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THE VALUE OF COMPUTER RECONSTRUCTION IN THE TREATMENT OF INTRA-ARTICULAR FRACTURES OF THE DISTAL PART OF THE HUMERUS

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The aim *of the work was to study the role of computer reconstruction and additive technologies in the planning of surgical treatment of intra-articular fractures of the distal part of the humerus in the early post-traumatic period.*

Materials and methods: *the results of treatment of 44 patients with fractures of the distal part of the humerus aged from 22 to 65 years were studied.*

All patients underwent MSCT in the preoperative period. In 45.5 % (20) cases, in order to increase the effectiveness of preoperative planning, simulation osteosynthesis was performed on an individual printed model of the damaged bone.

After completion of preoperative planning, all patients underwent osseous metallo-osteosynthesis in the first week after receiving the injury. In order to assess the effectiveness of the application of visualization techniques, a survey of the operating team was carried out regarding the informativeness of the conducted instrumental studies.

Results. *The average duration of surgical intervention among patients in the clinical group with standard preoperative planning was 105.9 ± 9.15 minutes. The average results of the survey of the surgical team after the surgical interventions in the specified clinical group were 21.2 ± 2.8 points.*

The average duration of surgery among patients of the second clinical group, whose preoperative planning included not only the assessment of MSCT results of the damaged segment, but also simulated osteosynthesis with the selection and application of optimal metal fixators, was 54.6 ± 7.14 minutes. The average results of the survey of the surgical team were 31.2 ± 1.7 points.

Conclusions. *The use of a combination of visualization technologies and 3D printing allows to reduce the time the patient spends in the operating room and increase the effectiveness of preoperative planning.*

Performing simulated osteosynthesis in the preoperative period allows you to develop an individual technique of repositioning bone fragments and use the optimal standard size of the cortical metal fixator with the distribution of the most favourable compression points of bone fragments

Keywords: *computed tomography, preoperative planning, distal humerus fracture, 3D printing, 3D modelling, fracture, treatment*

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1. Introduction

Computed tomography (CT) is a method of detailed medical imaging, which has been known since 1972, has a systematic set of clear protocols for studying the internal structure of the object and is considered particularly valuable in the diagnosis of joint pathology, which is why it is widely used in orthopedics – trauma clinics of the world. One of the modern achievements of biological technologies is the creation of a three-dimensional physical object by printing based on the data of a digital model – additive technologies or 3D printing [1–3].

According to data from separate scientific works, fractures of the bones forming the elbow joint are among the most difficult to restore to the function of the skeletal areas. The number of complications of the functional plan in the treatment of this pathology reaches 80 %.

According to statistical data from international medical, scientific publications, fractures of the distal part of the humerus, which is an important component of the guarantor of movement in the elbow joint, account for 0.5–3.0 % of all skeletal bone fractures in the adult population and 1/3 of all cubital fractures [4, 5].

During the last decade, there has been an increase worldwide in the number of low-energy multiscapular fractures of the distal humerus in adults, especially in women, which tend to progress to non-union or functional impairment with nonoperative treatment or implant failure due to osteoporosis. The largest number of high-energy injuries is also observed in young people with high labour and social activity. It is predicted that the frequency of distal humerus fractures will increase 3 times over the next 10 years [6].

The main prerequisite for a rational and patient-oriented treatment of fractures of this part of the humerus is the appropriate diagnosis of these injuries and in-depth preliminary knowledge about the specifics of the injury in a certain age group [7].

Finding out the patient's trauma history and performing a physical examination allows the doctor to recommend an appropriate imaging method to confirm or rule out a humerus fracture.

At the stage of initial diagnosis, in most cases of fractures with displacement of suspected fragments, X-ray imaging remains the standard. For the most accurate visualization of fractures of the distal part of the humerus, at least 6 standardized radiological projections are described, which include only 3 options of the anterior-posterior projection [8].

During an urgent examination, a minimum of two standard projections - direct and lateral - are required. Due to the forced position of the limb in the conditions of transport immobilization, it is not always possible to ensure this requirement qualitatively. Therefore, such visualization is often of limited quality, resulting in predominantly low reliability of the primary characterization and classification of fractures.

In the case of examination of an adult patient with a fracture with displacement of fragments in this location, preference is given to multispiral computed tomography (MSCT) with 3D reconstruction as the most informative visualization, which further minimizes radiation exposure to the patient [9]. At present, the possibility of carrying out MSCT must necessarily be in the centers of providing emergency medical care of a high level.

The use of ionizing radiation in persons of older age groups, unlike children, is safer due to a lower tendency to pathological effects, but determining the benefit/risk ratio is a decisive criterion when choosing between radiography and computed tomography [10]. Among the modern options for visualizing fractures in children, ultrasound diagnostics is singled out [11].

Considering that the accuracy of the visualization assessment is affected by the quality characteristics of the image, several scientists investigated the informativeness of visualization when using two standard projections during the use of radiography and multispiral computed tomography of the elbow joint, which was in the range of 65–73 % and 90-95 %, respectively. Further, clinical-diagnostic search, the transition from radiographic examination to MSCT and the use of additive technologies lead to a change in the operative tactics predicted by the data of urgent radiography in 70–90 % of cases [12].

A separate topic for discussion is problems with visualization of damage to the distal part of the shoulder in the conditions of using standard or situational immobilization. The use of most of the existing standardized tyres excludes the possibility of conducting a magnetic resonance examination (MRI) due to the presence of metal components in the fixing means. Nevertheless, magnetic resonance imaging is very useful in cases of resolving the issue of reconstructive interventions on the capsular-ligamentous apparatus of the elbow joint both in the early and in the remote period after the injury [13, 14].

The above data became the reason for conducting this clinical study.

The aim of the work: to investigate the role of computer reconstruction and additive technologies in the planning of surgical treatment of intra-articular fractures of the distal part of the humerus in the early post-traumatic period.

2. Materials and methods

A study of the results of the staged treatment of 44 patients in the trauma department of the communal enterprise "City Clinical Hospital #1 of Poltava city council", who were treated in the period from 2022 to 2024, for multi fragmentary intra-articular fractures of the distal part of the humerus, aged from 22 to 65 years, average age 44.2±14.6 years. According to the gender distribution, female patients predominated among them – 25 (56.8 %), male patients made up 19 (43.2 %).

The work was carried out within the framework of the Department of Surgery No. 3 "Age aspects of the staged provision of orthopaedic and trauma care to patients with comorbid pathology" No. 0122U002528 (excerpt from the minutes of the meeting of the Bioethics Committee of Poltava State Medical University No. 228 dated June 20, 2024).

According to the conclusions of the Ethics Commission of the PSMU, the paper meets the requirements of the Helsinki Commission. Patients, assigned in the clinical groups, participated with informed consent.

According to the WHO age classification, 23 (52.3 %) were young, 9 (20.5 %) middle-aged, and elderly – 12 (27.2 %). The average age of female patients was 44.7±14.1 years, male patients – 43.6±15.3 years.

Among the causes of fractures of the distal part of the humerus in the studied cases, namely in 36 (81.8 %), injuries by a traumatic agent with high kinetic energy prevailed: as a result of traffic accidents, falls from a height, hooligan actions, sports injuries, etc. Injury because of falling from a height of one's height was the initiating agent of injury in 8 (18.2 %) cases.

In all 100 % of cases, closed intra-articular fractures of the distal part of the humerus type 13B and 13C were diagnosed. According to the AO classification, type 13B fractures were detected in 17 (38.6 %) people, and type 13C fractures in 27 (61.4 %). Detailed characteristics of fractures according to the AO classification are given in Table 1.

Table 1

Distribution of fractures of the distal part of the humerus among the studied cases according to the AO classification

No.	Type of fracture according to the AO classification	The number of fractures, n	The number of fractures, %
1.	13 B1	9	20.5
2.	13 B2	7	15.9
3.	13 B3	1	2.3
4.	13 C1	13	29.5
5.	13 C2	7	15.9
6.	13 C3	7	15.9
Total		44	100.0

All patients with intra-articular fractures of the distal part of the humerus underwent MSCT in the preoperative period to improve the effectiveness of preoperative planning using 3D reconstructive technologies. In 45.5 % (20) cases, to increase the effectiveness of preoperative planning, simulation osteosynthesis was performed on an individual printed model of the damaged bone.

MSCT of the damaged limb segment was performed on a Siemens device, 3D printing of the fracture model was performed on a Creality K1 Max 3D printer. After completion of preoperative planning, all patients underwent osseous metallo-osteosynthesis in the first week after receiving the injury.

To assess the effectiveness of the use of visualization techniques, the operating team was surveyed according to the "Surgical feedback" questionnaire. For each of the questions, the respondents had the opportunity to decide on a 5-point Likert scale, where:

1 point corresponded to the value – categorically disagree,

2 – disagree,

3 – neutral,

4 – agree,

5 – completely agree.

Operating physicians were asked to answer the questions shown in Table 2.

Table 2

List of questions for surveying operating surgeons according to the questionnaire "Surgical feedback"

No.	Question	Scores
1.	Correspondence of radiography with MSCT data by the number of fragments	1–5
2.	Correspondence of radiography to MSCT data by topography of fragments	1–5
3.	Correspondence of radiography with MSCT data in terms of spatial orientation of fragments	1–5
4.	Correspondence of radiography with 3D printing data by the number of fragments	1–5
5.	Correspondence of radiography with 3D-printing data according to the topography of fragments	1–5
6.	Correspondence of radiography with 3D printing data by spatial orientation of fragments	1–5
7.	Correspondence of the simulation osteosynthesis technique to the intraoperative surgical situation	1–5

The processing of the research results was carried out in accordance with the rules of medical and biological statistics using the mean square deviation, the method of mass observation, the method of groupings and the method of generalizing indicators.

3. Results

As a result of the study, two groups of patients were distinguished depending on the type and combination of applied visualization techniques.

The first clinical group consisted of 24 patients aged 23 to 65 years who underwent MSCT with the use of anatomical digital 3D modelling of the damaged area of the humerus at the stage of preoperative planning. According to the gender distribution, males predominated – 13 (54 %). According to the age classification of the WHO, among the observed cases, young and elderly persons were found in the same number, namely 33.3 % each 8.

According to the AO classification, type 13B fractures among patients of the second clinical group were diagnosed in 10 (41 %), multifragmentary type 13C fractures in 14 (59 %).

The second clinical group included 20 patients aged 22 to 63 years with fractures of the distal part of the humerus at the stage of preoperative planning who underwent MSCT with 3D reconstruction, subsequent 3D printing of the damaged segment and simulation surgery. According to the gender distribution, women dominated among them – 14 (70 %). By age distribution, in accordance with the WHO classification, young patients predominated, accounting for 13 (65 %).

The distribution of the type of fracture according to the AO classification was as follows: intra-articular fractures of type 13 B were diagnosed in 7 (35 %) of patients, multifragmentary intra-articular fractures of type 13 C – in 13 (65 %).

During the study, the average values of the duration of surgical intervention were measured and evaluated among patients of the first and second clinical groups, and the results of the survey of the participants of the surgical intervention were analyzed.

The average duration of surgical intervention among patients of the first clinical group was 105.9±9.15 minutes. The average results of the survey of the surgical team after the performed surgical interventions for the treatment of patients of the specified clinical group according to the "Surgical feedback" questionnaire were 21.2±2.8 points.

The average duration of surgical intervention among patients of the second clinical group, whose preoperative planning included not only the assessment of MSCT results of the damaged segment but also simulated osteosynthesis (Fig. 1) with the selection and application of optimal metal fixators, was 54.6±7.14 minutes. The average results of the survey of the surgical team after the performed surgical interventions for the treatment of patients of the specified clinical group according to the "Surgical feedback" questionnaire were 31.2±1.7 points.

Expanded averaged data of the comparative analysis of the questionnaires of the surgical team of the first and second clinical groups according to the "Surgical feedback" questionnaire is shown in Fig. 1.

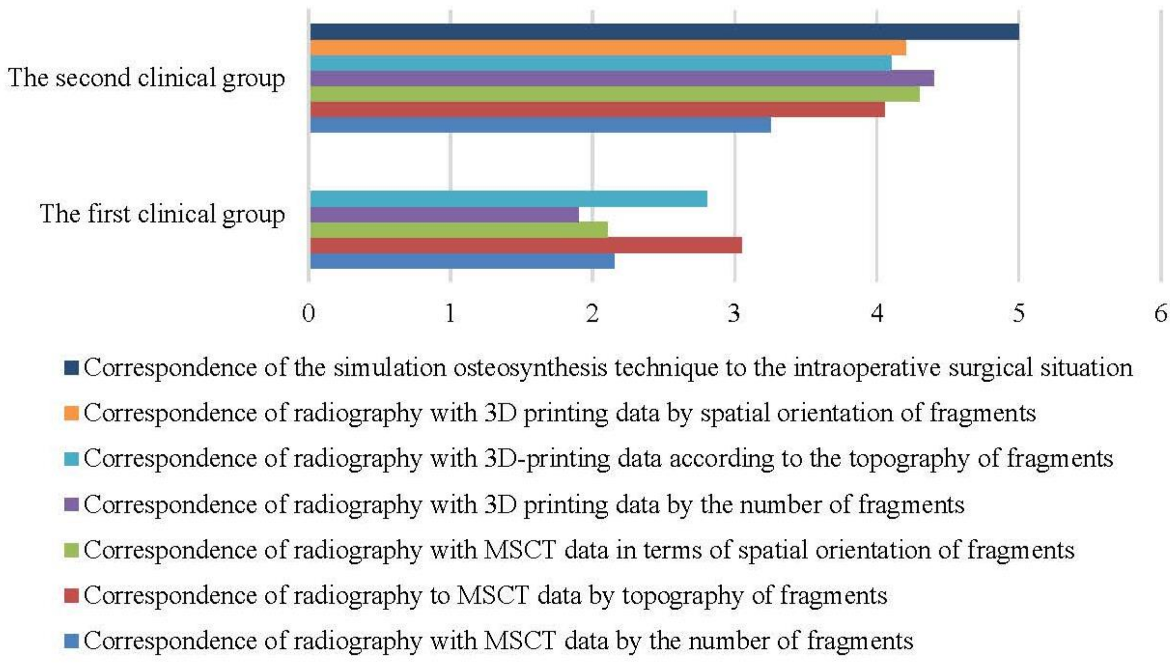

Fig. 1. The results of the survey of the surgical team for the first and second clinical groups according to the questionnaire according to the questionnaire "Surgical feedback"

Therefore, after the analysis of the averaged results of the duration of the surgical intervention, an increase of the specified indicator among the patients of the first clinical group compared to the patients of the second clinical group by 51.3 ± 8.56 minutes was found. This indicates a 93.9 % increase in the effectiveness of preoperative planning and the intraoperative period among patients of the second clinical group in whom a combination of MSCT and 3D printing followed by simulated osteosynthesis was applied (Fig. 2).

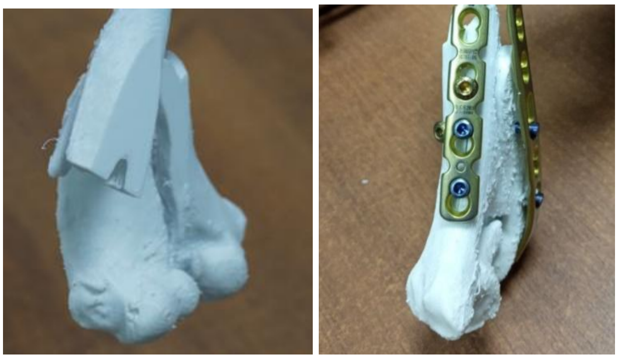

Fig. 2. Visual display of simulated osteosynthesis for a fracture of the distal part of the humerus

The average results of assessing the surgical team's satisfaction with the correspondence of the available data of additional research methods with the intraoperative situation according to the "Surgical feedback" questionnaire are 10±2.1 points higher among patients of the second clinical group.

4. Discussion of research results

The use of visualization individual 3D modelling followed by 3D printing at the stages of preoperative planning in the treatment of patients with fractures of the distal part of the humerus allows to perform preliminary simulated osteosynthesis of the damaged segment. This makes it possible to develop an optimal atraumatic method of repositioning bone fragments, their intermediate fixation with bone holders and spikes, to choose the size and type of metal fasteners for osteosynthesis in a targeted manner, and to prevent damage to important soft tissue structures.

The specified features of preoperative planning using 3D printing allow to significantly reduce the time of surgical intervention and the probability of risks associated with it, as well as to prepare the surgical team to perform the planned tasks and increase the efficiency and coherence of their actions.

A number of researchers in their scientific works note the incredible benefits of additive technologies with the point of their application in orthopaedics and traumatology in order to improve the effectiveness of treatment of complex combined and atypical injuries of the human musculoskeletal system [15–18]. Some authors see an increase in the effectiveness of the treatment of patients with complex bone injuries in the combination of individual 3D printing of the damaged segment with the manufacture of individual anatomical metal fasteners for their osteosynthesis [19, 20].

The indicated studies confirm the effectiveness of the introduction of individual 3D printing of the damaged segment at the stages of preoperative planning to improve the quality of the intraoperative period and perform osteosynthesis.

Study limitations. The limitation of this study is the need to produce an anatomical 3D model of the damaged segment of the humerus using a 3D printer based on 3D reconstruction based on MSCT data.

Prospects for further research. In further research, with the aim of individualizing the performance of osteosynthesis, research will be conducted on the combination of the use of individual 3D printing with individually designed bone metal fixation devices, namely plates and screws. This will make it possible to achieve better results at all stages of treatment of a patient with a complex skeletal injury in today's conditions.

5. Conclusions

The use of 3D printing followed by simulated osteosynthesis at the stages of preoperative planning allows to reduce the duration of the intraoperative period by an average of 51.3±8.56 minutes. This indicates a 93.9 % improvement in the efficiency of preoperative planning and the intraoperative period among patients who used a combination of MSCT and 3D printing followed by simulated osteosynthesis.

Correspondence of the intraoperative clinical picture according to the results of the survey of the surgical team according to the "Surgical feedback" questionnaire is 10±2.1 points higher among patients whose preoperative planning included visualization and simulation techniques.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship, or any other, that could affect the study and its results presented in this article.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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