



## Complications of total elbow arthroplasty: experience with 622 cases and implant developments

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### Abstract

**Introduction** Total elbow arthroplasty (TEA) is increasingly used for the treatment of advanced elbow conditions with the rate of adverse events after surgery being high.

The **objective** was to analyze the spectrum and causes of complications following TEA depending on the biomechanical implant design and evaluate the effect of humeral trochlear resection on hand grip strength.

**Material and methods** A retrospective non-randomized cohort study of 622 primary and revision TEA procedures was performed between 2002 and 2025. Depending on the biomechanical principle of implant fixation, patients were stratified into two groups to include constrained implants (ESI,  $n = 404$ ) and semi-constrained implants (Zimmer Coonrad – Morrey, Conmet, Treza, Logeeks,  $n = 218$ ). Clinical and radiological data, intraoperative findings during revisions, and instrumented dynamometry results ( $n = 80$ ) were analyzed preoperatively and at 6 weeks of surgery. Statistical analysis was performed using non-parametric tests (Mann – Whitney U, Wilcoxon, Chi-square).

**Results** The overall complication rate was 7.0 % (44/622). Aseptic loosening of TEA was more common for constrained implants (4.5 %, 18/404) due to stress concentration at the bone-cement interface. Mechanical failure of the hinge joint/polyethylene wear (3.2 %, 7/218) was the leading cause of revision in the semi-constrained group. Resection of the humeral trochlea had no clinically significant effect on hand and pinch grip strength ( $p > 0.05$ ).

**Discussion** Existing TEA constructs exhibit a predictable complication profile directly related to their biomechanical design. Optimizing outcomes is associated with advanced surgical techniques and a transition to new-generation implants considering the complex three-dimensional kinematics of the joint and providing balanced load transfer with a reinforced, wear-resistant hinge system.

**Conclusion** The complication profile after TEA was implant dependent. Constrained systems could predispose to aseptic loosening, and semi-constrained systems can be associated with fatigue wear of the hinge. Trochlear resection did not compromise the hand strength. Future implant developments should focus on optimization of controlled varus-valgus laxity (5–7°), reinforcing the hinge coupling mechanism, considering the anatomical torsion of the distal humerus.

**Keywords:** elbow joint, total elbow arthroplasty, complications, revision arthroplasty, biomechanics, implant design

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## INTRODUCTION

Total elbow arthroplasty (TEA) is the surgery of choice for patients with severe rheumatoid arthritis, posttraumatic arthrosis, and distal humeral fractures unsuitable for reconstruction, allowing for pain relief and restoration of limb function [1, 2, 3]. Severe rheumatoid arthritis with persistent loss of joint function and pain was traditionally the main indication for TEA. Over time, TEA has become a treatment option for severe comminuted distal humeral fractures in the elderly thanks to improvements in prosthetic designs and surgical techniques. Kholinne et al. reported in the meta-analysis that 71.7 % of TEA patients were over 70 years of age [4, 5, 6]. The functional and clinical results of TEA, the survival rate of implants in post-traumatic patients are statistically significantly better than in patients who underwent this type of surgical intervention for rheumatoid arthritis [5, 7, 8]. With more than a half-century of development, the frequency of complications and revision interventions after TEA, according to the world literature, reaches 20-40 %, which is significantly higher than similar indicators for hip and knee arthroplasty [9, 10, 11, 12, 13, 14].

TEA implant designs have evolved from unconstrained to constrained and semi-constrained systems. Constrained implants, primarily providing maximum stability, are unable to withstand torsional and bending force changes, leading to stress concentration at the bone-cement-prosthesis interface and, consequently, to aseptic loosening. Semi-constrained constructs, offering some mobility at the hinge, are designed to reduce the loads; however, the insufficient mechanical strength of the joint is the vulnerable point [15, 16, 17]. Humeral trochlea is commonly resected in cases of severe post-traumatic or rheumatoid defects of the distal humerus, in correction of persistent flexion contractures to achieve sufficient range of motion and proper component placement. This manipulation inevitably alters the attachment points of the collateral ligaments and stabilizer muscles, which can potentially impact the biomechanics of the hand grip. There are conflicting data in the literature regarding the impact of trochlear resection on functional outcome. Some authors report a decrease in grip strength post-op [18], which can critically limit patients' daily activities. Maintaining intact tendon-muscle complexes objective evidence of clinically significant impairment of hand strength remains insufficient, and assessment methodology varies between studies.

With the clinical significance of a strong grip for patients' quality of life, its relationship with the extent of bone resection and the type of implanted device has been insufficiently studied. Therefore, an analysis of the complication rate depending on implant design, an objective assessment of the impact of humeral trochlea resection on hand strength, are relevant issues in modern orthopedics [19, 20, 21, 22, 23].

The **objective** was to analyze the spectrum and causes of complications following TEA depending on the biomechanical implant design and evaluate the effect of humeral trochlear resection on hand grip strength.

## MATERIAL AND METHODS

A retrospective, non-randomized cohort study was conducted at the Tsivyan Novosibirsk Research Institute of Traumatology and Orthopedics. Outcomes of 622 primary and revision TEA surgeries performed between 2002 and 2025 were reviewed. Patients were divided into two groups based on the biomechanical fixation principle of the implanted constructs:

- group of constrained systems ( $n = 404$ ): ESI endoprosthesis (Russia), Fig. 1 a;
- a group of semi-constrained systems ( $n = 218$ ): combined cohort, including:
  - Zimmer Coonrad – Morrey endoprotheses (Zimmer Biomet, USA), Fig. 1 b;
  - Conmet (Russia), Fig. 1 c;
  - Treza (Russia) and Logeeks (Russia), Fig. 1 d.



**Fig. 1** Elbow joint implants: ESI (a); Zimmer Coonrad – Morrey Total Elbow (b); Conmet (c); Logeeks (d)

Russian analogues (Conmet, Treza, Logeeks) combined into a single subgroup are characterized by identical design principle (the presence of varus-valgus play in the hinge joint of 5–7°) and insufficient sample power for pairwise statistical comparison of each model ( $n < 30$  for Conmet, Treza, and Logeeks separately).

The clinical and demographic characteristics of the patients are presented in Table 1. Statistical analysis suggested the comparability of the groups by gender, age, observation period, and nosological structure ( $p > 0.05$ ), which minimizes the influence of covariates on the assessment of the frequency and nature of complications.

Table 1

Clinical and demographic characteristics of patients

| Description                            |                                                  | All patients ( $n = 622$ ) |      | Constrained systems ( $n = 404$ ) |      | Semi-constrained systems ( $n = 218$ ) |      | $p$   |
|----------------------------------------|--------------------------------------------------|----------------------------|------|-----------------------------------|------|----------------------------------------|------|-------|
| Age, years, Me [Q1; Q3]                |                                                  | 61.0 [52; 71]              |      | 61.5 [53; 72]                     |      | 59.0 [50; 69]                          |      | 0.312 |
| Observation period, years, Me [Q1; Q3] |                                                  | 7.2 [4.1; 11.5]            |      | 9.5 [5.8; 14.2]                   |      | 4.8 [2.3; 7.9]                         |      | 0.184 |
|                                        |                                                  | abs.                       | %    | abs.                              | %    | abs.                                   | %    |       |
| Gender                                 | Male                                             | 199                        | 32,0 | 106                               | 26.2 | 93                                     | 42.7 | 0.415 |
|                                        | Female                                           | 423                        | 68,0 | 298                               | 73.8 | 125                                    | 57.3 |       |
| Nosology                               | Post-traumatic arthrosis                         | 280                        | 45.0 | 179                               | 44.3 | 101                                    | 46.3 | 0.682 |
|                                        | Rheumatoid arthritis                             | 236                        | 38.0 | 123                               | 30.4 | 113                                    | 51.8 |       |
|                                        | Acute comminuted fractures of the distal humerus | 75                         | 12.1 | 71                                | 17.6 | 4                                      | 1.8  |       |
|                                        | Other conditions                                 | 31                         | 4.9  | 31                                | 7.7  | 0                                      | 0.0  |       |

Note: Me is the median, [Q1; Q3] is the interquartile range;  $p$  is the level of statistical significance (Mann–Whitney test for quantitative variables, Pearson  $\chi^2$  or Fisher's exact test for qualitative variables).

### ***Surgical technique and intraoperative protocol***

Surgical procedures were performed through a standard posterior approach with preservation or re-fixation of the triceps tendon [24, 25]. Constrained ESI was implanted through the triceps tendon and the preserved attachment to the olecranon process provided sufficient visualization for the installation and assembly of components in the wound to allow for early function without additional re-fixation.

Semi-constrained systems were implanted through expanded access creating additional medial and lateral "windows" for visual control of the collet installation and the hinge mechanism axis. The triceps tendon was temporarily dissected in some Logeeks cases to be followed by transosseous re-fixation and adherence to a gentle orthopedic regimen early post-op.

Ulnar nerve management was based on the initial clinical status. In primary TEA, the ulnar nerve was not isolated to preserve the vascularity and anatomical relationship with surrounding tissues. Revision procedures involved decompression performed by opening the aponeurotic membrane without complete mobilization. Total ulnar nerve isolation using traction devices was used exclusively for newly diagnosed neuropathy.

### ***Methods of diagnosis and verification of complications***

Verification of postoperative complications was based on a comprehensive analysis of the clinical manifestations, standard radiography with two views, and multislice computed tomography (MSCT). The radiographic criteria for aseptic loosening included:

- progressive areas of radiolucency > 2 mm at the bone-cement-implant interface involving the entire fixation zone of the component;
- migration, subsidence, or change in the inclination angle of components;
- fracture or avulsion of the cement mantle;
- periprosthetic osteolysis: localized areas of bone resorption associated with a reaction to wear particles;
- periprosthetic fractures, which are a cause or consequence of instability;
- mechanical failure of the structure (liner wear, axle breakage, hinge dissociation).

Intraoperative assessments during revision interventions included:

- the degree of wear of the polyethylene liner;
- the integrity of the hinge locking mechanism;
- the stability of the stem fixation;
- the condition of the cement mantle;
- the nature of the bone bed.

### ***Evaluation of functional results (dynamometry)***

Instrumentation dynamometry was performed in a subset of patients ( $n = 80$ ) to objectively assess the impact of humeral trochlea resection on hand function. Wrist grip strength (wrist dynamometer) and pinch grip strength (pinch dynamometer) were measured on the dominant and non-dominant limbs. The study was performed preoperatively and at six weeks to allow primary soft tissue healing to be completed, a stable scar to be formed, and safe functional loading to be performed.

### ***Ethical Standards***

The study was approved by the Local Ethics Committee of the Ya.L. Tsivyan Novosibirsk Research Institute of Traumatology and Orthopedics of the Russian Ministry of Health (extract No. 014/25 from protocol No. 006/25 dated September 5, 2025). All patients signed informed voluntary consent to participate in the study and process their personal data.

### ***Statistical analysis***

Data processing was performed using the SPSS v.26 / R v.4.2 software. The normality of distribution of quantitative variables was assessed using the Shapiro – Wilk test. Due to the absence of a normal distribution, comparison of independent samples was performed using the nonparametric Mann – Whitney test, and the Wilcoxon test was employed for paired measurements (dynamics before/after surgery). Qualitative variables were compared using Fisher's exact test or Pearson's  $\chi^2$  test. The results are presented as median and interquartile range [Q1; Q3], absolute ( $n$ ) and relative (%) frequencies. Differences were considered statistically significant at a significance level of  $p < 0.05$ .

## RESULTS

In a cohort of 622 TEA procedures performed, 44 cases of various complications were identified in the late postoperative period, accounting for 7.0 % of the total number of procedures. Analysis of adverse outcomes demonstrated a direct correlation between the nature and frequency of complications and the biomechanical principle of the implanted device.

*The nature of complications in the group of constrained systems (Fig. 2)*

Revision interventions were required in 29 cases (7.2 %) who underwent ESI implantation ( $n = 404$ ). Poor results were caused by aseptic loosening of the components, recorded in 18 patients (4.5 %), mainly at the site of the humeral component. Biomechanically, this is due to the complete coupling of the system with the physiological torsional and varus-valgus loads being transferred directly to the bone-cement interface, initiating periprosthetic osteolysis and loss of fixation stability (malignant osteolysis). Other adverse events in this group included fatigue fracture of the metal hinge axis ( $n = 3$ ; 0.7 %); deep tissue periprosthetic infection ( $n = 3$ ; 0.7 %); ulnar nerve neuropathy ( $n = 3$ ; 0.7 %); Periprosthetic fracture ( $n = 1$ ; 0.2 %). No cases of dislocation or dissociation of the hinge were recorded, suggesting the high primary stability of the constrained construct; however, this was associated with an increased risk of aseptic instability.



**Fig. 2** Radiographs of the elbow joint, complications of ESI implant: (a) malignant osteolysis; (b) destruction of the hinge joint

*Complications in the group of semi-constrained systems (Fig. 3)*

Patients with semi-constrained implants (Zimmer Coonrad – Morrey, Conmet, Treza, Logeeks;  $n = 218$ ) developed 15 adverse events (6.9 %). Revisions ( $n = 7$ ; 3.2 %) were caused by mechanical failure of the articulation unit including critical wear of the polyethylene liner or fatigue fracture of the locking mechanism leading to dissociation of the hinge. Aseptic loosening of the components was detected in five patients (2.3 %). Other complications included periprosthetic joint infection ( $n = 1$ ;



**Fig. 3** Broken hinge of the Zimmer Coonrad – Morrey implant

0.5 %), periprosthetic fracture ( $n = 1$ ; 0.5 %), and ulnar nerve injury ( $n = 1$ ; 0.5 %). Due to insufficient sample power for each individual model of domestic semi-constrained implants (Conmet, Treza, Logeeks;  $n < 10$ ), statistical analysis was performed for the combined subgroup. One case of aseptic loosening and two cases of hinge mechanism failure were recorded in the cohort.

The complication rate in the Zimmer Coonrad – Morrey group was consistent with global rates for this design. The exact absolute and relative values for each type of complication are presented in Table 2.

Table 2

Complications in the Zimmer Coonrad – Morrey group

| Type of complication         | ESI  |     | Coonrad – Morrey |     | Conmet / Trez / Logeeks |     | Total |     |
|------------------------------|------|-----|------------------|-----|-------------------------|-----|-------|-----|
|                              | abs. | %   | abs.             | %   | abs.                    | %   | abs.  | %   |
| Aseptic loosening            | 18   | 4.5 | 4                | 1.8 | 1                       | 0.4 | 23    | 3.7 |
| Destruction/wear of the lock | 3    | 0.7 | 5                | 2.3 | 2                       | 0.8 | 10    | 1.6 |
| PJI                          | 3    | 0.7 | 0                | 0.4 | 0                       | 0.0 | 3     | 0.5 |
| Periprosthetic fracture      | 3    | 0.7 | 1                | 0.4 | 0                       | 0.0 | 4     | 0.6 |
| Ulnar neuropathy             | 1    | 0.3 | 1                | 0.4 | 0                       | 0.0 | 2     | 0.3 |
| Triceps tendon reinsertion   | 1    | 0.3 | 0                | 0.0 | 1                       | 0.4 | 2     | 0.3 |

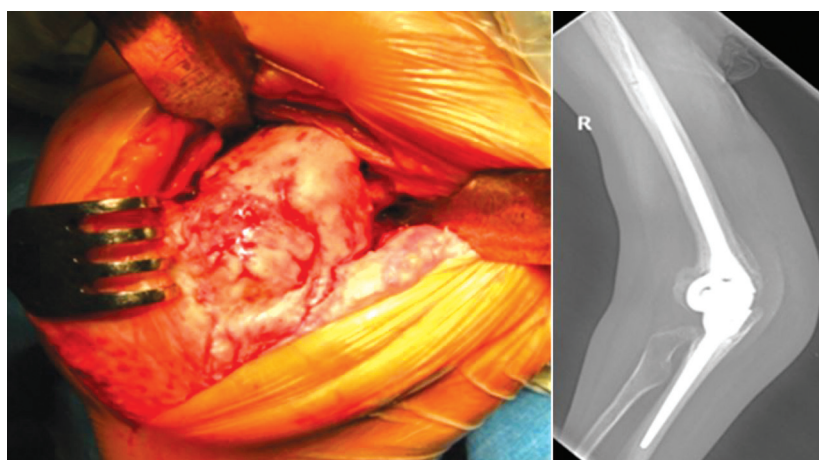
*Note:* The data are presented in the  $n$  (% of the group) format. The combination of domestic systems was performed due to the identical design principle and low sample power for pairwise analysis.

### **Structural and biomechanical features of the late period**

An analysis of the long-term results in the semi-constrained group revealed changes in the mechanical axis of the limb. Some patients developed a static varus deformity of the elbow joint, a "gunstock deformity", due to the peculiarities of ligamentous apparatus balance and the structural geometry of the humeral component (Fig. 4). The design of the semi-constrained lock creates a sensation of "dropping" of the forearm due to play in the hinge joint. The problem of heterotopic ossification (HO) is essential. In a subgroup of 10 patients who underwent implantation of the constrained ESI with preserved humeral epicondyles, heterotopic ossifications in the projection of the hinge mechanism developed in all cases (100 %) post-op. Radiological and clinical monitoring confirmed that ectopic bone formation led to a significantly limited range of motion in the elbow joint, requiring surgical correction in some cases (Fig. 5).



**Fig. 4** Varus deformity of the elbow joint: photograph of the patient after TEA



**Fig. 5** Heterotopic ossification around the ESI lock

### Assessment of the functional condition of the hand (dynamometry)

Instrumentation dynamometric examination was conducted for a subgroup of 80 patients (primary and revision TEA with confirmed trochlea defect) to objectively assess the impact of distal humeral trochlea resection on upper limb function. The results are presented in Table 3.

Table 3

Results of dynamometry and pinch grip tests

| Description                                              | Pre-op             | At 6 weeks      | Effect               | Wilcoxon test, <i>p</i> -level |
|----------------------------------------------------------|--------------------|-----------------|----------------------|--------------------------------|
|                                                          | MED [Q1; Q3]       |                 | PSEUDO MED [95 % ДИ] |                                |
| Dynamometry of the right hand<br>( <i>n</i> = 80, 100 %) | 38.5 [25; 50]      | 38.5 [25; 52.5] | -1 [-1; -0.5]        | 0.152                          |
| Pinch grip on the right<br>( <i>n</i> = 79, 99 %)        | 9 [7.25; 10.75]    | 10 [7; 11.75]   | -0.25 [-0.25; -0.25] | 0.009*                         |
| Dynamometry of the left hand<br>( <i>n</i> = 78, 98 %)   | 39.5 [20.5; 53.75] | 40 [24.25; 53]  | -0.5 [-0.5; -0.5]    | 0.187                          |
| Pinch grip on the left<br>( <i>n</i> = 77, 96 %)         | 9 [7; 11]          | 9 [7.4; 11]     | 0 [0; 0]             | 0.290                          |

\*  $p < 0.05$ .

A dynamic analysis of the dynamometry performed (comparing preoperative and six-week postoperative measurements) revealed maintenance of dynamometry in both the right and left hands, and the pinch grip on the left. Postoperative pinch grip measurements on the right showed statistically significant differences compared to preoperative values.

### DISCUSSION

The findings of this study suggested that the incidence and nature of complications after TEA were directly related to the biomechanical design of the implant. The overall revision rate in our cohort was 7.0 %, which is at the lower end of the ranges reported in the current literature (10–25 %) [7, 10, 26, 27]. This figure may be due to strict adherence to the surgical protocol, centralization of operations in a specialized center, and patient selection characteristics. However, analysis of the failure pattern revealed a fundamental biomechanical trade-off between primary stability and long-term durability of the implant [9, 15, 22, 23, 28].

*Constrained systems and aseptic loosening.* Aseptic loosening of the humeral component was the most common complication (4.5 %) in the ESI group. The biomechanical mechanism of this phenomenon is well described in the literature: full coupling of the hinge compensates for pathological instability but blocks physiological varus-valgus and torsional mobility. As a result, peak loads are not absorbed by the soft tissue complex but are transmitted directly to the bone-cement interface. This initiates a body response to wear microparticles (metal, polyethylene, cement), the formation of a thick fibrous membrane, and the progression of periprosthetic osteolysis, which we objectively verified during revision surgeries. Our data are fully consistent with the results of studies reporting that constrained constructs demonstrate earlier radiographic instability despite the absence of hinge dissociation [1, 30, 31]. In this case, the fatigue fracture of the metal axis (0.7 %) suggests extreme cyclic loads exceeding the ultimate strength of the material under conditions of blocked kinematics [26, 29, 32, 33].

*Semi-constrained systems and mechanical failure of the articular joint.* Revisions in semi-constrained (3.1 %) were caused by fatigue failure of the locking mechanism or critical wear of the polyethylene liner followed by dissociation of the hinge. The engineering solution incorporated into the Coonrad Morrey design and its analogs involved the presence of an inherent varus-valgus play (5–7°). This allowed for the redirection of some angular and torsional loads from the bone bed to the articular joint, significantly reducing the risk of early aseptic loosening. However, the hinge module became a new "weak link", subject to cyclic shear and compressive loads. The frequency of joint failure in our sample corresponded to global rates for this type of design [9, 29, 32].

It is noteworthy that, unlike constrained systems, we rarely observed total osteolysis of the bone bed during revision of semi-constrained implants. Instability was commonly localized, with massive debris in the projection of the hinge joint [1, 30].

*The influence of the surgical approach and heterotopic ossification.* Preservation of the humeral epicondyles is essential. A subgroup of 10 patients with preserved epicondyles who underwent implantation of a constrained systems developed heterotopic ossification around the hinge in all cases. This confirms the literature data that the preservation of bony prominences creates areas of increased soft tissue friction and local ischemia, triggering a cascade of ectopic bone formation [25, 34]. We believe that resection of the epicondyles at the level of the cubital fossa is practical to prevent heterotopic ossification in TEA. The design of the hinge joint should be developed taking into account delicate handling of soft tissues, excluding or minimizing a technically more complex approach with the formation of additional medial and lateral "windows" [35, 36, 37, 38].

*Functional outcome: dynamometry and humeral trochlea resection.* The absence of a clinically significant decrease in the strength of the hand and pinch grip after resection of the distal humeral trochlea was an important practical observation. The statistically significant improvement in the pinch grip on the right ( $p = 0.009$ ) by 1.0 kg did not exceed the minimal clinically important difference (MCID) and probably reflected pain relief and postoperative rehabilitation, rather than biomechanical changes. Our results refute claims about a critical weakening of the grip after trochlea resection [19, 20, 22]. This could be explained by the fact that the main traction of the flexor and extensor muscles of the fingers was intact, and the collateral ligaments attached to the epicondyles retained their function with proper balancing. This observation has a clinical role: the surgeon can perform the necessary resection for adequate placement of the components without the risk of functional disability of the hand.

*Prospects for biomechanical design.* Analysis of our own data and the results of revision procedures allows us to formulate a development vector for next-generation implants. First, the concept of "controlled axial rotation" in the elbow component is essential, as the implant is an artificial hinge placed in pathologically altered tissue and cannot replicate the native elbow joint. Priority should be given to optimizing the hinge's varus-valgus mobility within  $5-7^\circ$ , with reinforcement of the coupling unit capable of withstanding cyclic shear loads. Second, the humeral component should accommodate the natural anteversion and torsion of the distal metaphysis to minimize asymmetric contact of the cement mantle. Thirdly, further development should be aimed at creating modular systems with wear-resistant friction pairs and improved stem geometry, which will reduce stress concentration at the implant-cement-bone interface and ensure balanced load redirection [1, 17, 38, 39, 40].

The existing TEA designs exhibit a predictable complication profile directly related to the biomechanical design. Optimizing outcomes requires an improved surgical technique and transition to new-generation implants that would consider the complex three-dimensional kinematics of the joint, ensure balanced load transfer providing a reinforced, wear-resistant hinge system.

## CONCLUSION

The overall complication rate after total elbow arthroplasty in the cohort of patients was 7.0 %. The nature and frequency of adverse outcomes were associated with the biomechanical principle of implant fixation.

Aseptic loosening of components was the common mechanism of failure for constrained caused by the transfer of peak varus-valgus and torsional loads to the systems bone-cement interface without physiological cushioning.

Revision surgery with the semi-constrained systems was caused by mechanical failure of the hinge and critical wear of the polyethylene liner, being associated with cyclic shearing effects on the coupling mechanism. Implantation of these systems was associated with the development of static varus deformity of the limb.

Instrumentation dynamometry suggested that the distal humeral trochlea resection required for proper component placement had no clinically significant effect on hand and pinch grip strength. The statistically significant improvement in right-sided pinch grip strength did not exceed the minimum clinically significant difference and was associated with postoperative rehabilitation rather than biomechanical change.

The development of next-generation implants should be based on the principles of balanced load transfer including optimization of varus-valgus joint mobility within  $5-7^\circ$ , engineering reinforcement of the coupling unit and locking mechanisms, and consideration of the natural anatomical torsion and the distal metaphysis of the humerus.

**Conflict of interest** None of the authors has any potential conflict of interest.

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**Ethical review** The study was approved by the Local Ethics Committee of the Ya.L. Tsvyann Novosibirsk Research Institute of Traumatology and Orthopedics of the Ministry of Health of the Russian Federation (extract No. 014/25 from protocol No. 006/25 dated September 5, 2025).

**Informed consent** The patients gave informed consent for publication of the findings without identification.

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