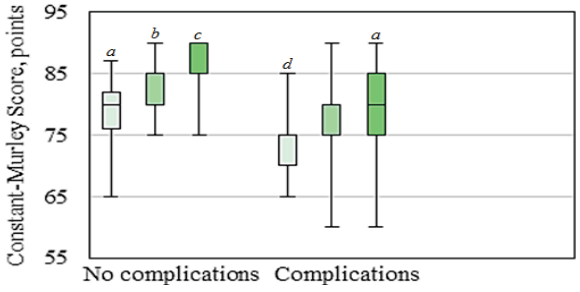

Fig. 6. Dynamics of changes in functional outcomes in patients from subgroups without and with complications: axis X – group type; axis Y – Constant-Murley score; upper and lower borders of the rectangle – 25% and 75% quartiles; horizontal line within the rectangle – median; vertical line – minimum and maximum values; results at 3, 6, and 12 months post-surgery are indicated in light green, green, and dark green, respectively; different letters indicate values that were significantly different from each other

To analyze the impact of two preoperative indicators on functional outcomes, the mean functional results 12 months after the intervention were analyzed for subgroups with different types of fractures across two ranges of cortical index for patients in the age range of 55–78 years (Fig. 7). For type 11-B fractures, the mean CMS values 12 months after the intervention were almost the same across different cortical index values and did not differ from the CMS for type 11-C fractures at cortical index values of 0.38-0.49. However, the mean CMS in the type 11-C fracture subgroup with a cortical index of ≤ 0.36 was significantly lower compared to other subgroups.

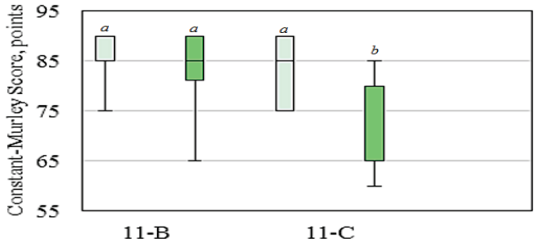

Fig. 7. Functional outcomes in patients aged 55–78 years for subgroups with two types of fractures according to the AO/OTA classification and different cortical index values at 12 months post-surgery: axis X – type of fracture; axis Y – Constant-Murley score; upper and lower borders of the rectangle – 25% and 75% quartiles; horizontal line within the rectangle – median; vertical line – minimum and maximum values; results for cortical index 0.38–0.40 are indicated in light green, while results for cortical index ≤ 0.36 are indicated in dark green; different letters indicate values that were significantly different from each other

Thus, functional outcomes, as determined by CMS, were analyzed over the 3- to 12-month postoperative period, considering various preoperative indicators (sex, age, affected side, time between injury and surgery, fracture type according to the AO/OTA classification, cortical index), treatment methods, and the presence of postoperative complications. All functional outcomes, as determined by CMS, showed statistically significant improvements at the 12-month follow-up compared to the values at 3 months postoperatively.

Discussion

Analysis of the demographic characteristics of the study group showed that the mean age of treated patients was 61.1 ± 8.1 years, while the majority of them (90 individuals, 88.2%) were over 50 years of age, which overall corresponds to the well-known global trends in the prevalence of complex proximal humeral fractures predominantly in the older age category against the background of progressive bone density loss (McLean et al., 2019; Iglesias-Rodríguez et al., 2021). The gender distribution in the group (78 females and 24 males, with females outnumbering males by a ratio of 3.25:1) aligns with epidemiological data on the prevalence of shoulder injuries: in the EU, women sustain up to two-thirds of all accidental fractures, with a 1:1 ratio of females to males up to 50 years of age, 4:1 in individuals over 50 years, and in those over 75 years, females exceed males by almost 33% (Czarnecki et al., 2024; Iglesias-Rodríguez et al., 2021; Patel et al., 2021).

Similar to other published results, which highlight the absence of bias in CMS regarding age, sex, race, or ethnicity (Iglesias-Rodríguez et al., 2021; Roche et al., 2021), no statistically significant differences in CMS values were found in this study with respect to age (within the available group range of 45–78 years with a mean of 61.1 years), as well as gender and affected side, both in the analysis of the entire sample and when stratified by age. However, these results, obtained based on available data within a limited age range, do not provide grounds to either assume or refute a possible relationship between the functional outcomes of patients with complex proximal humeral fractures and their age.

The mean functional status scores of patients showed a consistent positive trend from 3 to 12 months postoperatively, irrespective of preoperative indicators, treatment method, or the presence of postoperative complications (Fig. 2–6).

Numerous contemporary medical publications focus on the treatment of proximal humeral fractures. However, it has proven difficult to find studies comparable to the present one in terms of a combination of features: surgical treatment results of patients with proximal humeral fractures over 50 years of age, with more than 100 patients treated by a single surgeon in the group, three- and four-part fractures, a postoperative follow-up period of at least 12 months, evaluation of results using the CMS scale, and available data on the rate of postoperative complications. Existing recent publications on the results of such surgical treatment vary considerably in terms of the number of patients, their age and demographic composition, the proportions of different types of fractures, the duration of postoperative follow-up, and the scales used for evaluating functional outcomes.

A qualitative assessment of the success of the treatment can be obtained, in particular, by comparing the results with the CMS scores, which are indicated as significant improvements relative to the initial assessment at 24 months after surgical treatment of rotator cuff tears (85.0 ± 12.0) and radial head fractures (73.8 ± 13.9) (Malavolta et al., 2018). The results obtained in the study fit within these limits.

Regarding the rate of postoperative complications, the literature reports that for similar types of interventions, namely for proximal humeral fractures treated with open reduction and internal fixation in patients over 60 years of age, the overall complication rate is 44%, with a tendency towards an increased frequency of complications in elderly patients and in more complex fractures (Barlow et al., 2020). Other authors (depending on the surgical treatment method) report complication rates of 42.6% (Czarnecki et al., 2024), 23.3% for ORIF and 10.3% (Alrabaa et al., 2022), 12.1% (Dolci et al., 2021) for RTSA, and the proportion of patients with avascular necrosis 4% (Czarnecki et al., 2024). Thus, the obtained rate of postoperative complications is consistent with the results of other studies. The CMS scores for patients with complications (Fig. 6) indicate functional improvement 12 months postoperatively.

With the rapid advancement of surgical methods, recent literature highlights the growing importance of patient involvement in treatment decisions, emphasizing the necessity of assessing treatment effectiveness not only through traditional scales but also from the patient's perspective (Xu et al., 2020). It is considered that for the critical assessment of any observed differences in treatment, it is not sufficient to use only clinical indicators – although changes in scores may be statistically significant, they may not be significant from the patients' perspective (Yang et al., 2024).

The concept of threshold scores has been introduced – absolute cutoff values in specific outcome measures with high sensitivity and specificity for determining patient-perceived treatment success; a score equal to or exceeding the threshold indicates treatment success, whereas a score below the threshold indicates unsuccessful treatment from the patients' perspective (Xu et al., 2020). Such an evaluation relates to the maximally acceptable level of symptoms when patients feel well, thus allowing surgeons to interpret treatment effectiveness, and its value can be used in comparative studies (Yang et al., 2024).

Threshold scores have been reported for arthroscopic Bankart repair; the indicators depend on time, with a higher score required to achieve treatment success at longer follow-up: 6 months CMS 68, 12 months CMS 84 (Xu et al., 2020). In a study that included data from 87 patients, threshold values for reverse total shoulder arthroplasty at 3, 6, and 12 months were determined at CMS levels of 42, 39, and 52, respectively; these thresholds suggest increasing expectations with a trend towards higher functional requirements at each time point (Yang et al., 2024). The results in Fig. 2-6 show that the mean CMS values in the study were higher than those reported in the literature, especially at 12 months after surgery.

As already noted, the European Society of Trauma and Emergency Surgery guidelines for proximal humeral fracture in the elderly tend to indicate reverse shoulder arthroplasty, especially in patients over 75 years of age (Wendt et al., 2021).

In the present study, the reverse total shoulder arthroplasty method was applied in Group 3, which included 6 (75%) patients with type 11-C fractures. The mean functional outcomes recorded in this group after 12 months of follow-up (Fig. 5) showed no statistically significant differences from those of other treatment groups, confirming the effective choice of treatment method according to the fracture type, the degree of bone density decrease, and the patient's condition, as well as the successfully performed intervention and rehabilitation.

Analysis of the results of patients in groups with different treatment methods allows us to propose a differentiated approach to the choice of surgical treatment for patients with 11-B, 11-C type fractures, according to which ORIF is considered possible and necessary for 11-B, 11-C type fractures, cortical index = 0.4; for 11-B, 11-C type fractures, cortical index < 0.4 ORIF is possible, with the mandatory use of 3D porous polylactide implants as a reinforcing material; for 11-C type fractures; cortical index ≤ 0.36, if stable ORIF is technically impossible, primary reverse total arthroplasty is necessary.

The initial use of RTSA in cases of 11-B, 11-C type fractures and when ORIF was technically impossible allowed positive results to be obtained in 75% of patients with a mean CMS score in the subgroup (81.2 ± 6.4) at 6 to 12 months after surgery, with restoration of shoulder joint function in the absence of signs of instability of the endoprosthesis components. However, a limitation of this study is the relatively small number of patients undergoing RTSA, preventing a quantitative analysis of key risk factors for postoperative complications associated with this treatment method.

Some of the observed associations between CMS and preoperative indicators may reflect intuitively evident patterns for experienced clinicians, indicating poorer functional outcomes in older individuals with greater bone mineral density loss compared to younger patients with higher cortical index values. At the same time, the identified dependencies characterize CMS as a reliable and predictable tool that does not produce "outliers" or unexpected results.

The analysis of CMS values for the combination of two individual preoperative indicators – fracture type and cortical index (Fig. 7) – and, in particular, the significantly lower functional outcomes at a cortical index ≤ 0.36 in type 11-C fractures compared to other preoperative indicator values for patients in the age range of 55–78 years, provides grounds for considering fracture type and cortical index as candidates for risk factors for a negative functional outcome within 12 months after surgical treatment. The combination in elderly patients of a cortical index ≤ 0.36 with type 11-C fractures requires special attention from the physician regarding the choice of an effective treatment method and postoperative rehabilitation conditions.

This approach aligns with findings from a study involving 472 patients (mean age 68 years), where machine learning most accurately predicted postoperative improvement after shoulder arthroplasty, particularly when morphological changes associated with reduced bone mineral density were incorporated into the analysis, indicating that structural pathology is critical for optimizing the outcomes of shoulder arthroplasty (McLendon et al., 2021).

Thus, the functional outcomes of patients following surgical treatment for proximal humeral fractures, as determined by the CMS score, enable assessment and comparison of treatment dynamics and effectiveness over 12 months of postoperative recovery, considering individual preoperative parameters such as cortical index and fracture type. The results also allow to determine the potential impact on the outcome of both individual preoperative indicators and their combinations, as well as to assess the impact of postoperative complications.

However, this study is limited by the amount of data to establish not only a qualitative but also a defined quantitative relationship between the initial patient condition data, depending on the type of proximal humeral fracture and cortical index, and functional status indicators at a certain time after surgery. In addition, this study did not take into account the possible connection between the factors – since lower bone density can not only influence the choice of surgical intervention method and the dynamics of functional recovery, but also to a large extent determine the type of fracture in terms of complexity. Thus this issue also requires further research.

The authors believe that the CMS scale can serve as a basis for developing a digital tool for assessing and predicting the success of treatment for proximal humeral fractures when designing a differentiated surgical treatment strategy for shoulder joint injuries. Considering the possibilities outlined in the literature for the convenient adaptation and transfer of the assessment process to a mobile patient device, CMS indicators may be recommended for longitudinal self-assessment without additional and excessive radiological examinations. The development and implementation of such approaches can free up additional resources, particularly in logistics, to improve the efficiency of surgical fracture treatment, especially in elderly patients.

The development of such a tool is crucial for improving the quality of medical care and objectively evaluating patient outcomes in the long-term under conditions of limited healthcare system resources. Such efficiency assessments require the application of metrics that are both convenient for determination and suitable for use in data processing and analysis systems based on big data technologies. This will create opportunities for generating large observational samples, making it possible to achieve a more accurate prediction of rehabilitation effectiveness under multiple influencing factors using modern machine learning and artificial intelligence technologies. Additionally, it will help identify reliable predictors among preoperative factors and surgical interventions. Such findings can be applied across a wide range of fields, from assessing the value of clinical treatment to managing national healthcare systems.

Conclusion

Given the increasing prevalence of humeral fractures in the elderly and their impact on the healthcare system in Ukraine, identifying factors that can enhance the functional outcomes of surgical treatment is crucial.

For 102 patients (mean age 61.1 ± 8.1 years) with proximal humeral fractures associated with decreased bone mineral density, an analysis of functional treatment outcomes was conducted. The outcomes were assessed using the Constant-Murley Score at 3, 6, and 12 months postoperatively. These improvements were observed regardless of individual preoperative parameters (sex, age, side of injury, time between trauma and surgery, fracture type according to the AO/OTA classification, cortical index), treatment methods, or the presence of postoperative complications.

Further research involving larger cohorts of elderly patients with reduced bone mineral density and three- or four-part displaced fractures after RTSA is necessary to establish quantitative correlations between preoperative factors and functional outcomes.

The development of a digital tool based on the CMS scale for assessing and predicting treatment success in proximal humerus fractures holds promise for establishing a strategy for differentiated surgical treatment of shoulder joint injuries, leveraging modern machine learning and artificial intelligence technologies.

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The authors declare that there are no conflicts of interest related to this study.

References

Alrabaa, R. G., Ma, G., Truong, N. M., Lansdown, D. A., Feeley, B. T., Zhang, A. L., & Ma, C. B. (2022). Trends in surgical treatment of proximal humeral fractures and analysis of postoperative complications over a decade in 384,158 patients. The Journal of Bone and Joint Surge, 7(4), e22.00008.

Barlow, J. D., Logli, A. L., Steinmann, S. P., Sems, S. A., Cross, W. W., Yuan, B. J., Torchia, M. E., & Sanchez-Sotelo, J. (2020). Locking plate fixation of proximal humerus fractures in patients older than 60 years continues to be associated with a high complication rate. Journal of Shoulder and Elbow Surgery, 29(8), 1689–1694.

Chelli, M., Levy, Y., Lavoué, V., Clowez, G., Gonzalez, J.-F., & Boileau, P. (2019). The "auto-constant": Can we estimate the Constant-Murley score with a self-administered questionnaire? A pilot study. Orthopaedics and Traumatology: Surgery and Research, 105(2), 251–256.

Constant, C. R., & Murley, A. H. (1987). A clinical method of functional assessment of the shoulder. Clinical Orthopaedics and Related Research, (214), 160–164.

Czarnecki, P., Falis, M., Bonczar, M., Ostrowski, P., Wcisłek, J., & Romanowski, L. (2024). Assessing complications and functional outcomes in proxymal humerus fracture management: A retrospective comparison between conservative and intramedullary nailing treatments. European Journal of Orthopaedic Surgery and Traumatology: Orthopedie Traumatologie, 34(3), 1427–1433.

den Teuling, J. W. A. M., Pauwels, B. S., Janssen, L., Wyers, C. E., Janzing, H. M. J., van den Bergh, J. P. W., & Morrenhof, J. W. (2017). The influence of bone mineral density and cortical index on the complexity of fractures of the proximal humerus. Bone and Joint Research, 6(10), 584–589.

Dolci, A., Melis, B., Verona, M., Capone, A., & Marongiu, G. (2021). Complications and intraoperative fractures in reverse shoulder arthroplasty: A systematic review. Geriatric Orthopaedic Surgery and Rehabilitation, 12, 21514593211059865.

Du, S., Ye, J., Chen, H., Li, X., & Lin, Q. (2017). Interventions for treating 3- or 4-part proximal humeral fractures in elderly patient: A network meta-analysis of randomized controlled trials. International Journal of Surgery, 48, 240–246.

Gupta, P., Marigi, E. M., & Sanchez-Sotelo, J. (2023). Research on artificial intelligence in shoulder and elbow surgery is increasing. Journal of Shoulder and Elbow Surgery International, 7(1), 158–161.

Iglesias-Rodríguez, S., Domínguez-Prado, D. M., García-Reza, A., Fernández-Fernández, D., Pérez-Alfonso, E., García-Piñeiro, J., & Castro-Menéndez, M. (2021). Epidemiology of proximal humerus fractures. Journal of Orthopaedic Surgery and Research, 16(1), 402.

Karimi, A. H., Langberg, J., Malige, A., Rahman, O., Abboud, J. A., & Stone, M. A. (2024). Accuracy of machine learning to predict the outcomes of shoulder arthroplasty: A systematic review. Arthroplasty, 6(1), 26.

Korzh, M., Makarov, V., Gupalov, I., Pertseva, O., Boyko, K., & Pidgaiska, O. (2023). Results of a differential approach to surgical treatment of proximal humerus fractures in patients with osteoporosis. Orthopaedics, Traumatology and Prosthetics, 3–4, 13–21.

Kumar, V., Allen, C., Overman, S., Teredesai, A., Simovitch, R., Flurin, P.-H., Wright, T., Zuckerman, J., Routman, H., & Roche, C. (2022). Development of a predictive model for a machine learning – derived shoulder arthroplasty clinical outcome score. Seminars in Arthroplasty: Journal of Shoulder and Elbow Surgery, 32(2), 226–237.

Kumar, V., Roche, C., Overman, S., Simovitch, R., Flurin, P. H., Wright, T., Zuckerman, J., Routman, H., & Teredesai, A. (2020). What is the accuracy of three different machine learning techniques to predict clinical outcomes after shoulder arthroplasty? Clinical Orthopaedics and Related Research, 478(10), 2351–2363.

Kumar, V., Roche, C., Overman, S., Simovitch, R., Flurin, P.-H., Wright, T., Zuckerman, J., Routman, H., & Teredesai, A. (2021). Using machine learning to predict clinical outcomes after shoulder arthroplasty with a minimal feature set. Journal of Shoulder and Elbow Surgery, 30(5), e225–e236.

Larose, G., & Virk, M. S. (2022). The evolution of reverse total shoulder arthroplasty and its current use in the treatment of proximal humerus fractures in the older population. Journal of Clinical Medicine, 11(19), 5832.

Leino, O. K., Lehtimäki, K. K., Mäkelä, K., Äärimaa, V., & Ekman, E. (2022). Proximal humeral fractures in Finland: trends in the incidence and methods of treatment between 1997 and 2019. The Bone and Joint Journal, 104-B(1), 150–156.

Lin, C. C., Karlin, E., Boin, M. A., Dankert, J. F., Larose, G., Zuckerman, J. D., & Virk, M. S. (2022). Operative treatment of proximal humeral fractures with reverse total shoulder arthroplasty in patients ≥65 years old: a critical analysis review. The Journal of Bone and Joint Surgery. Reviews, 10(5), e21.00245.

Louwerens, J. K. G., van den Bekerom, M. P. J., van Royen, B. J., Eygendaal, D., van Noort, A., & Sierevelt, I. N. (2020). Quantifying the minimal and substantial clinical benefit of the Constant-Murley score and the disabilities of the arm, shoulder and hand score in patients with calcific tendinitis of the rotator cuff. Journal of Shoulder and Elbow Surgery International, 4(3), 606–611.

Malavolta, E. A., Assunção, J. H., Gracitelli, M. E. C., Simões, P. A. A., Shido, D. K., & Ferreira Neto, A. A. (2018). Correlation between the UCLA and Constant-Murley scores in rotator cuff repairs and proximal humeral fractures osteosynthesis. Revista Brasileira de Ortopedia, 53(4), 441–447.

Marongiu, G., Leinardi, L., Congia, S., Frigau, L., Mola, F., & Capone, A. (2020). Reliability and reproducibility of the new AO/OTA 2018 classification system for proximal humeral fractures: a comparison of three different classification systems. Journal of Orthopaedics and Traumatology, 21(1), 4.

McLean, A. S., Price, N., Graves, S., Hatton, A., & Taylor, F. J. (2019). Nationwide trends in management of proximal humeral fractures: An analysis of 77,966 cases from 2008 to 2017. Journal of Shoulder and Elbow Surgery, 28(11), 2072–2078.

McLendon, P. B., Christmas, K. N., Simon, P., Plummer, O. R., Hunt, A., Ahmed, A. S. Mighell, M. A., & Frankle, M. A. (2021). Machine learning can predict level of improvement in shoulder arthroplasty. The Journal of Bone and Joint Surgery Open Access, 6(1), e20.00128.

Müller, M. E., Koch, P., Nazarian, S., & Schatzker, J. (2012). The comprehensive classification of fractures of long bones. Springer Berlin, Heidelberg.

Patel, A. H., Wilder, J. H., Ofa, S. A., Lee, O. C., Savoie, F. H., 3rd, O'Brien, M. J., & Sherman, W. F. (2021). Trending a decade of proximal humerus fracture management in older adults. Journal of Shoulder and Elbow Surgery International, 6(1), 137–143.

Pires Rodrigues, G. A., Vuistiner, P., Konzelmann, M., Léger, B., Burrus, C., & Luthi, F. (2018). Are psychological factors associated with the 4 components of the Constant–Murley score? Annals of Physical and Rehabilitation Medicine, 61, e140–e141.

Relvas Silva, M., Linhares, D., Leite, M. J., Nunes, B., Torres, J., Neves, N., & Ribeiro Silva, M. (2022). Proximal humerus fractures: epidemiology and trends in surgical management of hospital-admitted patients in Portugal. Journal of Shoulder and Elbow Surgery International, 6(3), 380–384.

Roche, C., Kumar, V., Overman, S., Simovitch, R., Flurin, P. H., Wright, T., Routman, H., Teredesai, A., & Zuckerman, J. (2021). Validation of a machine learning-derived clinical metric to quantify outcomes after total shoulder arthroplasty. Journal of Shoulder and Elbow Surgery, 30(10), 2211–2224.

Samborski, S. A., Haws, B. E., Karnyski, S., Soles, G., Gorczyca, J. T., Nicandri, G., Voloshin, I., & Ketz, J. P. (2022). Outcomes for type C proximal humerus fractures in the adult population: comparison of nonoperative treatment, locked plate fixation, and reverse shoulder arthroplasty. Journal of Shoulder and Elbow Surgery International, 6(5), 755–762.

Vall, M., Natera, L., Witney-Lagen, C., Imam, M. A., Narvani, A. A., Sforza, G., Levy, O., Relwani, J., & Consigliere, P. (2022). Reverse shoulder replacement versus hemiarthroplasty for proximal humeral fracture in elderly patients: A systematic review. Musculoskeletal Surgery, 106(4), 357–367.

Vrotsou, K., Ávila, M., Machón, M., Mateo-Abad, M., Pardo, Y., Garin, O., Zaror, C., González, N., Escobar, A., & Cuéllar, R. (2018). Constant–Murley Score: Systematic review and standardized valuation in different shoulder pathologies. Quality of Life Research, 27(9), 2217–2226.

Wendt, K. W., Jaeger, M., Verbruggen, J., Nijs, S., Oestern, H. J., Kdolsky, R., & Komadina, R. (2021). ESTES recommendations on proximal humerus fractures in the elderly. European Journal of Trauma and Emergency Surgery, 47(2), 381–395.

Xu, S., Chen, J. Y., Hao, Y., Chang, C. C. P., & Lie, D. T. T. (2020). Threshold scores for treatment success after arthroscopic bankart repair using Oxford Shoulder Instability Score, Constant-Murley Score, and UCLA shoulder score. Journal of Orthopaedics, 22, 242–245.

Yang, C., Yang, A. Z., Xu, S., Yew, A., & Lie, D. T. T. (2024). Determining patient acceptable symptom states from patient reported outcome measures following reverse shoulder arthroplasty: Constant-Murley, UCLA, Oxford Shoulder Scores. Journal of Orthopaedics, 54, 143–147.

Zheng, Y., Tang, N., Zhang, W. J., Shi, W., Zhao, W. W., & Yang, K. (2024). Comparative efficacy and safety of medical treatments for proximal humerus fractures: A systematic review and network meta-analysis. BMC Musculoskeletal Disorders, 25(1), 17.