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Ways to improve the results of treatment of severe combined pelvic injuries in modern conditions

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Objective. To analyze the treatment of victims with severe combined pelvic trauma in the conditions of the existing trauma care system in Ukraine and to identify ways to improve the results of treatment of such injuries. Methods. The work was based on a study of the results of treatment of 406 victims with unstable pelvic injuries in polytrauma (UPIP) (ISS ≥ 17 points). Of these, 249 (61.3 %) patients died in different periods of traumatic illness (TI). Two clinical groups were formed: the first — 137 (33.7 %) patients, in whom differential surgical treatment tactics were performed based on the developed scales for assessing the severity of injury, the prognosis of the course of TI depending on its periods, as well as the proposed modern methods of diagnosis and surgical treatment of injuries of the pelvis and other anatomical areas, the second — 269 (66.3 %) patients, in whom generally accepted surgical treatment tactics were used. Results. Active surgical tactics using a differential approach allowed to increase the number of internal (combined) metal osteosynthesis in this category of victims from 40.4 to 72.1 %, to reduce the proportion of conservative treatment from 53.7 to 30.6%, and the active implementation of an improved protocol scheme for surgical treatment of victims with NUTP during hospitalization allowed to reduce mortality in the acute period of TC (up to 48 hours) from 77.7 to 63.9 %, p < 0.05, overall mortality from 69.9 to 44.5% (p < 0.01). Conclusions. The timing of delivery of a victim with a severe combined pelvic injury to a specialized trauma department is crucial at the prehospital stage of saving the patient's life. The tactics of surgical interventions for injuries of extrapelvic localization, unstable pelvic fractures, pelvic organ trauma in the acute period of TI should be based on urgent indications, aimed primarily at stopping intrapelvic bleeding, the possibility of conducting single-stage or sequential emergency external fixation of the pelvic ring.

Мета. Проаналізувати лікування постраждалих із тяжкою поєднаною травмою таза в умовах існуючої системи надання травматологічної допомоги в Україні та визначити шляхи покращення результатів. Методи. Досліджено результати лікування 406 постраждалих із нестабільними ушкодженнями таза в разі політравми (НУТП) (ISS ≥ 17 балів). Із них 249 (61,3 %) пацієнтів померли в різні періоди травматичної хвороби (ТХ). Сформовано дві клінічні групи: перша — 137 (33,7 %) осіб, у яких проводилась диференційна тактика операційних втручань на основі розроблених шкал оцінки тяжкості травми, прогнозу перебігу ТХ залежно від її періодів, а також запропонованих сучасних методів діагностики і хірургічного лікування ушкоджень таза й інших анатомічних ділянок; друга — 269 (66,3 %) пацієнтів, яким застосовували загальноприйняті втручання. Результати. Активна оперативна тактика з використанням диференційного підходу дозволила збільшити кількість внутрішнього (комбінованого) металоостеосинтезу в цій категорії постраждалих з 40,4 до 72,1 %, зменшити питому вагу консервативного лікування з 53,7 до 30,6 %, а активне впровадження удосконаленої протокольної схеми втручань в осіб із НУТП під час госпіталізації дозволило знизити летальність у гострому періоді ТХ (до 48 годин) з 77,7 до 63,9 % (p < 0,05), загальну летальність із 69,9 до 44,5 %, (p < 0,01). Висновки. Термін доставлення постраждалого з тяжкою поєднаною травмою таза до спеціалізованого травматологічного відділення має вирішальне значення на догоспітальному етапі для збереження його життя. Тактика операційних втручань у разі ушкоджень позатазової локалізації, нестабільних переломів таза, травми тазових органів у гострому періоді ТХ повинна ґрунтуватися на невідкладних показаннях, направлених на зупинку внутрішньотазової кровотечі, із можливістю проведення одномоментної або послідовної екстреної зовнішньої фіксації тазового кільця. Ключові слова. Політравма, нестабільний таз, хірургічне лікування.

Keywords. Polytrauma, unstable pelvis, surgical treatment

Introduction

In the context of polytrauma, pelvic injuries constitute approximately 11.6 % to 15.3 % of cases [5, 10]. Modern injuries of this location are mainly (in 60–70 % of cases) severe multiple and combined. The quality of medical care organization at the incident scene is crucial during treatment. According to the German trauma registry, injuries to the abdomen and pelvic bones are observed in 25–35 % of all cases in patients with polytrauma with a mortality rate of up to 55 % [5]. Irreversible blood loss due to intrapelvic bleeding is the main cause of mortality in the acute period of injury in 10–58 % of cases [4]. The average hospitalization time of patients with polytrauma in Germany and the USA is from 18 to 46 minutes [5], with the majority using aeromedical evacuation (helicopters). At the same time, more than 90 % of cases in Ukraine are delivered by ambulance.

The quality of treatment at the hospital stage largely depends on the equipment of the hospital, the availability of specialists (surgeon, anesthesiologist, traumatologist, neurosurgeon), knowledge and practical skills in the basic treatment and tactical algorithms for unstable pelvic injuries and trauma to other anatomical areas, which, in turn, is determined by the presence in the country of institutions (trauma centers) for the development of schemes (guidelines, protocols) and practical training of specialists for different levels of medical care (district, city, regional hospitals). In most developed countries, regional trauma systems have been created to transport patients from the place of injury to specialized trauma centers (TCs) of various levels. At the same time, the type of ambulance transport and the level of TCs are determined by the severity of the patient's injury. Rapid transportation of patients with severe combined trauma to level 1 trauma centers can be achieved if there is the necessary number, completeness of territorial coverage and transport accessibility of these trauma centers. For example, in Germany in 2006, there were 108 level 1 trauma centers, 209 level 2, and 431 level 3–4 centers [5].

Purpose: to conduct an analysis and identify ways to improve the results of treatment of patients with severe combined pelvic trauma in the existing trauma care system in Ukraine.

Material and methods

The study materials were reviewed and approved by the Bioethics Committee (protocol No. 70 dated 25.03.2024). All patients gave informed consent.

The study was based on an assessment of the treatment outcomes (prehospital and hospital stages) of 406 patients with unstable pelvic injuries in case of polytrauma (UPIP) (ISS ≥ 17 points), undergoing inpatient treatment in the polytrauma department of Kyiv City Clinical Hospital of Emergency Medical Care ("KCC HEMC"). Of these, 249 (61.3 %) patients died at different periods of traumatic condition. To establish directions for improving the treatment outcomes of patients with severe combined pelvic injuries in the conditions of the existing trauma care system in Ukraine, two clinical groups were formed using the example of "KCC HEMC". The first (main) group included 137 (33.7 %) subjects who underwent differential surgical intervention tactics based on the developed scales for assessing the severity of trauma, the prognosis of the course of traumatic condition (TC) depending on its periods, as well as the proposed modern methods of diagnosis and surgical treatment of pelvic injuries and other anatomical areas (AA). The second (comparison) group consisted of 269 (66.3 %) patients who were treated with surgical tactics in accordance with the "Temporary Industry Unified Standards of Medical Technologies for the Diagnostic and Treatment Process of Inpatient Care for the Adult Population in the Hospitals of Ukraine", approved by the Order of the Ministry of Health of Ukraine No. 226 dated 27.07.1998. All the patients were hospitalized to the "KCC HEMC" in the acute period of TC (up to 48 hours). To objectify the obtained data, the main group and the comparison group were formed in such a way that they did not differ in gender, age of patients, type of trauma and mechanism of injury, number and severity of injured AA, severity of damage and traumatic shock, nature of injuries of the pelvic ring and pelvic organs. A retrospective analysis revealed that over half (51.9 %) of patients with combined pelvic trauma had unstable fractures. Of these, 303 cases (74.6 %) were rotationally unstable (type B), with type VI representing 84.8 % of these cases. At the same time, vertically unstable injuries (type C) were observed in 103 (25.4 %) patients, among which type SI was 61.2 %. It should be noted that, along with unstable pelvic bone injuries, 48 (11.8 %) individuals had hip fractures. Combined pelvic organ injuries (bladder, urethra, rectum) were observed in 98 (24.1 %) patients.

The severity of anatomical injuries in both groups was assessed using the ATS scale developed by us [3]. K. C. Pape et al. have suggested categorizing patients into groups according to the ISS scale, as illustrated in Table 1 [2].

In general, 33 % of the patients were in stable and borderline condition, 38.9 % in unstable, and 28.1 % in critical condition. The majority of patients (67 %)

Table 1

Distribution of patients by severity of anatomical injuries according to the ISS/ATS scale in the study groups

Status (ISS) points	Anatomical injury severity (ATS) points	Group		Chi-square test
		main (n = 137)	comparison (n = 269)	
Stable, borderline 17–25	Mild trauma ≤ 24	43 (31.38 %)	91 (33.83 %)	0.245
Unstable 26–40	Severe trauma 25–41	57 (41.61 %)	101 (37.55 %)	0.629
Critical > 40	Extremely severe trauma ≥ 42	37 (27.01 %)	77 (28.62 %)	0.118

Note: the differences between the indicators of the main and comparison groups are not statistically significant ($p > 0.05$).

required urgent decisions to determine the scope and sequence of operations.

Results and Discussion

Our prehospital study showed that the average time to deliver a patient with severe combined pelvic trauma was (52.1 ± 2.6) min, ranging from 10 min to 2 h 20 min. According to the literature [8, 10], if this time is more than 15–20 min, then only a specialized team or, best of all, aeromedical evacuation can prevent the negative consequences of the injury. Therefore, the time to deliver the patient to a specialized hospital plays a crucial role in saving life.

Diagnostic measures were determined by the hemodynamic stability of the patient and fully included CT, radiological data, ultrasound (FAST protocol), minimally only radiological (multi-projection oblique radiographs) and ultrasound in an abbreviated version with the clarification of the direct correlation between the volume and localization of the intrapelvic hematoma with the type of pelvic ring instability, which allowed in 67.9 % of cases to establish a reliable diagnosis. In an emergency, CT was performed only in hemodynamically stable patients without inotropic support in case of suspected damage to the posterior pelvic structures.

UPIP patients, during hospitalization in a hospital for surgical hemostasis, underwent emergency external fixation of the pelvic ring in 134 (33 %) cases: in 75 (54.7 %) subjects of the main group and 59 (21.9 %) of the comparison group ($p < 0.01$; $\chi^2 = 44.195$). In the majority of cases (89.6 %), an external fixation device (EFD) was applied using various versions of the anterior frame. In 14 patients (10.5 %), stabilization of the pelvis was achieved with Ganz forceps. Additionally, in 10 patients (7.5 %), a combination of the anterior frame and forceps was utilized. Among the deceased patients of both groups, emergency external fixation was used during admission in only 48 (19.3 %) cases, which was due to both the severity of the injury (which led to minimal diagnostic work) and insufficient organization of the work of urgent surgical teams. In 62 (82.7 %) patients of the main group and 26 (44.1 %) of the comparison group, pelvic stabilization was performed in the first 3 hours after admission ($p < 0.01$; $\chi^2 = 21.824$). In individuals with a stable, borderline or unstable condition, there was a statistically significant ($p < 0.05$) increase in systolic blood pressure (BP) by 10–15 mm Hg. As early as 1–3 hours after performing emergency external fixation and adequate intensive care, in the case of extremely severe trauma (critical condition), systolic blood pressure was at a critically acceptable level (not lower than 90 mm Hg) for up to 8–10 hours because of emergency surgical hemostasis.

In hemodynamically unstable patients of the main group (systolic blood pressure less than 90 mm Hg for 2 hours, despite emergency external fixation of the pelvis and exclusion of further bleeding in other BP), tamponade of the pelvic cavity was performed for the purpose of hemostasis in 5 (3.7 %) cases. At the same time, all pelvic injuries were type C: in 4 cases, a ventral frame and Ganz forceps were applied, vascular ligation (*a. iliaca interna* — 1, *a. et v. iliaca interna* — 2, *v. v. iliaca externa et interna* — 1) with extraperitoneal pelvic tamponade was performed; in 1 person, due to damage to the veins of the presacral plexus, pelvic stabilization with a ventral frame, argon-plasma coagulation of the bleeding zone, and tamponade were performed. Four out of five patients died. Some authors [8, 9] believe that during the provision of specialized surgical care, it is necessary to use more widely endovascular techniques for stopping intrapelvic bleeding (REBOA — resuscitation endovascular balloon occlusion of the aorta) in critical patients with the involvement of vascular surgeons, if necessary and when indicated, to conduct angiographic studies. In 17–45 % of such cases, it is necessary to perform sequential angiography with vessel embolization and final hemostasis, especially in the case of arterial bleeding [10]. This article addresses the challenges of performing minimally invasive interventions during the acute phase for stable and borderline patients (ISS 17–25 points).

Specifically, it focuses on the fixation of the posterior pelvis through methods such as percutaneous sacroiliac fixation using cannulated screws, and percutaneous posterior bridging transiliac fixation with a transpedicular system [11]. For patients in unstable and critical conditions (ISS 26–40 and > 40 points) for the acute period, according to many doctors, the most optimal are Ganz forceps on the posterior structures (vertical displacement of half of the pelvis), the anterior frame in a simple modification or their combination together with extraperitoneal pelvic tamponade [6, 7].

Depending on the localization and severity of the extrapelvic injury, we have proposed schemes of actions of the surgical team in the acute period of TC for severe and extremely severe injuries.

Fixation of the unstable pelvic ring in the case of pelvic-craniocerebral trauma was performed simultaneously with EFD or Ganz forceps (9 cases), in pelvic-thoracic trauma sequentially after emergency operations on the chest organs (CO) (13 patients), in pelvic-abdominal trauma with a vertically unstable pelvic ring (type C) sequentially before interventions on the abdominal organs (AO), or after performing abdominal tamponade in compression of parenchymal organs and significant blood loss (6 patients), for rotationally unstable injuries sequentially, after emergency operations on the AO, in pelvic-skeletal trauma, fixation of the unstable pelvic ring was performed first.

Active implementation of an improved protocol scheme for surgical treatment of UPIP patients upon admission with determination of the severity of the injury, sequence and priority of surgical interventions, use of "damage control" principles for unstable and critical patients (ISS 26–40, > 40 points); implementation of protocols of actions of surgical teams depending on the localization and severity of extrapelvic injury allowed to reduce mortality among patients with TC (up to 48 hours) from 77.7 to 63.9 %, $p < 0.05$, overall mortality from 69.9 to 44.5 % ($p < 0.01$).

Active surgical tactics in the II, III, IV periods of TC using a differential approach allowed to increase the number of internal (combined) metal osteosynthesis (MOS) in this category of patients from 40.4 to 72.1 %, and to reduce the proportion of conservative treatment from 53.7 to 30.6 %.

In order to establish criteria for choosing surgical tactics in UPIP patients in the II, III, IV periods of TC, an analysis of the further treatment of 221 (54.4 %) subjects from both groups, 98 (71.5 %) of the main group and 123 (45.7 %) of the comparison group who did not die in the acute period was conducted. The severity of the injury, the prognosis of the clinical course of TC, the type of pelvic instability, the presence of concomitant injuries of pelvic and extrapelvic localization, and the method of treatment of unstable pelvic ring fractures were taken into account.

Surgical treatment of unstable pelvic ring injuries, which included EFD in various modifications as the final treatment method, internal MOS (primary internal, replacement of EFD with internal fixation), combined MOS, was performed in 68 (69.4 %) of the injured in the main group and in 57 (46.3 %) in the comparison group, ($p < 0.01$; $\chi^2 = 11.791$). Conservative treatment took place in 30 (30.6 %) of the patients in the main group and 66 (53.7 %) in the comparison group, which was primarily due to both the severity of the injury and the late diagnosis of unstable pelvic injuries. Characteristics of surgical treatment methods for unstable pelvic ring depending on the type of fracture are given in Table 2.

Our approach to the selection of methods, timing, invasiveness and volume of operations aimed at correcting pelvic ring injuries in the main group of victims was individual depending on the type of pelvic instability and the prognosis of the clinical course of TC.

The most optimal were considered to be invasive interventions (internal MOS, combined MOS) in the early and late periods of TC up to 21 days after injury. According to our data, in the main group, invasive operations on the pelvic bones in 2.9 % of cases (MOS of the ventral pelvis during interventions on the pelvic organs) were performed on the first day after injury, in 51.5 % up to 21 days after injury, in 20.6 % in periods of more than 21 days. For the comparison group, there is a statistically significant decrease in the number of invasive interventions within 21 days after the injury of 10.5 % ($p < 0.01$; $\chi^2 = 23.584$), and an increase in their number within 21 days to 29.8 % (the difference with the main group is not statistically significant, $p > 0.05$; $\chi^2 = 1.418$). A detailed analysis of the timing of surgical interventions depending on the type of pelvic fracture in the study groups is given in Tables 3, 4. The S. A. Majeed scale was used to analyze the functional results of treatment [1]. The use of only a conservative method for unstable pelvic injuries leads to unsatisfactory results in 35–66.7 % or to unsatisfactory and satisfactory results together in 72.8–85 % [5]. The analysis of functional outcomes of treatment of patients with UPIP was performed in 121 (77.1 %) patients out of 157 who survived and underwent both

surgical correction and conservative treatment of unstable pelvic ring.

In rotationally unstable fractures (type B), 6 months after the injury, the number of excellent and good results increased almost 2-fold from 37.2 to 78.1 %, $p < 0.01$; $\chi^2 = 14.294$; unsatisfactory results decreased 3-fold from 25.6 to 7.3 %, $p < 0.05$; $\chi^2 = 14.294$ due to the following:

– an increase in the number of internal MOS together with the combined EFD MOS in relation to the external MOS from 27.9 to 58.5 %, $p < 0.05$; $\chi^2 = 4.253$;

– increase in pelvic bone surgeries performed 3–21 days after injury, taking into account its severity and concomitant injuries of extrapelvic localization from 33.3 to 83.3 %, $p < 0.01$; $\chi^2 = 9.000$;

Table 2

Methods of surgical treatment of unstable pelvic ring depending on the type of fracture in the II, III, IV periods of TC

Intervention	Group				Total
	main (n = 98)		comparison (n = 123)		
	type B	type C	type B	type C	
EFD, as a final option	16 (32 %)	3 (16.7 %)	29 (59.2 %)	5 (62.5 %)	53 (42.4 %)
Replacement of MOS	17 (34 %)	9 (50 %)	8 (16.4 %)	3 (37.5 %)	37 (29.6 %)
Primary internal MOS	14 (28 %)	4 (22.2 %)	6 (12.2 %)	—	24 (19.2 %)
Combined MOS	3 (6 %)	2 (11.1 %)	6 (12.2 %)	—	11 (8.8 %)
Total	50 (51 %)	18 (18.4 %)	49 (39.8 %)	8 (6.5%)	125 (100 %)

Note: n is the number of patients who survived the acute period of TC; the difference between the indicators is statistically significant: for type B injuries — $p < 0.01$; $\chi^2 = 7.605$; C — $p < 0.05$; $\chi^2 = 6.286$.

Table 3

Timing of surgical interventions for unstable pelvic ring injuries of type B in patients in the study groups

Method	Group				Total
	main (n = 50)		comparison (n = 49)		
	day 3–21	day > 21	day 3–21	day > 21	
Replacement of MOS	12 (48.0 %)	5 (55.56 %)	2 (4.08 %)	6 (12.24 %)	25 (46.30 %)
Primary internal MOS	10 (40.0 %)	4 (44.44 %)	2 (4.08 %)	4 (8.16 %)	20 (37.04 %)
Combined MOS	3 (12.0 %)	—	2 (4.08 %)	4 (8.16 %)	9 (16.67 %)
Total	25 (50.0 %)	9 (18.0 %)	6 (12.24 %)	14 (28.57 %)	54 (100 %)

Note: the difference between the indicators of the main group and the comparison group is statistically significant: replacement of MOS — $p < 0.05$; $\chi^2 = 4.588$; by total number (replacement of MOS + primary internal MOS + combined MOS) — $p < 0.01$; $\chi^2 = 7.436$; statistically insignificant: primary internal MOS — $p > 0.05$; $\chi^2 = 2.540$; combined MOS — $p > 0.05$; $\chi^2 = 3.600$.

Table 4

Timing of surgical interventions for unstable type C pelvic ring injuries in patients in the study groups

Method	Group				Total
	main (n = 18)		comparison (n = 8)		
	day 3–21	day > 21	day 3–21	day > 21	
Replacement of MOS	4 (22.22 %)	5 (27.78 %)	—	3 (37.50 %)	12 (66.67 %)
Primary internal MOS	4 (22.22 %)	—	—	—	4 (22.22 %)
Combined MOS	2 (11.11 %)	—	—	—	2 (11.11 %)
Total	10 (55.55 %)	5 (27.78 %)	—	3 (37.50 %)	18 (100 %)

Note: the difference between the indicators of the main group and the comparison group is statistically significant: replacement of MOS — $p < 0.05$; $\chi^2 = 4.588$; by total number (replacement of MOS + primary internal MOS + combined MOS) — $p < 0.01$; $\chi^2 = 7.436$.

– decrease in conservative treatment methods from 37.2 to 17.1 %, $p < 0.05$; $\chi^2 = 4.280$;

– in the case of final treatment with external MOS, remounting of the EFD with its modification for closed reduction of pelvic injuries from 20 to 80 %.

In the case of vertically unstable injuries (type C), 6 months after injury, no statistically significant difference in functional treatment results was found, and after 12 (18) months, the number of good results increased from 10.5 to 44.4 % (50 %), $p < 0.05$; $\chi^2 = 5.392$ ($p < 0.01$; $\chi^2 = 6.894$) and unsatisfactory decreased from 47.4 (42.1 %) to 11.1 %, $p < 0.05$; $\chi^2 = 5.816$ ($\chi^2 = 4.502$). All these changes were achieved due to:

– increasing the share of internal MOS together with combined in relation to external MOS by 2.5 times ($p < 0.05$; $\chi^2 = 4.500$);

– performing most operations (80 %) on the 3rd–21st day after the injury ($p < 0.05$; $\chi^2 = 4.800$);

– reducing conservative treatment methods from 68.4 to 33.3 % ($p < 0.05$; $\chi^2 = 4.555$).

The analysis of the conclusions of forensic medical examinations of 249 UPIP patients who died showed that in the main group the total mortality was 61 (44.5 %) cases, with 188 (69.9 %) in the comparison group. Among UPIP patients who died in both groups, no statistically significant difference was found in the number of injured AAs or in the types of pelvic ring instability, which gives grounds to consider the severity of anatomical injuries at the time of admission as the main objective criterion for choosing the correct predicted differential surgical tactics for treating injuries of both pelvic and extrapelvic localization. In general, in 149 (59.8 %) patients who died, injuries to other AAs were usually of a competing and sometimes dominant nature, in the other 100 (40.2 %) pelvic injury was dominant and it played a leading role in thanatogenesis.

According to the data obtained, in the case of mild trauma (ATS ≤ 24 points) in the main group, the mortality rate was 25.6 % compared to 49.5 % in the comparison group ($p < 0.01$; $\chi^2 = 6.839$); for severe trauma (ATS 25–41 points) it significantly increased, in the main group it was 50.9, with 83.2 % ($p < 0.01$; $\chi^2 = 21.995$) in the comparison group; for extremely severe trauma (ATS ≥ 42 points) it remained at a high level in both study groups, with 56.8 in the main group, and 76.6 %, $p < 0.05$; $\chi^2 = 4.713$ in the comparison group, which indicates the effectiveness of the differential surgical tactics we proposed for the treatment of victims of NUTP.

The largest number of deaths occurred in the acute period of TC — 185 (74.3 %) patients, 63.9 in the main group, 77.7 % in the comparison group ($p < 0.05$; $\chi^2 = 4.543$). The main causes were traumatic shock and blood loss. In the early period of TC, 21.4 % of patients died from complications (increasing multiorgan failure). The analysis of the results obtained corresponds to literary sources [9, 10], where the overall mortality in the acute period of TC was 63.6 %, of which 22.7 % during the first 3 days.

It should be noted that in 72 (28.9 %) cases the conclusion of the forensic medical examination did not coincide with the final diagnosis in determining the severity of pelvic ring damage in the direction of its simplification, which significantly affected the quality of trauma care. The largest number of discrepancies in intraday mortality — 45 (39.5 %) cases (in the main group 33.3 vs. 40.9 % in the comparison group, $p > 0.05$; $\chi^2 = 0.406$), in the case of a fatal outcome on the 2nd–7th day — 8.6 and 25.9 %, $p < 0.05$; $\chi^2 = 4.486$, respectively, which is associated with more accurate diagnostics of pelvic injuries, in the main group with a mortality period of more than 7 days there were no discrepancies with the conclusions of the forensic medical examination.

Conclusions

The timing of delivery of patients with a severe combined pelvic injury to a specialized trauma department is crucial at the prehospital stage for saving the patient's life.

The scheme of radiological diagnostics of unstable pelvic injuries in severe and extremely severe cases with hemodynamic instability, which includes pelvic radiography in multi-projection oblique projections with ultrasound in a shortened version with the establishment of a direct correlation between the volume and localization of intrapelvic hematoma with the type of pelvic ring instability, allowed to establish a reliable diagnosis in 67.9 % of cases.

Tactics of surgical interventions in case of injuries of extrapelvic localization, unstable pelvic fractures, injuries of pelvic organs in the acute period of traumatic disease should be based on urgent indications, with observance of the principles of "damage control", aimed primarily at stopping intrapelvic bleeding (EFD, REBOA, pelvic tamponade, angiography with embolization), with the possibility of performing single-stage or sequential emergency external fixation of the pelvic ring.

Active surgical tactics in the early and late periods of traumatic disease using a differential approach allowed to increase the number of internal (combined) MOS of unstable pelvic injuries from 40.4 to 72.1 %, to reduce the proportion of conservative treatment from 53.7 to 30.6 %.

The implementation of an improved treatment regimen for patients with polytrauma and unstable pelvic injuries during hospitalization using protocol actions of surgical teams depending on the severity and localization of extrapelvic injury, the use of differential surgical tactics allowed to significantly reduce both mortality in the acute period of traumatic illness (up to 48 hours) from 77.7 to 63.9 %, and overall mortality from 69.9 to 44.5 %.

Conflict of interest. The authors declare the absence of a conflict of interest.

Prospects for further research. The proposed tactics of surgical treatment of unstable pelvic ring injuries depending on the periods of traumatic illness can be implemented in the work of traumatology departments of Ukraine with an assessment of its effectiveness and determination of further steps to reduce mortality and improve functional treatment results.

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Authors' contributions. Burluka V. V. — substantiated the feasibility of the study, developed its methodology, conducted the study, analyzed the results, drafted 80 % of the text of the article; Dorosh V. M. — participated in the analysis of the study results and in the formulation and drafting of the conclusions of the work, formed the list of references.

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WAYS TO IMPROVE THE RESULTS OF TREATMENT OF SEVERE COMBINED PELVIC INJURIES IN MODERN CONDITIONS

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The effect of time since injury on the progression of rotator cuff arthropathy of the shoulder (retrospective study)

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Rotator cuff disease is a disease of the shoulder joint, which is characterized by insufficient function of the rotator cuff of the shoulder, degenerative changes in the joint capsule and migration (displacement) of the humeral head. The objective of the study is to investigate the influence of time since injury on the progression of rotator cuff arthropathy of the shoulder joint. Materials and methods. We included 91 patients in the study who, at the time of examination, had rotator cuff arthropathy of varying degrees. The age of the patients ranged from 35 to 80 years. The average age was (48.2 ± 19.8) years. The inclusion criteria for the study were as follows: the presence of rotator cuff arthropathy of any degree, clear indication to the patient of the time since the injury, the presence of an MRI scan with a magnetic field strength of 1.5 Tsl, age 35 to 80 years, the absence of concomitant pathology of the shoulder (homarthrosis, calcifying tendinitis and any bone pathology of the proximal epimetaphysis of the humerus. The degree of rotator cuff arthropathy, damage to the soft tissue structures of the shoulder joint, and the time from injury to the patient's visit were determined. Results. The vast majority of patients had stage 2 rotator cuff arthropathy — 60.4 %, a slightly smaller number of patients had stage 1. rotator arthropathy — 23.1 %, patients with 3–5th degree. rotator arthropathy was significantly less — a total of 16.5 %. With an increase in the average terms from the moment of injury, the degree of rotator arthropathy increases. For the development of rotator arthropathy of the 1st degree, an average term of (5.16 ± 1.54) months after injury is required, while for the development of rotator arthropathy of the 4th degree, an average term of (11.25 ± 4.6) months after injury is required. Conclusions. There is a weak (r = 0.31; p = 0.051), but significant dependence of the influence of the term from the moment of injury on the degree of rotator arthropathy. Thus, with an increase in the terms from the moment of injury, the degree of rotator arthropathy of the shoulder joint may also increase.

Ротаторна артропатія — це захворювання плечового суглоба, яке характеризується недостатньою функцією ротаторної манжети плеча, дегенеративними змінами плечового суглоба і міграцією (зміщенням) головки плеча. Мета. Дослідити вплив термінів із моменту травми на прогресування ротаторної артропатії плечового суглоба. Методи. До дослідження включили 91 хворого, які на момент огляду мали діагноз «ротаторна артропатія плечового суглоба» різного ступеня. Вік пацієнтів складав від 35 до 80 років, середній (48,2 ± 19,8) року. Критерії включення до дослідження були наступними: наявність ротаторної артропатії ПС будь-якого ступеня, чітке вказання хворим термінів із моменту травми, наявність МРТ-дослідження з силою магнітного поля 1,5 Тсл, вік 35 до 80 років, відсутність супутньої патології ПС (омартроз, кальцинуючий тендиніт та будь-яка кісткова патологія проксимального епіметафізу плечової кістки. Визначали ступінь ротаторної артропатії, ушкодження м'якотканинних структур плечового суглоба, термін від травми до звернення пацієнта. Результати. Переважна більшість хворих мали 2 ст. ротаторної артропатії — 60,4 %, дещо менша кількість пацієнтів із 1 ст. — 23,1 %, осіб із 3–5 ст. було значно менше — сумарно 16,5 %. Зі збільшенням середніх термінів від моменту травми зростає ступінь ротаторної артропатії, для розвитку 1-го ступеня необхідні середні терміни (5,16 ± 1,54) міс. після травми, тоді як для 4-го — (11,25 ± 4,6) міс. Висновки. Існує слабка (r = 0,31; p = 0,051), але достовірна залежність впливу терміну з моменту травми на ступінь ротаторної артропатії. Отже, зі збільшенням часу із моменту травми може зростати й ступінь ротаторної артропатії плечового суглоба. Дане дослідження потребує продовження для визначення тенденцій прогресування ротаторної артропатії та більш точної статистичної обробки даних хворих з 3–5 ст. захворювання. Ключові слова. Плечовий суглоб, ротаторна манжета плеча, ротаторна артропатія.

Keywords. Shoulder joint, rotator cuff of the shoulder, rotator arthropathy

Introduction

Shoulder joint arthropathy (SJ) is a condition of the joint characterized by insufficient function of the rotator cuff of the shoulder (RCS) due to or as a result of its damage, degenerative changes in the SJ, and migration (displacement) of the humeral head [1–4]. SJ arthropathy in the English-language literature is more often described as the phrase "rotator cuff tear arthropathy" or "cuff tear arthropathy", in the Ukrainian-language literature the expression "rotator arthropathy" is quite often used, which we will continue to use. The tendons of the RCS play a crucial role in the dynamic stabilization of the naturally unstable SJ [1]. Violation of this dynamic stabilization for any reason leads to the development of degenerative changes in the joint, the so-called rotator arthropathy.

The etiology and factors that influence the progression of SJ rotator arthropathy remain poorly studied. It is known from the literature that only 4 % of patients with RCS tendon injuries develop rotator cuff arthropathy [1–4]. In cases of extensive RCS tendon ruptures, the likelihood increases significantly, reaching 50 % or more. However, it is important to note that not all extensive RCS tendon ruptures result in rotator cuff arthropathy, nor does it always lead to its progression [5–7].

According to some data, the timing of RCS injury has an impact on the progression of rotator cuff arthropathy [8–10]. In clinical practice, it is not uncommon to observe patients exhibiting signs of rotator cuff arthropathy without notable progression over several months.

There are very few publications on the impact of the timing of the disease on the progression of rotator cuff arthropathy. That is why most practitioners neglect the possibility of progression of rotator cuff arthropathy, which causes late referral of patients, when the only possible option for surgical treatment is reversible prosthetic replacement of the shoulder joint.

Purpose: to investigate the impact of the timing of injury on the progression of rotator cuff arthropathy of the shoulder joint.

Material and methods

From 2014 to 2024, 1,094 patients with various RCS tendon ruptures were treated at the Clinic of Reconstructive and Restorative Surgery of the Upper Limb of the State Institution "National Institute of Traumatology and Orthopedics of the National Academy of Medical Sciences of Ukraine" (Kyiv). Of these, 433 patients had a supraspinatus tendon rupture (partial or complete), 402 had supraspinatus tendon damage in combination with partial ruptures of the subscapularis (298 cases) and infraspinatus (104 cases). In 259 patients, we observed massive ruptures of the RCS tendons (full-layer ruptures of 2 or more).

We included 91 patients in the study who had rotator cuff arthropathy of varying degrees at the time of examination. The patients' ages ranged from 35 to 80 years. The average age was (48.2 ± 19.8) years. Table 1 shows the distribution of the study group by age and sex. All the patients were examined clinically and radiographically before the start of treatment. Direct projection radiography of the shoulder was performed (Fig. 1) to determine the degree of rotator cuff arthropathy according to Hamada [1, 7]. The normal value of the acromio-humeral interval was considered to be 8–12 mm [11–13]. All the patients also underwent MRI of the anatomical structures of the shoulder, including the tendons and muscles of the RCS in T1, T2, Pd and Pdfatsat modes. The degree of rotator cuff arthropathy, damage to the soft tissue structures of the shoulder, and the time from injury to treatment were determined.

The inclusion criteria for the study were as follows: the presence of rotator cuff arthropathy of any degree, clear indication of the patient's time from the moment of injury, the presence of MRI with a magnetic field strength of 1.5 Tsl, age from 35 to 80 years, the absence of concomitant disorders of the shoulder (homarthrosis, calcifying tendinitis and any bone condition of the proximal epimetaphysis of the humerus).

Statistical data processing was carried out using the STATISTICA 12.0 software by StatSoft, Inc. of USA (license No. ALXR712D833252FAN3). Descriptive statistics methods were used, the data were presented as the sample mean and its standard deviation (M ± SD) under normal distribution conditions and as the median and quartiles (Me [25Q–75Q]) in the case of a distribution other than normal.

Table 1

Distribution of the study group by age and gender

Age (years)	Gender, (%)		p*
	male	female	
35–45	0	4	—
46–60	10	24	0.084
61–80	14	39	0.033
Total	24	67	0.026

Note. * — Mann-Whitney criterion.

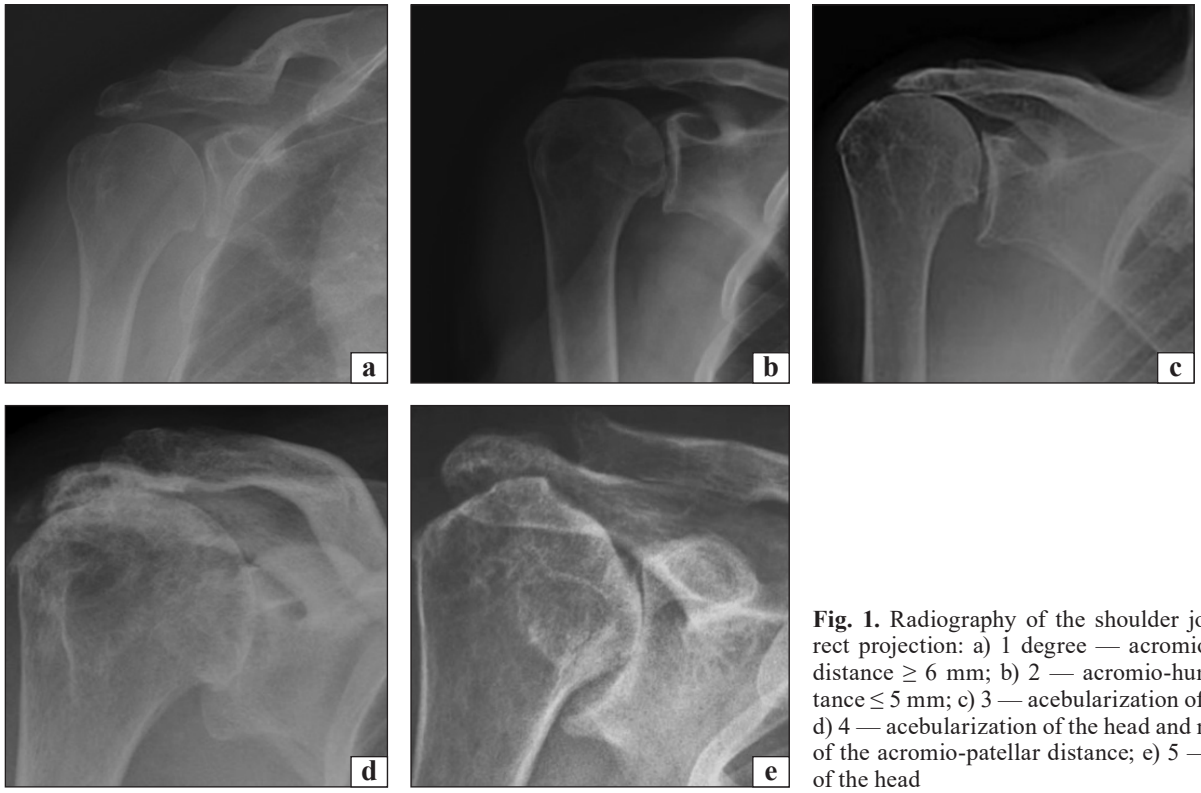

Fig. 1. Radiography of the shoulder joint in direct projection: a) 1 degree — acromio-humeral distance ≥ 6 mm; b) 2 — acromio-humeral distance ≤ 5 mm; c) 3 — acebularization of the head; d) 4 — acebularization of the head and narrowing of the acromio-patellar distance; e) 5 — collapse of the head

To compare the results, we used the Student's t-test (for two groups under normal distribution of indicators) and the Mann-Whitney test (for two or more groups during the analysis of indicators that demonstrated a distribution other than normal). The differences in the distribution of the two samples were assessed using the χ^2 test. Quantitative data are presented as n (%). The calculation (M ± SD) under nonparametric distribution of values was used to compare the results we obtained. Differences between indicators were considered significant at $p < 0.05$.

Results

Table 2 shows the distribution of patients by degree of rotator cuff arthropathy according to radiographic examination. The majority of patients were diagnosed with stage 2, comprising 60.4 % of the cases. A smaller proportion, 23.1 %, were in stage 1, while stages 3 to 5 accounted for a total of 16.5 %.

Table 3 shows the average time from injury to diagnosis for each degree of rotator arthropathy. The degree of rotator arthropathy tends to increase with the average time from injury. For the development of stage 1, the average time (5.16 ± 1.54) months after injury is required, while for stage 4, it is (11.25 ± 4.6) months. However, this trend is not observed in all cases. The average rates of development of stage 5 rotator arthropathy may appear earlier than stage 4. This is likely attributable to the influence of additional factors that require further investigation. To clarify the influence of time from injury on the degree of rotator arthropathy, we conducted a correlation analysis, taking into account the indicators of each patient (Fig. 2).

Table 2

Distribution of patients by degree of rotator cuff arthropathy according to radiographic examination

Degree of rotator cuff arthropathy	Number of patients, (%)
1	21 (23.1)
2	55 (60.4)
3	8 (8.8)
4	4 (4.4)
5	3 (3.3)

Table 3

Average time from injury to diagnosis for each degree of rotator cuff arthropathy

Degree	Average duration of the disease, (months)
1	5.01 ± 1.71
2	6.35 ± 3.5
3	7.56 ± 2.37
4	11.25 ± 4.6
5	10.70 ± 6.03

Notes: Results are presented as (M ± SD); where M is the mean value of the indicator in the group, SD is the standard deviation.

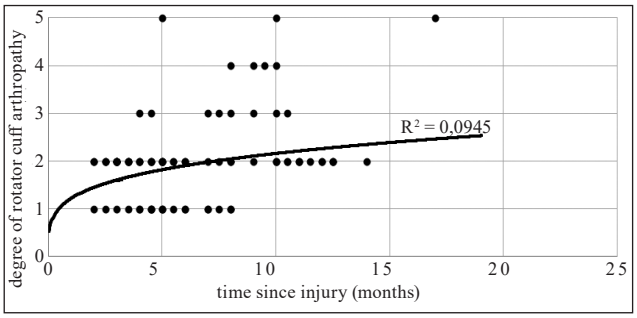

Fig. 2. The influence of time since injury on the degree of rotator cuff arthropathy of the shoulder joint

As can be seen from Fig. 2, there is a weak (r = 0.31; p = 0.051), but significant dependence of the influence of the time since the injury on the degree of rotator arthropathy. As time progresses following the injury, the severity of rotator arthropathy is likely to increase.

Discussion

The influence of the time since the injury on the progression of RCS tendon rupture is widely discussed in the literature [11, 14–16]. Most authors note that stable RCS tendon ruptures do not increase with time, progressive ones tend to increase. At the same time, the number of progressive ruptures is significantly greater than the number of stable ones [13–16]. In conclusion, we note that we can observe massive RCS tendon ruptures even without their traumatic damage.

A. Bedi et al. divide RCS tendon ruptures into those with pain syndrome and so-called asymptomatic ones. The study conducted by the authors using an ultrasound device showed that in 49 % of patients with an asymptomatic course of the disease, the size of the rupture increases by 5 mm or more in an average period of 2.8 years. In 46 % of patients who had an asymptomatic course of the disease, pain syndrome appeared in an average period of 2.6 years. The risks of increasing full-thickness RCS tendon ruptures were significantly greater than partial ruptures and were 26, 58 and 80 % after 2, 5 and 8 years, respectively [16]. In this study, the authors identified risks for the progression of RCS tendon rupture, including the patient's age, time since diagnosis, the nature of tendon damage (full-thickness or partial rupture), and the location of the rupture.

A somewhat similar study was conducted by C. A. Kwong et al., in which they identified a large number of patients with progression of full-thickness RCS tendon ruptures over a period of 3 years or more and recommended arthroscopic suture of RCS tendons to prevent progression of damage [17]. The authors did not pay sufficient attention to the study of factors that influence the progression of RCS tendon ruptures.

There is a limited body of literature on the progression of knee arthropathy and the factors that influence its development. This is primarily since patients at the time of referral have severe pain syndrome, contracture of the knee and require treatment, which is mainly surgical. Therefore, most of the literature sources relate to reversible knee prosthesis, which is the most effective in the treatment of this group of patients [11, 14]. Given the impossibility of long-term observation of patients, statistical analysis methods are optimal in these cases.

Our study results show that the time since the injury has a negligible effect on the progression of rotator cuff arthropathy. This may be due to the short observation period (up to 2 years), or it may be due to other factors: the size of the RCS tendon rupture, the presence of damage or medial dislocation of the long head of the biceps tendon.

In the study of R. Furuhata et al. analyzed the displacement of the humeral head by 21° of the SJ, which revealed that ruptures of the tendons of the infraspinatus muscle and the long head of the biceps play the main role in the migration of the humeral head cranially, and in the case of damage to the subscapularis muscle and the long head of the biceps, there is a decrease in the distance between the shoulder and the scapula, i.e. the articular cartilage of the SJ [18].

A promising direction of our research is the study of the following factors: age, gender, combination and magnitude of rupture of the tendons of the RCS and other structures of the SJ on the progression of rotator arthropathy.

Conclusions

There is a weak (r = 0.31; p = 0.051), but significant dependence of the influence of the period since the injury on the degree of rotator arthropathy.

The severity of rotator arthropathy of the SJ may increase with the time elapsed since the injury.

This study needs to be continued to determine the trends in the progression of rotator arthropathy and more accurate statistical processing of data from patients with 3–5 stages of this disease.

Conflict of interest. The author declares the absence of a conflict of interest.

Prospects for further research. A promising direction of our research is the study of other factors, such as age, gender, combination and magnitude of rupture of the tendons of the RCS and other structures of the SJ on the progression of rotator arthropathy. In addition, it is necessary to continue the study of patients with 3rd, 4th, and 5th degree rotator cuff arthropathy to increase the statistical significance of our study.

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Author's contribution. Bogdan S. V. — collection and processing of materials, analysis of the obtained data, drafting the article.

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THE EFFECT OF TIME SINCE INJURY ON THE PROGRESSION OF ROTATOR CUFF ARTHROPATHY OF THE SHOULDER (RETROSPECTIVE STUDY)

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Predictor scale of upper extremity function recovery in military trauma of the upper arm (offer to use)

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Objective. To determine the prognostic value of the extent of damage in military trauma to the upper arm for surgical intervention to improve the results of restoring upper limb function. Methods. A retrospective analysis of 30 cases of military trauma of the upper arm in combatants of the Armed Forces of Ukraine was conducted from the stage of admission to our hospital for treatment until 4 months after surgery. Functional outcomes were assessed using the Oxford Shoulder Score (OSS) scale 4 months after surgery. A previously developed scale was used to predict the recovery of upper limb function after military trauma of the upper arm to predict the consequences of surgery. Results. All 30 patients had a gunshot injury to the upper arm as a result of a shrapnel or bullet wound received during combat missions in the war on the territory of Ukraine. All 30 combatants received qualified medical care, underwent staged surgical interventions and a course of rehabilitation recovery. Based on the data of a retrospective analysis of patients, the correlation of rehabilitation results according to the OSS scale and the results of the assessment according to the scale-predictor of recovery of upper limb function in case of gunshot injury to the upper arm is traced. Conclusions. The results obtained after the assessment using the predictor scale serve as an aid in deciding on the feasibility and scope of surgical intervention. The decisive factor is the professionalism of the doctor and the patient's willingness to take risks to restore limb function in severe injuries of the upper arm in a large scope of trauma.

Мета. Визначити прогностичне значення обсягу ушкоджень у разі вогнепальної травми надпліччя для проведення хірургічного втручання з метою покращення результатів відновлення функції верхньої кінцівки. Методи. Виконано ретроспективний аналіз 30 випадків вогнепального ураження надпліччя військовослужбовців ЗСУ починаючи з госпіталізації та через 4 міс. після операції. Оцінювання функціональних результатів проводили за шкалою Oxford Shoulder Score (OSS) через 4 міс. після хірургічного втручання. Використовували попередньо розроблену шкалу-предиктор відновлення функції верхньої кінцівки в разі вогнепального ушкодження надпліччя для прогнозування наслідків втручання. Результати. Усі пацієнти мали вогнепальну травму надпліччя внаслідок осколкового або кульового поранення отриманого під час виконання бойових завдань у війні на території України. Комбатантам надано кваліфіковану лікарську допомогу, здійснено етапні хірургічні втручання та курс реабілітаційного відновлення. Відповідно до показників ретроспективного аналізу, прослідковано кореляцію результатів реабілітації щодо значень за шкалою OSS і оцінюванням за шкалою-предиктором відновлення функції верхньої кінцівки за вогнепальної травми надпліччя. Висновки. Проаналізовано існуючі шкали оцінювання функції верхньої кінцівки, сфери їхнього використання та питання, за якими визначають ефективність застосування цих класифікацій під час лікування та реабілітації пацієнтів. Запропонована нами шкала слугує допоміжним елементом для прийняття рішення про доцільність та обсяг хірургічного втручання в разі вогнепальної травми надпліччя, бо прогнозує його ефективність та можливі наслідки, також може використовуватись для інформування пацієнта про результативність відновлення. Вирішальним фактором є професіоналізм лікаря та готовність хворого ризикувати за для відновлення функції кінцівки за умов важких поранень надпліччя та значного травмування. Ключові слова. Надпліччя, шкала оцінювання, шкала-предиктор, бойова травма, війна, хірургічне втручання, військовослужбовці.

Keywords. Upper arm, assessment scale, predictor scale, combat injury, war, gunshot wound, surgical intervention, military personnel

Introduction

The relevance of the use of upper limb function assessment scales is due to the need to have a detailed tool for determining the disorder due to the growing number of people with injuries to the upper arm area, therefore it is an integral part of the work of a modern orthopedic traumatologist. They help assess structural damage and pain levels in patients. In a gunshot injury to the upper arm, several anatomical structures are affected: bones, joints, muscles, tendons, nerves [1]. Ukrainian scientists assess the functional state of the shoulder joint using the Oxford Shoulder Score (OSS) and Visual Analog Scale (VAS) 6 and 12 months after surgery [2]. However, in significant pain syndrome, it is sometimes impossible to adequately determine the degree of upper limb dysfunction using existing scales, such as OSS [3], Disabilities of the Arm, Shoulder and Hand (DASH) [4], American Shoulder and Elbow Surgeons Standardized Assessment Form (ASES) [5], University of California Los Angeles Shoulder Score (UCLASS) [6], etc. The question arises of the need to create an adapted scale, that is, a completely new tool for assessing or forming a rehabilitation prognosis for the upper limb in such individuals, the number of whom is constantly increasing during the continuation and intensification of hostilities in Ukraine.

Purpose: to determine the prognostic value of the extent of damage in case of gunshot injury to the upper arm for surgical intervention to improve the results of restoring upper limb function.

Material and Methods

The study materials were reviewed and approved by the Bioethics Committee at the Institute of Traumatology and Orthopedics of the NAMSU (protocol No. 2 dated 07.02.2025). All patients involved in the study were familiarized with the surgical intervention plan and signed an informed consent.

During almost 3 years of the war, we surgically treated 52 male individuals, aged 32 to 53, with gunshot injuries to the upper arm.

However, when analyzing the structure of gunshot injuries to the upper arm, data on age, gender, and concomitant injuries are not decisive for making a decision on the appropriateness of treatment. The vast majority of wounded underwent complex reconstructive surgeries to restore limb function. They included replacement of bone defects using autograft bone tissue from the iliac wing in 43 patients, transplantation of non-free flaps such as: thoracodorsal on the neurovascular pedicle in 14 wounded, local rotational flap in 8. Implantation of an articulating spacer of the humeral head was performed in 19 patients with subsequent replacement with a shoulder joint endoprosthesis. Metal osteosynthesis of various categories of complexity was performed in 52 patients. All these surgical interventions took quite a long time and required significant physical and psychological efforts of the surgeon and the patient at the subsequent stages of postoperative rehabilitation. Gunshot injury to the upper arm requires special attention, since the effectiveness of the operation in this area is a prerequisite for further rehabilitation and restoration of the function of the entire upper limb. Complications that developed in the postoperative period significantly influenced or prevented a satisfactory rehabilitation outcome. Their analysis in the case of gunshot injury to the upper limb was given by G. B. Kolov et al. [7]. When studying such fractures of the humerus bones, the following well-known classifications were used:

1. Craig — clavicle fractures (clavicle and clavicular-coracoid ligaments) [8];
2. Goss-Ideberg — fractures of the articular surface of the scapula in combination with the body and processes [9];
3. Ogawa — fractures of the coracoid process [10];
4. Gustilo Classification — soft tissue defects [11];
5. Oxford Shoulder Score (OSS) — assessment of functional outcomes.

We also used a previously developed scale-predictor of the restoration of upper limb function in gunshot injuries of the upper arm to predict the consequences of surgical intervention and determine the degree of rehabilitation potential of the patient.

The distribution of points is based on a subjective assessment of the rehabilitation potential of such patients. In our opinion, damage to the underlying muscles or nerves that innervate them and bone defects require more time and effort for recovery. Therefore, they received 10 points each (min — 0, max — 65) (Table 1).

We identified 3 groups of patients with a distribution by the number of points scored according to the structure of injuries in the area of the upper arm and shoulder joint at the time of hospitalization in our department (1 — 35+; 2 — 20–30; 3 — up to 20).

To analyze the results of assessing the effectiveness of this scale, 30 subjects out of 52 were selected, their observation was long-term and long-term results are available [12]. These combatants had a score of more than 5.

Table 1

Scoring system for the structure of upper arm injuries

Damage	Score
Deltoid muscle or *n. axillaris*	10
Bone defects requiring plastic surgery	10
Thoracodorsal bundle	10
Rotator cuff of the shoulder — more than 5 months*	5
Soft tissue defect in the upper arm area	5
N. subscapularis	5

Note. * — the degree of fatty degeneration and/or hypertrophy after 5 months is problematic for treatment.

Results

All 30 patients had a gunshot injury to the upper arm as a result of a shrapnel or bullet wound received during combat missions in the war on the territory of Ukraine. They received qualified medical care, underwent staged surgical interventions and a course of rehabilitation recovery. The structure of injuries is given in Table 2.

The OSS scale is a subjective scale for assessing the functional state of the shoulder joint: the patient answered twelve questions, the answer to each of them was rated from 0 to 4 points. Their maximum number was 48, the minimum was 0. The number of points from 0 to 19 was rated as an unsatisfactory

Table 2

Structure of upper arm injuries

Patient	Scapula	Clavicle	Shoulder	Deltoid / *n. axillaris*	Thoracodorsal bundle	Rotator cuff of the shoulder	Soft tissue defect	*n. subscapularis*	Score
1	+	–	+	+	–	–	–	–	30
2	+	–	+	+	–	–	+	–	35
3	+	–	–	–	–	+	–	–	15
4	+	–	–	–	–	+	–	–	15
5	+	–	–	–	–	–	–	–	10
6	+	–	–	–	–	+	+	–	20
7	+	–	+	+	–	+	+	–	40
8	+	–	–	+	–	–	+	–	25
9	+	–	–	–	–	+	+	–	20
10	+	–	–	+	–	+	–	–	25
11	+	–	+	–	+	–	–	+	35
12	–	+	+	+	–	+	–	–	35
13	+	–	–	+	–	+	+	–	30
14	+	–	+	+	–	–	–	+	35
15	+	–	+	–	–	–	–	–	20
16	+	–	–	–	+	–	–	+	25
17	–	+	+	–	–	–	+	–	25
18	–	–	+	–	–	–	+	–	15
19	–	+	–	+	–	–	–	–	20
20	+	–	–	–	–	–	–	+	15
21	–	–	+	–	+	–	–	–	20
22	–	–	+	–	–	+	+	–	20
23	+	–	–	–	–	+	–	–	15
24	+	–	–	–	–	–	–	+	15
25	+	–	+	–	–	–	–	–	20
26	+	–	–	–	–	–	–	–	10
27	–	–	–	–	–	+	+	+	15
28	+	–	–	–	–	–	+	–	15
29	–	–	+	–	–	–	+	–	15
30	+	+	+	+	–	+	+	–	50

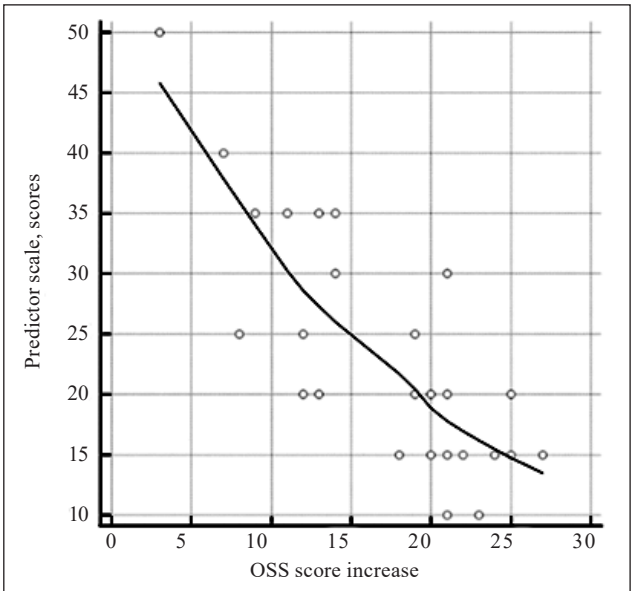
Table 3

Oxford Shoulder Score survey results

Patient	Before intervention	After intervention	Score increase
1	19	33	14
2	13	26	13
3	29	47	18
4	20	40	20
5	22	43	21
6	20	33	13
7	15	22	7
8	23	31	8
9	22	35	13
10	19	31	12
11	12	23	11
12	15	29	14
13	11	32	21
14	14	25	9
15	19	38	19
16	15	34	19
17	13	32	19
18	20	42	22
19	19	39	20
20	24	46	22
21	17	38	21
22	22	37	25
23	19	44	25
24	21	45	24
25	19	31	12
26	25	48	23
27	21	42	21
28	20	47	27
29	23	44	21
30	18	21	3

result, 20–29 as a satisfactory result, 30–39 as good, 40–48 as excellent. The results of the OSS scale survey are presented in Table 3.

According to the retrospective analysis of patients, the correlation of rehabilitation results according to the OSS scale assessment and the results of the scale-predictor of recovery of upper limb function in case of gunshot injury to the upper arm is observed: 6 patients (No. 2, 7, 11, 12, 14, 30) — 35+ points, 4 months for OSS — 22, 26, 23, 29, 25, 21 points respectively; 13 patients (No. 1, 6, 8, 9, 10, 13, 15, 16, 17, 19, 21, 22, 25) — 20–30 points, 4 months for OSS — 33, 33, 31, 35, 31, 32, 38, 34, 32, 39, 38, 37, 31 points respectively; 11 combatants



Sample size	30
Spearman's coefficient of rank correlation (rho)	–0,752
Significance level	p < 0,0001
95 % Confidence interval for rho	–0,875 to –0,538

Fig. 1. Spearman's rank correlation coefficient R = –0.752; statistical significance level p < 0.0001

(No. 3, 4, 5, 18, 20, 23, 24, 26, 27, 28, 29) — up to 20 points, 4 months for OSS — 47, 40, 43, 42, 46, 44, 45, 48, 42, 47, 44 points, respectively. A 4-month period was considered sufficient for postoperative healing and initial rehabilitation, so the preoperative OSS score, surgical intervention extent, and functional outcomes at 4 months were evaluated.

Inverse proportional relationship between the score on the predictor scale and the increase in OSS points has been statistically proven.

With a large number of patients injured as a result of military operations, as well as at the stage of the triage point in combat conditions, it is necessary to understand and try to predict the outcome of treatment and care for the wounded based on the volume of injury. We developed and conducted an internal assessment of the effectiveness of the predictor scale for gunshot injuries of the upper arm based on retrospective data from 30 patients who were operated on by one team of surgeons. The scale-predictor proposed by us is an auxiliary tool for making a decision on the feasibility and scope of intervention in case of gunshot injury of the upper arm. After all, using the "disposable" reserves of the body such as: bone grafting from the wing of one iliac bone or from both at once, *n. suralis*, tendon of *m. palmaris* (if available) or *m. semitendinosus*, various rotational and non-free

flaps, we reduce the depot for further reconstructive surgical interventions and the possibility of treating the patient with autografts in the future. The prospect of restoring the function of the limb is, if not the determining one, then one of the most important factors in the feasibility of performing the operation. The apparent severity of the injury of 35+ points on the scale-predictor of restoring the function of the upper limb in case of gunshot injury of the upper arm is shown in a clinical case.

Clinical case

A complex gunshot injury of the upper arm with damage to almost all structures (Fig. 1, 2). 10 points each — bone defect of the acromial end of the clavicle; proximal part of the humerus; spine and acromial process of the scapula with fracture of the body of the scapula, damage to the deltoid muscle and *n. Axillaris*; 5 points each — injury to the rotator cuff of the shoulder, soft tissue defect in the area of the humerus.

The patient underwent a long-term surgical intervention, more than 8 hours. A bone graft was used to replace the defect of the spine and acromial process of the scapula 11 cm. An articulating spacer of the humeral head was implanted. Metal osteosynthesis was performed with four overlay plates (Fig. 3).

A non-free active thoracodorsal flap was transplanted to replace the defect of the deltoid muscle and skin (Fig. 4).

The use of the thoracodorsal flap is not due to vascular damage, but to a musculocutaneous defect in the area of the shoulder blade, or a non-functioning deltoid muscle.

Three months after surgery, the increase on the OSS scale was 3 points, from 18 to 21.

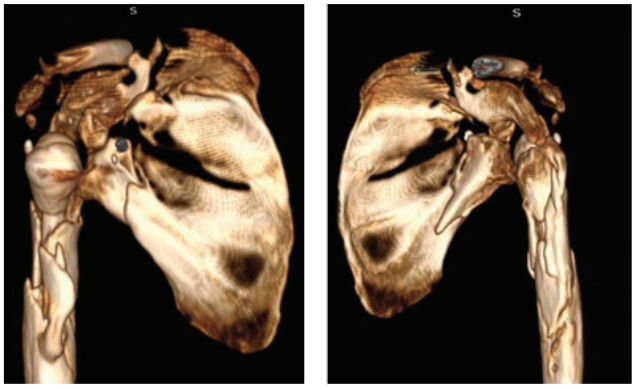


Fig. 1. CT scan of a serviceman with a complex gunshot wound to the upper arm (50 points on the predictor scale, included in the group of 35+ points)

Fig. 2. Skin of the same patient at the time of surgery

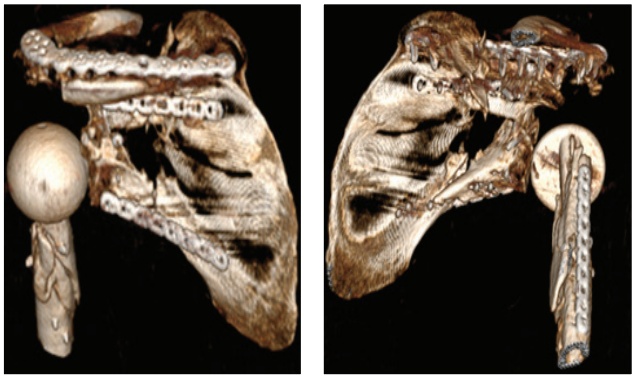


Fig. 3. Postoperative CT scan of the same patient

Fig. 4. Involuntary active thoracodorsal flap

Discussion

Existing scales for assessing upper limb function, their areas of use, and questions that determine the effectiveness of these classifications in the treatment and rehabilitation of patients were analyzed.

G. Hohenberger et al. found the DASH score to be positively correlated with the corresponding severity score of deformed limbs. However, the authors note that there is a need for further studies with a larger number of patients to verify the results obtained to draw conclusions about accurate predictors [13].

Meta-analysis by H. M. Kim et al. assessed 252 studies (32,072 patients; mean age 59.6 years; mean body mass index 28.7; mean follow-up time 27.8 months). The authors noted that the most frequently used were the American Shoulder and Elbow Surgeon (ASES) (n = 183; 73 %) and the Visual Analog Scale (VAS) (n = 163; 65 %). They recommend the widespread implementation of the ASES and UCLA scores for clinical and scientific standardization; however, the UCLA PROM requires in-person testing of range of motion and strength, which is a practical limitation and an obstacle to long-term follow-up [14]. Summarizing the available information, we concluded that it is inappropriate to compare these classifications with our proposed predictor scale for the recovery of upper limb function in gunshot injuries of the upper arm. Since they assess upper limb functionality only before and after surgery. However, using our predictor scale, it becomes possible to assess and predict the outcome of surgical treatment and subsequent rehabilitation.

The literature describes the use of predictor scales for predicting the duration of surgical intervention [15], assessing and predicting risks during surgical intervention [16], predicting the level of pain syndrome in patients in the postoperative period [17], but the use of classifications for predicting the level of recovery of upper limb function at the stage of preoperative examination is not defined and requires further development in modern medical practice. Our predictor scale may be one of the first steps towards popularizing and promoting this prediction method.

Conclusions

The scale we have proposed serves as an auxiliary element for planning on the feasibility and scope of surgical intervention in case of gunshot injury of the upper arm, because it predicts the effectiveness of treatment and possible consequences, and can also be used to inform the patient about the effectiveness of recovery. Score ranges on the predictor scale are as follows: 35 points or higher indicates that surgery is considered high risk or technically infeasible, with an unfavorable or minimal expected prognosis; 20–30 points suggests surgical intervention is technically possible, with a likely improvement in quality of life; up to 20 points indicates that intervention and reconstruction are recommended, with patients in this group having a favorable prognosis for rehabilitation and near-complete restoration of limb function.

The decisive factor is the professionalism of the doctor and the patient's willingness to go through a difficult path to restore limb function in case of severe injuries of the upper arm and a large volume of trauma.

Conflict of interest. The authors declare the absence of a conflict of interest.

Prospects for further research. In-depth study of the long-term consequences of injuries and the results of treatment of these patients.

Information on funding. This study is not commercial and has no external funding.

Authors' contribution. Strafun S. S. — idea and concept of the study, evaluation of the findings, drawing conclusions; Gayovych V. V. — literature search, evaluation and discussion of the findings; Telepenko G. V. — structuring and drafting the article, choosing research methods, data summarization of the findings, statistical processing of the findings, compiling the reference list, patient sampling, processing of medical documentation, data summarization in an Excel spreadsheet.

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PREDICTOR SCALE OF UPPER EXTREMITY FUNCTION RECOVERY IN MILITARY TRAUMA OF THE UPPER ARM (OFFER TO USE)

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Total wrist arthrodesis efficiency in various upper limb orthopedic pathologies

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Wrist arthrodesis for different pathologies has important specific features and yields varying functional outcomes. Objective. Based on the analysis of functional parameters dynamics to assess the total wrist arthrodesis efficacy for different upper limb pathologies. Methods. An analysis was performed on the dynamics of cylindrical grip strength and upper limb disability (qDASH score) before and one year after total wrist arthrodesis in 49 patients with various conditions, including wrist osteoarthritis, chronic brachial plexus injuries, distal radius giant cell tumor, rheumatoid arthritis, and wartime wrist joint injuries. Results.Wrist arthrodesis improved cylindrical grip strength in patients with degenerative wrist osteoarthritis by a median of 14 kg (range: 7–15 kg; IQR: 1 kg), in tumors by a median of 10 kg (range: 8–11 kg; IQR: 1,5 kg), and in consequences of wartime injuries involving joint surface defects by a median of 4 kg (range: 2–39 kg; IQR: 3 kg). In cases of rheumatoid arthritis, the median improvement was 3,4 kg (range: 2–9 kg; IQR: 2 kg). Effectiveness was minimal in patients with chronic brachial plexus injuries. The greatest reduction in upper limb disability (qDASH score) was observed in patients with of wartime wrist trauma consequences, with a median improvement of 40 points (range: 0–68 points; IQR: 27 points). In wrist osteoarthritis, the median improvement was 20 points (range: 9–39 points; IQR: 9 points), while relatively minor improvements were noted in patients with tumors, rheumatoid arthritis, and brachial plexus injuries. Total wrist arthrodesis is an effective surgical procedure; however, depending on the pathology, the indications, surgical conditions, techniques, and outcomes differ significantly and are notably varied.

Артродез кистьового суглоба за різних патологій має важливі особливості та різниться за функціональними результатами. Мета. На підставі оцінювання динаміки функціональних показників визначити ефективність операції повного (тотального) артродезу кистьового суглоба за умов патологій верхньої кінцівки. Методи. Аналіз динаміки показників сили циліндричного захвату кисті та ступеня недієздатності верхньої кінцівки (qDASH) до і через рік після тотального артродезу кистьового суглоба в 49 пацієнтів із різними (деформуючий артроз кистьового суглоба, застаріле ушкодження плечового сплетення, гігантоклітинна пухлина дистального метаепіфіза променевої кістки, ревматоїдний артрит суглоба, наслідки вогнепальних поранень зап'ястка) патологіями. Результати. Артродез кистьового суглоба покращує силу циліндричного захвату під час лікування деформуючого артрозу кистьового суглоба на — 14 кг (медіана) (діапазон: 7–15 кг; IQR: 1 кг); під час лікування пухлин — медіана 10,0 кг (діапазон: 8–11 кг; IQR: 1,5 кг); наслідків вогнепальних поранень із дефектом суглобових поверхонь — медіана 4 кг (діапазон: 2–39 кг; IQR: 3 кг), ревматоідного артриту — медіана 3,4 кг (діапазон: 2–9 кг; IQR: 2 кг), а за ушкоджень плечового сплетення його ефективність мінімальна. Найкраще артродез знижує недієздатність верхньої кінцівки за шкалою qDASH у пацієнтів із наслідками вогнепальної травми — медіана 40 (діапазон: 0–68; IQR: 27) балів; помітно менше під час лікування артрозу кистьового суглоба — медіана 20 (діапазон: 9–39; IQR: 9) балів та відносно невелику динаміку зменшення недієздатності за наслідків пухлин, артритів та уражень плечового сплетення. Артродез кистьового суглоба — дієва хірургічна процедура, проте залежно від патології покази, умови та техніка виконання, як і результати, достовірно відрізняються поміж собою, але в значному ступені неоднорідні. Ключові слова. Артродез, кистьовий суглоб, артроз, артрит, вогнепальні ушкодження, плечове сплетення.

Keywords. Arthrodesis, wrist joint, osteoarthritis, arthritis, wartime injuries, brachial plexus

Introduction

The issue of studying the effectiveness of wrist arthrodesis currently requires additional attention due to the high percentage of combat injuries. The first scientific publications on wrist arthrodesis and ankylosis date back to the beginning of the 20th century. Thus, in 1911, R. Eden [1] described this ccondition in the case of tuberculosis, and already in 1923, E. Hey-Groves [2] studied in detail the operation of wrist arthrodesis as a surgical treatment option for various diseases, including post-traumatic conditions.

In recent decades, surgical interventions that preserve movement in the wrist joint have become widely developed: removal of a number of wrist bones; partial intercarpal arthrodesis [3, 4]; endoprosthetic repair of the wrist joint [5]. However, firstly, some of them lose their effectiveness after a certain time and eventually lead to the performance of total arthrodesis as the final treatment procedure [4]. Secondly, due to pronounced structural and functional disorders of both the wrist and the entire limb, it is mostly impossible to preserve movements in the wrist joint, which requires its primary arthrodesis [6]. Information from literary sources on the use of wrist arthrodesis differs significantly [6, 7]. Therefore, we consider it advisable to clarify the results of wrist arthrodesis, especially taking into account various disorders of the upper limb, because there is a significant specificity of the intervention in these conditions, both in terms of indications and in terms of the technique of execution. It is also important to study the degree of restoration of the cylindrical grip strength of the hand and changes in the disability of the upper limb according to qDASH, and to outline important technical features of the procedure.

Purpose: based on the assessment of the dynamics of functional indicators, to determine the effectiveness of the operation of complete (total) wrist arthrodesis in conditions of upper limb disorders.

Material and Methods

Study Design: Retrospective, single-center, case series. Inclusion criteria: adult patients (≥ 18 years) who underwent total wrist arthrodesis for the following five types of lesions and injuries: degenerative changes (deforming arthrosis of the wrist due to post-traumatic or degenerative lesions); rheumatoid arthritis; giant cell tumor of the distal metaepiphysis of the radius; old injuries of the brachial plexus; gunshot wounds of the wrist with defects of the bones and articular surfaces.

The Bioethics Commission of the State Institution "Institute of Traumatology and Orthopedics of the National Academy of Medical Sciences of Ukraine" reviewed the materials of the article and concluded that the research was carried out in compliance with bioethical requirements in accordance with the Helsinki Convention of the Council of Europe on Human Rights and Biomedicine, relevant laws of Ukraine (No. 3 of 26.04.2025).

Table 1 shows the population distribution of patients by pathologies that necessitated arthrodesis.

In order to determine the effectiveness of arthrodesis, the strength of the cylindrical grip was determined using a certified hand dynamometer and the indicators of upper limb disability up to 12 months and more after surgery using the standard qDASH scale [8].

Surgical treatment. All patients underwent the intervention via a standard posterior approach using metal plates and screws. Before arthrodesis, the future position of the wrist joint was agreed with the patient, and where possible, it was modeled using a plaster cast, orthosis, or simple manual fixation. In most cases, either a neutral position or 10° extension, a neutral position relative to the elbow/radial deviation was chosen. For degenerative and inflammatory diseases, standard specialized metal structures for wrist arthrodesis were used, for other disorders, straight plates (as for forearm bone synthesis), which are thicker and longer than specialized ones.

The position of the plate is traditional: the distal-dorsal surface of the third metacarpal, proximal to the back of the radius. The articular surfaces of the radiocarpal, mid-carpal and third carpal-metacarpal joints were resected. For local structural needs

Table 1

Patient demographics and time since onset of illness/injury

Characteristics	Rheumatoid arthritis (n = 10)	Brachial plexus injury (n = 7)	Carpal tumors (n = 11)	Carpal osteoarthritis (n = 9)	Gunshot injury (n = 12)
Age, years, M ± SD	31 ± 7	22 ± 4	37 ± 7	54 ± 11	39 ± 7
Male	3 (30 %)	6 (86 %)	6 (55 %)	7 (78 %)	12 (100 %)
Female	7 (70 %)	1 (14 %)	5 (45 %)	2 (22 %)	0
Disease duration (M ± SD), months	93 ± 58	22 ± 4	7 ± 3	106 ± 57	6 ± 5

(after gunshot wounds in 7 of 12 patients, and always in the case of giant cell tumors), bone grafting was performed. In the case of ulnar-carpal conflict, marginal resection of the trihedral and part of the lunate bones was performed, and in the case of radioulnar conflict, tangential resection of the ulnar head was performed. Wrist immobilization lasted 2 months.

The peculiarities of arthrodesis for giant cell tumors of the distal metaepiphysis of the radius were the need for complete resection of the entire metaepiphysis in a single block, often with soft tissue components of the tumor extending beyond the metaepiphysis. After such a resection, it is easy to lose anatomical landmarks, disrupting the axis, rotation, and length of the segment during arthrodesis. Therefore, before removing the tumor, we used a temporary imposition of the future fixation plate on the unaffected segments of the radius and third metacarpal bones on 4–5 screws. Then, the plate was removed before the resection stage, and the holes remained as a reliable landmark for completing arthrodesis with bone grafting.

Results and Discussion

In all cases considered for quantitative analysis, wrist ankylosis developed within 2–3 months after arthrodesis.

Preoperative average indicators of the strength of the cylindrical grip, disability of the upper limb and their final values one year after the intervention due to the achievement of ankylosis of the wrist are shown in the histograms in the Figure.

The effectiveness of arthrodesis was characterized by the indicators of the dynamics of strength and disability of the upper limb, presented in Table 2.

Both according to the initial data and according to the results and dynamics of changes, the calculated parameters fundamentally and reliably differed in different groups (significance level from 0.02 to 0.001).

Summing up the results of arthrodesis, we note that the minimum increase in the strength of the cylindrical grip and the decrease in disability were recorded in patients with the consequences of brachial plexus damage. This can be explained from the standpoint of the principles of orthopedic correc-

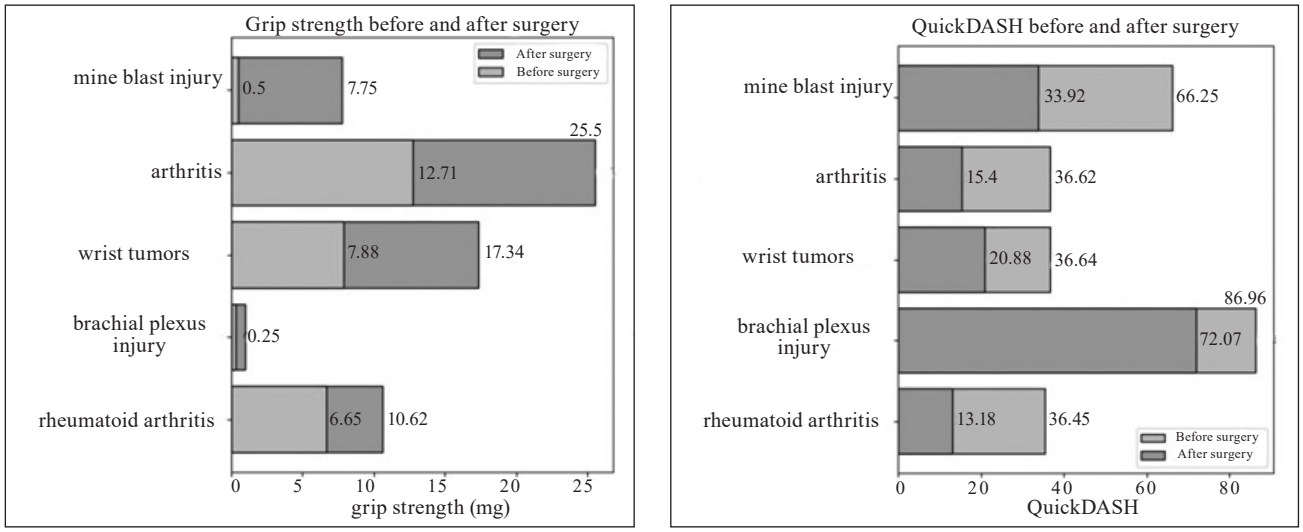

Figure. Average values of cylindrical grip strength and upper limb disability before and one year after carpal arthrodesis for various disorders

Table 2

Dynamics of hand grip strength and functional disability of the upper limb according to the qDASH scale

Lesion	Median grip strength, kg (IQR)	Grip strength range, kg	Median qDASH, points (IQR)	qDASH range, points
Gunshot wound	4.0 (3.0)	2–39	39.7 (27.4)	0.0–68.1
Arthritis deformans	14.0 (1.0)	7–15	20.4 (9.0)	9.1–38.6
Tumor	10.0 (1.5)	8–11	15.9 (10.2)	4.6–34.1
Brachial plexus injury	0.0 (1.0)	0–3	15.9 (6.8)	6.8–22.7
Rheumatoid arthritis	3.4 (2.0)	2–9	15.9 (26.1)	4.5–50.0

Notes: IQR — interquartile range, qDASH — abbreviated Disabilities of the Arm, Shoulder and Hand questionnaire

tion of this disorder [9], when arthrodesis of the wrist joint is only the first, largely preparatory operation, which precedes a complex of function-forming interventions (tendon-muscular transpositions, arthrodesis of the shoulder joint, etc.) and does not independently change the integral functions of the limb. It does not improve arthrodesis and grip strength but only creates conditions for further reconstructions.

The best increase in grip strength dynamics and qDASH scores is demonstrated by the limb against the background of its severe polystructural injury, which from the point of view of structural and functional losses of the wrist and hand often looks catastrophic. The increase in strength and ability may be associated with the restoration of both direct and indirect consequences of the injury. After arthrodesis, immobilization is removed, healing occurs, pain syndrome is reduced, the frequency of neuropathies and trophic disorders is reduced, finger contractures and the consequences of ischemic and other concomitant injuries of both the affected limb and polytrauma are eliminated.

Wrist arthrodesis in case of deforming arthrosis of the wrist joint is performed quite regularly. According to recent publications by L. Adey [10], the limits of effectiveness of arthrodesis in this condition were: for restoration of grip strength of the hand — up to 79 % of the healthy hand, and residual functional disability of the upper limb — an average of 25 points on the DASH scale. According to our results, arthrodesis in case of arthrosis provided restoration of grip strength on average up to Me 27.0 kg (range: 17–30 kg; IQR: 4.0 kg), which generally corresponds to the known data. Restoration of the level of functional disability was less significant — up to Me 16 points (range: 6.8–20.5; IQR: 3.5) on the qDASH. This discrepancy may be due to our small sample size and requires further clarification.

The effectiveness of arthrodesis and the dynamics of disability data in the conditions of the consequences of arthritis and tumors are generally similar. However, the indicators of grip strength in rheumatoid arthritis were restored noticeably worse — Me 11 kg (range: 4–18 kg; IQR: 7.5 kg), versus Me 17.5 kg (range: 14–20 kg; IQR: 2.5 kg) after arthrodesis for tumors, presumably due to systemic damage to other small joints of the hand and fingers in the case of arthritis.

Therefore, this study presents the results of arthrodesis of the wrist joint in patients with five fundamentally different ddisorders of the upper limb. This operation is infrequently required for the specified conditions, but further research is necessary. Given that movements in the wrist are important for manipulating the hand in tight spaces, as well as for hygiene, their value is obvious. It should be noted that arthrodesis fundamentally solves the problem of joint instability, significantly reduces pain, improves the appearance and indicators of grip strength, and the integral function of the upper limb. Therefore, despite the disappearance of movements in the joint, patients decide to perform this procedure.

Despite the obvious limitations of this study (retrospectiveness, single-center, low representativeness of groups), certain conclusions about the effectiveness of carpal arthrodesis for these patients can be made, but the obtained indicators should be considered approximate.

Conclusions

Among the five disorders of the upper limb, carpal arthrodesis best increases the cylindrical grip strength during the treatment of deforming arthrosis of this localization, namely by Me 14 kg (range: 7–15 kg; IQR: 1 kg).

Arthrodesis demonstrates a somewhat lower rate of strength recovery in the treatment of tumors — Me 10 kg (range: 8–11 kg; IQR: 1.5 kg); gunshot wounds with a defect in the articular surfaces — Me 4 kg (range: 2–39 kg; IQR: 3 kg); rheumatoid arthritis Me 3.4 kg (range: 2–9 kg; IQR: 2 kg). Its effectiveness is minimal in cases of brachial plexus injuries.

Arthrodesis best reduces upper limb disability according to the qDASH scale in case of gunshot injury — Me 40 (range: 0–68; IQR: 28) points, noticeably less than in case of carpal joint arthrosis — Me 20 (range: 9–39; IQR: 9) points, and demonstrates even less dynamics during the treatment of tumors, arthritis, and brachial plexus lesions.

Conflict of interest. The authors declare the absence of a conflict of interest.

Prospects for further research. Further study of the effectiveness of arthrodesis in prospective studies is relevant. Comparison of multicenter studies and increasing the representativeness of groups will allow to improve the results.

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Authors' contribution. Tymoshenko S. V. — idea, concept of the study, drafting the article, data calculations; Kotova M. V. — participation in surgical interventions, filling in primary documentation and registration of remote results.

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TOTAL WRIST ARTHRODESIS EFFICIENCY IN VARIOUS UPPER LIMB ORTHOPEDIC PATHOLOGIES

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Short-term outcomes of using custom 3D printed base plates in reverse shoulder arthroplasty for patients with glenoid cavity defects

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Objective. To conduct a retrospective analysis of the short-term clinical and radiographic outcomes of reverse total shoulder arthroplasty using custom glenoid base plates in patients with glenoid cavity defects. Methods. We retrospectively studied the surgical outcomes of 10 patients with defects of the glenoid cavity who underwent reverse total shoulder arthroplasty using individual glenoid base plates. The average follow-up period post-surgery was (2.6 ± 1.6) years. The mean age of the patients was (62.4 ± 5.6) years, including 7 women (70 %) and 3 men (30 %). Two patients (one woman and one man) underwent RTSA on both shoulders, resulting in a total of 12 RTSA procedures performed on 10 patients. All patients underwent shoulder joint imaging using spiral computed tomography, modeling of the individual base plate implant for the glenoid part of the endoprosthesis, and fabrication of the implant using 3D printing with titanium powder. The function of the shoulder joint was evaluated using the Constant-Murley Shoulder Score (CMS). Results. The mean cortical index was 0.38 ± 0.06. Lateralization and distalization angles were measured at 80° ± 5.6° and 55° ± 8.2°, respectively. The average active range of motion for external rotation was 60° ± 5.5°, flexion and elevation of the upper limb at the shoulder joint (including the scapula) was 135° ± 8.4°, internal rotation was 85° ± 3.4°, and abduction of the shoulder joint (including the scapula) was 145° ± 10.2°. The mean score on the CMS scale was 85. Conclusion. The retrospective analysis demonstrates a significant reduction or complete absence of pain syndrome along with improved functional outcomes in patients after RTSA with glenoid cavity defects when using custom base plates for the glenoid part of the reverse shoulder endoprosthesis. Keywords. Reverse total shoulder arthroplasty, RTSA, proximal humerus fracture, glenoid cavity defect, shoulder osteoarthritis, additive technology, 3D printing, porous titanium custom implants, Constant-Murley Score.

Мета. Провести ретроспективний аналіз короткострокових клінічних і рентгенографічних результатів зворотного ендопротезування плечового суглоба з використанням індивідуальних базових пластин у пацієнтів із дефектами суглобової западини лопатки. Методи. Вивчено результати хірургічного лікування 10 осіб із дефектами суглобової впадини лопатки, яким було проведене RTSA з використанням індивідуальних гленоїдальних базових пластин. Середній післяопераційний термін спостереження — (2,6 ± 1,6) року. Середній вік пацієнтів становив (7 жінок і 3 чоловіків) (62,4 ± 5,6) років. Двом особам (жінка та чоловік) виконано RTSA обох плечових суглобів. Отже проведено 12 RTSA 10 хворим. Усім здійснено моделювання та друк на 3D-принтері індивідуального імплантата базової пластини гленоїдальної частини ендопротеза. Функцію плечового суглоба за результатами лікування оцінювали в балах за шкалою Constant-Murley Shoulder Score (CMS). Результати. Середній кірковий індекс склав (0,38 ± 0,06). Кут латералізації склав 80° ± 5,6°, дисталізації — 55° ± 8,2°. Активний обсяг рухів зовнішньої ротації в середньому склав 60° ± 5,5°, згинання та підйому верхньої кінцівки в плечовому суглобі до переду разом із лопаткою — 135° ± 8,4°, внутрішньої ротації — 85° ± 3,4°, відведення в плечовому суглобі, разом з лопаткою — 145° ± 10,2°. Середній бал за школою CMS — 85. Висновок. Ретроспективний аналіз довів, що в пацієнтів після RTSA з дефектами гленоїдальної западини фіксується зменшення або повна відсутність больового синдрому з одночасним покращенням функціональних показників за умов використання індивідуальних базових пластин гленоїдальної частини зворотного ендопротеза плечового суглоба.

Ключові слова. Зворотне ендопротезування плечового суглоба, перелом проксимального відділу плечової кістки, дефект гленоїдальної западини, остеоартроз плечового суглоба, адитивні технології, 3D-друк, пористі титанові індивідуальні імплантати, Constant-Murley Score

Introduction

Reverse total shoulder arthroplasty (RTSA) is an effective surgical treatment for multifragmentary fractures of the proximal humerus with reduced bone mineral density and their sequelae, especially in elderly patients [1]. Over the past decades, there has been an increase in the use of RTSA worldwide, with a simultaneous increase in the number of different types of reverse shoulder arthroplasty [2]. Despite the existing experience of RTSA for 40 years, complex bone loss of the articular part of the scapula and its deformations remain a significant problem [3]. Curvatures and defects of the glenoid fossa can occur as a result of severe degenerative or post-traumatic changes, congenital anomalies, tumors, or after primary total shoulder arthroplasty. The lack of sufficient contact area with the base plate of the glenoid component of the endoprosthesis and poor bone quality lead to early instability, dysfunction, and pain [3, 4].

Various approaches have been used to address this complex issue: eccentric expansion of the glenoid cavity with burrs, bone auto- or alloplasty, the use of metal base plates with an alternative location of the central screw or metal base plates with a porous surface or augments [5]. However, clinical results with their use remain ambiguous. The high rate of complications, including implant instability and lack of its integration, prompts the search for new methods for solving the problem of defects in the scapular glenoid cavity [6].

Several literature sources have already reported satisfactory short-term clinical and radiological results of RTSA using individual implants obtained using additive technologies [4–7]. The introduction of computer modeling with subsequent 3D printing from titanium powder to create an individual base component of the glenoid cavity to replace defects is one of the promising directions for solving this issue.

Purpose: to retrospectively analyze the short-term clinical and radiographic results of reverse shoulder arthroplasty using individual base plates in patients with scapular socket defects.

Material and Methods

The retrospective study included 10 patients with scapular socket defects who underwent RTSA using individual base plates. The study was approved by the Bioethics Commission of the State Institution Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Medical Sciences of Ukraine (22.04.2019, protocol No. 191, 20.02.2023, protocol No. 229). All the patients provided written informed consent, confirming their voluntary participation and understanding of the study procedures, potential risks and benefits. The mean postoperative follow-up period was (2.6 ± 1.6) years (range 2 to 5), and the mean age of the patients was (7 women, 3 men) (62.4 ± 5.6) years (range 50 to 70). Two patients (a woman and a man) underwent RTSA of both shoulder joints. Thus, 12 RTSA were performed in 10 patients.

Surgical treatment of patients was performed in the period 2019–2025 at the City Clinical Hospital No. 16 (Dnipro, Ukraine). All patients met the following inclusion criteria:

– age not less than 50 years;

– fracture of the proximal humerus of type 11-B or 11-C according to the AO/OTA classification or its consequences [8];

– stage 3 osteoarthritis of the shoulder joint with a defect in the glenoid cavity;

– pronounced decrease in bone mineral density with a cortical index (CI) value ≤ 0.4.

In 8 patients (3 men and 5 women), the defect of the glenoid cavity was caused by post-traumatic changes, in 2 (women) by osteoarthritis of the shoulder joint.

All patients underwent a standard clinical examination and X-ray examination of the injured upper limb in the preoperative period. To identify the features of the displacement of the fragments of the glenoid cavity and defects of the glenoid cavity, all patients underwent spiral computed tomography (SCT).

The study of the shoulder joint was performed on an AQUILION spiral computed tomography (Toshiba, Japan) with the acquisition of slices for building a three-dimensional model and further modeling of an individual implant of the base plate of the glenoid part of the endoprosthesis. At the stage of cooperation with engineers, the possible dimensions of the implant, its location, directions of insertion and the number of screws for fixation were determined. A device made of sterilized plastic was also created for the correct orientation and insertion of the axial pin into the glenoid cavity. Then, according to the obtained models, implants were printed on 3D printers from titanium powder.

Features of the surgical technique

Under general anesthesia in the “beach chair” position, deltopectoral access was performed in all cases. Special attention was paid to the careful release of soft tissues from the humeral fragments and scars, both interfragmentary and between the humeral fragments and the glenoid cavity in the case of old fractures of the proximal humerus. It is mandatory to mobilize the proximal humerus so that it is possible

to make a correct cut of the humeral head according to the guides, with the subsequent installation of a retractor to shift the humerus downward. Depending on the specific situation, it is possible to mobilize the deltoid muscle from the acromion. Scar tissue in the subacromial space is always carefully removed, as well as the scars that fill the glenoid cavity defect with remnants of the labrum and long head of the biceps tendon. In all cases, a 3D-printed plastic guide device was used to guide the central pin. After that, a plastic base support implant similar to the titanium one was placed on the pin to determine its orientation, location, and the need for soft tissue and bone removal (but excessive removal should be avoided). Next, a press-fit fixation of the printed porous implant was achieved using an impactor. Visual confirmation of complete placement was performed by checking the presence of clearance in the screw holes and light manual testing using a hook. The implant was tightly positioned without wobble in all cases, and for additional initial stability, fixation was performed with 3.5 mm titanium screws according to 3D planning. A diamond-like carbon (DLC) coated metal glenosphere was then placed on the Morse taper of the base plate (Fig. 1), followed by placement of the humeral component of the prosthesis and standard surgical completion. All RTSAs were performed by the same surgeon. Additional cementation of the base plate was not used in any case.

Retroversion of the prosthesis stem was 10° in 12 cases.

The rehabilitation protocol was standard. Postoperative fixation of the upper limb in all patients was performed with a Dezo bandage for 4 weeks. Passive movements in the elbow and shoulder joints were allowed for 2–3 days after surgery under the supervision of a physiotherapist instructor, active movements were allowed in 3–4 weeks. After surgery, patients had appointments for control examinations in 3, 6 and 12 months, as well as annually for radiographic evaluation in two projections.

When using standard reverse shoulder endoprostheses, lateralization and offset depend on the hemisphere and design of the shoulder component, as well as inserts. In our cases, individual three-dimensional biomechanical modeling allowed lateralization to be laid in the base plate.

Bone mineral density in all patients was assessed by radiographic images of the humerus in the anteroposterior projection with calculation of the CI [9]. The presence of a scapular neck defect was assessed according to the Nerot-Sirveaux classification [10, 11].

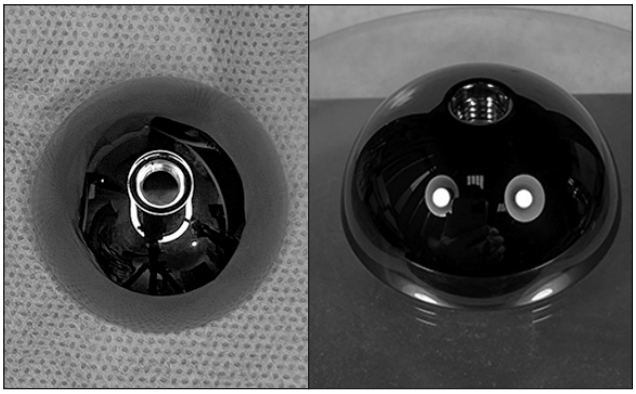

Fig. 1. Glenosphere covered with DLC

Lateralization and distalization were measured using the angles described by Boutsiadis et al. [12].

Radiographic characterization of signs of bone lysis around the glenoid cavity was performed according to the Souter's-Deutsch classification [13].

In 3 patients, a multifragmentary fracture of the scapula was observed as a result of trauma, simultaneously with a fracture of the glenoid cavity: type IB according to the Ideberg-Goss classification [14] in 1 patient, type II in 2. Due to the lack of surgical treatment in the first months after the trauma, a post-traumatic defect of the glenoid cavity was formed. In conclusion, we consider these cases within the concept of post-traumatic osteoarthritis of the shoulder joint with a glenoid cavity defect, which is subject to classification according to Walch [15].

Shoulder function after treatment was assessed using the Constant-Murley Shoulder Score (CMS) [16], a functional scale with a maximum total score of 100, reflecting optimal shoulder function. Treatment outcomes were assessed 3, 6, and 12 months after surgery. CMS scores for each patient were determined to the nearest integer due to the integer nature of the scale.

Statistical analysis. Quantitative assessments were defined as mean (x) ± standard error (SE). Differences between functional outcomes in CMS scores were assessed using the Tukey test at a significance level of $p < 0.05$ based on the results of one-way analysis of variance (ANOVA).

Results and Discussion

12 RTSAs were performed in 10 patients. The average postoperative follow-up period was (2.6 ± 1.6) years (from 2 to 5). At the time of the last control, none of the operated patients had complications that affected the final outcome.

The CI was determined at 0.38 ± 0.06 (0.30–0.40). Type 11-C fracture according to AO/OTA was

observed in 8 patients, stage 3 osteoarthritis of the shoulder joint in 2.

According to the Walch classification of glenoid cavity defects, type B1 was observed in 2 patients, B2 in 2, and type C in 6 [15].

Lateralization and distalization [12] were noted at the following level: lateralization angle — 80° ± 5.6°, distalization — 55° ± 8.2°.

In 2 patients, radiological characteristics of signs of bone tissue lysis around the base plate showed grade II after 2 years according to the Souter's-Deutsch classification [13] without signs of functional impairment and pain syndrome.

Scapular notch, which is a specific complication of reverse shoulder arthroplasty, did not occur in any case during the observation period.

The active range of motion of external rotation was on average 60° ± 5.5°, flexion and elevation of the upper limb in the shoulder joint to the front together with the scapula 135° ± 8.4°, internal rotation 85° ± 3.4°, abduction in the shoulder joint, together with the scapula 145° ± 10.2°. All patients are satisfied with the result of the operation. The average CMS score was 85.

Clinical case

A 60-year-old patient C. was admitted to the polytrauma department of the CNE CCH No. 16 DCC with a diagnosis of old fracture dislocation of the right and left shoulder joints with pronounced adductor contracture and pain syndrome (AO / OTA 11-C3, CI = 0.3), 2 months after injury, Walch type C defect of the articular surface of the glenoid cavity (Fig. 3, 4).

According to the SCT, both individual design of plastic 3D conductors for the axial pin and individual modeling and manufacturing of a porous glenoid support plate for the hemisphere of the Evolutis endoprosthesis were performed (Fig. 5, 6).

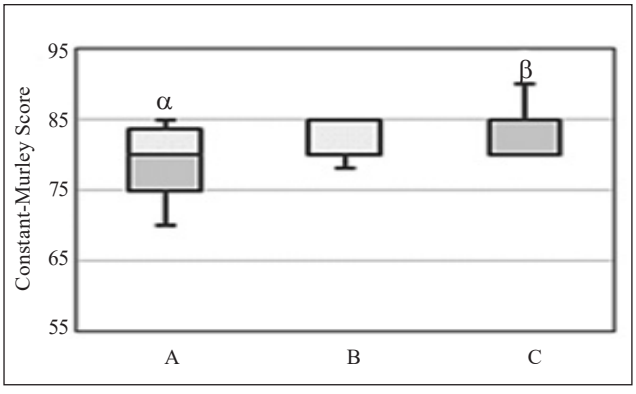

Fig. 2. Dynamics of changes in functional results of patients according to mean CMS scores 3 (A), 6 (B) and 12 (C) months after surgery; upper and lower borders of the rectangle are lines of 25 and 75% quartiles; horizontal line inside the rectangle is the median; dark and light color indicate 50 and 75 % quartiles, respectively; borders of vertical lines are minimum and maximum values; different letters indicate results with statistically significant ($p < 0.05$) differences

Under general and conductive anesthesia, patient S. underwent the following first stage: primary total hybrid reversible arthroplasty of the right shoulder joint with an individual porous titanium support 3D plate, taking into account the replacement of glenoid cavity defects (Fig. 7, 8).

Immobilization with a Dezo bandage lasted 4 weeks. Passive movements in the shoulder joint under the control of a physical therapy instructor were started on the 1st week after the operation, active ones in 4 weeks. The function of the right shoulder joint was restored: the Constant-Murley index 3 months after the operation was 80 points, and 85 points in 6 months (Fig. 8).

At the second stage, after 8 months, under general and local anesthesia, patient S. underwent primary total hybrid reversible endoprosthesis of the left shoulder joint Evolutis with an individual porous titanium support 3D plate, taking into account the replacement of defects in the glenoid cavity (Fig. 9–12).

The use of 3D modeling, considering the defect of the glenoid articular surface and the creation of an individual glenoid part of the reversible endoprosthesis of the humerus from trabecular titanium, allowed obtaining an excellent stable result, namely 85 points according to the Constant-Murley Shoulder Score system.

The superiority of RTSA over conservative treatment in very elderly patients (over 80 years) with varus posteromedial and valgus impact fractures is not clearly proven [17]. At the same time, in patients under 80 years of age, RTSA has shown its superiority in functional outcomes compared with conservative treatment and hemiarthroplasty in most studies. Recent observations also demonstrate the superiority of RTSA over open reduction and internal fixation in patients over 60 years of age [18]. Most authors recommend performing RTSA in the acute phase after a proximal humerus injury, although some studies have not found a significant difference compared with performing RTSA in the delayed period after the injury [19].

Reverse shoulder arthroplasty has become a successful surgical solution for many patients with proximal humerus fractures. The benefits of RTSA are recognized for fractures with severe head involvement, but are not as evident for borderline varus posteromedial and valgus fractures [20].

Current RTSA base plate designs have a low failure rate, but further analysis is needed in the setting of glenoid fossa defects to determine whether

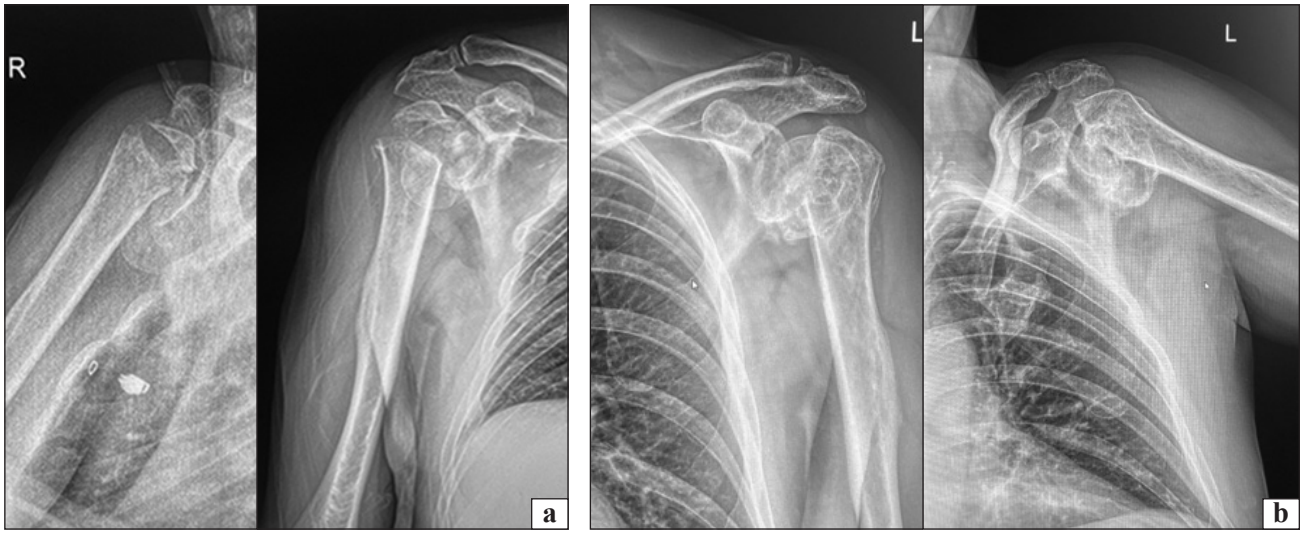

Fig. 3. Radiographic images of patient C., 60 years old, 11-C3, 2 months after injury, defect of the articular surface of the glenoid cavity of the right (a) and left (b) shoulder joints

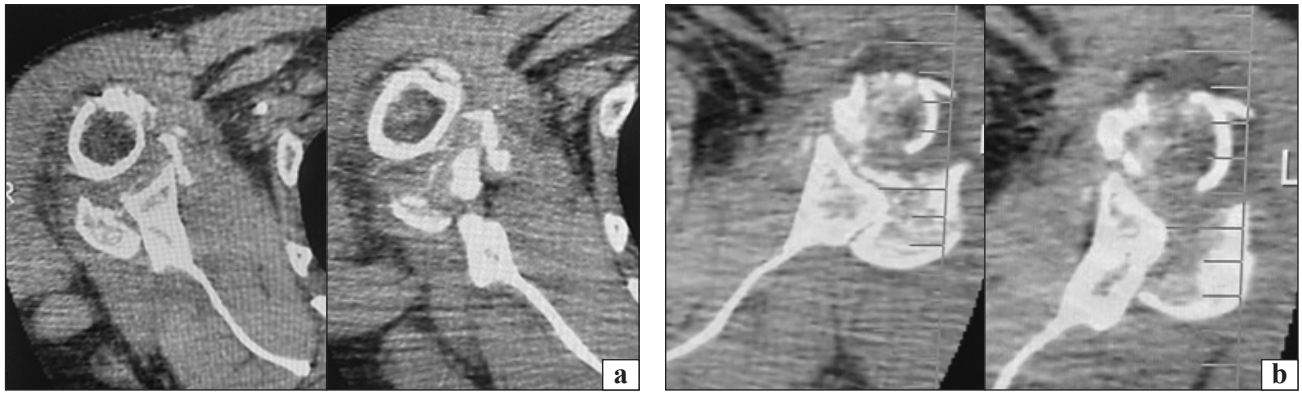

Fig. 4. Photo of CT scans of patient C., 60 years old, 11-C3, 2 months after injury, defect of the articular surface of the glenoid cavity of the right (a) and left (b) shoulder joints

the degree of feasibility is critical or whether custom 3D-printed glenoid augments or base plates are preferable [21].

Early designs of reverse total shoulder arthroplasty demonstrated high rates of complications and reoperations related to the standard glenoid baseplate design. Although modern versions of the arthroplasty have reduced the failure rate, an increased risk of complications has been reported for RTSA when bone grafts are used to replace glenoid socket defects during the first two years after surgery [22].

Several studies [23, 24] have shown that clinically significant improvements, as reported by patients and measured by scales, after RTSA in the case of glenoid socket defects and the use of custom baseplates are only observed one year after surgery. This makes our observations valid for comparison.

The anatomic and functional improvement rates we obtained are consistent with those of previous studies that used custom implants to correct glenoid socket bone deficiencies after RTSA [25].

Today, the implantation of the base plate after RTSA remains a challenge and is technically difficult even for an experienced surgeon. Instability of the glenoid component is one of the common reasons for revision shoulder arthroplasty [22–25]. Therefore, we consider it appropriate to use individual base plates of the glenoid part of the reverse shoulder arthroplasty in case of defects in the bone tissue of the articular process of the scapula. Our observations indicate a decrease or complete absence of pain syndrome in patients after RTSA with a simultaneous increase in functional results. Thus, a significant increase in the volume of active movements and an improvement in the quality of life due to the full use of the upper limb in daily life was recorded.

This retrospective study is limited by a small patient sample and short follow-up; longer observation is needed to assess implant stability over time.

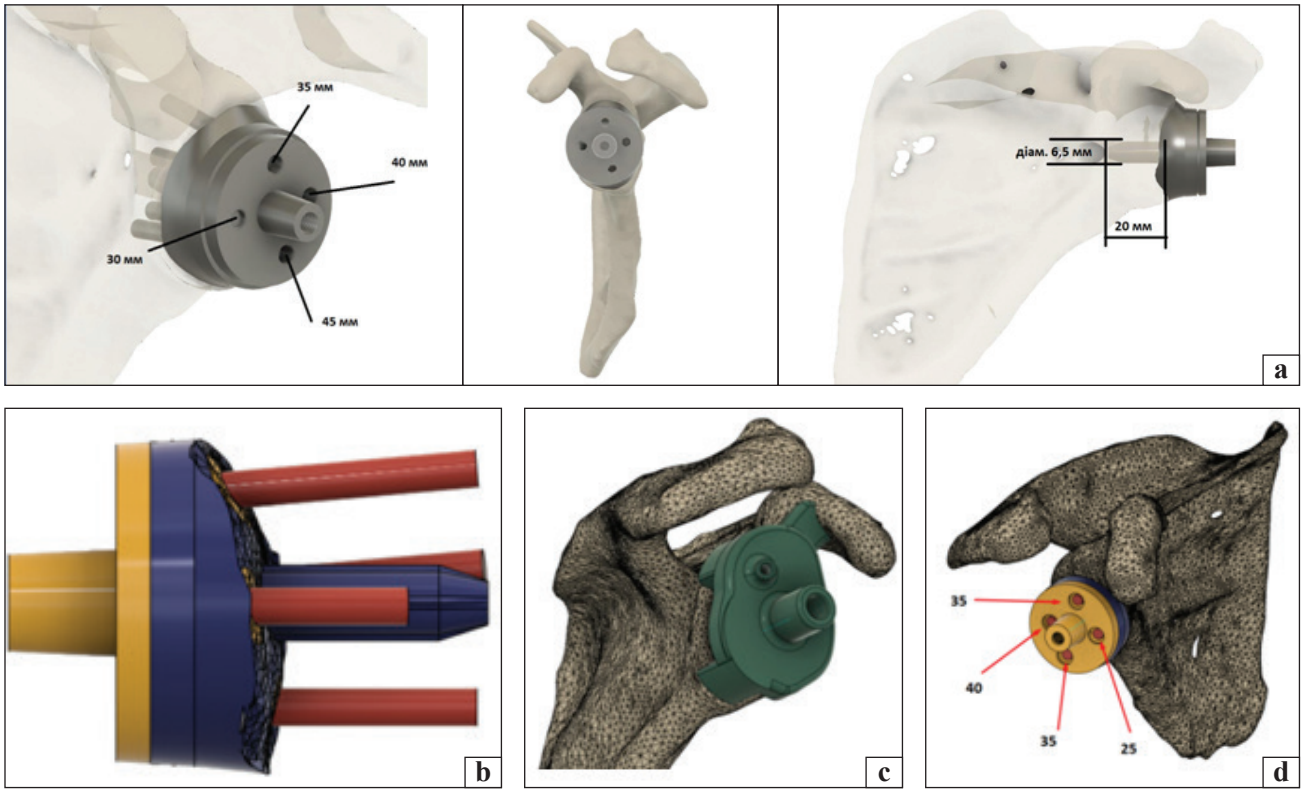

Fig. 5. Stages of modeling in the presence of a glenoid cavity defect: multi-projection image of the glenoid base plate (a); Custom modeling and manufacturing of a porous glenoid base plate for the hemisphere of the Evolutis endoprosthesis (b); computer 3D model with a conductor for the axial wire (c) and the glenoid base plate for the hemisphere of the Evolutis endoprosthesis taking into account the replacement of defects (d)

Fig. 6. Plastic printed model of the developed glenoid base plate taking into account the defects of the glenoid cavity of the scapula on the right

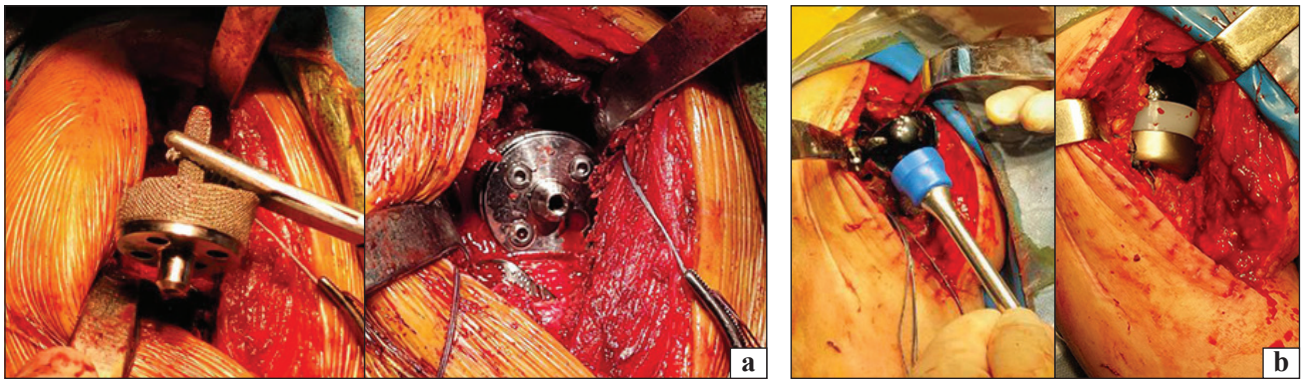

Fig. 7. Stage and surgical treatment of patient S.: implantation of a 3D glenoid support plate (a) and its appearance in the surgical wound (b)

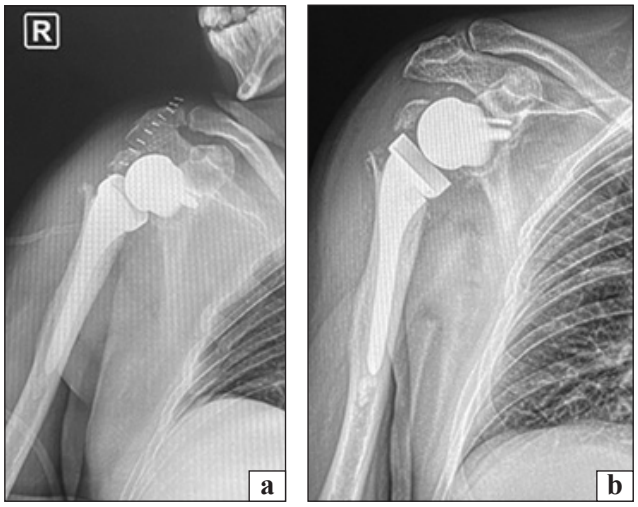

Fig. 8. Radiographic images of patient S. immediately (a) and 3 months (b) after surgery

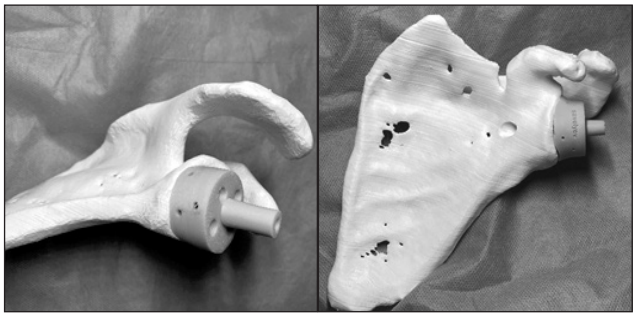

Fig. 9. Plastic printed model of the developed glenoid support plate taking into account defects in the glenoid cavity of the left scapula

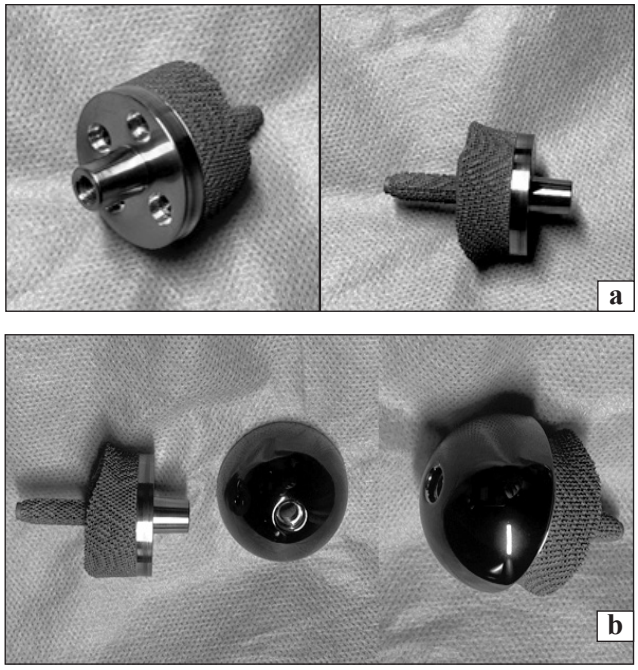

Fig. 10. Printed titanium porous base individual glenoid plate taking into account defects (a); glenoid plate with a glenosphere covered with a diamond-like carbon (DLC) (b)

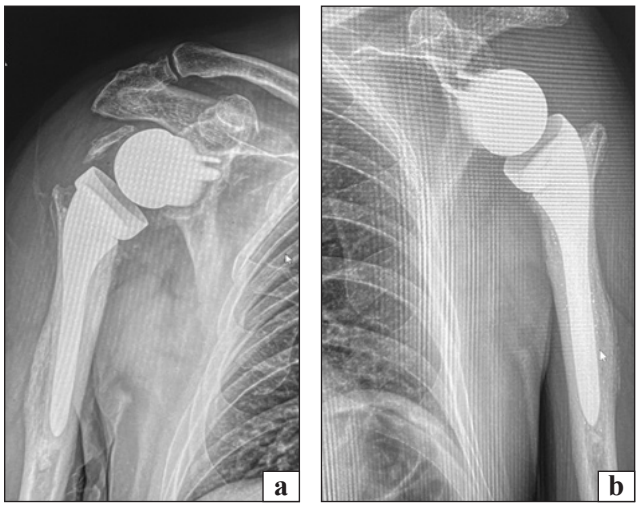

Fig. 11. Radiographic images of the right (a) and left (b) shoulder joints of patient S. 2 years after surgery — complete osseointegration without signs of lysis

Fig. 12. Photo of patient S. 2 years after RTSA — functional outcome

Conflict of interest. The authors declare the absence of a conflict of interest.

Prospects for further research. Promising are studies on the analysis of osseointegration of individual titanium porous structures printed on a 3D printer and the study of long-term results after reverse shoulder arthroplasty.

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Authors' contribution. Makarov V. B. — concept and design, collection and processing of materials, analysis of the

obtained data, drafting the article; Korzh M. O. — concept, drafting the article, editing the text.

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SHORT-TERM OUTCOMES OF USING CUSTOM 3D PRINTED BASE PLATES IN REVERSE SHOULDER ARTHROPLASTY FOR PATIENTS WITH GLENOID CAVITY DEFECTS

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Manifestations of heterotopic ossification in patients with radial head fractures combined with forearm dislocations

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Heterotopic ossifications (HO) is one from the negative consequences of the joint injuries, and they are especially significant for fractures and fracture-dislocations of the elbow, reaching 37 %. Objective. To study the frequency of occurrence and form of manifestation of HO in patients with fractures of the radial head (RH) in combination with dislocations of the forearm under the conditions of restoration of the head and the impossibility of its preservation. Methods. The study is based on a retrospective analysis of clinical observation material of 48 patients with dislocations of the forearm in combination with fractures of the RH, among which during surgical treatment in 39 patients the head of the radius was preserved (1st group), in 9 patients it was not possible to save the head (2nd group). Results. In 9 patients (23 %) of the 1st group and in 5 (56 %) of the 2nd group for an average period of 6 months, X-ray examination revealed manifestations of HO. Surgical interventions were performed later than 48 hours. It is noteworthy that among patients of the 1st group, HO, which caused limitation of the range of motion in the joint, occurred in 2 cases out of 9, that is, in 22 %, and among patients of the 2nd group, significantly more often — in 4 out of 5 patients, that is, in 80 % of cases. Differences between these indicators in groups are statistically significant ($p < 0.05$). The functional assessment of the elbow joints by the Mayo Clinic Score in groups was significantly higher in the patients of the 1st group — (87 ± 9) points compared to (49 ± 16) in the patients of the 2nd group ($p < 0.05$). Conclusions. In patients with fractures of the RH in combination with dislocations of the forearm in cases of impossibility of preserving the head, the formation of HO in the area of the elbow joint is observed more than twice as often compared to patients with preserved head (56 % vs. 23 %). HO of forms II and III are observed more than three times more often in patients with fractures of the RH in combination with dislocations of the forearm in cases of impossibility of preserving the head compared to cases of its restoration (80 % vs. 22 %). Given the high risk of HO in the elbow joint of patients with fractures of the RH in combination with dislocations of the forearm in case of impossibility of preserving the head, as well as in cases of postponement of the necessary surgical treatment for fractures in the elbow joint, it is necessary to take care of the available measures for the prevention of HO.

Одним із негативних наслідків травм ліктьового суглоба є гетеротопічна осифікація (ГО), що сягає 37 % . Мета. Вивчити частоту виникнення і форми прояву гетеротопічних осифікатів у пацієнтів і+з переломами головки променевої кістки в поєднанні з вивихами передпліччя за умов відновлення головки та неможливості її збереження. Методи. Дослідження базується на ретроспективному аналізі клінічного матеріалу спостереження 48 пацієнтів із вивихами передпліччя разом із переломами головки променевої кістки (ГПК), серед яких у процесі хірургічного лікування у 39 осіб вона була збережена (перша група), у 9 — ні (друга). Результати. У 9 випадках (23 %) першої групи та у 5 (56 %) другої на середній строк 6 міс. під час рентгенологічного обстеження виявлено прояви ГО. Хірургічні втручання їм виконано пізніше 48 годин. Зазначимо, що серед пацієнтів першої групи гетеротопічні осифікати, які обумовлювали обмеження обсягу рухів у суглобі, зафіксовано в 2 випадках із 9, тобто у 22 %, а серед осіб другої групи суттєво частіше — у 4 із 5 хворих, тобто в 80 % випадків. Різниця цих показників у групах статистично значуща ($p < 0,05$). Функціональна оцінка ліктьових суглобів у групах за бальною шкалою клініки Мауо виявилась суттєво вищою в пацієнтів першої групи — (87 ± 9) балів проти (49 ± 16) другої групи ($p < 0,05$). Висновки. У осіб із переломами ГПК у поєднанні з вивихами передпліччя в разі неможливості збереження головки формування гетеротопічних осифікатів у ділянці ліктьового суглоба діагностовано більш ніж у 2 рази частіше порівняно з хворими зі збереженою головкою (56 проти 23 %). Гетеротопічні осифікати II і III форм спостерігаються більш ніж у 3 рази частіше у пацієнтів із переломами ГПК разом із вивихами передпліччя у разі неможливості збереження головки як порівняти з випадками її відновлення (80 проти 22 %). Ураховуючи високий ризик виникнення гетеротопічних осифікатів у ділянці ліктьового суглоба хворих із переломами ГПК у поєднанні з вивихами передпліччя в разі неможливості збереження головки, а також у випадках відтермінування необхідного хірургічного лікування за умов переломовивиху в ліктьовому суглобі, потрібно потурбуватись про доступні заходи профілактики ГО. Ключові слова. Гетеротопічні осифікати, ліктьовий суглоб, переломовивих.

Keywords. Heterotopic ossifications, elbow joint, fracture dislocation

Introduction

Fractures of the radial head (RH) account for about 30 % of injuries in the elbow joint [1]. RH serves as one of the primary stabilizers of the elbow joint [2]. Additionally, approximately 60 % of the axial load transmitted through the elbow is borne by the humeral-radial articulation [1]. RH plays an essential role in the normal functioning of the joint. Unfortunately, it is not always possible to restore the damaged head in the case of its multi-fragment fracture, although this possibility has increased after the creation of new low-profile plates that are more adapted to the size of the fragments [3, 4]. In cases of RH type II and even type III fractures (according to the Mason classification in the Broberg-Morrey modification [5]), its removal has almost no effect on the functioning of the joint [6, 7], however, in the case of impossibility of performing osteosynthesis of multi-fragmentary head fractures, the use of its endoprostheses is increasingly widespread [7, 8]. In the case of a type IV head fracture, i.e. in combination with a forearm dislocation, the consequences of its removal are manifested both by functional limitations and daily pain in the joint [9]. One of the manifestations of the negative consequences of elbow joint injuries is heterotopic ossification (HO) [10]. In type III and IV RH fractures, the development of HO according to C. S. Fischer et al. reaches 52.1 % [11].

Purpose: to study the frequency of development and forms of manifestation of heterotopic ossification in patients with radial head fractures in combination with forearm dislocations under conditions of head repair or impossibility of its preservation.

Material and Methods

Clinical observation materials of 48 patients with type IV RH fractures without fractures of other bones of the elbow joint, who were treated at the State Institution Professor M. I. Sytenko ISJP of the NAMS of Ukraine in the period 2009–2024. The materials of the study were considered and approved at the meeting of the Committee on Bioethics and Deontology at the State Institution Professor M. I. Sytenko ISJP of the NAMS of Ukraine (protocol No. 250 dated 10.03.2025). All patients signed an informed consent.

The average age of the patients was (41 ± 2) years, 18 men and 30 women. Two groups were distinguished according to the preservation of the RH or the removal of its fragments. The first group consisted of 39 patients (16 men and 23 women), average age (45 ± 2) years (from 18 to 70), who underwent surgical intervention to eliminate the dislocation and restore the RH. The second group consisted of 9 subjects (2 men and 7 women), mean age (40 ± 3) years (from 27 to 52), in whom osteosynthesis of the radial head was not possible, i.e. the head was not preserved. In 14 patients out of 48, manifestations of HO were detected during X-ray examination. The presence and intensity of pain were assessed, focusing on the indicators according to the Mayo Elbow Performance Index (MEPI) [5]: absence (0), slight (1), moderate (2) and severe (3) pain. The presence and degree of manifestation of instability of the elbow joint was also studied according to the following criteria: the presence of excessive amplitude of valgus/varus movements (with the forearm extended) up to 10° was characterized as instability of the 1st degree; > 10° as the 2nd degree. The HO was assessed taking into account radiological characteristics of ossification and reduction in the range of motion in the elbow joint proposed by several authors [12, 13], according to which three forms were distinguished:

I (mild) — limitation of the amplitude of movements < 30°;

II (moderate) — ≥ 30° (II A — flexion-extension, II B — rotation, II C — both options);

III (severe) — presence of bone ankylosis (III A — shoulder-elbow joint, III B — proximal radioulnar joint, III C — both joints).

The volume of movements in the joint was also recorded and an integral assessment of the limb function was determined using the MEPI system. Tables 1 and 2 show data on gender, age, presence of HO and its form, presence and degree of joint instability, amplitude of movements in it, assessment of its function according to MEPI, as well as the period of testing the condition of the joint from the moment of injury in these 14 patients according to their group category.

To determine the statistical significance of the differences in frequency values, the analysis employed both the comparison of two proportions and the Mann-Whitney U test for independent samples using Statistica software.

Results and Discussion

X-ray and functional study of the condition of the elbow joints of patients was carried out in the period from 5 to 9 months (after (6.5 ± 0.4) months in the first group and after (6.2 ± 0.4) in the second). Among 48 individuals, HO was detected in 14 (29 %): 9 cases out of 39 in representatives of the first group, i.e. with preserved RH, which amounted to 23 %, 5 out of 9, i. e. 56 % of the second group, where the head could not be preserved. The difference in the indicators of the relative frequency of HO observation in the groups is statistically significant ($p < 0.05$).

O. A. Ilahi et al. [14] found that HO limiting joint motion occurred in 33 % of elbow injury patients who had

surgery more than 48 hours after injury but was not observed in those treated earlier. In our study, 14 subjects with HO underwent interventions later than 48 hours due to various circumstances. Among these cases, HO II and III were observed in 6 patients (42.8 %). In the first group, 2 out of 9 patients (22 %) presented with these forms, whereas in the second group, HO II and III occurred significantly more frequently — in 4 out of 5 patients (80 %). The difference in these indicators of the frequency of more severe forms of OA in the groups is statistically significant ($p < 0.05$).

The limitation of movements in the joint cannot be unambiguously associated only with the presence of HO, without taking into account other factors (fibrosis of the capsule and ligaments, the condition of the muscles associated with the functioning of the joint, etc.). Figure 1 presents radiographic images of the elbow joint from a patient in the first group (case No. 9). These images indicate that the size, location, and positional changes of the ossifications relative to variations in the angle between the shoulder and forearm do not provide sufficient evidence to conclude that they are the primary cause of the observed movement limitation. Consequently, it is appropriate to categorize these ossifications as representing the mild form (I).

Fig. 2 presents radiographic images of the elbow joint from a patient in the first group (case No. 4) taken seven months after injury, following head consolidation. The images indicate a compact ossification of notable size situated in the area of the coronoid process of the ulna. It has no obvious relation to the proximal radioulnar joint. Such a radiological picture is the basis for believing that this heterotopic formation is indeed the main cause of the limitation of flexion-extension movements, that is, it refers to HO form II A.

In patients of the second group, HO form II was radiographically distinguished by a significantly greater prevalence compared to ossifications in patients of the first group.

Figure 3 presents radiographic images of the elbow joint from a patient in the second group (case No. 4), obtained seven months following reduction of the forearm dislocation and excision of radial head fragments due to the inability to perform osteosynthesis.

Radiographic images demonstrate the following HO II C presentation: dense, significant ossification occupies the space necessary for the movements

Table 1

Data of patients in the first group with the presence of HO

No.	Gender	Age (years)	Pain	Instability	HO (form)	Range of motion (degrees)		Joint function assessment (score)	Time since injury (months)
						extension/flexion	supination/pronation		
1	f	70	1	—	I	0/20/120 (100)	55/0/60 (115)	85	6
2	f	55	1	—	I	0/5//125 (120)	65/0/65 (130)	85	6
3	f	50	—	—	I	0/5/120 (115)	65/0/75 (140)	100	6
4	m	45	—	—	IIA	0/20/115 (95)	75/0/75 (150)	95	7
5	f	48	1	—	I	0/45/110 (65)	5/0/5 (10)	80	5
6	m	20	—	—	IIIB	0/50/95 (45)	0/5/5 (0)	75	7
7	m	50	—	—	I	0/10/125 (115)	75/0/75 (150)	100	7
8	f	49	1	—	I	0/5/120 (115)	65/0/65 (130)	85	6
9	m	37	1	—	I	0/50/125 (75)	75/0/70 (145)	80	9
Total		48 ± 7	—	—	—	94 ± 9	108 ± 20	87 ± 3	6.5 ± 0.4

Table 2

Data of patients in the second group with the presence of HO

No.	Gender	Age (years)	Pain	Instability	HO (form)	Range of motion (degrees)		Joint function assessment (score)	Time since injury (months)
						extension/flexion	supination/pronation		
1	f	50	1	1	I	0/25/120 (95)	55/0/45 (100)	75	6
2	f	46	1	1	IIA	0/45//95 (50)	45/0/45 (90)	45	7
3	f	43	1	1	IIA	0/40/105 (65)	65/0/60 (125)	45	5
4	f	45	1	—	IIC	0/38/58 (20)	5/0/5 (10)	30	7
5	m	52	—	—	IIIC	0/55/55 (0)	0/10/10 (0)	50	6
Total		47 ± 2	—	—	—	46 ± 17	65 ± 25	49 ± 7	6.2 ± 0.4

Fig. 1. Radiographic images of the elbow joint of the patient of the first group in the lateral projection in the position of maximum flexion (a) and extension (b), mild HO (I)

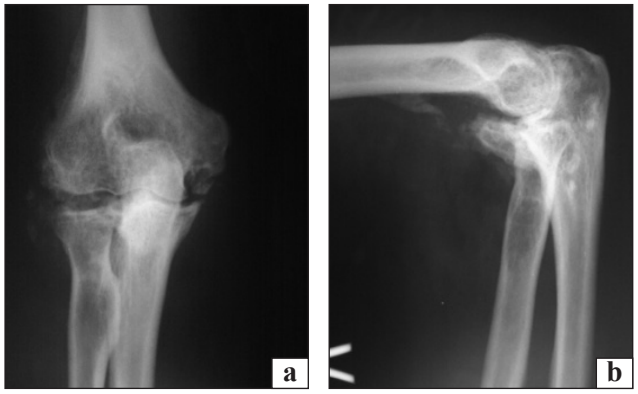

Fig. 2. Radiographic images of the elbow joint of the patient of the first group in the direct (a) and lateral (b) projections after removal of the fixators from the proximal part of the radius, HO II A

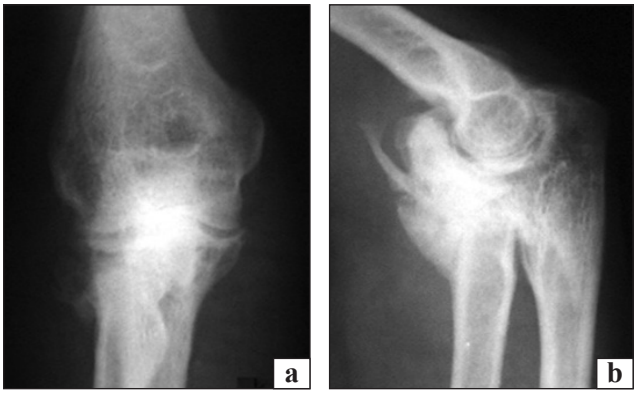

Fig. 3. Radiographic images of the elbow joint of the patient of the second group in the direct (a) and lateral (b) projections, HO II C

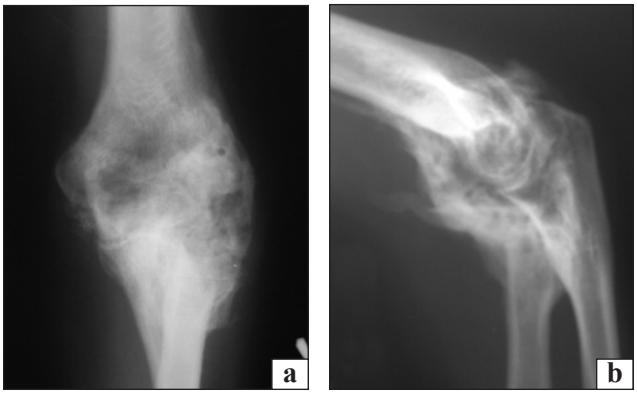

Fig. 4. Radiographic images of the elbow joint of the patient of the second group in the direct (a) and lateral (b) projections, HO III C

of bone articular formations and therefore is an obvious cause of limitation of flexion-extension and rotational movements of the forearm.

The most severe form of HO (III) was observed in both groups. Fig. 4 shows radiographic images of the elbow joint (case No. 5) 6 months after removal of the forearm dislocation and removal of fragments of the RH due to the impossibility to perform osteosynthesis. Ossification of a mature structure forms a bone bridge between the bone formations of the joint, which completely blocks flexion-extension and rotational movements of the forearm.

In 3 cases among patients of the second group, a mild degree of instability of the elbow joints in the frontal plane was observed, and in the presence of HO form II A in 2 individuals. Minor intermittent pain in this area at the time of assessment of the immediate results was noted by 55 % of patients in the first group and 60 % of patients in the second. As evidenced by the data of O. O. Korzh [15], the dependence of the development of HO on the age or sex of patients has not been established. Taking into account the similarity of patients in the groups by the nature of the injuries, it can be assumed that the difference in the preservation and absence of the RH is the main reason for the discrepancy in the frequency of HO formation and the degree of its manifestation, which was also reflected in the results of assessing the functional capabilities of the elbow joints in the groups according to the Mayo Clinic scoring scale. These indicators were significantly higher in the first group, (87 ± 9) versus (49 ± 16) in patients in the second group ($p < 0.05$).

Thus, the absence of RH along with significant damage to the soft tissue structures of the elbow joint, which occurs during forearm dislocation, suggests a decrease in the degree of its stability, which probably affects the frequency and nature of the formation of HO in this area.

The combination of several negative factors, including delayed surgical intervention (more than 48 hours after injury) and a decrease in the degree of stability of the damaged joint, leads to a more pronounced and severe form of HO.

Conclusions

In patients with fractures of the radial head in combination with forearm dislocations in cases where it is impossible to preserve the head, the formation of heterotopic ossifications in the elbow joint is observed more than twice as often as in patients with a preserved head (56 versus 23 %).

Heterotopic ossifications of forms II and III are diagnosed more than three times more often in patients with fractures of the radial head in combination with dislocations of the forearm in case of impossibility of preserving the head as compared to cases of its restoration (80 vs. 22 %).

Considering the high risk of heterotopic ossifications in the elbow joint of patients with fractures of the radial head in combination with dislocations of the forearm in case of impossibility of preserving the head, as well as in cases of postponing the necessary surgical treatment in case of fracture-dislocations in the elbow joint, it is necessary to take care of available measures for the prevention of HO.

Conflict of interest. The author declares that there is no conflict of interest.

Prospects for further research. The data presented can be used by traumatologists-orthopedicians to reduce the number of such complications and reduce the degree of their manifestation.

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MANIFESTATIONS OF HETEROTOPIC OSSIFICATION IN PATIENTS WITH RADIAL HEAD FRACTURES COMBINED WITH FOREARM DISLOCATIONS

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Critical parameters of tunnel positioning in ACL reconstruction: a retrospective MRI analysis

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Anterior cruciate ligament (ACL) rupture is one of the most common knee injuries requiring surgical intervention. The increasing number of revision surgeries indicates the potential presence of technical errors during primary reconstruction, emphasizing the importance of outcome analysis and careful surgical planning. MRI remains the gold standard not only for diagnosing ACL injuries and associated lesions, but also for evaluating postoperative changes. Objective. To assess MRI-based measurements of femoral and tibial tunnel inclination and entry point location as potential technical causes of ACL graft failure. Methods. A retrospective analysis was conducted on 105 knee MRI scans from patients following primary ACL reconstruction. The parameters evaluated included femoral and tibial tunnel inclination angles on coronal views, femoral tunnel entry point using a modified Bernhard and Hertel method, and tibial tunnel entry point assessed via the Amis and Jacob line. Results. A femoral tunnel angle within the 30°–50° range was found in 63 % of cases, with the optimal range of 32°–39° observed in 21 %. In 16 % of cases, the angle exceeded 50°, and in 3 % it was less than 17°. The femoral tunnel entry point fell within the normal range in 46 % of cases, while in 42 cases it was located outside the defined measurement rectangle. Tibial tunnel position on sagittal projection was anatomically correct in 38 % of cases, anteriorly displaced in 21 %, and posteriorly displaced in 41 %. The optimal tibial tunnel inclination angle (≥ 65°) was found in 61 % of cases. Graft integrity was preserved in 24 % of cases with posterior tibial tunnel positioning, and in only 6 % with anterior placement. Conclusions. Technical errors in tunnel formation are a common cause of ACL graft failure. Accurate determination of the tunnel entry point is the most critical factor, while tunnel angle plays a secondary, yet diagnostically valuable, role. These findings highlight the need for meticulous planning, including the use of MRI and intraoperative navigation techniques to optimize tunnel placement.

Розрив передньої схрещеної зв'язки (ПСЗ) — одна з найпоширеніших травм колінного суглоба. Зростання кількості ревізійних операцій свідчить про можливі технічні помилки під час первинної реконструкції, що актуалізує необхідність аналізу результатів і ретельного планування. Магнітно-резонансна томографія (МРТ) є «золотим стандартом» у діагностиці як розривів ПСЗ, так і супутніх ушкоджень, а також ефективним інструментом для вивчення післяопераційних змін. Мета. Оцінити показники нахилу та розташування феморального та тібіального каналів за допомогою МРТ для виявлення можливих технічних причин ушкодження трансплантата ПСЗ. Методи. Проведено ретроспективний аналіз 105 МРТ обстежень колінного суглоба в пацієнтів після первинної пластики ПСЗ. Вимірювались: кут нахилу феморального і тібіального каналів у коронарній проєкції, положення точки входу феморального каналу. Результати. Кут нахилу стегнового каналу в межах 30°–50° виявлено у 63 % випадків, оптимальні 32°–39° — у 21 %. У 16 % пацієнтів він перевищував 50°, у 3 — менше 17°. Точка входу феморального каналу відповідала нормі в 46 % осіб, у 42 випадках спостерігалося розташування феморального каналу поза межами вимірюваного прямокутника. Положення тібіального каналу на сагітальній проєкції зберігало анатомічну межу в 38 % обстежень; у 21 він був зміщений допереду, у 41 — дозаду. Кут нахилу тібіального каналу був оптимальним (≥ 65°) у 61 % випадків. За заднього розташування каналу трансплантат зберігався у 24 % випадків, за переднього — у 6. Висновки. Поширеність технічних помилок під час формування кісткових каналів може бути причиною ушкодження трансплантата. Найкритичнішим є правильне визначення точки входу каналів, тоді як кут нахилу відіграє другорядну роль, проте є маркером технічної похибки. Результати підкреслюють необхідність ретельного планування, зокрема з використанням МРТ і додаткових методик навігації під час операції. Ключові слова. Передня схрещена зв'язка, МРТ, кісткові канали, трансплантат.

Keywords. Anterior cruciate ligament (ACL), MRI, bone tunnels, graft

Introduction

Anterior cruciate ligament (ACL) rupture is the most common ligamentous injury in the knee. The annual incidence in the United States alone is approximately 1 in 3,500 individuals, requiring 400,000 ACL reconstructions annually [1]. Information is limited by the lack of any standard epidemiological surveillance mechanism in the general population and may be imprecise. Overall, available evidence suggests that the incidence of ACL ruptures has increased in patients of all ages over the past decades [2–10]. The incidence of revision reconstructions is also increasing [11]. Although the literature is not unanimous regarding the ability of ACL reconstruction to prevent post-traumatic osteoarthritis (OA), some studies have found evidence of improved stability and prevention of further meniscal and cartilage damage after ACL reconstruction [12–14]. The frequency of revision reconstruction of the ACL (RRACL) ranges from 6–12 % according to some authors [15] to 20–25 % [16, 17] by others.

RRACL leads to worse functional outcomes than primary (PRACL) [18]. Additional problems associated with revision include prolonged recovery time, longer disability, and higher economic costs, especially in the case of 2-stage revisions. Therefore, the issue of planning revision reconstruction and the possibility of performing a single-stage revision is important, as this technique leads to better outcomes [19–21].

In ACL injuries, imaging with magnetic resonance imaging (MRI) is a high-quality tool for confirming the injury and diagnosing concomitant injuries. However, MRI is also useful for determining postoperative changes after a previous PRACL and for planning further RRACL.

Purpose: to determine the main indicators that can be detected on magnetic resonance imaging for planning further treatment tactics in patients with graft damage, as well as to analyze the technical factors that lead to its damage.

Material and Methods

The results of MRI examinations in patients with previously performed PRACL were analyzed. The examination was carried out on the basis of the "Diagnostic Center M24", Kyiv from 2014 to 2024. The study was performed in compliance with ethical principles, including the provisions of the Declaration of Helsinki (2000) and relevant legislation of Ukraine.

The work is based exclusively on anonymized MRI data obtained in compliance with ethical requirements and without the possibility of identifying individuals. A total of 105 MRI examinations of patients with primary ACL reconstruction and unsatisfactory, according to MRI data, results in terms of graft integration were studied. The age of the patients was (36 ± 1) years. The study protocol included MRI images, as well as MRI examination findings. The following were measured: the angle of inclination of the femoral and tibial canals in the coronal projection, the position of the femoral canal entry point according to the adapted Bernhard and Hertel method, the tibial canal entry point according to the Amis and Jacob line. All calculations were performed using MRI viewing software (RadiAnt DICOM Viewer). The measurements were entered into an Excel spreadsheet, after which statistical analysis of the data was performed. Additionally, the angle of inclination of the lateral plateau, the area of the femoral fossa, migration and failure of fixators, and concomitant meniscal injuries were determined.

Coronal projection, angle of inclination of the femoral canal

In anatomic single-bundle reconstruction of the ACL, the femoral tunnel should be located at the site of attachment of the native ACL. The correct location of the tunnel entry point and its inclination are of fundamental importance for the best clinical outcome. The optimal angle of inclination in direct projection in various sources is considered to be about 32°–39° [22, 23]. It provides sufficient length of the channel for fixation of the ligament, but an angle less than 32° is also acceptable. But it should be remembered that the longer the channel, the greater the likelihood of its expansion after surgery, which can lead to instability of the graft and its integration. Also, the angle of inclination of the channel may indirectly indicate an incorrectly determined entry point. An angle less than 17° may cause verticalization of the ligament and, accordingly, instability.

Too sharp an angle may lead to insufficient length of the channel for fixation of the ligament. The measurement was performed in the coronal projection, on the slice with the most optimal visualization of the canal, between the line drawn through the middle of the femoral diaphysis and the line drawn through the femoral tunnel.

A range of 30° to 50° can be considered a good result. In the study, the angle of inclination of the femoral canal in the range of 30° to 50° was in 63 % of the examined. In 37 %, the angle of inclination of the femoral canal was outside the optimal range. Table 1 shows the angles and percentages among 105 MRI examinations.

Point of entry of the femoral canal in the sagittal projection

In anatomic single-bundle reconstruction of the ACL, the point of entry of the femoral canal should be located at the attachment site of the native ACL. To determine the correctness of its location, the Bernhard and Hertel method is most often used, in which a rectangle with a grid is applied to an X-ray or computed tomography image. The main line that forms it is the Blumensaat line, tangent to the roof of the intercondylar fossa. Next, a parallel tangent to the lower edge of the lateral condyle is formed to this line. After that, a perpendicular is drawn to the previous two lines along the posterior edge of the lateral condyle and a perpendicular along its anterior edge. The resulting rectangle is evaluated in two directions — posterior-anterior and superior-inferior and divided evenly with a 5 × 10 mm grid. The optimal location in the posterior-anterior direction is considered to be 27 %, in the superior-inferior direction — 34 % [24, 25].

In our study, we adapted the Bernhard and Hertel method for MRI images and measured distances in mm and calculated in percentages by adding a standard proportion. Coronal, sagittal, and axial views were compared to visualize the entry point.

In anatomic single-bundle reconstruction of the ACL, the graft must provide anteroposterior and rotational stability. Therefore, the location of the femoral canal entry point is extremely important, as deviation from the anatomical one can lead to instability in a certain range of motion, limitation of movement, and graft damage. The optimal location was previously considered to be 24 % in the posteroanterior direction and 28 in the superior-inferior direction [24]. However, in recent anatomical studies, the average value is considered to be 27 % for the posteroanterior direction and 34% for the superior-inferior direction [24, 25]. In observation, taking into account the error, the optimal range is 20–30 % for the posteroanterior direction and 28–38 % for the superior-inferior direction.

In 42 cases, at least one indicator was equal to 0, that is, it went outside the rectangle and is 44 % of the total. In 25 % of patients in the posterior-anterior direction, the location of the canal was within 20–30 %, in the superior-inferior direction in 34 % of patients at the level of 28–38 %. However, only in 44 cases did the location of the canal in both directions correspond to the optimal limits, which is 46 % (Table 2).

Table 1

Femoral canal inclination angle on coronal projection

Inclination angle (reference values) (°)	≤ 17	17–32	32–39	39–50	≥ 50
Number of observations (%)	3	30	21	30	16

The location of the femoral canal entry point is a critically important step for the successful reconstruction of the ACL, since a significant error can lead to a negative result.

Position of the tibial tunnel on the sagittal projection

The location of the tibial tunnel on the sagittal projection should be localized along the Blumensaat line. The most commonly used method for measuring its position is the Amis and Jacob line, which passes through the widest part of the posterior angle of the medial tibial plateau, parallel to the medial joint line [24]. The center of the tunnel should ideally be located 43 % of the total sagittal distance of the tibial plateau, measured from the anterior edge of the tibial plateau. MRI measurements of the native ACL range from 27 to 60 % in some studies [24, 26] and from 28 to 63 % in others [27].

To measure the location of the tibial canal entry point, the projection on which the canal is best visible is selected and the Amis and Jacob line is drawn. First, the distance from the anterior edge of the tibia to the anterior edge of the tunnel is determined. Then, the same steps are performed for the middle of the tunnel and its posterior edge. The data are estimated in percentages by adding proportions.

Among all patients, the tibial canal was located at the anterior point less than 28 % in 21 % of cases. This indicator may indicate that in these individuals the tibial canal is located behind the Blumensaat line. It leads to impingement with the roof of the intercondylar fossa and the development of “cyclops syndrome”. In 19 patients out of 20, the ACL graft was destroyed, and in 1 case, signs of “cyclops syndrome” and graft damage were observed.

In 39 people, the canal was located at its posterior point by more than 63%, if it is located too posteriorly to the plateau, it can lead to rotational instability of the knee joint (Table 3).

Measurement of the distance of the tibial canal entry point

In Fig. 6, the canal is located at the anterior point by 59% and at the posterior point by 73%. The indicators indicate a too posterior location of the canal and a vertical graft.

Measurement of the inclination of the tibial canal in the coronal projection

The angle of inclination of the tibial canal is fundamental for the transtibial technique of anterior

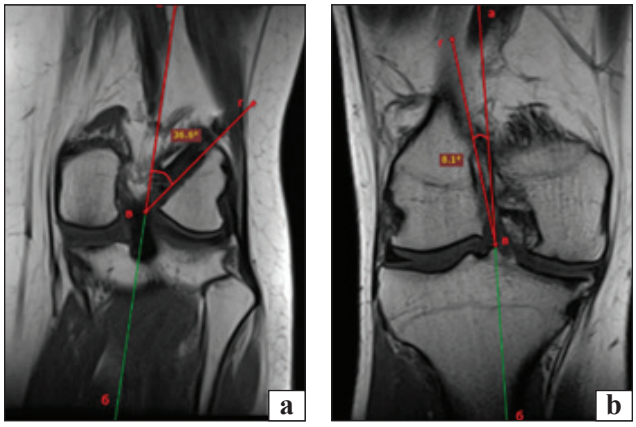

Fig. 1. Measurement of the angle of inclination of the femoral canal on the coronal projection: a) the angle is optimal and equal to 36.6°; b) the angle is too vertical and equal to 8.1° Line a–b is drawn through the middle of the diaphysis of the femur; line c–d is drawn through the femoral canal; abd is the angle of inclination of the canal

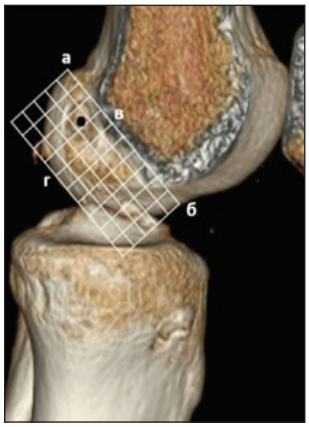

Fig. 2. Bernhard and Hertel method, 5 x 10 mm grid on the CT image to determine the point of entry of the femoral canal. Distance a–b is the posterior-anterior direction; c–d is the upper-lower; the black mark is the point of entry of the femoral canal, which is approximately 30% in the posterior-anterior direction and 27 in the upper-lower

cruciate ligament plastic surgery and should be within 65°–70° [28]. For the anatomical technique of PSL plastic surgery, it is not so fundamental, because the passage of the femoral canal does not depend on it. However, if the angle of inclination is too small due to the anatomical features of the tibial plateau, the length of the canal may be too short.

Insufficient canal length can make graft fixation difficult, especially with interference screws, and can also result in incorrect placement of the canal entry point. The sharper the angle, the more oval the exit point will be, rather than round, as the angle of inclination is directly related to the shape of the tibial canal exit [29]. Table 4 shows the relationship between the diameter of the canal entry point and the angle of inclination.

If the tibial canal exit point is oval, this can lead to widening of the canal and insufficient graft fit, which will complicate graft integration. Studies have shown that the most correct angle of inclination of the canal is ≥ 65° [30–34].

The angle of inclination of the tibial canal was measured as follows: the projection was chosen, where the beginning of the canal in the knee joint and its length were best visualized, a line was drawn parallel to the tibial plateau, a line was formed along the tibial canal to the plateau line, and the angle between these two lines was measured. If the distance was insufficient for accurate measurement of the angle, the line along the canal was projected. Of the 105 MRI studies, in 61 % of cases the angle of inclination was ≥ 65° (accepted as optimal), in 39 — < 65°.

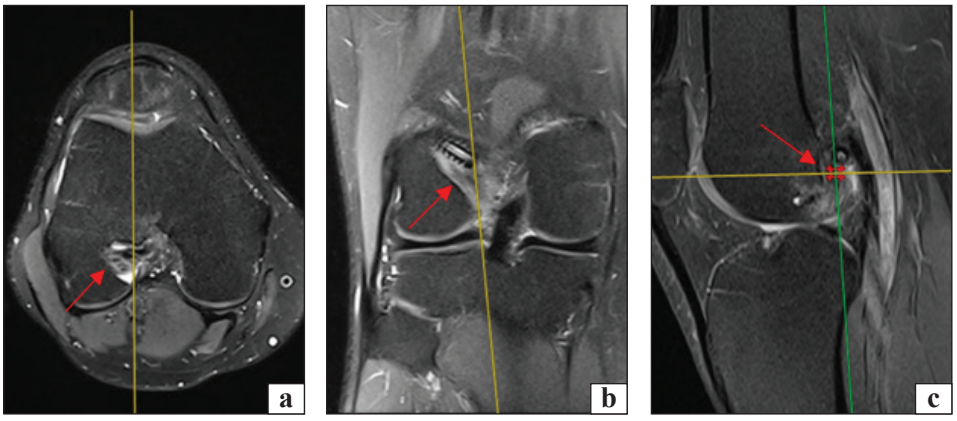

Fig. 3. Comparison of projections to determine the point of entry of the femoral canal. a — axial: the arrow indicates where the femoral canal is visualized in the extreme slice, the projection line of the sagittal slice; b — coronary: the arrow indicates the visualization of the femoral canal in the extreme slice, the projection line of the sagittal slice; c — sagittal, the arrow indicates the circle, the point of entry of the femoral canal, which is located at the intersection of the lines of the coronal and axial projections

Table 2

Femoral canal entry point measurement data using the Bernhard and Hertel method adapted for MRI

Direction	Posterior-anterior				Superior-inferior			
Reference values (%)	0	< 20	20–30	> 30	0	< 28	28–38	> 38
Number of observations (%)	11	4	25	60	34	19	34	13

Results

In 63 % of cases the angle of inclination of the femoral canal on the coronal projection was in the acceptable range of 30°–50°, and the most optimal values (32°–39°) were observed in 21 %. In 3 % of cases, the angle was less than critical (less than 17°), while in 16 % it exceeded 50°. The femoral canal entry point corresponded to the optimal limits in 46 % of examinations, while in 42 cases it went beyond the rectangle on the sagittal projection.

Regarding the tibial canal, its position on the sagittal projection corresponded to the anatomical limits in 38 % of cases, in 21 it was shifted anteriorly, and in 41 — posteriorly. In the posterior location, the graft was preserved in 24 % of examinations, and in the anterior location — only in 6 %. The angle of inclination of the tibial canal on the coronal projection was within the normal range in 61 % of studies.

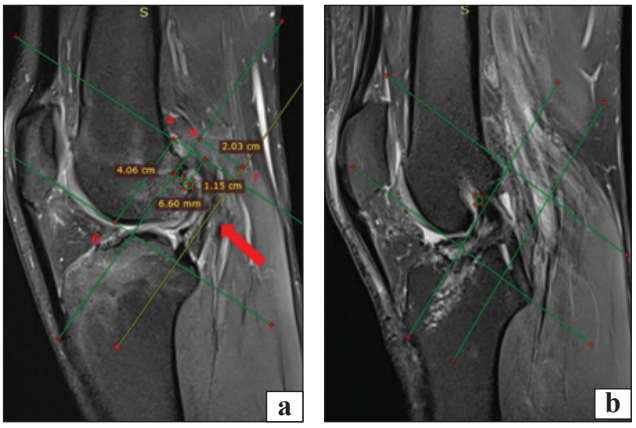

Fig. 4. MRI, sagittal projection. Line a–b is the posterior-anterior direction, line c–d is the superior-inferior. The arrow indicates the circle, the point of entry of the femoral canal. In the image, the point of entry is located in the posterior-anterior direction and 33% in the superior-inferior direction (a); the point of entry of the femoral canal is outside the Bernhard and Hertel rectangle (b)

Table 3

Data when measuring the tibial canal entry point on the sagittal projection

Reference values (%)	< 28	28–63	> 63
Number of observations (%)	21	38	41

Table 4

Dependence of the diameter of the channel entry point (mm) on the angle of inclination [29]

Tibial canal inclination angle	Canal diameter (mm)		
	8	9	10
35°	13,9	15,7	17,4
45°	11,3	12,7	14,1
55°	9,8	10,9	12,2
65°	8,8	9,9	11,0
75°	8,3	9,3	10,3

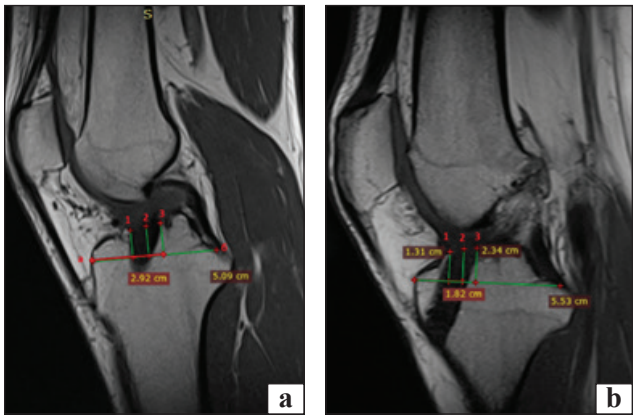

Fig. 5. Measurement of the point of entry of the tibial canal on the sagittal projection of MRI visualization. a–b is the Amis and Jacob line. 1 — the point of the anterior edge of the tibial canal, 2 — the point of the middle of the tibial canal, 3 — the point of the posterior edge of the tibial canal. In the image, the location of the canal is within: 33–57%, the middle is 46 % of the entire anterior-posterior distance of the plateau, and is within acceptable limits (a); 24–42 %, midpoint 33 % of the entire anterior-posterior distance of the plateau, and is too anterior. The graft is absent (b)

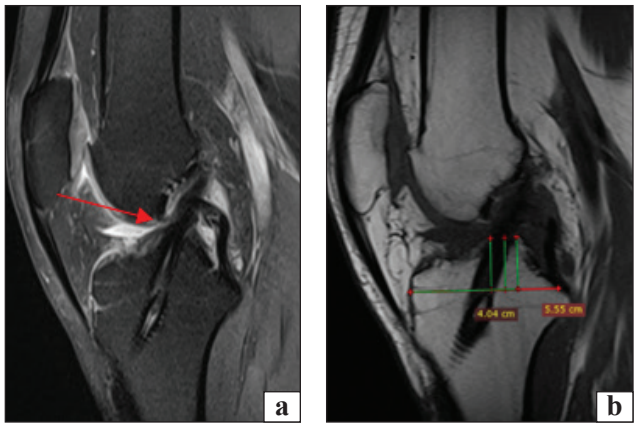

Fig. 6. Measurement of the tibial canal entry point on the sagittal projection of MRI imaging (a). Sagittal projection in T2 mode, the arrow indicates the integrated ACL graft (b)

The obtained results indicate widespread technical deviations during the formation of channels for ACL reconstruction, which may affect the success of graft integration.

Discussion

The results of our study confirm the important role of accurate shaping of the femoral and tibial canals during ACL plastic surgery. In particular, deviations in the angles of inclination and the location of the entry points were found to directly affect the stability of the graft and the success of integration.

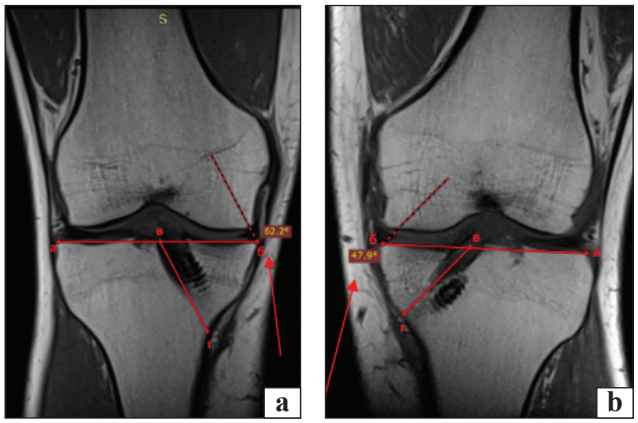

Fig. 7. Measurement of the tibial canal angle on the coronal projection. Line a–b is drawn parallel to the plateau, line c–d is drawn through the tibial canal. bcd — the angle of inclination of the canal, the arrow indicates degrees. The angle of inclination is 62°. The angle of inclination of the canal is too acute — 48° (b)

Similar values to ours are given in the works of K. D. Illingworth et al. and A. P. Parkar et al., who note that the optimal angle is 35°–45°, which prevents excessive verticalization of the ligament and joint instability [22, 34, 35].

J. P. Rue et al. also confirm the negative impact of angles < 25° on clinical outcomes [33]. Thus, our data are consistent with the above and demonstrate a significant frequency of technical errors in canal shaping.

The femoral canal entry point was located within the optimal anatomical landmarks in only 46 % of cases. Similar results were obtained by S. K. Nema et al., who found that only 35 % of femoral canals were correctly positioned, which caused graft impingement in 34 % of patients [36].

Our study showed that the tibial canal entry point corresponded to the anatomical boundaries on the sagittal projection in only 38 % of cases. This is consistent with the data of M. Sharma et al., who found that incorrect location of this canal leads to graft impingement and knee instability [37].

Regarding the tibial canal angle, the optimal angle of inclination of ≥ 65° was recorded in only 61 % of examinations. S. M. Howell et al. and R. Simmons et al. recommend 65°–70°, as acute angles are associated with shorter canals, poorer graft fixation, and an increased risk of loss of flexion [30, 31].

E. Pena et al. showed that an excessively acute angle promotes an oval canal outlet, which reduces graft adhesion to the walls [32]. In our study, it was smaller than recommended in 49 % of cases, which is consistent with other sources as a possible cause of impaired integration.

The use of MRI to study the location of the canals is effective. However, as noted in the study by A. Hart et al., even with the use of 3D MRI, accurate reproduction of their anatomical position remains a challenge [38].

Our study has several limitations: first, the retrospective nature may affect the objectivity of the assessment; second, the lack of clinical correlation with functional outcomes affects the analysis of technical errors.

Conclusions

Incorrect determination of the femoral canal inclination was found in 37 % of cases. Only in one of 105 examinations did this indicator exceed the normal range under optimal other parameters and a destroyed graft. This does not allow us to state that only the inclination of the canal in the coronal projection is the cause of failure. However, it may indicate a general error in the formation of the canal, in particular regarding its length.

The point of entry of the femoral canal is critically important. According to the adapted Bernhard and Hertel method, it was within the normal range in only 46 % of cases; in 42 cases, it was outside the rectangle in the sagittal projection. This indicates a possible error in determining the anatomical attachment site of the PSR, which can lead to instability, impingement, impaired integration and graft loss. The method requires further improvement, in particular, the development of software for MRI processing.

When measuring the angle of inclination of the tibial canal, it often turned out to be too sharp. Its influence is difficult to assess in isolation due to other technical errors. However, a dependence of the angle on the entry point was found, which may affect the integration of the graft.

In most cases, the canal was placed more posteriorly, which is probably related to the avoidance of impingement. In such cases, the graft was preserved 4 times more often than in the anterior location, which indicates the risk of impingement. At the same time, a too vertical location may not provide rotational stability.

The most anatomical placement of the canals is critical for successful reconstruction. The most important technical factors remain the determination of the entry points of the femoral and tibial canals. The angle of inclination is less fundamental, but may indicate technical errors. Accordingly, thorough planning, precise identification of anatomical landmarks, and, when appropriate, the implementation of navigation or EOC are essential.

Conflict of interest. The authors declare that there is no conflict of interest.

Prospects for further research. Despite the limitations, the results of our study highlight the importance of accurately determining the entry point and angle of the canals during ACL reconstruction. The use of MRI as a tool for preoperative planning and postoperative analysis may help surgeons avoid technical errors and improve treatment outcomes.

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Authors' contributions. Kostrub O. O. — idea and concept of the study, assessment of findings, drawing conclusions; Didukh P. V. — structuring and drafting the article, choosing research methods; Nikiforova I. M. — preparation and selection of MRI studies; Zasadnyuk I. A. — data summary of the study results, statistical analysis of the results; Blonsky R. I. — evaluation and discussion of the results; Podik V. A. — literature search, compiling the reference list, data summary in Excel spreadsheet.

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CRITICAL PARAMETERS OF TUNNEL POSITIONING IN ACL RECONSTRUCTION: A RETROSPECTIVE MRI ANALYSIS

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Assessment of the accuracy of reproduction of the lower limb axis using an individual instrument during endoprosthetics with kinematic alignment of the knee joint

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Objective. To assess the accuracy of reproduction of the kinematic axis of the lower limb using an individual instrument during total knee arthroplasty (TKA) by comparative radiographic analysis before and after surgery. Methods. Using radiographic analysis, an analysis of the knee arthroplasty of 10 patients operated on using an individual instrument was performed, the kinematic axis was restored (3 men and 7 women). The age range was from 56 to 71 years. Before surgery, patients underwent computed tomography of the lower limbs, and after it, radiography with vertical positioning of the feet. The individual instrument was manufactured using the original method. Results. A comprehensive assessment of the accuracy of reproduction of spatial landmarks of the lower limb during TKA was carried out using an individual surgical instrument developed on the basis of computed tomography and the principles of kinematic alignment. Analysis of deviations of the proximal medial tibial angle in the postoperative period revealed a mean absolute error of 0.15°, with a mean relative error of 0.74 %. At the same time, for the distal lateral femoral angle, an absolute error of 0.24° and a relative error of 0.27 % were established. Preoperatively, the mean value of the planned axis was 88.71°, postoperatively — 86.58°, which corresponds to a mean varus deviation of 2.15° and a relative error of 2.47 %. At the same time, it was found that the technical axis indicators were 88.55° before surgery and 86.67° after, respectively, with a mean varus deviation of 1.88° and a relative error of 2.28 %. Conclusion. A custom instrument allows for accurate reproduction of the kinematic axis of the lower limb, which can be crucial for achieving functional outcome and patient satisfaction.

Мета. Оцінити точність відтворення кінематичної осі нижньої кінцівки за допомогою індивідуального інструмента під час тотального ендопротезування колінного суглоба (ТЕКС) шляхом порівняльного рентгенометричного аналізу до та після операції. Методи. Використовуючи рентгенометрію, проведено аналіз ендопротезування колінного суглоба 10 пацієнтів, оперованих за допомогою індивідуального інструмента. Було відновлено кінематичну вісь (3 чоловіки та 7 жінок). Віковий діапазон становив від 56 до 71 року. До операції хворим виконували комп'ютерну томографію нижніх кінцівок, а після неї рентгенографію з вертикальним установленням положення стоп. Індивідуальний інструмент виготовляли за оригінальною методикою. Результати. Здійснено комплексне оцінювання точності відтворення просторових орієнтирів нижньої кінцівки під час ТЕКС із застосуванням індивідуального хірургічного інструмента, розробленого на основі комп'ютерної томографії та принципів кінематичного вирівнювання. Аналіз відхилень проксимального медіального великогомілкового кута в післяопераційному періоді виявив середню абсолютну похибку 0,15°, за середньої відносної похибки 0,74 %. Водночас, для дистального латерального стегнового кута встановлено абсолютну похибку 0,24°, а відносну — 0,27 %. Доопераційно середнє значення запланованої осі становило 88,71°, післяопераційно — 86,58°, що відповідає середньому варусному відхиленню 2,15° та відносній похибці 2,47 %. Водночас, виявлено, що показники технічної осі становили відповідно 88,55° до операції та 86,67° після, із середнім варусним відхиленням 1,88° і відносною похибкою 2,28 %. Висновок. Індивідуальний інструмент дозволяє точно відтворити кінематичну вісь нижньої кінцівки, що може мати вирішальне значення для досягнення функціонального результату та задоволення пацієнтів. Ключові слова. Ендопротезування колінного суглоба, кінематична вісь, індивідуальний інструмент, рентгенографія, артропластика.

Keywords. Knee joint, endoprosthesis, kinematic axis, surgical treatment, individual instrument, radiography, arthroplasty

Introduction

For many years, total knee arthroplasty (TKA) has remained one of the leading treatment options for degenerative and dystrophic disorders of the knee joint. However, alongside the growing number of procedures performed, there has also been an increase in the proportion of patients who report dissatisfaction with the outcome — currently reaching up to 30 % [1, 2]. This trend has prompted the development of new technologies and refinement of existing techniques, including the introduction of computer navigation systems, patient-specific instruments, robotic-assisted platforms, and continuous improvement in surgical expertise [5, 6].

For a long time, mechanical alignment of the lower limb during prosthesis implantation was considered the «gold standard» [3]. Nevertheless, even proponents of this approach acknowledge that up to 20 % of patients remain unsatisfied with the results [4], which has driven the search for alternative concepts.

One such contemporary concept is kinematic alignment, which is based on individualizing component placement according to the patient's native anatomy. Although the idea itself is not new — first described by Hungerford, Kenna, and Krackow in the 1980s [9, 10], and approved by the FDA in 1984 — its practical implementation was limited for decades due to technological constraints. Only in 2006 were the first procedures performed using the kinematic alignment approach, at that time still employing conventional surgical instruments.

The essence of the method lies in positioning the prosthetic components in a manner that most accurately replicates the patient's pre-arthritic limb alignment, even if it differs from the mechanically neutral axis. The femoral component is implanted to reflect the patient's original anatomy prior to disease progression. The tibial component is likewise aligned to match the natural tibial slope and orientation, which helps achieve optimal soft tissue balance.

To date, an increasing body of literature supports the superiority of kinematic alignment over mechanical alignment in terms of functional outcomes [11–14], with revision rates remaining comparable to those of traditional mechanical alignment techniques [15, 16].

Objective: to evaluate the accuracy of reproducing the kinematic axis of the lower limb following total knee arthroplasty using a patient-specific instrument, based on a comparative analysis of preoperative and postoperative radiographic measurements.

Materials and Methods

The study was approved by the Bioethics Committee (protocol No. 8 dated December 26, 2022) in accordance with the ICH GCP guidelines, the 2002 Helsinki Declaration of Human Rights, the Council of Europe Convention on Human Rights and Biomedicine (adopted in 1977), and the current legislation of Ukraine. Statistical processing of the obtained numerical data was performed using a computer and licensed software packages Office Excel 2010 and STATISTICA 13.0 TIBCO Software Inc. (License JPZ804I382130ARCN10-J).

This study presents the results of total knee arthroplasty (TKA) in 10 patients who underwent surgery using patient-specific instrumentation (PSI) for kinematic alignment. All procedures were performed at the Department of Traumatology and Orthopedics of the «Motor Sich» Clinic. The study cohort included 10 patients treated for degenerative pathology of the knee joint. Among them were 3 men (30 %) and 7 women (70 %). The age range of the patients was from 56 to 71 years. Four patients (40 %) were classified as middle-aged (44–60 years), and six patients (60 %) as elderly (60–75 years).

The mean age of the cohort was 64.1 years, indicating a predominance of elderly patients. The body mass index (BMI) ranged from 24.3 to 32.3 kg/m², with an average value of 27.2 kg/m², reflecting a tendency toward overweight in the majority of cases. In three male patients, the BMI was within normal limits or slightly elevated (24.3–28.8 kg/m²). Among female patients, five were classified as overweight (25.7–27.2 kg/m²), and two had class I obesity (30.8 and 32.3 kg/m²).

All patients exhibited varus deformity of the lower limb, with angular deviation not exceeding 9°. The minimum measured value was 6°, and the maximum was 9°. The mean varus deformity was 7.8° (Table 1). These data were taken into account during preoperative assessment of limb alignment and planning of the surgical intervention.

Table 1

General characteristics of the patients

No.	Sex	Age (years)	BMI (kg/m²)	Varus (°)
1	M	58	24.5	7
2	M	60	28.8	8
3	M	62	24.3	9
4	W	56	26.1	6
5	W	63	25.7	7
6	W	65	26.8	8
7	W	67	27.2	7
8	W	69	25.9	8
9	W	70	30.8	9
10	W	71	32.3	9
Mean		64.1	27.2	7.8

Prior to surgery, all patients underwent full-length computed tomography (CT) scans of the lower limbs in a standing position with standardized foot alignment. Postoperatively, full-length weight-bearing radiographs of the lower limbs were performed using the same positioning protocol. To evaluate the outcome, the position of the kinematic axis in the frontal plane at the level of the tibial plateau was compared pre- and postoperatively.

Statistical analysis of the collected data was performed using Microsoft Office Excel 2010 and STATISTICA 13.0 (TIBCO Software Inc., License JP-Z804I382130ARCN10-J). The study protocol was approved by the Bioethics Committee of Zaporizhzhia State Medical and Pharmaceutical University (Protocol No. 7 dated October 26, 2016).

Results

All patients underwent postoperative full-length radiographic examination of the lower limbs in order to measure the kinematic axis, as well as the medial tibial and lateral femoral angles.

Figure 1 illustrates the radiograph of the lower limbs of patient S., 65 years old, prior to surgery on the left knee. The image shows the result of three-dimensional alignment of the limb and the postoperative radiograph.

Radiographic measurement methodology for the lower limb. The image illustrates the three key parameters assessed, along with an example of kinematic alignment measurement and the corresponding postoperative full-length radiograph (Fig. 2).

The results of the initial 10 cases of kinematic alignment planning using a patient-specific instrument are presented in Table 1.

Postoperative full-length radiographs of the lower limbs were successfully obtained for all 10 patients (100 % of those operated). Within the scope of this study, a comprehensive evaluation was conducted to assess the accuracy of reproducing the spatial anatomical landmarks of the lower limb during total knee arthroplasty using a patient-specific surgical instrument. This instrument was designed based on computed tomography data and the principles of kinematic alignment. The primary objective was to determine the degree of conformity between the actual positioning of the prosthetic components and the preoperatively planned parameters within the plane of the anatomical kinematic axis.

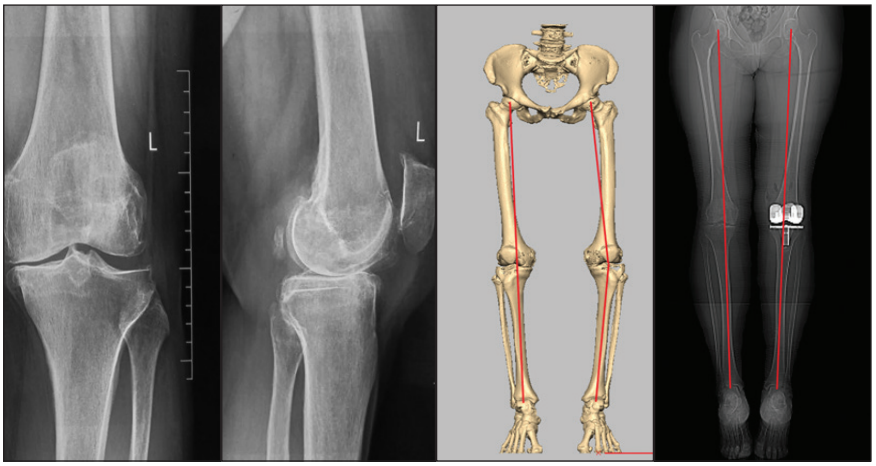

Fig. 1. Patient S., 65 years old. Alignment result of the left lower limb achieved precisely according to the kinematic alignment plan. The postoperative radiograph of the left knee demonstrates the reconstructed kinematic axis

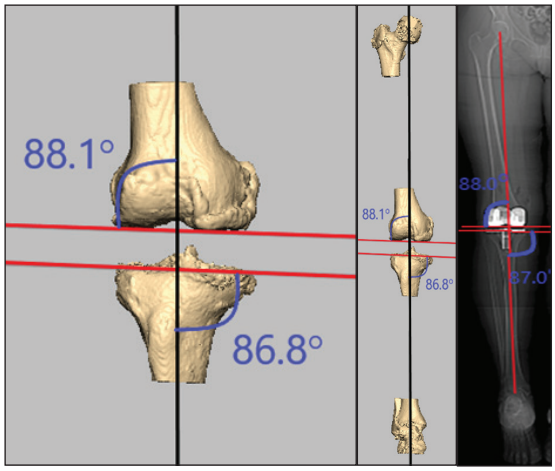

Fig. 2. Preoperative planning showed a distal lateral femoral angle of 88.1°, which postoperatively measured 88.0°. The planned proximal medial tibial angle was 86.8°, with a postoperative result of 87.0°. The planned kinematic axis demonstrated a 1° varus deviation

Analysis of deviations in the proximal medial tibial angle in the postoperative period revealed a mean absolute error of 0.15°, with a mean relative error of 0.74 %, indicating a high level of reproducibility for this anatomical landmark (Fig. 3). Meanwhile, assessment of the distal lateral femoral angle showed an absolute error of 0.24° and a relative error of 0.27 % (Fig. 4). These results demonstrate consistent accuracy in prosthetic component positioning at the distal femur and tibia when utilizing individualized preoperative planning.

Additionally, a comparison was made between the planned and achieved kinematic axis, derived from the aforementioned angular measurements (Table 2 and Fig. 5). The average preoperative planned axis was 88.71°, while the postoperative measurement was 86.58°, corresponding to a mean varus deviation of 2.15° and a relative error of 2.47 %. Similarly, when evaluating the actual (measured) axis based on the postoperative angular values, the preoperative value was 88.55° and the postoperative value was 86.67°, reflecting a mean varus deviation of 1.88° and a relative error of 2.28 %.

Discussion

The obtained results confirm that the use of patient-specific instrumentation (PSI) in total knee arthroplasty (TKA) allows for high-precision replication of both anatomical angles and the complete kinematic axis of the lower limb. The observed absolute and relative deviations remained within clinically acceptable limits, demonstrating the reliability of the technique and its suitability for routine application in orthopedic reconstructive surgery.

The application of kinematic alignment principles, as opposed to the traditional mechanical axis concept, enables a more physiological placement of prosthetic components, taking into account the patient's native rotational and coronal anatomy. This is particularly relevant in patients with pronounced individual anatomical variations, where a mechanically neutral axis may not correspond to the pre-arthritic limb configuration.

Table 2

Radiographic measurements of the lower limb in patients operated using a patient-specific instrument for kinematic axis restoration, before and after surgery

Patient number	Proximal medial tibial angle (°)		Absolute error (°)	Relative error (%)	Distal lateral femoral angle, °		Absolute error (°)	Relative error (%)
	according to plan	result			according to plan	result		
1	86.8	87.0	0.2	0.23	88.1	88.0	0.1	0.11
2	86.4	86.6	0.2	0.23	89.0	88.8	0.2	0.22
3	86.0	86.0	0	0	88.4	88.0	0.4	0.45
4	87.0	87.0	0	0	88.9	88.5	0.4	0.45
5	87.4	87.5	0.1	0.11	89.0	88.8	0.2	0.22
6	86.6	87.0	0.4	0.46	89.2	89.0	0.2	0.22
7	87.0	87.0	0	0	87.8	88.0	0.2	0.23
8	86.2	86.0	0.2	0.23	88.8	89.0	0.2	0.23
9	86.0	86.0	0	0	89.2	89.0	0.2	0.22
10	86.4	86.6	0.3	0.23	88.7	88.4	0.3	0.34
Average value	86.58	86.67	0.15	0.74	88.71	88.55	0.24	0.27

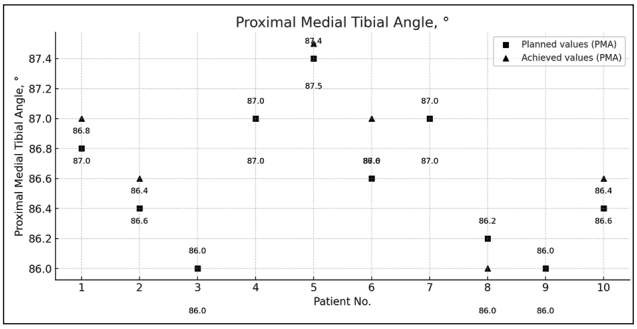

Fig. 3. Radiographic assessment of the proximal medial tibial angle in patients operated using a patient-specific instrument, before and after surgery

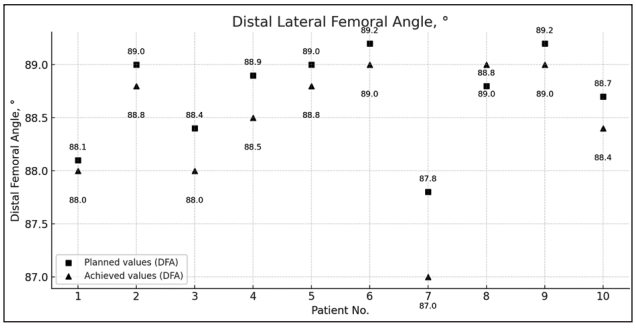

Fig. 4. Radiographic assessment of the distal lateral femoral angle in patients operated using a patient-specific instrument, before and after surgery

Table 3

Evaluation of the kinematic axis position of the lower limb in patients operated using a patient-specific instrument, before and after surgery

Patient number	The planned kinematic axis is formed by the proximal medial tibial angle (°) and distal lateral femoral angle (°)		Axis (°) (Varus)	Relative error (%)	The resulting kinematic axis is formed by the proximal medial tibial angle (°) and distal lateral femoral angle (°)		Absolute error (°) (Varus)	Relative error (%)
	before the operation	after surgery			before the operation	after surgery		
1	88.1	86.8	1.3	1.5	88.0	87.0	1.0	1.2
2	89.0	86.4	2.6	3.0	88.8	86.6	2.2	3.5
3	88.4	86.0	2.4	2.8	88.0	86.0	2.0	2.3
4	88.9	87.0	1.9	2.3	88.5	87.0	1.5	1.7
5	89.0	87.4	1.8	1.8	88.8	87.5	1.3	1.5
6	89.2	86.6	2.6	3.0	89.0	87.0	2.0	2.3
7	87.8	87.0	0.8	0.9	88.0	87.0	1.0	1.2
8	88.8	86.2	2.6	3.0	89.0	86.0	3.0	3.5
9	89.2	86.0	3.2	3.7	89.0	86.0	3.0	3.5
10	88.7	86.4	2.3	2.7	88.4	86.6	1.8	2.1
Average value	88.71	86.58	2.15	2.47	88.55	86.67	1.88	2.28

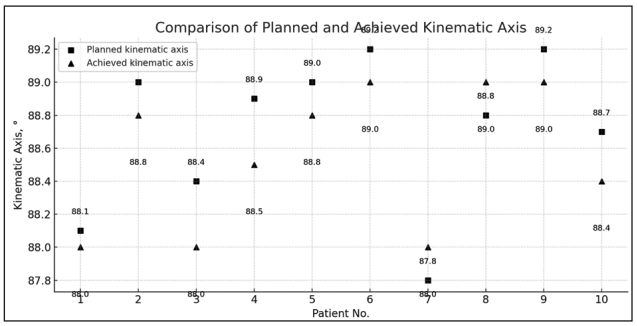

Fig. 5. Evaluation of the kinematic axis position of the lower limb in patients operated using a patient-specific instrument, before and after surgery

The positive outcomes associated with kinematic axis restoration suggest that patient-specific 3D planning can serve as an effective tool for improving component positioning accuracy and constructing a stable, balanced prosthesis functioning in accordance with the patient's natural biomechanics. Consequently, this approach may potentially reduce the risk of postoperative instability, revision surgeries, and contribute to improved long-term functional outcomes.

Our findings are consistent with those reported by other authors who have evaluated the efficacy of kinematic alignment in TKA. For instance, Sosio et al. (2023) analyzed 55 patients undergoing TKA using kinematic alignment in combination with a medial pivot implant design. The authors observed significant improvements in both clinical and functional outcomes, which persisted up to 24 months postoperatively, regardless of the final limb alignment. Radiographic analysis confirmed restoration of physiological limb alignment and joint line orientation parallel to the floor [17].

Moreover, Wang et al. (2024), in a randomized controlled trial, demonstrated that modified kinematic alignment provides a more physiological plantar pressure distribution during gait compared to mechanical alignment. This suggests more natural gait biomechanics following kinematically aligned TKA [18].

A meta-analysis by Gao et al. (2022) further supported these findings, showing that patients who underwent kinematically aligned TKA achieved better functional outcomes, including higher WOMAC and KSS scores, compared to those treated with mechanical alignment. These data emphasize the clinical advantage of KA in enhancing both functional recovery and patient satisfaction [19].

Thus, both our findings and those from current literature support the conclusion that kinematic alignment in TKA facilitates more accurate reproduction of native anatomy and knee biomechanics, which in turn improves functional outcomes and patient satisfaction. This highlights the rationale for considering KA as an effective alternative to conventional mechanical alignment in clinical practice.

Conclusion

A patient-specific instrument enables accurate reconstruction of the kinematic axis of the lower limb, which may play a crucial role in achieving favorable functional results and higher patient satisfaction.

Conflict of interest. The authors declare no conflict of interest.

Prospects for further research. research include expanding the study sample to improve the statistical significance of the results, as well as implementing a wider range of clinical scenarios. Long-term follow-up of patients after knee joint replacement is planned to assess the durability of the obtained results and their impact on the patients' quality of life. An important area of research is also the study of the effect of the individual instrument on postoperative rehabilitation, particularly on the speed of joint functionality recovery and the reduction of complication risks. Further clinical trials will allow for a more precise determination of the optimal parameters for planning knee replacement and reducing the percentage of patients dissatisfied with the results.

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Author's contribution. Golovakha M. L. — concept and design of the study, article editing, final approval of the article; Bondarenko S. A. — data collection, data analysis and interpretation, writing the article.

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ASSESSMENT OF THE ACCURACY OF REPRODUCTION OF THE LOWER LIMB AXIS USING AN INDIVIDUAL INSTRUMENT DURING ENDOPROSTHETICS WITH KINEMATIC ALIGNMENT OF THE KNEE JOINT

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Results of surgical treatment of high-grade spondylolisthesis

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Spondylolisthesis of Grade III–IV according to the Meyerding classification, referred to in English literature as "high-grade spondylolisthesis," involves a significant degree of vertebral displacement and leads to substantial impairment of spinal function, gait disturbances, and early disability in patients. Despite the fact that clinical symptoms, classifications, and diagnostic methods have been known and established for quite some time, the issue of surgical treatment remains a subject of debate to this day. Objective. To evaluate the outcomes of surgical treatment in patients with high-grade spondylolisthesis. Methods. A retrospective analysis was conducted on the surgical outcomes of 24 patients with significant vertebral displacement who underwent intraoperative traction and transpedicular fixation using a "spine–pelvis" system. Pre- and postoperative radiographic measurements included the slip angle, pelvic incidence, lumbar lordosis, sacral slope, pelvic tilt, as well as evaluation of sagittal vertical axis alignment and pelvic tilt angle. Results. All patients demonstrated a reduction in slip angle and restoration of sagittal vertical axis alignment to within normal limits. Other parameters of spinopelvic balance were also moderately improved, thereby bringing sagittal spinal alignment closer to normal values and enhancing the biomechanical conditions for spinal function. Conclusions. The use of intraoperative traction via ligamentotaxis allowed for repositioning of the displaced vertebra and facilitated the placement of transpedicular screws. The combination of intraoperative spinal traction and pulling on transpedicular screws using reduction devices enabled correction of the displaced vertebra to Grade I–II according to Meyerding, thereby restoring the supportive function of the spine.

Спондилолістез III–IV ступеня за класифікацією Meyerding (в англомовній літературі «high-grade spondylolisthesis») — із високим ступенем зсуву, призводить до значних порушень функції хребта та ходи, ранньої інвалідизації пацієнтів. Незважаючи на той факт, що клінічні симптоми, класифікації та методи діагностики розроблені та відомі досить давно, питання вибору тактики лікування залишається дискутабельним і дотепер. Мета. Вивчити результати хірургічного лікування пацієнтів із істмічним спондилолістезом із великим ступенем зсуву. Методи. Проведено ретроспективний аналіз результатів операцій 24 осіб зі спондилолістезом зі значним ступенем зсуву, яким застосували інтраопераціну тракцію та транспедикулярну фіксацію за системою «хребет – таз». На рентгенограмах проводили до- та післяопераційні вимірювання кутів ковзання хребця, тазового нахилу, поперекового лордозу, крижового нахилу, скосу таза, а також оцінювали положення сагітальної вертикальної осі і кут нахилу таза. Результати. Усім пацієнтам вдалося зменшити кут ковзання хребця та повернути до норми положення сагітальної вертикальної осі. Інші показники хребетно-тазового балансу також були дещо зменшені, завдяки чому вдалося наблизити сагітальний баланс хребта до нормативних значень і покращити біомеханічні умови його функціонування. Висновки. Використання інтраопераційної тракції за рахунок лігментотаксису дозволило змінити положення зміщеного хребця та полегшити встановлення в нього транспедикулярних гвинтів. Поєднання інтраопераційної тракції хребта та тяги за умов використання транспедикулярних гвинтів із застосуванням вправляючих пристроїв уможливило досягти вправлення зміщеного хребця до I–II ступеня за Meyerding та відновлення опорної функції хребта. Ключові слова. Спондилолістез, інтраопераційна тракція, транспедикулярна фіксація, вправлення.

Key words. High-grade spondylolisthesis, intraoperative traction, pedicular fixation, reduction

Introduction

Spondylolisthesis is a condition characterized by the displacement of a vertebra forward. It most often occurs in children and adolescents, causes pain in the lumbar spine, and in some cases is accompanied by neurological symptoms. Its development is caused by a combination of factors that cause spondylolisthesis: dysplasia of the "bone hook" (intervertebral joints), increased lordosis, stress fractures of the interarticular part, leading to its elongation, disc degeneration and deformation of the sacrum. When these factors reach a certain level, the progression of the pathological process becomes inevitable. They occur either simultaneously or sequentially in a growing person. At the same time, in 11.3 % of cases, the displacement reaches a value of more than 50 % of the surface of the upper endplate of the vertebra below [1].

High-grade spondylolisthesis (HGS), grades III–IV according to the Meyerding classification causes significant impairment of the functions of the spinal column and gait, early disability of patients [2].

Even though clinical symptoms, classifications and diagnostic methods of spondylolisthesis have been developed quite a long time ago, the question of choosing treatment tactics remains debatable to this day. All surgical methods can be conditionally divided into three groups: operations with in situ fixation, complete or partial reduction of the displaced vertebra using implants of various designs, and vertebrectomy.

Each of these surgical techniques has its own indications, advantages and disadvantages. Like most other surgical interventions on the spine, any treatment method should restore its supporting and protective function, eliminate pain syndrome, as well as neurological symptoms, in combination with a minimum number of complications that may occur both during and after surgery [3, 4].

One of these treatment methods may be open reduction of the displaced vertebra using intraoperative traction of the spine and transpedicular construction according to the "spine-pelvis" system, the results of which are not yet sufficiently studied.

Purpose: to study the results of surgical treatment of patients with isthmic spondylolisthesis with a large degree of displacement.

Material and Methods

A retrospective analysis of the results of surgical treatment of 24 subjects (20 female and 4 male) with spondylolisthesis with a significant degree of displacement was conducted. The average age in the study group was 33.2 years (from 10 to 55 years).

The study materials were reviewed and approved by the Bioethics Committee at the CNPE Professor M. F. Rudnev City Multidisciplinary Clinical Hospital for Mothers and Children (protocol No. 1 dated 14.05.2025). All patients involved in the study were informed of the surgical intervention plan and signed informed consent.

The intervention technique was as follows: with the patient in the prone position, under general anesthesia and using multimodal spinal cord monitoring, transpedicular screws were inserted into the L_I vertebra, which were connected to each other by a fixing rod, and a temporary traction device with two fixation points was installed between the rod on the L_I vertebra and the wings of the pelvis. After that, stepwise traction of the spine was performed, radiologically controlling the process of reduction of the L_V vertebra. The screws were placed in the latter after achieving correction and improving its position [7]. Then, transpedicular screws were used in the L_{IV} and S_I and pelvic screws were inserted according to the S2AI method [5, 6]. The next step was to install the fixing rods that connected the screws. The final translational displacement of the L_V was eliminated using rod introducers installed on the heads of the L_V screws (Fig. 1, a). The reduction process was accompanied by verification of evoked sensory and motor potentials. If their values fell by more than 60 % compared to the baseline data obtained before surgical manipulation, the reduction was stopped, and the correction was reduced until normal spinal cord monitoring parameters were restored.

After the reduction was completed, the transpedicular fixation system was stabilized, the intraoperative traction device was dismantled, and the screws installed in the L_I vertebra were removed (Fig. 1, b). After preliminary decortication of the posterior parts of the fixed vertebrae, a bone autograft taken from local tissues was placed. The wound was sutured in layers. X-ray control was performed directly on the operating table.

Patients were verticalized the next day after surgery.

During the analysis of medical histories, clinical manifestations of spondylolisthesis with a significant degree of displacement were studied both before and after surgery. The degree of displacement was determined according to the Meyerding classification. Pre- and postoperative measurements of the angles of vertebral slip, pelvic tilt, lumbar lordosis, sacral tilt, pelvic obliquity were performed on the radiographs, and the position of the sagittal vertical axis and the angle of pelvic tilt were also assessed.

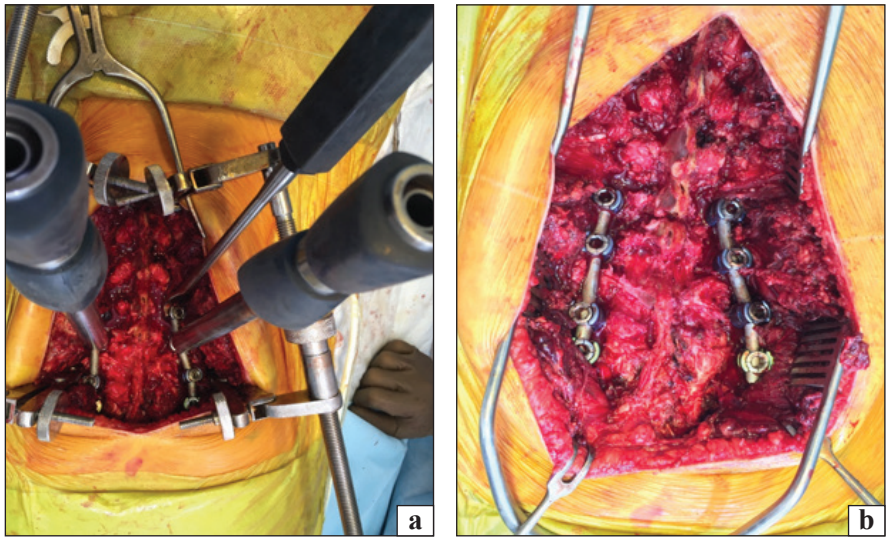

Fig. 1. View of the operating field: a) after installation of the intraoperative distance device, transpedicular structure and rod introducers on the heads of L_V screws; b) after reduction of the displaced vertebra and final stabilization of the transpedicular system according to the "spine-pelvis" scheme

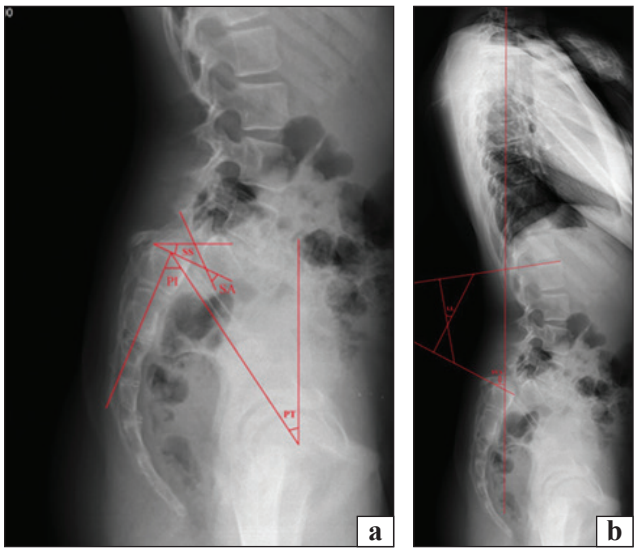

Fig. 2. Radiographic parameters determined in patients with spondylolisthesis with a high degree of displacement: a) vertebral slip angle (SA), pelvic inclination angle (PI); sacral tilt angle (SS), pelvic tilt (PT); b) lumbar lordosis (LL), sagittal vertical axis position (SVA)

The reference values for lumbar lordosis were an angle equal to PI ± 9°, the angle of sacral tilt was 20°–25°, and the distance from the sagittal vertical axis to the posterior-upper edge of the sacral platform was 0–4 cm. The normative value of pelvic tilt (PT) was an angle less than 20° [8].

The quality of the spinal fusion was assessed radiographically using a computed tomography (CT) scan of the lumbosacral spine, which was performed in the long term after surgery [9].

The inclusion criteria for the study were: patients with spondylolisthesis grades III and IV according to Meyerding and spondyloptosis, absence of previous surgical interventions on the spine, presence of results of clinical and instrumental examination methods within 3–5 years after surgery.

Results

All the patients in the study group mainly presented with pain in the lumbar spine, fatigue during prolonged walking. Six patients were found to have L_V and S_I radiculopathy. One patient had lower paraparesis. The other two were diagnosed with secondary thoracolumbar scoliosis (Fig. 3).

In the postoperative period, irritation of the L_V and S_I spinal roots was noted in 3 patients, and in 8 patients, gait disturbance was observed, which developed as a result of tension in the muscles of the lower extremities and regressed within 3–6 months after surgery and a course of rehabilitation treatment. In 3 patients, respectively, 1, 2 and 5 years after the operation, a fracture of the fixing rods occurred, which required revision surgery. At the same time, only in one of them, signs of pseudarthrosis in the lumbosacral junction area were detected during implant replacement. A study of computed tomography scans of all operated patients 3–5 years after treatment showed the presence of mature spondylofusion masses in the posterior spine (Fig. 4).

The results of radiography before and after surgery are given in Table 1. The average vertebral slip angle was 62.1º, after surgery — 23.2º. The pelvic tilt index was 68.2º on average before surgery and 63.2º after, the sacral tilt — 42.5º and 36.2º, respectively. The lumbar lordosis value was 54.1º on average before surgery and 49.4º after. The position of the sagittal vertical axis before treatment changed from 7.7 cm before surgery and 3.3 cm after. The pelvic tilt — 23.8º and 24.2º, respectively (Table 1). According to the criteria given in [10], 20 patients were diagnosed

with grade I spondylosis, 3 with grade II, and 1 with grade IV. According to the Meyerding scale, before surgery, 13 patients had grade III displacement, 7 with grade IV, and 4 with spondyloptosis. After surgery, the distribution was as follows: grade III — 4, II — 14, and I — 6 subjects.

Discussion

Despite the general opinion that patients with spondylolisthesis with a significant degree of displacement require surgical treatment, the choice of adequate tactics is a debatable issue. Various surgical techniques are proposed in scientific literature, each with its own advantages and disadvantages. They can be conventionally divided into three main types: *in situ* fixation, reduction of the displaced vertebra, and vertebrectomy.

In situ fixation, both with and without a corset in the postoperative period, is a relatively safe and effective treatment that reduces pain and neurological symptoms.

A. Joelson et al. studied the results of *in situ* fusion in 35 patients aged 15 years with SIDS. They found that all patients had a good treatment outcome, which ensured the absence of pain, disability, and allowed most of them to work in their specialty for 29 years after treatment [11].

S. Noorian conducted a systematic analysis of 6 randomized clinical trials and 9 observational studies, where he evaluated the results of treatment in 1,538 patients with SIDS. Most of these studies showed that reduction and fusion lead to the same clinical outcome as *in situ* fixation [12].

At the same time, A. M. Lak et al. studied the results of treatment of 188 people with HGS who underwent *in situ* fusion or reduction [13]. *In situ* fixation was found to be accompanied by greater intraoperative blood loss, neurological complications, pseudarthrosis and infection.

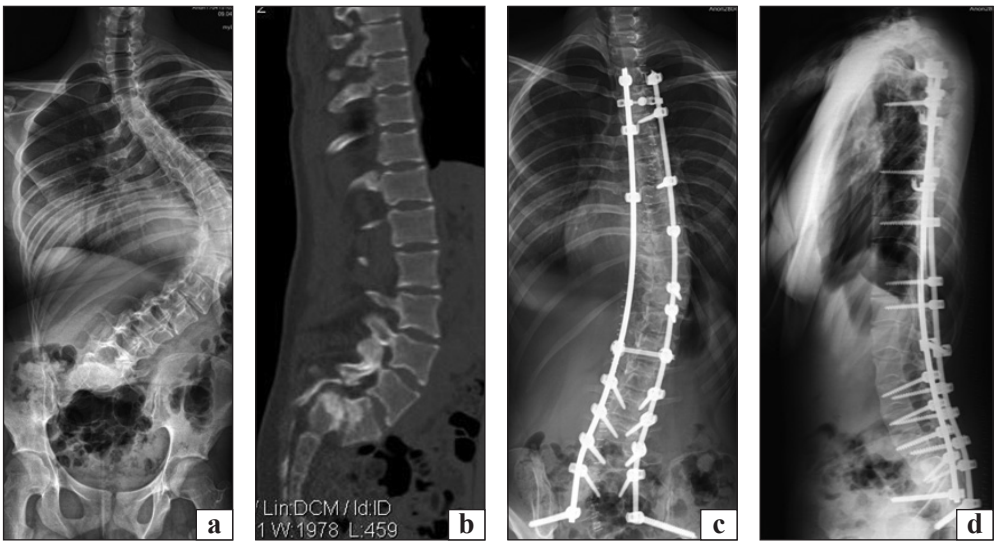

Fig. 3. Radiographic (a) and computed tomography images (b) of a 16-year-old patient with spondylolisthesis and left-sided thoracolumbar scoliosis before surgery and after polysegmental correction of scoliotic deformity and reduction of spondylolisthesis using intraoperative distraction. The extent of fusion Th_{II} is the pelvis. Spondylolisthesis was reduced to Meyerding grade I (c, d)

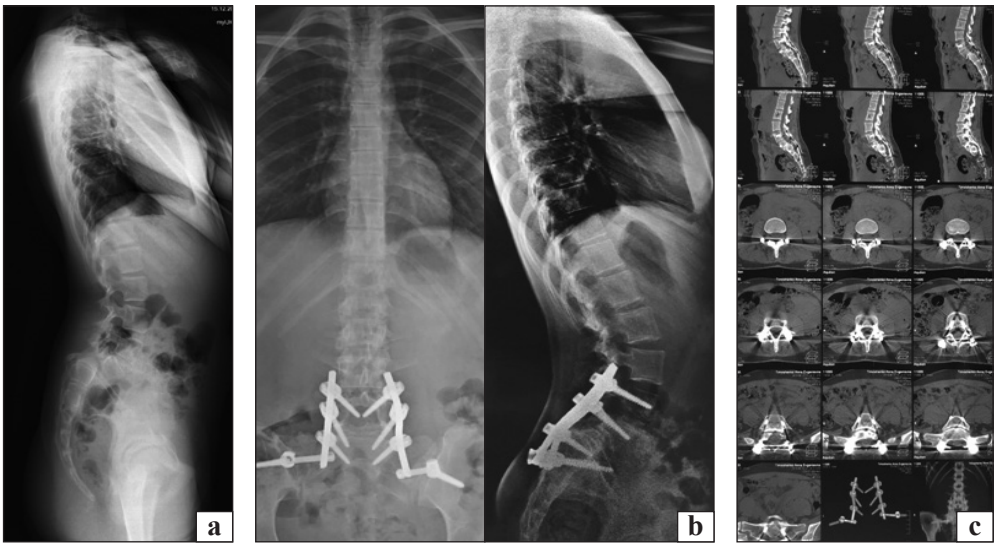

Fig. 4. Radiographic images of a 14-year-old patient with Meyerding grade IV spondylolisthesis before surgery (a) and after surgery (b). L_{IV} spondylodesis is extended to the pelvis. Spondylolisthesis was reduced to Meyerding grade II. A computed tomography 6 years after surgery showed the presence of a mature bone block in the fusion area (c)

Table 1

Radiographic parameters before and after surgery

Indicator	Surgical treatment	
	before	after
Slip angle (SA)	62.1º	23.2º
Pelvic inclination (PI)	68.2º	63.2º
Sacral tilt (SS)	42.5º	36.2º
Lumbar lordosis (LL)	54.1º	49.4º
Sagittal vertical axis (SVA)	7.7 sm	3.3 sm
Pelvic tilt (PT)	23.8º	24.2º

Thus, reduction, despite such complications as damage to the dural sac, reduces pain, the angle of displacement of the vertebra, changes the pelvic tilt, and also improves the Oswestry Disability Index. The authors of the study further note that both surgical techniques can be used in clinical practice, but reduction of the displaced vertebra provides a better treatment outcome.

Full or partial reduction of the vertebra in HGS has a large number of supporters. The main arguments indicating the advantage of its implementation are the ability to restore the disturbed biomechanics of the spine, improve the quality of fusion by more evenly distributing the load on the graft, change the shape of the spinal canal, and also obtain a positive cosmetic effect. But the main risk of complete reduction of a displaced vertebra by more than 50 % is the occurrence of neurological disorders [14, 15]. That is why most authors insist on partial elimination of the displacement, which allows to reduce the risk of developing radiculopathy of the L_{IV} and L_V roots [11]. The Spine Deformity Study Group has developed a classification of spondylolisthesis, which allows to determine the indications for performing a vertebral reduction. According to it, elimination of the displacement of the vertebra is not indicated in the case of a balanced pelvis, i.e. when the SS indicator is greater than the PT indicator, and in the opposite situation (PT greater than SS), the pelvis is considered unbalanced, and reduction is necessary [16].

In [17], a method for eliminating SIDS is presented by temporarily installing screws in vertebrae L_{II}–L_{III} with the use of further intraoperative distraction until partial L_V reduction is achieved. To decompress the spinal canal, a wide L_V laminectomy is performed and a cage is installed in the L_V–S_I intervertebral space, due to which a better fusion is achieved and thus the lumbar lordosis is restored.

K. Min suggested that, in addition, to facilitate reduction, the deformed upper locking plate of the S_I should be resected, which, in his opinion, is an obstacle to eliminating ventral displacement in the case of spondylolisthesis [18]. Similar results were reached in their work by M. A. Anjhazzallah et al. [19].

M. Kumar et al. proposed a method for correcting HGS using minimally invasive interbody fusion with a cage in 18 patients. The results of the study showed an improvement in spine-pelvic balance and Oswestry and VAS scores [20].

Another alternative for surgical treatment of spondylolisthesis with a significant degree of displacement is L_V vertebrectomy, proposed by R. Gaines, who presented the results of using this operation in 30 patients [21]. Over 25 years, according to the author, only two patients had complications in the form of screw fracture and pseudarthrosis. Also, in the period from 6 weeks to 3 years, L_V root radiculopathy and retrograde ejaculation were recorded as complications of anterior access to the ventral spine. At the same time, the clinical symptoms accompanying spondylolisthesis were eliminated in all patients.

K. Kalra presented the results of a modified Gaines operation, which consists in partial resection of the L_V vertebra in its lower part. According to the author, the advantages of this technique are as follows: the possibility of additional insertion of screws into the displaced vertebra, which facilitates its reduction; prevention of L_V root radiculopathy; prevention of spinal cord shortening, which occurs as a result of a decrease in the number of vertebrae and can lead to impaired function [22]. We conducted a retrospective analysis of the results of treatment of patients with isthmic HGS using intraoperative traction and transpedicular fixation of the L_{IV}-pelvis. According to the results of the operations, all patients managed to reduce vertebral slip angle (SA), as well as return the position of the sagittal vertical axis (SVA) to normal. Other indicators of spine-pelvic balance [23] were also slightly reduced, which made it possible to bring the sagittal balance of the spine closer to the normative indicators and improve the biomechanical conditions of its functioning.

At the same time, the reduction of the displaced vertebrae contributed to the regression of clinical symptoms, improvement of gait, as well as the maturation of a high-quality spinal fusion block, which was confirmed by postoperative CT scan. Fractures of the fixation rods in 3 patients occurred in the area of the lumbosacral junction, which is traditionally the least favorable for the formation of a bone block, but the replacement of the implant allowed to obtain a satisfactory result in the future.

The radicular-irritative syndrome and gait disorders that developed in patients in the postoperative period are explained by the fact that they managed to achieve significant reduction of the displaced vertebra and significantly change the pathological patterns of muscle function that arose as a result of anterior displacement of the vertebra during spondylolisthesis. Perhaps in patients of the older age group due to the greater rigidity of the spine, the number of potential neurological complications could be greater, but the use of intraoperative spinal cord monitoring allowed for controlled correction of the deformity (Fig. 5). The use of pelvic fixation made it possible to achieve stable fixation of the spine without the installation of interbody cages, for the introduction of which it is necessary to perform laminectomy [24] and manipulation of the dural sac, which increases the risk of its damage. Refusal of laminectomy in favor of indirect decompression of the spinal canal by eliminating the displacement of the vertebra allowed to preserve the supporting function of the posterior supporting column of the spine and increased the area of the bone graft zone, which also had a positive effect on the formation of a high-quality bone block. Table 2 presents the results of other studies on the surgical treatment of HGS for comparison. These studies show that our proposed technology provides approximately the same number of neurological complications and pseudarthrosis as compared to the methods of correction of vertebral displacement

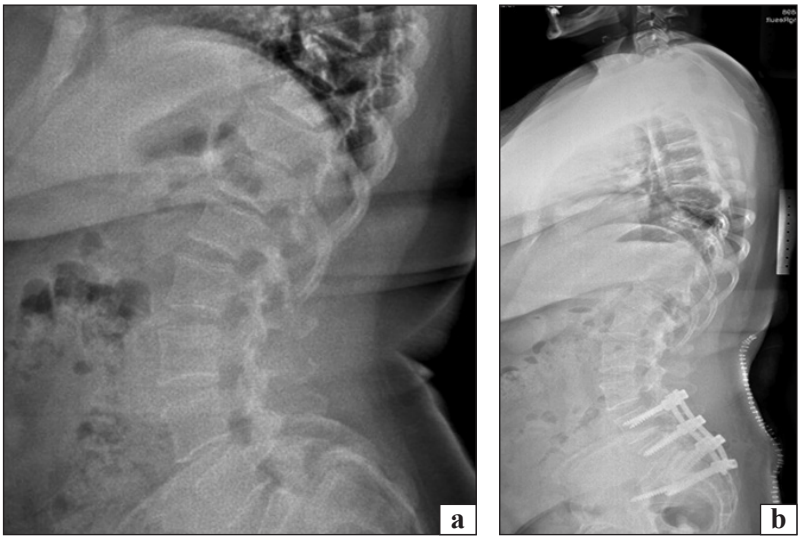

Fig. 5. Radiographic images of a 55-year-old patient with Meyerding grade IV spondylolisthesis in lateral projection before surgery (a) and after surgery (b) using intraoperative traction. L_{IV} spondylodesis is extended to the pelvis.

Table 2

Comparison of research results regarding surgical treatment of HGS

Author	Number of patients	Surgical technique	Complication (abs. / %)	Neurologic complications (abs. / %)	Pseudoarthrosis (abs. / %)
J. A. Smith et al. [25]	9	*In situ* fixation	10/111	2/22	2/22
O. Boachie-Adjei et al. [26]	6	Transpedicular fixation, decompression	3/50	3/50	0
I. Helenius et al. [27]	21 23 26	Posterolateral *in situ* spondylodesis Anterior *in situ* spondylodesis Anterior-posterior *in situ* spondylodesis	3/14 2/22 3/12	4/19 0 0	3/13 1/4 4/12
J-M. Mac-Thiong et al. [28]	61	*In situ* spondylodesis, transpedicular fixation and interbody spondylodesis, *in situ* screw and cage fixation	14/23	7/11	0
K. Min et al. [18]	15	Transpedicular fixation, S_I locking plate resection, interbody cage spondylodesis	4/26	4/26	0
M. K. Ashan et al. [29]	20	Intraoperative traction, decompression, transpedicular fixation	4/20	0	0
Our study	24	Intraoperative traction, spine – pelvis fixation	4/16	3/12	1/4

and a lower number of pseudarthrosis compared to in situ fixation. One of the complications reported in the observation [29], where spinal canal decompression was performed, resulted in a rupture of the dura mater in 2 cases.

Conclusions

The use of intraoperative traction due to ligamentotaxis allowed to change the position of the displaced vertebra and facilitate the installation of transpedicular screws in it.

The combination of intraoperative spinal traction and traction under the conditions of using transpedicular screws with the use of adjusting devices allowed to achieve reduction of the displaced vertebra to Meyerding grade I–II and restore the supporting function of the spine.

Increasing the area of the fusion zone by preserving the arch of the displaced vertebra in combination with decortication of the posterior spine contributed to the formation of a mature bone block.

Postoperative complications did not affect the final outcome of the treatment of patients in the study group.

Conflict of interest. The authors declare the absence of a conflict of interest.

Prospects for further research. Conducting prospective comparative studies of different methods of treating spondylolisthesis.

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Authors' contribution. Mezentsev A. O. — operated on some of the patients, analysis of the obtained research results, drawing of conclusions, editing the text; Petrenko D. Ye. — operated on some of the patients, analysis of the obtained results, drafting the article; Demchenko D. O. — operated on some of the patients, analysis of literary sources, formation of the reference list and preparation of clinical cases.

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RESULTS OF SURGICAL TREATMENT OF HIGH-GRADE SPONDYLOLISTHESIS

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Interleukin-6 and acute phase proteins as biomarkers of septic osteoarthritis

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Septic arthritis (SA) is a severe and rapidly progressive joint infection and a potentially life-threatening condition that can affect all age groups. Due to the lack of effective methods for early detection and assessment of treatment outcomes, measurement of biochemical markers (biomarkers) is a promising method for monitoring the disease. The aim of the study was to determine the diagnostic significance of inflammatory biomarkers (IL-6, CRP, haptoglobin, ceruloplasmin) in patients with septic joint inflammation of various localizations. Methods. The study analyzed blood serum from 54 male and female subjects. Of these, 18 were conditionally healthy and entered group I (control), and 36 patients were diagnosed with septic osteoarthritis of joints of various localization in the skeleton. Of these, 18 had SA of the knee joint; 13 patients had SA of the hip joint and 5 had SA of the ankle joint. Results. Patients with septic arthritis of the knee and hip joints had significantly increased levels of IL-6 and acute phase proteins in the blood serum. We believe that it is the enhanced synthesis of the pro-inflammatory cytokine IL-6 and acute phase proteins that plays a significant role in the pathophysiology of the inflammatory response, which initiates a chain of reactions that lead to cartilage degradation and further complication of inflammatory processes in the joint. Therefore, these biomarkers can be tools for diagnosing the progression of this disease in both preclinical and clinical studies. The results obtained emphasize the importance of identifying inflammatory biomarkers for diagnosing the progression of septic arthritis in both preclinical and clinical studies to establish the stage of the disease and predict clinical outcome.

Септичний артрит (СА) — це важка та швидко прогресуюча інфекція суглобів і потенційно небезпечний для життя стан, який може вплинути на всі вікові групи. Через відсутність ефективних методів раннього виявлення й оцінювання результатів лікування, вимірювання біохімічних маркерів (біомаркерів) є перспективним методом моніторингу захворювання. Мета. Визначити діагностичну значущість запальних біомаркерів (ІЛ-6, СРБ, гаптоглобіну, церулоплазміну) в пацієнтів із септичним запаленням суглобів різної локалізації. Методи. У дослідженні проаналізовано сироватку крові 54 осіб чоловічої і жіночої статі. Із них 18 були умовно здоровими і увійшли до І групи (контроль), а 36 хворих мали діагноз септичний остеоартрит суглобів різної локалізації в скелеті. Із них 18 — СА колінного суглоба; 13 — СА кульшового і 5 — СА надп'ятково-гомілкового. Результати. У пацієнтів із септичним артритом колінного та кульшового суглобів були значно підвищені рівні ІЛ-6 та білків гострої фази в сироватці крові. На нашу думку саме посилений синтез прозапального цитокіну ІЛ-6 та білків гострої фази відіграє значну роль у патофізіології запальної відповіді, за якої ініціюється ланцюг реакцій, що призводять до деградації хряща і подальшого ускладнення запальних процесів у суглобі. Тому ці біомаркери можуть бути інструментами діагностики прогресування цього захворювання як на доклінічних, так і в клінічних дослідженнях. Одержані результати підкреслюють важливість визначення біомаркерів запалення для діагностики прогресування септичного артриту як на доклінічних, так і в клінічних дослідженнях для встановлення стадії захворювання та прогнозування клінічного результату. Ключові слова. Інтерлейкін-6, білки гострої фази, септичний остеоартрит.

Keywords. Interleukin-6, acute phase proteins, septic osteoarthritis

Introduction

Septic arthritis (SA) is a severe and rapidly progressive joint infection [1, 2]. It is a potentially life-threatening condition that can affect all age groups. The annual incidence of SA ranges from 1 to 35 cases per 100,000 people in different countries [3]. The mortality rate can be high, ranging from 3 to 25 % [4]. Despite the severity of the disease, many patients do not have classic signs, symptoms, or laboratory abnormalities [4]. Diagnosis is complicated by the large number of conditions that can mimic SA, further complicating the diagnosis. Major risk factors include advanced age, pre-existing joint disease such as rheumatoid arthritis or osteoarthritis, diabetes, immunosuppression, recent joint surgery, intravenous drug use, and systemic infections. The increase in SA incidence is partly due to an aging population and an increase in comorbidities [2].

Each joint of the skeleton is characterized by a certain kinetics of the development of the pathological process, which is associated with symptoms of inflammation, stiffness and loss of mobility. Usually, SA develops in the knee, hip, talocrural joints and in the spinal vertebrae [5]. Diagnosis, which is based on clinical examination and radiography, provides little information about the onset and progression of the disease, metabolic changes in the tissues of the joint. Due to the lack of effective methods for early detection and analysis of treatment results, measurement of biochemical markers (biomarkers) is a promising method for monitoring the disease. Of particular interest are inflammatory biomarkers of SA, which are present in biological fluids such as blood, urine and synovial fluid, sources that are easily isolated from the body [6]. By examining these biochemical markers: cytokines (interleukin-6, (IL-6) and acute phase proteins (C-reactive protein (CRP), ceruloplasmin and haptoglobin) in the patient's serum, it is possible to accurately determine the level and activity of the inflammatory process. After all, it is known that the heterogeneity of the pathogenesis of AS is reflected in the combinations of different markers indicating the degree of joint degradation [7]. Cytokines are small proteins that are secreted by cells and have a unique effect on their interaction and communication. These signaling molecules are responsible for the regulation of immune responses and inflammation, and also cause cell growth and differentiation. Inflammatory cytokines are released in response to tissue damage or infection and have the potential to activate nerve fibers, contributing to the development of chronic pain [8]. Interleukins play an important role in modulating immune responses in various scenarios, from infectious diseases to pain and postoperative period. They act as pro- and anti-inflammatory and have a crucial role in the activation of immune cells, tissue repair and the overall balance of the immune system. Proinflammatory ILs, including IL-6, can lead to tissue damage if overexpressed [9–11]. The production of proinflammatory cytokines is primarily attributed to activated macrophages that induce inflammatory responses. The proinflammatory biomarker IL-6 initiates a chain of reactions that causes cartilage degradation and other inflammatory processes [12]. CRP, ceruloplasmin and haptoglobin are acute phase reactants that positively correlate with inflammation and joint pain in osteoarthritis and have been shown to predict pre- and post-operative outcomes [13–15]. The analysis of the above literature sources proves that AS is one of the most common causes of disability among people of all ages and can affect almost all joints of the skeleton. Each joint is characterized by certain kinetics of the development of the pathological process. However, the most vulnerable among them are the hip and knee. Determination of biochemical markers of inflammation demonstrates their variability for detecting pathological processes in the joints according to SA.

Purpose: to determine the diagnostic significance of inflammatory biomarkers (interleukin-6, C-reactive protein, haptoglobin, ceruloplasmin) in patients with septic inflammation of the joints of various localization.

Material and Methods

The study analyzed the blood serum of 54 male and female subjects. Of these, 18 were relatively healthy and included in group I (control), and 36 patients were diagnosed with septic osteoarthritis of joints of various locations in the skeleton. Of these, 18 (group II) had CA of the knee joint; 13 patients (group III) had CA of the hip joint, and 5 (group IV) had CA of the talocrural joints.

The study was carried out after approval by the Bioethics Committee of the Institute of Traumatology and Orthopedics (protocol No. 4 dated 11.17.2023) in accordance with the Declaration of Helsinki 2000, the European Community Directive 86/609 on the participation of humans in biomedical research and orders of the Ministry of Defense of Ukraine No. 690 dated 23.09.2009, No. 944 dated 14.12.2009, No. 616 dated 03.08.2012. All patients signed an informed consent form to participate in the study.

The concentration of IL-6 in the patients' blood serum was determined on the Cobas 411 analyzer using Roche Diagnostics test systems. The analysis of CRP, haptoglobin and ceruloplasmin was performed on the Cobas 311 biochemical analyzer using Roche Diagnostics test systems.

Statistical processing of the obtained results was carried out using the Origin Pro 8.5 program package. The mean values of the obtained indicators (M) with standard deviations (SD) were determined. The significance of the difference between groups with a normal distribution of comparison was assessed by the Student's t-test. Changes were considered significant at $p < 0.05$. In order to determine the statistical significance of the differences between groups for quantitative (with a distribution different from normal) and ordinal variables, the Kruskal-Wallace test was applied. Comparison of quantitative and ordinal variables in dependent samples was carried out using the Wilcoxon test. The data in the graphs are presented as medians and 5–95 percentiles.

Results and Discussion

According to our findings, the average concentration of IL-6 in the blood serum of individuals in the control group was (2.07 ± 0.22) pg/ml. In the remaining patients, its significant and probable increase was noted. Thus, in group II, the concentration of IL-6 increased by 695.7 %, and in group III by 1884.1 % ($p < 0.05$; Table). In group IV, a tendency to increase this indicator was recorded.

The pro-inflammatory biomarker IL-6 plays a crucial role in the development of the inflammatory response in SA and initiates a chain of reactions that lead to cartilage degradation and further complication of inflammatory processes in the joint [12]. An increase in its concentration triggers the synthesis of acute phase proteins, such as CRP, ceruloplasmin and haptoglobin, and also activates the innate immune system [16].

The level of CRP in the blood serum increased the most in patients with SA of the hip joint by 2635.4 % relative to control values ($p < 0.05$; table).

Almost half as much, namely by 1126.02 %, the level of this indicator increased in SA of the hip joint ($p < 0.05$; Fig. 2). In the case of septic arthritis of the talocrural joint, a tendency to its increase was recorded.

Thus, an increased level of CRP in the blood serum reflects the activity and risk of progression of the disease of the knee and hip joints.

Table

Concentration of interleukin-6 and acute phase proteins in patients with septic joint inflammation of various localizations

№	Indicator	Control	Joint		
			knee	hip	talocrural
1	Interleukin-6, pg/ml	2.07 ± 0.22	16.47 ± 3.42*	39.0 ± 8.81*	69.17 ± 52.93
2	C-reactive protein, mg/l	2.46 ± 0.75	30.16 ± 5.66*	67.29 ± 16.10*	65.82 ± 33.83
3	Ceruloplasmin, g/l	0.23 ± 0.01	0.36 ± 0.02*	0.33 ± 0.03*	0.28 ± 0.02*
4	Haptoglobin, g/l	1.16 ± 0.09	3.60 ± 0.48*	3.33 ± 0.44*	2.93 ± 0.64*

Note. * — $p < 0.05$ realtive to control group.

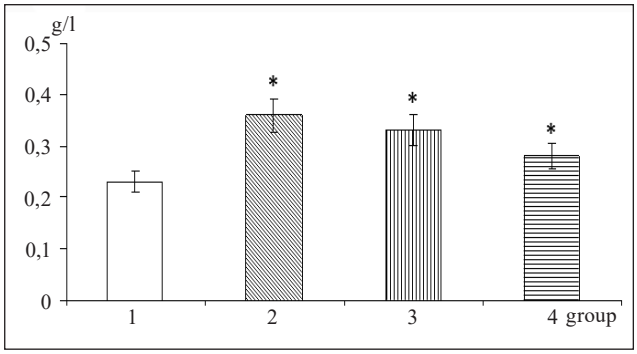

Fig. 1. Ceruloplasmin concentration in the blood serum of conditionally healthy subjects (1) and patients with SA of the knee (2), hip (3), and talocrural joints (4). * — $p < 0.05$ relative to group 1

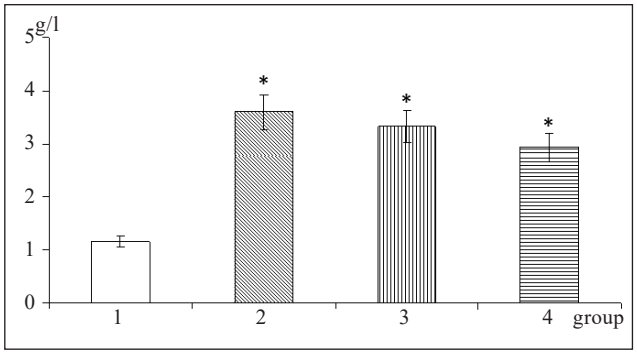

Fig. 2. Haptoglobin concentration in the blood serum of conditionally healthy subjects (1) and patients with SA of the knee (2), hip (3), and talocrural joints (4). * — $p < 0.05$ relative to group 1

The concentration of ceruloplasmin in the blood serum increased in all patients with SA of the studied joints. However, it was not as high as when determining IL-6 and CRP. The largest increase of 56.52 % was noted in SA of the knee joint ($p < 0.05$; table). In SA of the hip and talocrural joints, the level of this indicator significantly increased by 43.47 and 21.74 %, respectively ($p < 0.05$; Fig. 1) compared to the control.

The same trend was observed when determining the concentration of haptoglobin. The highest value was recorded when measuring in the blood serum of patients with SA of the knee joint. It was higher by 210.34 % compared to the control group ($p < 0.05$; Fig. 2).

In SA of the hip or talocrural joints, a significant increase in its level was observed by 187.07 and 152.59 % of the control values, respectively ($p < 0.05$; Fig. 2). According to our findings and literature data, patients with septic arthritis of the knee and hip joints had significantly increased levels of IL-6 and acute phase proteins in the blood serum [17, 18]. We believe that it is the enhanced synthesis of the pro-inflammatory cytokine IL-6 and acute phase proteins that plays a significant role in the development of the inflammatory response in SA. An increase in the concentration of IL-6 triggers the synthesis of acute phase proteins, primarily CRP, and initiates a chain of reactions that lead to cartilage degradation and further development of inflammatory processes in the joint. This is consistent with the results of other authors who observed a certain positive relationship between peak serum IL-6 and CRP levels in knee and hip osteoarthritis [12, 16]. Therefore, these biomarkers can be tools for diagnosing the progression of this disease in both preclinical and clinical studies, the main goal of which is to establish the diagnosis, stage of the disease and predict clinical outcome. The results obtained emphasize the importance of determining inflammatory biomarkers for the assessment and understanding of the inflammatory process.

Conclusions

Patients with septic arthritis of the knee and hip joints had significantly increased levels of IL-6 and acute phase proteins in the blood serum.

An increase in the concentration of IL-6 triggers the synthesis of acute phase proteins, primarily CRP, and initiates a chain of reactions that lead to cartilage degradation and further complication of inflammatory processes in the joint.

The results obtained emphasize the importance of determining inflammatory biomarkers for diagnosing the progression of septic arthritis in both preclinical and clinical studies to establish the stage of the disease and predict clinical outcome.

Conflict of interest. The authors declare the absence of a conflict of interest.

Prospects for further research. Studies of acute phase proteins, interleukins to identify the severity of the disease and metabolic changes in these indicators depending on the severity of the pathological process.

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Authors’ contribution. Magomedov S. — analysis of the findings, participation in drafting the article; Polyachenko Yu. V. — definition of research directions; Hrytsay M. P. — analysis of clinical material, drafting conclusions; Litovka I. G. — analysis of the findings, drafting the article; Sabadosh V. I. — analysis, diagnosis of patients; Dekhterenko N. O. — processing and conducting research; Kuzub T. A. — processing and conducting biochemical studies.

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INTERLEUKIN-6 AND ACUTE PHASE PROTEINS AS BIOMARKERS OF SEPTIC OSTEOARTHRITIS

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Clinical case of reconstruction of gunshot foot injury using the alt free flap technique

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With the onset of the full-scale war in Ukraine, the number of wounded individuals with soft tissue defects has significantly increased, necessitating the use of plastic surgery techniques for wound closure. However, to date, this surgical treatment method has not been widely adopted in military medicine due to the limited number of qualified specialists, the technical complexity of such procedures, and the need for specialized surgical department resources. Objective. To explore alternative surgical treatment approaches for patients with extensive foot defects using a free anterolateral thigh (ALT) flap to improve the functional, aesthetic, and weight-bearing properties of the foot. Methods. A single-stage reconstructive plastic surgery using a free composite flap (ALT free flap) was performed on a 49-year-old male serviceman due to the long-term consequences of a mine-blast injury. The injury resulted in a chronic combined non-healing granulating wound on the plantar surface of the right foot, comprising 60 % hypertrophic keloid scar tissue and 40 % non-healing granulating wound. To restore the anatomical integrity of the affected soft tissue, a free anterolateral perforator thigh flap (Anterolateral thigh flap) was used. Results. The transferred ALT flap successfully integrated into the plantar surface of the foot without complications. In the early postoperative period, venous congestion and epidermolysis were observed. This clinical case demonstrates that reconstructive plastic surgery using an ALT flap is an optimal approach for restoring the function of the damaged foot. Conclusions. The use of a free ALT flap addresses the issue of insufficient local donor site availability for volumetric, aesthetic, and functional reconstruction. Additionally, it enables microsurgical anastomosis at a favorable distance from the compromised area with impaired tissue trophism, which helps reduce technical difficulties and the rate of postoperative complications.

Через повномасштабну війну в Україні суттєво зросла кількість поранених із дефектами м'яких тканин, що зумовило необхідність використання методик пластичної хірургії для закриття ран. Анатомічне розташування та розмір певних травм часто унеможливлюють застосування місцевого донорського місця, що підкреслює важливість вільної шкірної пластики або трансплантації цілого комплексу тканин. Мета. Дослідити альтернативні хірургічні підходи до лікування пацієнтів із обширними дефектами стопи з використанням вільного передньолатерального клаптя стегна для покращення функціональних показників кінцівки. Методи. Одноетапна реконструктивна пластична операція з використанням вільного композитного клаптя (вільний клапоть ALT) проведена 49-річному військовослужбовцю через наслідки мінно-вибухової травми. Ушкодження призвело до утворення хронічної комбінованої рани на підошовній поверхні правої стопи, що складалася з 60 % гіпертрофічної келоїдної рубцевої тканини та 40 % рани, яка не загоювалася. Для відновлення анатомічної цілісності уражених м'яких тканин використано вільний передньолатеральний перфорантний клапоть стегна. Результати. Перенесений ALT-клапоть успішно інтегрувався в підошовну поверхню стопи без ускладнень. У ранньому післяопераційному періоді спостерігалися венозний застій та епідермоліз. Висновки. Використання вільного ALT-клаптя вирішує проблему недостатності. функціональної реконструкції. Крім того, це дозволяє мікрохірургічне анастомозування на сприятливій відстані від ураженої ділянки з порушенням трофіки тканин, що допомагає зменшити технічні труднощі та частоту післяопераційних ускладнень. Ключові слова. Вільний клапоть, дефекти рани, передньолатеральний клапоть стегна, вогнепальна рана, реконструкція.

Keywords. Free flap, wound defects, anterolateral thigh flap, gunshot wound, reconstruction

Introduction

Structure of combat trauma and reconstruction of lower limb injuries

Lower limb injuries continue to dominate the structure of combat trauma [3]. Several factors contribute to this: the lack of widespread use of personal protective equipment for the lower extremities (particularly the foot), the active use of mine-explosive weapons in combat operations, and the relatively large surface area of the lower limbs, making them more susceptible to injury.

Among the various mechanisms of trauma encountered in military conflicts, mine-explosive injuries rank first in both frequency and severity. Moreover, current trends indicate an increasing prevalence of this type of injury in the future. Mine-explosive trauma is one of the most severe and specific forms of combat injury, often involving multiple anatomical regions — typically two or three, but sometimes even more. The extensive damage associated with these injuries, the inherent tendency of gunshot wounds to become infected, and the frequent severe impairment of local blood supply and innervation all contribute to prolonged treatment and recovery periods for affected patients.

The foot plays a critical role in human mobility, providing support, movement, shock absorption, and balance. Reconstructive surgery on this segment of the lower limb aims to restore these functions as fully as possible, a challenging task when dealing with gunshot wounds as the etiological factor of injury [7]. In recent years, one of the most promising surgical approaches for treating such injuries has been the use of complex polystructural (chimeric) flaps, which incorporate multiple tissue types with an axial vascular supply [2, 9–11]. These procedures can be performed using either pedicled (non-free) flap transposition or free flap microsurgical autotransplantation.

The advantage of axial flaps, which were experimentally and clinically validated as early as the 1970s [10], lies in their ability to provide large and morphologically diverse tissue complexes for transplantation to almost any region of the human body. It is important to note that the foot, as the most distal segment of the lower limb, presents unique challenges for plastic wound closure. Additionally, the clinical scenario may be complicated by periwound tissue transformation [4, 5], which in some cases makes the use of local axial flaps virtually impossible. This necessitates consideration of axial flaps harvested from distant donor sites, which not only offer better tissue quality but also reduce trauma to the recipient site, thereby minimizing functional impairments.

Experience gained by the global reconstructive-plastic surgery community has shown that when designing free flaps for lower limb soft tissue reconstruction, the vascular pedicle should be of sufficient length (at least 8.0 cm) and diameter (approximately (2.0 ± 0.56) mm). These requirements are most easily met by harvesting free polystructural tissue complexes based on the radial artery, thoracodorsal artery, or lateral circumflex femoral artery. The vascular pedicle characteristics of these donor sites enable microvascular anastomosis to be performed at a considerable distance from the compromised zone, which is often affected by trophic disturbances and gunshot-related soft tissue transformation. Specifically, the anterolateral thigh (ALT) free flap used in this study can be designed with a vascular pedicle length of up to (16 ± 1.5) cm, incorporating a large skin-fascial component (up to 25×10 cm), a substantial portion of the vastus lateralis muscle (up to 500 cm^3), or a combination of these elements.

Objective: the aim of this study is to explore alternative surgical treatment options for patients with extensive foot defects by utilizing an anterolateral thigh (ALT) free flap to enhance the functional, aesthetic, and weight-bearing capabilities of the foot.

Materials and methods

During the full-scale war in Ukraine, on May 3, 2022, a 49-year-old Ukrainian Armed Forces serviceman sustained a mine-explosive injury while maneuvering on the battlefield in Donetsk region. The injury resulted from the detonation of a PFM-1 «Lepestok» anti-personnel mine (Fig. 1), causing a gunshot fragmentation wound to the right foot, a gunshot fracture of the calcaneus and cuboid bones, extensive soft and bone tissue defects, and hemorrhagic shock of grade-1.

The patient was evacuated from the site of injury and transported within two days to a Level III medical facility. He underwent two months of inpatient treatment in Ministry of Defense healthcare institutions, including staged necrosectomies. During the final surgical intervention, the wound defect on the plantar surface of the right foot was closed using a split-thickness skin graft.

Over the following two years, the patient experienced persistent numbness in the heel area, swelling and cyanosis of the foot, and limping on the right lower limb during prolonged physical exertion. In the past year, while wearing personal protective equipment that increased axial loading, he reported recurrent skin tears on the weight-bearing surface

of the right foot, circular foot infiltration, and chronic pain syndrome.

The patient was referred for further examination and treatment at the Military Medical Clinical Center of the Southern Region of the Ukrainian Armed Forces. He was evaluated by a surgical specialist and subsequently hospitalized in the Department of Reconstructive and Restorative Surgery.

During the examination, the presence of a wound on the postoperative scar of the plantar surface of the right foot was noted (60 % in the form of a hypertrophic keloid scar and 40 % in the form of a sluggishly granulating wound) (Fig. 2). At the time of the examination, the wound was covered with a scab, with a small amount of wound discharge and almost no signs of inflammation. The periwound tissues were transformed due to inflammatory-destructive changes.

Due to the lack of a loco-regional donor reserve, the possibilities of transplanting a tissue complex from distant areas are being actively considered. Taking into account the existing pathomorphological transformation and data from additional research methods, a decision was made to perform a one-stage reconstructive surgical intervention using a free anterolateral skin-fascial thigh flap harvested from the unilateral side.

During the preoperative preparation, the patient underwent standard clinical examinations (complete blood count, biochemical blood analysis, coagulation profile, blood type and Rh factor determination, serological markers for viral hepatitis B and C, HIV, syphilis, ECG, and chest fluorography). Additionally, specialized diagnostic methods were performed, including X-ray imaging of the right foot with visualization of the ankle joint and distal epiphyses of the tibia (Fig. 4), angiography of the vessels of the right lower limb (Fig. 3), dynamic digital thermography (Table, Fig. 7), and ultrasound Doppler sonography of skin perforators of the lateral circumflex femoral artery.

As part of the preoperative preparation, the wounded soldier was also examined by a physician to identify any comorbid conditions. The surgery was performed under combined anesthesia (spinal anesthesia + intravenous sedation). The total duration of the surgical procedure was 7 hours, while the anesthesia time was — 7 hours and 15 minutes. The intraoperative blood loss amounted to 100 ml.

The surgery was performed by an extended team of four surgeons, allowing the division of work between the donor and recipient sites. Throughout the procedure, a warm and moist environment in the surgical wound was maintained by regularly instilling saline solution. Intraoperative ultrasound

Fig. 1. Local Condition of the Right Foot at the Time of Initial Medical Care During Medical Evacuation on May 3, 2022: The plantar surface of the right foot exhibited a defect with a gunshot fracture of the calcaneus and cuboid bones. The wound defect measured 15×12×6 cm, with torn and infiltrated wound edges of a cyanotic-burgundy color. The wound bed consisted of soft tissues in shades of gray and pale pink, interspersed with brown and black areas, indicating necrotic transformation (eschar formation)

Fig. 2. Local status of the right foot at the time of admission to the Department of Reconstructive and Restorative Surgery of the Military Medical Clinical Center of the Southern Region on December 10, 2024: a hypertrophic keloid scar measuring 5×4.5×0.8 cm; along the medial surface of the calcaneus, there is a chronic sluggishly granulating wound with a diameter of 3.5 cm with calloused edges. The surface is covered with multilayered plaques of desquamated epidermis of a gray-yellow color

Fig. 3. Angiography of the right lower limb: a main-type blood flow with satisfactory contrast filling of the anterior and posterior tibial arteries. A — anterior tibial artery, B — posterior tibial artery

Fig.4. X-ray of the right foot: defects of calcaneus and cuboid bones with the signs of consolidation

audiodopplerographic monitoring was periodically performed to assess the pulsation of the perforator artery of the harvested flap and the anastomosis.

In the postoperative period, daily wound dressings were carried out with clinical and dynamic multimodal monitoring, including audiodopplerography and thermometric assessment of flap viability and surrounding tissue condition.

On the second postoperative day, venous congestion of the flap was observed during dressing changes, and on the third day, epidermolysis affected the entire surface of the flap. However, clinical, morphological, and thermometric evaluations confirmed flap viability. Throughout the early postoperative period, the tension test remained positive, with capillary refill time up to 5 seconds.

On the 10th postoperative day, every other suture securing the flap was removed, with complete suture removal on the 13th day. The sutures of the donor site were removed on the 12th postoperative day. The patient was discharged on the 19th postoperative day for early adaptive rehabilitation.

Surgical technique description

Flap Design

The blood supply of the anterolateral thigh (ALT) flap is provided by septocutaneous or musculocutaneous vessels branching from the descending branch of the lateral circumflex femoral artery (Fig. 5).

During flap marking on the lateral surface of the thigh, the guaranteed zone of these vessels was determined by drawing a line from the anterior superior iliac spine to the upper outer border of the patella. By marking the midpoint of this line and outlining a circle with a radius of 3 cm, thermographic and Doppler ultrasound monitoring was performed to precisely identify terminal blood supply at the epidermal level.

The second step in the preoperative period involved measuring and calculating the future defect area on the plantar surface of the right foot (considering the excision of scar tissue), and then transferring these dimensions onto the lateral surface of the right thigh. An additional 10 % was added to compensate for possible tissue shrinkage.

Flap Elevation

Following the pre-marked incision line, a scalpel was used to dissect the skin, subcutaneous fat, and deep fascia along the medial border of the flap. Step by step, in accordance with the classical ALT free flap dissection technique, soft tissue dissection was performed to expose the previously identified perforator vessel and accompanying veins.

All small branches were ligated and clipped. The vascular pedicle was clipped and divided at the proximal level, forming a free fasciocutaneous flap with axial blood supply, measuring 20×7×1.5 cm and a vascular pedicle length of 12 cm.

The donor site was closed with primary tension sutures using a continuous intradermal Holsted suture without excessive tension.

Flap Transfer

In the recipient area, excisional surgical debridement was performed, followed by irrigation with 3 % hydrogen peroxide and Decasan solutions.

The free ALT flap was transferred to the defect area, and a microvascular anastomosis was performed using an end-to-side technique with a branch of the anterior tibial artery and accompanying veins, utilizing the Coupler system [10].

The flap was then secured to the wound defect in layers with interrupted sutures, fixing the dermis separately using Donati sutures. The subflap space was drained with rubber drains, covered with petroleum jelly gauze, and dressed with aseptic bandages. Additional orthotic fixation of the foot was applied, maintaining an elevated position at 10° relative to the horizontal body axis.

Throughout the procedure, meticulous hemostasis was ensured using electrocautery and a pneumatic tourniquet.

All stages of ALT free flap elevation and fixation were continuously monitored using thermography and Doppler ultrasound.

Results

The transplanted tissue complex successfully integrated into the recipient area, and the postoperative wound at the donor site healed by primary intention.

In the early postoperative period, signs of venous congestion and epidermolysis of the transplanted flap were observed, but without necrosis (Fig. 5).

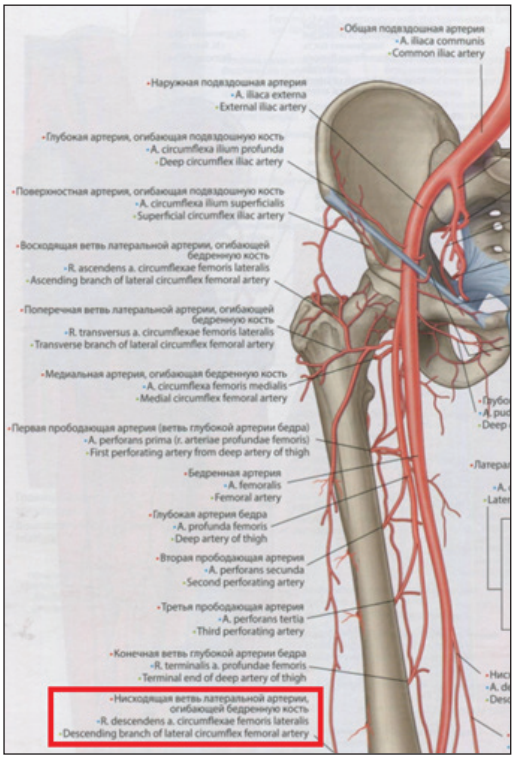

Fig. 5 Illustration of femoral arteries (anterior view). Gray's Anatomy Atlas, 2nd edition, 2020

Postoperatively, dynamic monitoring was conducted using digital thermography (DCT) and Doppler ultrasound:

– every hour during the first 24 hours;

– every 2 hours on the second postoperative day;

– every 4 hours on the third postoperative day.

At the time of this report, the patient has been discharged from the hospital for medical leave, with restored general and local status. The wound has healed by primary intention.

Fig. 6. Photographs of the right foot in lateral and frontal projections. Local status on the 7th postoperative day: signs of partial infiltration and venous congestion of the flap

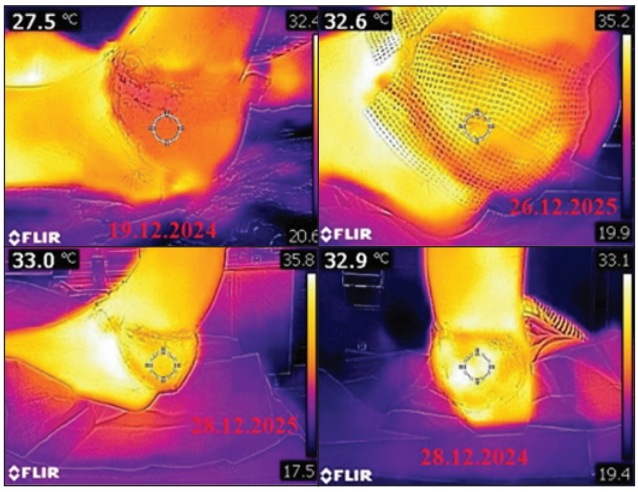

Fig. 5. Thermography of the Flap

Table

Indicators of thermographic monitoring of flap viability

Date	Indicators of Infrared Thermography of the Flap, °C
19.12.2024	27.5
26.12.2024	32.6
28.12.2024	33.0

Conclusions

The use of a free ALT flap allows for solving the problem of the absence of a loco-regional donor reserve (in terms of volumetric, aesthetic, and functional restoration). Additionally, it enables microvascular anastomosis at a favorable distance from the compromised pathological area with impaired trophism, which further helps reduce technical difficulties and the percentage of postoperative complications.

This flap can be formed and transplanted in a single-stage procedure to the recipient zone of all parts of the foot.

Conflict of interest. The authors declare no conflict of interest.

Prospects for further research. Inclusion of the use of the method of remote infrared thermography in the postoperative period to determine the course of wound regeneration, as well as monitoring the health of servicemen after pathological conditions detected during thermographic examination and appropriate treatment. Study of the health of servicemen after mine-explosive injuries, complications after diseases of the bronchopulmonary system, neuropathy. The information base of thermographic visualizations of detected pathological conditions will be expanded, which can be used by doctors of almost all specialties in medical practice. Include the use of plastic surgery methods for wound closure in military medicine. Reconstruction of soft tissue defects associated with gunshot wounds. Study of alternative surgical approaches to the treatment of patients with extensive defects.

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CLINICAL CASE OF RECONSTRUCTION OF GUNSHOT FOOT INJURY USING THE ALT FREE FLAP TECHNIQUE

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Cavernous medullary hemangioma of the distal left femur: a case report

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Bone hemangiomas occur in only one percent of primary bone neoplasms, and their diagnosis is difficult. The location of these benign neoplasms in long bones is even more rare. Objective. To describe the features of the diagnosis and surgical treatment of a woman with cavernous medullary hemangioma of the distal femur. Methods. The main diagnostic methods were computed tomography, radiography, and histopathological examination of the surgical specimens. Treatment was surgical removal of the neoplasm followed by rehabilitation with dosed loading of the limb. Results. A 45-year-old woman presented to the clinic with persistent aching pain in the left knee joint that did not stop after taking analgesics. Radiologically and using magnetic resonance imaging, an area of destruction and a neoplasm of irregular shape with clear uneven contours were found in the distal epimetaphysis of the left femur. Over 2 years of observation, the volumetric neoplasm did not increase on the radiographs, but the pain syndrome did not disappear and intensified during physical exertion. The results of the trephine biopsy did not allow to determine the exact diagnosis. Surgical treatment was carried outby means of parietal resection of the pathological focus of the distal part of the left femur and combined replacement of the defect with bone allograft with cement and fixation with a plate and screws. Morphological changes detected in the surgical specimens during histopathological examination corresponded to the diagnosis of cavernous hemangioma of the bone. At six months postoperatively, the patient demonstrated near-complete painless weight-bearing on the operated limb with minimal use of a cane, and the knee joint's range of motion was fully restored. Conclusions. Cavernous hemangioma of the femur is difficult to diagnose using trephine biopsy alone; accurate diagnosis is typically possible only through analysis of the surgical specimen. Surgical treatment enabled painless weight-bearing on the left limb by the sixth month of follow-up.

Кісткові гемангіоми зустрічаються лише в одному відсотку первинних новоутворень кісток, а їхня діагностика є складною. Розташування цих доброякісних новоутворень у довгих кістках є ще більш рідкісним. Мета. Описати особливості діагностики та хірургічного лікування жінки з кавернозною медулярною гемангіомою дистального відділу стегнової кістки. Методи. Основними діагностичними методами були комп'ютерна томографія, рентгенографія, патогістологічне дослідження операційного матеріалу. Лікуванням було хірургічне видалення новоутворення з подальшою реабілітацією з дозованим навантаженням кінцівки. Результати. Жінка 45 років звернулася до клініки з постійним ниючим болем у лівому колінному суглобі, який не припинявся після прийому анальгетиків. Рентгенологічно та за допомогою магнітно-резонансної томографії виявили в дистальному епіметафізі лівої стегнової кістки ділянку деструкції та новоутворення неправильної форми з чіткими нерівними контурами. За 2 роки спостереження на рентгенограмах об'ємне новоутворення не збільшувалося, але больовий синдром не зник і посилювався під час фізичних навантажень. Результати трепан біопсії не дали змогу визначити точний діагноз. Провели хірургічне лікування шляхом пристіночної резекції патологічного вогнища дистального відділу лівої стегнової кістки та комбінованого заміщення дефекту алоімплантатом із цементом і фіксацією пластиною та гвинтами. Морфологічні зміни виявлені в операційному матеріалі під час патогістологічного аналізу відповідали діагнозу кавернозна гемангіома кістки. Через 6 міс. після хірургічного втручання пацієнтка майже повністю навантажувала оперовану кінцівку без болю з частковим використанням тростини, обсяг рухів колінного суглоба відновився. Висновки. Кавернозну гемангіому в стегновій кістці складно виявити за допомогою трепан біопсії, лише аналіз операційного матеріалу дає змогу точно встановити діагноз. Хірургічне лікування допомогло відновити навантаження на ліву кінцівку без больового синдрому на 6-й місяць спостереження. Ключові слова. Новоутворення кісток, внутрішньокісткова гемангіома, рентгенографія, комп'ютерна томографія, магнітно-резонансна томографія, гістологія.

Keywords. Bone neoplasm, intraosseous hemangioma, radiography, computed tomography, magnetic resonance imaging, histology

Introduction

Vascular tumors of long bones are rare and difficult to diagnose. They are classified as benign (hemangioma), intermediate-locally aggressive (epithelioid hemangioma), intermediate with rare metastasis (pseudomyogenic hemangioendothelioma), and malignant (epithelioid hemangioendothelioma and angiosarcoma) [1]. Hemangioma is a proliferation of blood vessels lined by a single layer of flattened endothelial cells. Among primary bone neoplasms, they occur in less than 1 % of cases [2]. In the skeleton, hemangioma is most often found in the vertebral bodies or skull, while it is not common in other areas. The difficulty of diagnosing cavernous hemangioma is due to its extremely diverse presentation. Namely, from asymptomatic lesions and incidental findings on radiographs to severe pain syndrome [3]. Differential diagnosis of hemangioma of long bones includes giant cell tumor, aneurysmal bone cyst, plasmacytoma, etc. In the vast majority of patients with hemangiomas, surgical removal of the lesion is effective with a favorable prognosis, and there is usually no need for specific treatment.

Purpose: to describe the features of diagnosis and surgical treatment of a female patient with cavernous medullary hemangioma of the distal femur.

Material and Methods

In the described clinical case of a 45-year-old woman with cavernous medullary hemangioma in the distal part of the left femur, the following diagnostic methods were used: palpation of the knee joint, ultrasound diagnostics of the vessels of the lower extremities, complete blood count, biochemical blood test, magnetic resonance imaging (MRI), computed tomography (CT), radiography, pathohistological examination of biopsy and surgical material. Surgical removal of the neoplasm was performed for treatment. In the postoperative period, active rehabilitation with dosed loading of the operated limb was prescribed.

Results

The presented clinical case describes the results of the diagnosis and treatment of a patient at the State Institution Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Medical Sciences of Ukraine (Kharkiv) with a benign vascular tumor of the femur — cavernous medullary hemangioma. The patient signed an informed consent for the publication of her clinical case report.

In 2022, the 45-year-old woman was first hospitalized in the Department of Emergency Traumatology and Reconstructive Surgery with the Department of Bone Oncology presenting with constant aching pain in the area of the medial surface of the left knee joint (6–7 points on the VAS), which did not stop after taking analgesics and anti-inflammatory drugs. According to the patient, the pain first appeared in 2020. The severity of the pain syndrome gradually increased, so the patient had an appointment at our institution for further examination.

During a local examination of the left knee joint, edema of the medial surface was detected. The surrounding tissues had no signs of inflammation. During palpation of the knee joint, the patient felt pain in the projection of the medial condyle of the left femur. During flexion or extension of the joint, the pain increased, and the flexion angle was limited to 85°. No neurocirculatory disorders were found.

Further, a more detailed examination was performed using instrumental methods such as Dopplerography, ultrasound diagnostics of the vessels of the lower extremities, electrocardiography, all of which did not show any abnormalities. As a result of general and biochemical blood tests, an increase in the erythrocyte sedimentation rate to 20 mm/h, an increase in cholesterol levels (7.7 mmol/l) and B-lipoproteins (83 units) was determined. The blood coagulation system indicators were normal. After a general urine test, a moderate amount of amorphous phosphates was found.

The patient underwent spiral tomography and was diagnosed with osteochondrosis of the thoracic and lumbar spine.

After an X-ray examination of the left femur, an irregular oval-shaped area of destruction with indistinct contours and a heterogeneous structure was detected in the projection of its distal epimetaphysis, located on the anteromedial surface of the internal condyle of the bone (Fig. 1 a, b), which at this level was slightly thickened due to swelling, the cortical layer was thinned with signs of destruction on the anterior surface. The para-articular tissues were inhomogeneous and enlarged.

According to MRI in May 2022, an irregularly shaped neoplasm with clear uneven contours, measuring 39×43×37 mm, was identified in the distal metaepiphysis of the left femur, along the medial edge, which was hyperintense on T1, T2, in STIR, PD modes (Fig. 1 c–d).

All images revealed hypointense inclusions inside the neoplasm and its growth into the metaepiphyseal plate with extension into the diaphysis, which caused swelling of the bone (Fig. 1 c–d). The neoplasm caused moderate edema of the surrounding bone marrow and fatty tissue. A periosteal reaction of the cortical layer was recorded along the medial edge of the femur.

Fig. 1. Visualization of the left knee joint of a 45-year-old woman before (a–h) and after (i, j) surgical treatment of cavernous medullary hemangioma of the femur. Hemangioma in the distal femur on radiographic images (a — direct, b — lateral projections) and MRI scans in 2022 (c — lateral, d — axial, e — coronal projections); CT scans in 2024 (f — lateral, g — axial, h — coronal projections). Radiographic images after surgical removal of the hemangioma (i — direct, j — lateral projections) with replacement of the defect with a bone allograft and fixation with a plate and screws

The relationship of the bones in the knee and patellofemoral joints was preserved. The intercondylar tubercles of the tibia were sharpened, and the presence of minor marginal osteophytes of the condyles of the femur and tibia was determined.

The thickness of the articular cartilage of the condyles of these bones was preserved and with the corresponding MR signal characteristics. The articular cartilage of the patella was thinned, with defects with a depth of more than 50 % of its thickness and a size of 8×18 mm. Bone marrow edema was detected in the subchondral bone of the patella. Excessive content of homogeneous fluid was noted in the suprapatellar bursa and the cavity of the knee joint; the synovial membrane was not thickened, and its folds were not changed. Fat bodies were unremarkable. However, the fatty tissue around the joint was swollen.

During the observation of the patient's condition, control radiographs of the left knee joint were performed every 2, then 3 months. during 2022–2024, an increase in the volume of the neoplasm was not recorded. The formation of sclerosis of the contours of the neoplasm, densification of the bone structure, thickening of the newly formed bone trabeculae with the formation of a cellular structure and areas of calcification of uneven shape were observed. According to the CT scan in January 2024, in the anterior part of the medial epimetaphysis of the femur, a relatively delineated area of destruction with conditional dimensions of 41×29×49 mm remained, separated from the surrounding bone by a sclerotic rim (Fig. 1, a–h). At this level, swelling of the bone and thinning of the locking plate were detected, which was not clearly visible in some areas. Calcification of the matrix of the pathological area and a local calcification zone on the contact surface of the kneecap measuring 4×3×9 mm were noted. An enostomy measuring 3×6×6 mm was found in the lateral condyle of the left femur.

After examination, the preliminary diagnosis was determined as a focus of pathological reorganization of the distal part of the left femur, which is accompanied by impaired function of the left lower limb with persistent pain syndrome.

Given the presentation and history of the disease, the patient underwent a trepan biopsy, the results of which did not allow determining an accurate diagnosis. Namely, macroscopically these were fragments similar to bone and cartilage tissue. During microscopic examination, cartilage tissue and individual

bone trabeculae with destructive dystrophic changes in them were found.

Given the persistent pain syndrome, which intensified during physical exertion and interfered with the usual state of life, the patient's young age and active lifestyle, visible deformation of the knee joint due to edema and neoplasm, high risk of pathological fracture of the femur, she was offered surgical treatment. The intervention was performed by parietal resection of the pathological focus of the distal part of the left femur with preservation of subchondral and cartilage tissues and combined replacement of the defect with an alloimplant with fixation with a plate and screws.

After obtaining consent, the patient underwent surgical intervention. A linear incision of approximately 30 cm in length was made on the anterior surface of the left knee joint in the projection of the medial condyle. The soft tissues were separated in layers. Hemostasis was performed during surgical access. The medial condyle of the left femur was isolated and revised. There was soft tissue swelling around the tumor. A 4×4 cm zone of destruction of the cortical layer of the bone was detected with preservation of the periosteum and replacement of the spongy bone tissue of the medial condyle with a soft tissue component. A parietal resection of the tumor was performed with preservation of the articular surface and subchondral layer of the medial condyle. Careful debridement and pulse lavage were performed. The defect was replaced with a combined bone allograft in combination with Calcemex bone cement (Fig. 1, i, j). The fragments were fixed using a plate and screws, then the correct placement of the fragments was checked radiographically. The wound was washed with antiseptics, hemostasis was performed, and sutured in layers. There were no complications intraoperatively and in the early postoperative period. The removed surgical material was sent for pathological histological examination.

Macroscopic assessment of the surgical material showed a fragment of the femur with an oval-shaped neoplasm measuring 5.5×5×3.5 cm, of bone density, gray, red and brown in color. Cavities with bone trabeculae containing bloody fluid were identified on the section.

During microscopic examination, a chaotic arrangement of bone trabeculae adjacent to the defect zone was recorded, which had destructive changes (Fig. 2, a). Namely, uneven staining of the bone matrix of the trabeculae and microcracks were noted, and in some places dead osteocytes in the lacunae were found. Numerous capillary-type vessels surrounded by loose connective tissue were found in the intertrabecular spaces (Fig. 2, b, c). The vessels were arranged in a disordered manner, sometimes their groupings were determined as lobules, which were separated from each other by wide layers of fibrous tissue, there were cavernous structures, which consist of irregularly shaped and variously sized vascular cavities (Fig. 2, d). The elongated endothelial cells lining the vascular cavities were enlarged in size, had a hyperchromic nucleus and eosinophilic cytoplasm (Fig. 2, d), in which the presence of hemosiderin foci was noted in some places. Thus, the detected morphological changes corresponded to the diagnosis of cavernous hemangioma of the bone. In the early postoperative period, the patient had a significant decrease in pain syndrome. Three months after surgery, its complete regression was established. The patient was recommended to undergo active rehabilitation with dosed load on the limb. In 6 months the patient presented for follow-up with almost full weight-bearing on the operated limb and range of motion in the knee joint, with only partial support on a cane and no presenting complaints at the time of examination.

Discussion

Hemangioma of the long bones is a rare clinical case. In the population, this diagnosis is more common among women aged 40–50 years (60 %) [3, 4]. In our case, the patient was 45 years old.

The lower extremities are the predominant location of skeletal hemangioma in the appendicular skeleton. A. Rigopoulou and A. Saifuddin (Greece) [4] described 15 cases of histologically confirmed intraosseous hemangioma of the appendicular skeleton, in 9 of them the neoplasm was found in the lower extremities, mostly in the long bones (tibial — 4, femur — 3, fibula — 1). In a publication by authors from the USA, which described 5 episodes of skeletal hemangioma of the extremities, in 2 cases it was found in the lower extremities in the fibula [5]. In another series of cases (n = 24) in China, in most patients (n = 20) hemangioma was also diagnosed in the bones of the lower extremities (femur — 9, tibia — 7, fibula — 4) [2].

Depending on the location in the bone, hemangiomas are more often medullary (66 %), and less often periosteal (33 %) and intracortical (12 %) [5]. In our clinical case, a medullary hemangioma was observed in the metaphysis.

However, most hemangiomas of long bones are found in the diaphysis (80 %) or metadiaphysis, and the metaphysis occurs in only 10 % of such episodes [5]. A clinical case similar to ours was described by researchers from India, where a 38-year-old woman was also diagnosed with cavernous medullary hemangioma of the proximal metaphysis of the tibia [3].

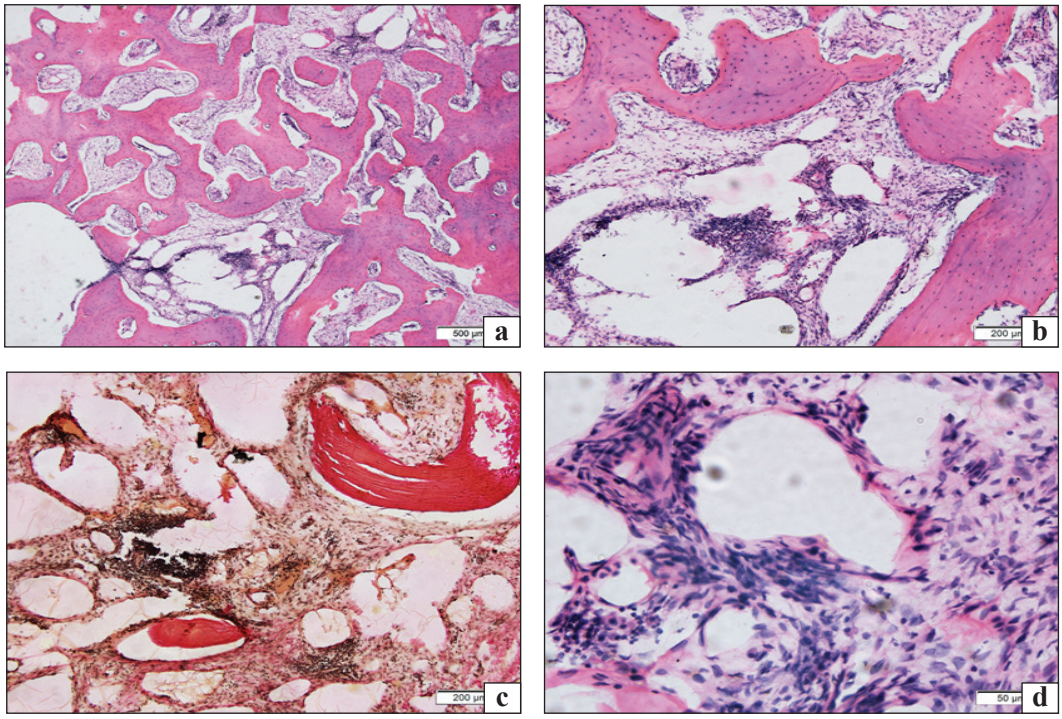

Fig. 2. Morphological features of cavernous medullary hemangioma of the femur in a 45-year-old woman. Bone trabeculae are arranged chaotically (a). Irregular sinusoidal capillaries (b–c), lined by a single layer of typical endothelium and surrounded by collagen fibers (d). Hemosiderin foci (b). Staining: hematoxylin and eosin (a, b, d); van Gieson (c). Magnification: a) 40; b-c) 100; d) 400

Common features were pain and swelling of soft tissues. According to other authors, these are characteristic symptoms specifically for hemangiomas of long bones, while hemangiomas of the vertebral bodies or skull are more often asymptomatic [4–6].

Radiological and clinical manifestations of hemangiomas in long bones are not characteristic and are nonspecific, which makes differential diagnosis difficult. Thus, according to the analysis of a series of 5 cases of this pathology, the preoperative diagnosis of venous medullary hemangioma was considered in only one. At the same time, in this series of cases, two were with cavernous medullary hemangioma of the long bones of the extremities, as described by us [5]. In a study of 36 cases of intraosseous hemangiomas outside the skull and spine, a common feature on CT scans was the germination of the neoplasm through the cortex [7]. The authors believe that this feature distinguishes bone hemangiomas with this localization from those in the skull or spine [7]. That is, in their opinion, this location is more aggressive, probably because of this they are often confused with malignant neoplasms. Similar features were found in our case in the form of periosteal reaction of the cortical layer and germination of the hemangioma into the metaepiphyseal plate with spread into the diaphysis of the femur.

The complexity of the diagnosis is confirmed by another case similar to ours, in which a patient with intraosseous hemangiomas of the distal femur and diaphysis of the left tibia was suspected of *cystic angiomatosis* and multiple myeloma until an open biopsy was performed [8].

Histologically, the most common type in the long bones of the extremities is cavernous hemangioma [2]. The morphological changes that we found were consistent with this diagnosis. Pathological and histological examination for its determination is not difficult. However, artifacts that arise from the collection of material during trephine biopsy, histological processing, and the preparation of histological sections can complicate the interpretation of microscopically detected changes in tissues. The reason for the appearance of such artifacts is the combination of tissues of different densities in the fragment: delicate thin-walled vessels and denser bone trabeculae.

Because of the above, in our opinion, a comprehensive approach is important for the diagnosis of cavernous hemangioma in severe clinical cases. Namely, the comparison of clinical indicators, imaging results (radiography, CT or MRI) and preoperative trepan biopsy data. At the same time, the final diagnosis of "cavernous hemangioma" can be confirmed only by the results of pathological histological examination of the surgical material.

Conclusions

Cavernous medullary hemangioma of long bones, especially with an unusual location in the distal femur, is a rare vascular tumor. Its differential diagnosis is difficult due to nonspecific clinical and radiological

manifestations, but surgical treatment has a favorable prognosis.

In the described clinical case, the 45-year-old woman underwent the necessary clinical and radiological examination, but this diagnosis was confirmed only after surgical intervention to remove the tumor due to the difficulty of obtaining the necessary material during trepan biopsy.

Surgical treatment by parietal resection of the tumor, replacement of the defect with a bone alloimplant with fixation with plates and screws was effective and helped to almost completely restore the load on the operated limb of the patient without pain syndrome after 6 months.

Conflict of interest. The authors declare the absence of a conflict of interest.

Prospects for further research. Development of a set of methods to improve the diagnosis of cavernous hemangioma localized in the long bones.

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Authors' contribution. Shevchenko I. V. — participation in the diagnosis of the disease, performed surgical intervention with a description of the technique; Gubsky S. S. — participation in the diagnosis of the disease, performed treatment in the pre- and postoperative period and described it; Zlatnik R. V. — participation in the diagnosis of the disease, performed radiological examinations with a description of the results; Danyshchuk Z. M., Ivanova N. V. — participated in the diagnosis of the disease, performed histopathological studies and description; Maltseva V. Ye. — drafted the discussion and final version of the manuscript, created figures. All authors approved the final manuscript.

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CAVERNOUS MEDULLARY HEMANGIOMA OF THE DISTAL LEFT FEMUR: A CASE REPORT

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Methods of reinnervation after amputationsin patients with the consequences of combat injuries (literature review)

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The full-scale aggression of the Russian Federation against Ukraine has significantly increased the number of cases and the structure of factors leading to the performance of such surgical interventions as amputation. There are no reliable statistics on the number of limb amputations performed since the beginning of the full-scale invasion of the Russian Federation into the territory of Ukraine due to objective factors, however, according to preliminary estimates, their number exceeds 50 thousand people. One of the significant problems after limb amputations is pain syndrome, which is observed in 60 to 86 % of patients, which is divided into two types: residual limb pain (RLP) and phantom limb pain (PLP). This problem is relevant for modern world orthopedics and traumatology, the solution of which requires a multidisciplinary approach, and further study will allow to improve treatment tactics and improve the final results. The purpose was to determine the optimal surgical technologies for performing amputations in victims with combat injuries and analyze modern reinnervation methods by studying literary sources. Methods. An assessment of modern publications, systematic reviews, and current recommendations published recently was conducted, which are devoted to methods of treatment and prevention of neuroma formation in limb amputations. A search was conducted in the PubMed, Scopus, Web of Science, and Google Scholar, databases using the following terms: «amputation», «RPNI», «VDMT», «TMR», «phantom», «clinical effectiveness», «post-amputation pain», «BNA», «ANA», «RLP», «PLP», «stump neuroma», «symptomatic neuroma», «pain neuroma». Relevant articles were included after reading the full text and determining the necessary parameters. The review was prepared in accordance with the recommendations of the "Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines". Conclusions. The results of scientific studies indicate that reinnervation methods (TMR, RPNI, VDMT) are clinically more effective than traditional amputation. These methods can be used with equal effectiveness both for the prevention of late post-amputation complications (symptomatic neuromas, phantom limb pain, residual limb pain) and for their treatment.

Повномасштабна агресія російської федерації проти України суттєво збільшила кількість випадків і змінила показання чинників щодо виконання таких оперативних втручань, як ампутація. Достеменних статистичних даних стосовно кількості проведених ампутацій кінцівок із початку повномасштабного вторгнення немає через об'єктивні фактори, проте за попередніми підрахунками їхня кількість перевищує 50 000 осіб. Однією зі суттєвих проблем після ампутацій кінцівок є больовий синдром, який спостерігається від 60 до 86 % пацієнтів та поділяється на два типи: біль у куксі (RLP — Residual Limb Pain) і фантомний біль у кінцівках (PLP — Phantom Limb Pain). Це питання є актуальним для сучасної світової ортопедії і травматології, його розв'язання потребує мультидисциплінарного підходу, а подальше вивчення дозволить удосконалити лікувальну тактику та покращити кінцеві результати. Мета. Визначити оптимальні хірургічні технології проведення ампутацій у постраждалих із бойовими ураженнями та проаналізувати сучасні реіннерваційні способи шляхом вивчення літературних джерел. Методи. Проведено дослідження сучасних публікацій, системних оглядів, діючих рекомендацій стосовно методик лікування та профілактики утворення невром за ампутацій кінцівок. Здійснено пошук у базах даних PubMed, Scopus, Web of Science та Google Sholar, за ключовими словами: «amputation», «RPNI», «VDMT», «TMR», «phantom», «clinical effectiveness», «post-amputation pain», «BNA», «ANA», «RLP», «PLP», «stump neuroma», «symptomatic neuroma», «pain neuroma». Огляд підготовлений згідно з рекомендаціями «Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines». Висновки. Результати наукових досліджень указують, що реіннерваційні способи (TMR, RPNI, VDMT) є клінічно ефективніші як порівняти з традиційною ампутацією. Ці методики з однаковою продуктивністю можуть застосовуватись як для профілактики пізніх постампутаційних ускладнень (симптоматичні невроми, фантомний або біль безпосередньо в куксі), так і під час їхнього лікування. Ключові слова. Поліструктурні ушкодження кінцівок, ампутації, способи реіннервації.

Keywords. Polystructural limb injuries, amputations, reinnervation methods

Introduction

Amputation is a surgical procedure that involves the removal of a limb. The main causes are vascular disease, diabetes, and peripheral arterial disease (54 %), trauma (45 %), and cancer (approximately 2 %). Studies using data from the Nationwide Inpatient Sample, the largest inpatient database in the United States, have found that nearly 115,000 people require lower limb amputations each year [1, 2, 20].

Military conflicts, often involving the deployment of high-energy weapons, frequently lead to severe polystructural limb injuries in over 50 % of cases. Such extensive damage renders modern reconstructive surgery insufficient in achieving positive functional outcomes for these victims. Thus, according to publications on wounded participants of the Joint Forces Anti-Terrorist Operation (ATO/JFO), the main cause of amputation was mine-explosive trauma (MET) in 78.4 % of cases. There are no reliable statistical values regarding the number of limb amputations performed since the beginning of the full-scale invasion of the Russian Federation into the territory of Ukraine due to objective factors, but according to preliminary estimates, there are more than 50 thousand people [1].

One of the significant problems after limb amputations is pain syndrome, which is observed from 60 to 86% of patients and is divided into two types: residual limb pain (RLP) and phantom limb pain (PLP) [9].

Phantom limb pain (PLP) is clinically recognized as the sensation of pain or discomfort in an absent limb, and it can present across a broad clinical spectrum with varying degrees of severity. Formerly known as “stump pain”, it is pain originating from the actual site of the amputated limb, most often occurring in the early postoperative period and tending to disappear during wound healing. In the majority of instances, these conditions occur together. Factors for the development of RLP include neuroma formation, nerve compression, ischemia, skin damage, or infection [6, 12].

PLP and RLP are relevant issues from the point of view of epidemiology and therapeutic difficulties. It is known that 95 % of patients experience pain associated with amputation, with 79.9 % experiencing phantom pain and 67.7 % experiencing pain directly in the stump [8].

Taking into account the problems outlined, determining the optimal surgical techniques for amputation in general and the treatment of nerve structures in particular is a relevant issue in modern orthopedics.

Purpose: to determine the optimal surgical techniques for performing amputations in combat-wounded patients and to analyze modern reinnervation techniques by studying literature sources.

Material and Methods

An analysis of modern publications, systematic reviews, and current recommendations on methods of treatment and prevention of neuroma formation in case of limb amputations was conducted. A search was conducted in the PubMed, Scopus, Web of Science, and Google Scholar databases using the following keywords: “amputation”, “RPNI”, “VDMT”, “TMR”, “phantom”, “clinical effectiveness”, “post-amputation pain”, “BNA”, “ANA”, “RLP”, “PLP”, “stump neuroma”, “symptomatic neuroma”, “pain neuroma”. The review was prepared in accordance with the “Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines”.

Inclusion criteria: 1) limb amputations in patients due to combat trauma; 2) late post-amputation complications, such as neuroma, phantom pain, stump pain, scar innervation; 3) use of reinnervation techniques: VDMT, TMR, RPNI; 4) articles with evidence levels I–IV; 5) follow-up duration of at least one year.

Exclusion criteria: 1) amputations due to non-combat trauma; 2) reviews, abstracts or articles that did not include sufficient data; 3) non-standardized reinnervation techniques.

According to the specified criteria, two independent researchers checked the search results by title, abstract and full text. The obtained data included: first author, level of evidence, year of publication, study design, type of amputation, number and age of patients, reinnervation techniques.

Meta-analysis was performed using the Meta package to generate risk ratios for categorical outcomes, mean differences for continuous outcomes, and 95% confidence intervals (CIs).

The results of studies on the development of symptomatic neuromas and phantom pain syndrome in cases of upper and lower limb amputations are presented in Table 3.

The results of prevention and treatment of late local post-amputation complications are shown in Table 4.

The results of the study on the risk of reoperation after performing reinnervation surgical methods and traditional amputation are given in Table 5.

Discussion

Neuroma develops from a transected peripheral nerve that regenerates and lacks a distal target for

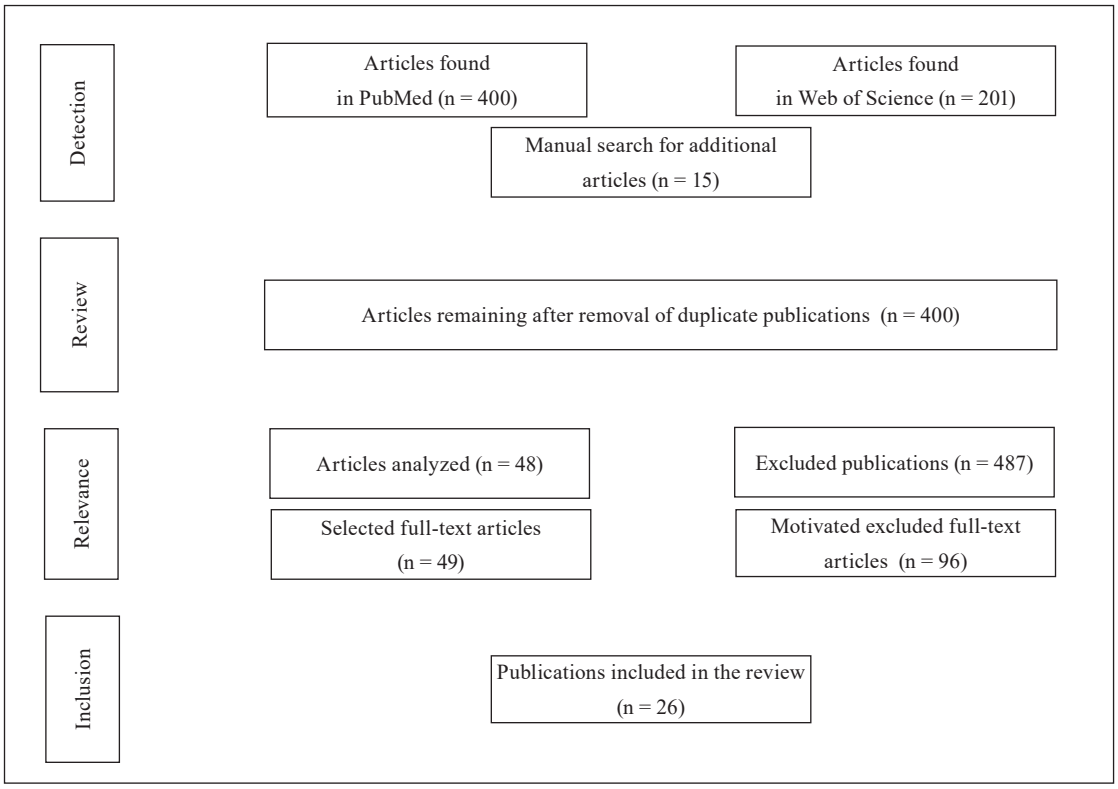

Figure. Flowchart of article selection for the study

Table 1

Assessment of reinnervation surgical techniques

Author, year, country	Characteristics of models	Method of reinnervation
C. S. Best et al., 2024, USA [4]	Lower limb amputations at different levels	RPNI
C. A. Kubiak et al., 2021, USA [14]	Lower limb amputations at different levels	RPNI
J. B. Bowen et al., 2019, USA [5]	Below-the-knee amputations (BNA)	TMR
S. Pejkova et al., 2022, Northern Macedonia [22]	Lower limb amputations at different levels	RPNI
F. Mereu et al., 2021, Italy [19]	Upper limb amputations	TMR
Z. W. Fulton et al., 2022, USA [10]	Upper and lower limb amputations	TMR
P. J. Hanwright et al., 2023, USA [11]	Lower limb amputations	VDMT

Table 2

Analysis of clinical outcomes of patient treatment using various reinnervation techniques

Author, year, country	Amputation	Method of reinnervation		Study design
V. Suresh, et al., 2023, USA [25]	Upper limbs	VDMT — 9	Traditional amputation — 4	Retrospective
Z. Lin et al., 2023, China [17]	Lower limbs	RPNI — 7	Traditional amputation — 7	Retrospective
C. A. Kubiak et al., 2019, USA [15]	Upper and lower limbs	RPNI — 45	Traditional amputation — 45	Randomized
E. Pettersen et al., 2024, USA [23]	Upper and lower limbs	TMR — 37 RPNI — 37	Traditional amputation — 37	Prospective

reinnervation. Symptomatic neuromas are a common cause of post-amputation pain that can result in significant disability in young adults [4].

Although many interventions have been proposed for the treatment of symptomatic neuromas, conventional techniques result in a high recurrence rate,

Table 3

Results of studies on the development of symptomatic neuromas and phantom pain syndrome in limb amputations

Author, year, country	Study characteristics	Summary
C. A. Kubiak et al., 2019, USA [15]	The results of treatment of patients who underwent amputation with and without the RPNI method were analyzed.	RPNI in individuals with limb amputations resulted in a lower incidence of both symptomatic neuromas and phantom limb pain compared with a control group who underwent amputation without RPNI. This suggests that prevention of symptomatic neuromas after amputation may reduce central pain mechanisms that, in turn, lead to phantom limb pain.
Z. Lin et al., 2023, China [17]	The indicators of individuals with lower limb amputations are presented. Clinical data were collected including general information, pathology of the underlying disease, history of surgical treatment, level of neurotomy, pain scales: Numeric Rating Scale (NRS) and Manchester Foot Pain and Disability Index (MFPDI). 3 months after amputation, the transverse diameter, anterior-posterior diameter and cross-sectional area of the stump neuroma were measured using ultrasound and compared with normal nerves of the opposite limb at the same level.	The NRS and MFPDI scores of patients in the RPNI group were significantly lower than those in the traditional amputation group and decreased with increasing follow-up time, indicating that RPNI may reduce symptomatic pain behind the nerve.
A. L. O'Brien et al., 2022, USA [21]	Data from patients undergoing TMR after limb amputation were analyzed. Outcomes included patient-reported severity of PLP and RLP, measured by a numerical rating scale (NRS). Secondary outcomes were compiled into patient-reported outcome information system (PROMIS) questionnaires.	At 3 months postoperatively, all PLP and RLP outcomes were compared with previously reported data, which demonstrated superiority over amputations without TMR. Mixed-model linear regression analysis revealed that PLP severity scores on the NRS scale continued to improve over the study period ($p = 0.022$). The remaining outcomes for RLP severity and PROMIS quality of life scores demonstrated that these scores remained stable over the study period ($p > 0.05$). TMR is an effective surgical procedure that improves the chances of reducing RLP and PLP when performed at the time of amputation
V. Suresh et al., 2023, USA [25]	The consequences of treating patients who underwent upper limb amputation using the VDMT method as a preventive measure against neuroma formation are considered.	The mean follow-up period was (5.6 ± 4.1) months (CI 0.5–13.2). The mean postoperative pain score was 1.1 (CI 0–8). This study demonstrated favorable short-term outcomes in individuals undergoing VDMT of the upper extremity.

and there remains considerable disagreement about the most optimal treatment and prevention strategy for PLP and RLP [14]. Reinnervation techniques such as RPNI (Regenerative Peripheral Nerve Interface), VDMT (vascularized denervated muscle target), TMR (Targeted Muscle Reinnervation) are aimed at preventing specific neuropathic pain after amputation [7].

The RPNI technique is performed by implanting the distal end of the transected peripheral nerve into a free, nonvascularized skeletal muscle graft. The neuroma or free end of the affected nerve is identified, the nerve is transected, and the nerve is mobilized proximally. A free muscle graft is harvested directly from the stump wound or from another anatomical site. The end of each transected peripheral

Table 4

Results of prevention and treatment of late local post-amputation complications (occurrence of symptomatic post-amputation neuromas, PLP, RLP)

Author, year, country	Flynn criterion, %				Summary (compared to traditional amputation)
	E	G	S	US	
C. S. Best et al., 2024, USA [4]	91.2 (RPNI) 7.1 (TA)	5.4 (RPNI) 5.3 (TA)	2.2 (RPNI) 16.2 (TA)	1.2 (RPNI) 71.4 (TA)	RPNI provides a reduction in the incidence of both symptomatic neuromas and phantom limb pain
C. A. Kubiak et al., 2021, USA [15]	93.2 (RPNI) 2.3 (TA)	5.2 (RPNI) 17.3 (TA)	1.6 (RPNI) 12.1 (TA)	— 68.3 (TA)	RPNI provides a lower incidence of symptomatic neuromas and phantom limb pain
J. B. Bowen et al., 2019, USA [5]	72.4 (TMR) 32.1 (TA)	22.6 (TMR) 58.6 (TA)	5.0 (TMR) 9.3 (TA)	— —	TMR showed better clinical results: the incidence of symptomatic neuromas was reduced, as well as the intensity of phantom pain
Z. Lin et al., 2023, China [17]	81.2 (RPNI) 2.9 (TA)	8.4 (RPNI) 67.3 (TA)	10.4 (RPNI) 22.8 (TA)	— 7.0 (TA)	Pain syndrome (RLP, PLP) NRS and MFPDI scores of patients in the RPNI group were significantly lower
A. L. O'Brien et al., 2022, USA [21]	84.5 (TMR) 3.8 (TA)	14.2 (TMR) 29.1 (TA)	1.3 (TMR) 1.7 (TA)	— 65.4 (TA)	TMR showed better clinical results: PLP severity scores on the NRS scale were lower
V. Suresh et al., 2023, USA [25]	74.1 (VDMT) 15.3 (TA)	22.5 (VDMT) 13.5 (TA)	3.4 (VDMT) 68.4 (TA)	— 2.8 (TA)	VDMT provides a lower incidence of symptomatic neuromas, as well as a reduction in PLP (as measured by the MFPDI scale)

Notes: E — excellent; G — good; S — satisfactory; US — unsatisfactory.

Table 5

Risk of repeat surgical interventions after performing reinnervation surgical techniques (TMR, VDMT, RPNI) and traditional amputation

Author, year, country	Risk of repeated surgical interventions according to the Flynn criterion, %		Summary
	traditional amputation	reinnervation techniques (RPNI, VDMT, TMR)	
C. S. Best et al., 2024, USA [4]	37.2	2.4	Provide a lower risk of re-surgery for late post-amputation complications (symptomatic neuromas)
P. J. Hanwright et al., 2023, USA [11]	27.4	2.6	Leads to a lower risk of reoperation for late post-amputation complications (PLP, RLP)
S. Pejkova et al., 2022, Northern Macedonia [22]	25.1	1.9	Cause a lower risk of re-surgery for late post-amputation complications (symptomatic neuromas)

nerve is implanted into the center of the free muscle graft using 6–0 nonabsorbable suture. RPNI can be performed directly at the time of amputation or as an elective procedure at any time after surgery. The skeletal muscle graft should ideally be approximately 35 mm long, 20 mm wide, and 5 mm thick to ensure survival and prevent central necrosis. Collection can be done using curved Mayo scissors. The end of the transected peripheral nerve should be implanted parallel to the direction of the muscle fibers, and the epineurium should be sutured to the free muscle graft in 1 or 2 places. A single suture should be used to secure the distal end of the epineurium to the middle of the muscle graft bed. It is then wrapped around the nerve in a cylinder with suture fixation. The RPNI should be avoided in the area of the load-bearing surface of the stump. It should be deep in the muscle tissue, away from the subcutaneous tissue and dermis. For large nerves, intraneural dissection into separate structures should be performed to create several (usually 2–4) separate RPNIs to avoid too many regenerating

Table 6

Results of the quality of life index study (PROMIS) after reinnervation surgical techniques (TMR, VDMT, RPNI) and traditional amputation

Author, year, country	Flynn criterion, %				Conclusion
	E	G	S	US	
A. L. O'Brien et al., 2022, USA [21]	74.5* 52.1**	19.3* 2.1**	3.8* 44.8**	2.4* 1.0**	PROMIS scores in patients after reinnervation surgical procedures are higher than those after traditional amputation
M. Byl et al., 2024, USA [6]	72.1* 48.4 **	24.1* 14.9**	1.2* 32.3**	2.6* 4.4**	
M. Diers et al., 2022, USA [8]	83.6* 22.1**	12.4* 24.6**	2.4* 42.3**	1.6* 11.0**	

Notes: E — excellent; G — good; S — satisfactory; US — unsatisfactory; * — reinnervation techniques (RPNI, VDMT, TMR); ** — traditional amputation.

axons in a single free muscle graft. The advantage of RPNI is its technical simplicity and versatility.

Regeneration occurs by direct neurotization of the muscle graft. Given the understanding that neuromas form when regenerating axons lack end organs for reinnervation, any strategy that reduces the number of untargeted axons in the residual limb should help minimize symptomatic neuromas. The use of free muscle grafts offers a large pool of denervated muscle targets for nerve axon regeneration and facilitates the restoration of neuromuscular junctions without compromising denervation of other stump muscles [4].

Because RPNIs are nonvascularized muscle grafts, they must initially survive by diffusion of nutrients from the surrounding wound bed until revascularization. If they are too large to allow sufficient diffusion of nutrients, necrosis will occur. Even when a small muscle graft is placed in an ideal wound bed, some degree of fibrosis and muscle resorption is expected during the healing process. This raises questions about whether RPNI provides a sufficient target to receive all axons regenerating from the peripheral nerve stump, especially when the technique is used on large-caliber nerves. Like RPNI, VDMTs are used to redirect regenerating axons from the transected nerve into the denervated muscle to prevent neuroma formation. By providing a vascularized muscle target that is reinnervated by direct neurotization, VDMT has advantages over other surgical options. Performing VDMT involves first elevating a muscle island on a vascular pedicle in such a way that it is denervated while remaining vascularized. The nerve stump is then implanted into the denervated muscle flap or wrapped around it in a manner similar to RPNI. This technique is similar to RPNI, but unlike the latter, it allows the use of larger muscle grafts without the risk of necrosis. VDMT is essentially vascularized RPNI [25].

TMR is a surgical technique in which peripheral nerve stumps are sutured to the adjacent muscle branch. These nerve transfers provide a pathway for axonal growth, limiting the disorganized regeneration of nerve endings that leads to neuroma formation. This method has also been used to improve control of a bionic prosthesis by increasing the number of independent muscle signals [3, 26].

Targeted sensory reinnervation (TSR) is performed using a similar surgical principle, in which a peripheral sensory nerve stump is sutured to a small cutaneous branch or simply implanted into the subcutaneous fat for "neurogenic capture" of skin receptors. TSR can be used to treat symptomatic neuromas, although this is not its primary purpose. It is mainly used to improve sensory response from the prosthesis. TSR is currently not used more frequently for the treatment and prevention of symptomatic neuromas than other described techniques and requires further research.

According to the results of the study by C. S. Best et al., the RPNI method for the treatment of pain after amputation showed favorable results, with a significant reduction in pain during neuroma and phantom pain syndrome approximately 7 months after surgery. Neuroma pain scores decreased by 71 %, and phantom pain scores on the visual analog scale (VAS) decreased by 53 %.

Prophylactic RPNI is also associated with a significantly lower incidence of symptomatic neuromas (0 vs. 13.3 %) and lower levels of phantom limb pain (51.1 vs. 91.1 %) compared with patients who underwent conventional amputation [4].

In a study of primary and secondary TMR by Z. W. Fulton et al., the majority of patients experienced resolution of neuroma pain (86.2 %) and overall reduction/absence of pain (90.7 %). No differences were found between primary and secondary TMR. Preliminary data suggest that TMR is effective in preventing or treating pain in amputees, whether used in the acute or delayed period [10].

According to V. Suresh et al., published in 2023, of the 9 subjects included in a retrospective study of VDMT, 7 underwent VDMT surgery as a prophylactic measure against neuroma formation, and 2 had symptomatic neuromas treated with VDMT. The mean follow-up period was (5.6 ± 4.1) months. The mean postoperative pain score was 1–2 points on the VAS scale [25]. J. B. Bowen et al. conducted an analysis that included 17 studies, 14 of which evaluated TMR (366 patients) and 3 evaluated RPNI (75 patients). They determined that TMR and RPNI for the treatment of pain reduced neuroma in 75–100 % of patients and phantom limb pain in 45–80% of cases. When TMR or RPNI was performed prophylactically, many patients reported no residual limb pain (48–100%) or phantom limb pain (45–87 %) at follow-up. Complication rates ranged from 13 to 31 %, with delayed wound healing being the most common [5].

Analysis of the results of comparisons of traditional amputation and reinnervation techniques in amputation surgery indicates that the disadvantage of the traditional method is the increased risk of late complications (symptomatic neuromas, phantom and stump pain) [4, 5, 14, 17, 21].

Reinnervation techniques have more advantages for the treatment of PLP and RLP, while allowing patients with amputated limbs to return to daily activities, improve quality of life and increase the duration of use of prostheses without correction. Recent studies in the field of reinnervation techniques demonstrate great potential to set a new standard in amputation surgery [4, 10, 14, 17, 25].

The described reinnervation techniques have a significant impact on prosthetic repair, providing better integration and interaction with the nervous system, which, in turn, increases the functionality, comfort and quality of life of patients. These technologies allow better adaptation to their new living conditions, improve the accuracy of prosthesis control and reduce psychological stress from the loss of a limb.

The presented analysis of literature sources has certain limitations: the observation period in the analyzed studies at the time of writing the article does not exceed 3–4 years, considering that the results obtained may differ from the indicators revealed over a longer period of observation.

Conclusions

The results of scientific studies indicate that reinnervation techniques (RPNI, VDMT, TMR) are clinically more effective compared to traditional amputation. These techniques can be used both for the prevention of late post-amputation complications (symptomatic neuromas, phantom and pain directly in the stump), and for their treatment.

Clinical results based on questionnaire data (PROMIS, VASH, MFPDI, NRS), imaging studies and functional data indicate that reinnervation techniques prevent the development of late post-amputation complications, which lead to a decrease in the frequency of repeated surgical interventions. At the same time, the quality of life index remains consistently high after any of the above reinnervation techniques, in contrast to traditional amputation, which is important for the comfortable integration of the patient into everyday life.

Modern reinnervation techniques used in amputation surgery play an important role in improving the functionality and quality of life of people who have undergone limb amputation, especially when it comes to prosthetic repair.

RPNI, VDMT and TMR allow to reduce the feeling of pain and discomfort directly in the stump, as well as to minimize the level of phantom pain during the use of the prosthesis, because the nerves receive new paths for transmitting impulses, as a result, control over the prosthesis improves, which has a positive psychological effect on patients, as it gives them a feeling of returning to normal life and provides greater independence in everyday activities.

Conflict of interest. The authors declare the absence of a conflict of interest.

Prospects for further research. The direction of the conducted research meets the challenges of today. The use of modern treatment methods allows to improve the quality of life of victims and requires further development, improvement and implementation of reinnervation technologies in amputation surgery.

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METHODS OF REINNERVATION AFTER AMPUTATIONS IN PATIENTS WITH THE CONSEQUENCES OF COMBAT INJURIES (LITERATURE REVIEW)

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Risk factors of recurrence lumbar intervertebral disk herniation after primary endoscopic transforaminal discectomy. Part 1 (literature review)

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Percutaneous endoscopic transforaminal discectomy (PETD) is a minimally invasive technique that improves clinical outcomes. However, limited visibility of the surgical field and the widespread use of endoscopic technology have led to complications after discectomy, among which recurrence of lumbar disc herniation is the main reason for repeated surgical interventions. The aim is to study epidemiological risk factors that potentiate the recurrence of lumbar intervertebral disc herniation after primary percutaneous endoscopic transforaminal discectomy. Methods. The study material is professional articles containing the definition of epidemiological risk factors for recurrence of lumbar disc herniation after primary PETD, for the period 2015–2024. A systematic review of relevant literature sources was performed using the following keywords: "recurrent lumbar disc herniation", «risk factor for recurrent lumbar disc herniation», "minimally invasive lumbar spine surgery", "percutaneous endoscopic lumbar discectomy», "percutaneous endoscopic transforaminal discectomy», "re-discectomy". Results. Research data on the reliability of the relationship between the recurrence of lumbar disc herniation after primary PETD and epidemiological risk factors are contradictory. The most significant among them was older age, ruptures of the annulus fibrosus. Conclusions. The most reliable epidemiological risk factors for rGMD of PVC after primary PETD are age > 50 years, body mass index > 25 kg/m2. The reasonable time for performing primary PETD of lumbar disc herniation from a medical and financial point of view is ≤ 8 weeks from the moment of clinical manifestation of the disease.

Перкутанна ендоскопічна трансфораміналь на дискектомія (ПТЕД) є малоінвазивною методикою, яка дозволяє покращити клінічні результати. Проте обмежений огляд операційного поля й широке застосування ендоскопічної технології призвели до ускладнень після дискектомії, серед яких рецидив грижі міжхребцевого диска (рГМД) поперекового відділу хребта (ПВХ) є основною причиною повторних втручань. Мета. Проаналізувати епідеміологічні фактори ризику, які потенціюють рецидив грижі міжхребцевого диска поперекового відділу хребта після первинної перкутанної ендоскопічної трансфораміналь ної дискектомії. Методи. Розглянуто фахові статті, які містять визначення епідеміологічних факторів ризику рГМД ПВХ після первинної ПТЕД, за період 2015–2024 р. Виконано систематичний огляд релевантних джерел літератури за ключовими словами як українською, так і англійською мовами: «рецидивуюча грижа міжхребцевого диска поперекового відділу хребта», «малоінвазивні хірургічні втручання на поперековому відділі хребта», «перкутанна ендоскопічна поперекова дискектомія», «перкутанна ендоскопічна трансфораміналь на дискектомія», «повторна дискектомія». Результати. Дані досліджень щодо достовірності взаємозв'язку рецидиву грижі міжхребцевого диска поперекового відділу хребта після первинної ПЕТД із епідеміологічними факторами ризику суперечливі. Найбільш значущими серед них виявилися старший вік, порушення цілості фіброзного кільця. Висновки. Найдостовірнішими епідеміологічними факторами ризику рГМД ПВХ після первинної ПЕТД вважаються вік > 50 років, індекс маси тіла > 25 кг/м^2. Доцільним терміном виконання первинної ПЕТД грижі міжхребцевого диска поперекового відділу хребта з медичної та фінансової точки зору є термін ≤ 8 тижнів із моменту клінічної маніфестації захворювання. Ключові слова. Первинна трансфораміналь на ендоскопічна дискектомія, рецидив грижі міжхребцевого диска поперекового відділу хребта, епідеміологічні фактори ризику.

Keywords. Primary transforaminal endoscopic discectomy, recurrence of lumbar intervertebral disc herniation, epidemiological risk factors

Introduction

Percutaneous (complete) endoscopic surgery for lumbar disc herniation using transforaminal or interlaminar approaches is an emerging technique that has taken its place in the current "gold standard" of microsurgical discectomy [1–4]. The use of endoscopic techniques for the removal of lumbar disc herniations (LDH) has been shown to improve clinical outcomes by reducing intraoperative blood loss [5, 6] and postoperative pain intensity with a corresponding reduction in the dose of opioid analgesics after surgery, a shorter recovery period [7] with earlier return to daily activities [8–11] and high patient satisfaction, and relatively low hospital costs [5]. Percutaneous endoscopic transforaminal discectomy (PETD) is considered a minimally invasive procedure because the posterior support structures of the spinal segment remain intact [11, 12].

However, the widespread use of endoscopic technology has led to complications after discectomy, among which recurrence of lumbar disc herniation (rLDH) is the main reason for reoperation [13]. The incidence of rLDH, reaching 5–18 % [14–16], is comparable to the failure rate in open microdiscectomy [11]. The main reason for most recurrences is limited intraoperative access, which may result in the retention of a subligamentous or sequestered component of the LDH, and the difficulty of controlling decompression of neural structures [17–19]. Failure of PETD is also the conversion of endoscopic discectomy into open surgery due to the technical impossibility of transforaminal access. In such cases, the conversion of the operation is most often caused by a structural change in the shape and size of the working area in the area of the intervertebral foramen, which is associated with the peculiarities of the orientation and deformation of the articular processes of the corresponding lumbar segment [20, 21].

A sufficiently high frequency of unsatisfactory PETD results requires the identification of clinical and radiological risk factors for rLDH with more careful selection of patients for transforaminal discectomy, because repeated surgical interventions lead to a deterioration in the clinical outcome with a decrease in the quality of life compared with the consequences of the primary surgical intervention [14], and subsequent significant financial costs (estimated costs: direct — 34,242 US dollars, indirect — 3,778) [22].

Purpose: To study the epidemiological risk factors that potentiate the recurrence of lumbar intervertebral disc herniation after primary percutaneous endoscopic transforaminal discectomy.

Material and Methods

The research material is professional articles that contain definitions of risk factors for recurrent lumbar disc herniation after primary PETD.

The literature search was conducted in the PubMed, Google Scholar and Medline databases for the period 2015–2024 using medical subject headings and keywords "recurrent lumbar disc herniation", "risk factors for recurrent lumbar disc herniation", "minimally invasive lumbar spine surgery", "percutaneous endoscopic lumbar discectomy", "percutaneous endoscopic transforaminal discectomy", "re-operation", "re-discectomy".

An additional search for articles from the bibliographic lists of selected literature sources was also carried out. If necessary, in some cases, sources published outside the search period were used.

Inclusion criteria: articles on risk factors for recurrence of monosegmental LDH after primary PETD. Exclusion criteria: publications on the results of open surgical treatment of herniated intervertebral discs of the lumbar spine, open and endoscopic discectomy of polysegmental and recurrent lumbar disc herniations .

Research method: systematic review of relevant literature sources.

Results and Discussion

Age

There is no single point of view in the literature on the relationship between the age of patients and recurrence of LDH after primary PETD. Some authors define young age of patients as a risk factor for the development of rLDH [23–25]. Other studies have not found a significant difference in age between groups of patients with recurrent disc herniation and uncomplicated postoperative course [14, 26]. Most experts believe that the frequency of recurrence of LDH is positively correlated with age > 50 years [27, 29–31]. Increased risk of rLDH [32] in elderly patients is associated with a decrease in mechanical stiffness of disc tissues due to a combination of involutive and degenerative changes with concomitant loss of part of the gelatinous nucleus, disruption of the integrity of the fibrous ring as a result of disc extrusion. In such biomechanical conditions, in the presence of intraoperative incision of the annulus fibrosus, the intervertebral disc becomes more susceptible to stress loads with the formation of irreversible deformation, which subsequently leads to ineffective healing of the outer layer of the annulus fibrosus after PETD and recurrence of LDH [32].

Gender

The results of studies on the gender effect on the incidence of rLDH also vary widely. Most publications have not found such an effect [14, 29, 31, 33–35]. At the same time, a predisposition to disc recurrence in males has been reported [16, 23, 36]. Some experts identify female gender as a risk factor for rLDH [37]. Interesting results of multivariate logistic regression analysis on the interaction of sex and age are given in the publication by F. Martens et al.: in women under 51 years of age, the risk of recurrent lumbar disc herniation was approximately 10 times higher than in other age groups [38]. The significantly higher frequency of rLDH in young women may be associated with the degradation of type II collagen (the predominant form of collagen in the intact intervertebral disc) with a decrease in the biomechanical properties of the disc under the influence of rapid changes in estrogen concentration, as well as changes in estrogen receptor expression in the premenopausal period [39].

Comorbidity

Increased body mass index (BMI) is a generally accepted risk factor for LDH [19, 25, 30–33, 36, 40–42], although some experts have reported different results [14, 37]. The negative impact of excess body weight on the lower lumbar spinal segments may be due to increased biomechanical loads with cumulative damage to the intervertebral discs [43, 44], especially in the case of abdominal obesity [40]. Overweight (BMI ≥ 25.0–29.9 kg/m^2) and obesity (BMI ≥ 30.0 kg/m^2) increased the absolute risk of LDH by 1.8 and 2.3 times, respectively [40].

Biochemical changes in the intervertebral disc tissues are also possible, associated with a decrease in the level of glycosaminoglycans in the nucleus pulposus [45] and with an increased concentration of leptin. It is a prototypical adipokine produced by adipose tissue [46] and is considered a major biochemical mediator of the inflammatory, degradative, and nociceptive effects of obesity and can be produced by other tissues, including elements of the intervertebral disc [47, 48]. *In vitro* studies have shown that an increase in the level of leptin and its receptors localized in the intervertebral disc can initiate a degenerative and inflammatory cascade through the activation of proteases involved in the degradation of aggrecan and proteases capable of destroying collagen and other matrix macromolecules at the gene and protein levels. In the nucleus pulposus, leptin activated the expression of proinflammatory molecules, especially the cytokines IL-6 and TNF-α [49]. This action of leptin may be of importance in vivo, as it and its receptors have been identified in degeneratively altered areas of the nucleus pulposus [47] and in cells of the annulus fibrosus [48, 50], which themselves produce leptin in the event of degeneration [48].

The results of studies on the relationship between rLDH and diabetes mellitus are contradictory. One group of authors did not find such relationships [13, 23, 27, 29, 37], while other experts consider diabetes mellitus as a risk factor for recurrent disc herniation [28, 51–53]. The possible influence of diabetes mellitus on the formation of rLDH may be due to the limitation of sulfation of glycosaminoglycan molecules [54] and a decrease in the content of proteoglycans [55] in the extracellular matrix of the intervertebral disc, which is accompanied by a weakening of its collagen matrix [54]. Hypertension may increase the frequency of rLDH [33, 56], although other reports deny such a relationship [14, 29, 37]. The specific mechanism linking hypertension to rLDH has not been studied; the assumption of the influence of arterial hypertension per se [56] is made.

Smoking

Active smoking is considered a modified risk factor for rLDH and can lead to an increase in absolute risk by 1.6–2.8 times [40, 57]. The clinical course of LDH in smokers is characterized by a low pain threshold, an increased incidence of postoperative complications, delayed healing of the postoperative wound and a long rehabilitation period, and reduced satisfaction with the results of surgical treatment [57–59].

The mechanisms by which the risk of recurrent disc herniation in active smokers increases are related to the fact that nicotine significantly inhibits diffusion and worsens the trophism of the intervertebral disc due to vasoconstriction of the endplate capillaries and subchondral bone [60]. The vasoconstrictive effect of nicotine can also lead to the suppression of cell proliferation and inhibition of the synthesis of extracellular matrix proteoglycans [61, 62], significantly impairing the rate of cellular absorption and production of metabolites in the disc [62, 63]. Such biochemical changes reduce the absorption capacity of the disc and potentiate the acceleration of degenerative processes [40]. In addition, nicotine inhibits the synthesis of collagen in the annulus fibrosus, which reduces the strength of the annulus and increases the risk of traumatic injuries and degenerative changes [64]. Chronic cough of a smoker can increase intradiscal pressure, which increases the risk of recurrent disc herniation under conditions of reduced mechanical stiffness [57]. At the same time, a number of authors deny the existence of a connection between smoking

and rLDH [37, 65]. It is noteworthy that under conditions of cessation of passive smoking, an increase in the content of mucin proteoglycan in the nucleus pulposus and annulus fibrosus was observed in mice, which reflects the possibility of correcting degenerative changes in the intervertebral disc caused by smoking [66].

Duration of "herniated" follow-up

Performing surgery within ≤ 8 weeks of clinical manifestation of LDH is considered preferable to PETD, which is used in a more distant period [67]. Despite the higher initial financial costs associated with conservative treatment in the acute and subacute periods of the disease, the final costs of surgical treatment in this category of patients are on average less than $11,200 compared to cases of surgical care in later periods. In such patients, additional financial costs are associated with prolonged conservative treatment during the chronic stage of LDH, decreased labor productivity with periodic loss of work capacity [68]. Based on this, it is logical that there is no relationship between rLDH and the duration of "herniated" follow-up in studies in which the average waiting time for PETD was on average 5.5; 7; 30 months. [20, 29, 32].

Conclusions

The most reliable epidemiological risk factors for recurrence of lumbar intervertebral disc herniation after primary PETD include age > 50 years, body mass index > 25 kg/m^2.

The appropriate time for performing primary PETD of lumbar intervertebral disc herniation from a medical and financial point of view is ≤ 8 weeks from the moment of clinical manifestation of the disease.

Conflict of interest. The authors declare the absence of a conflict of interest.

Prospects for further research. An analysis of the literature on the influence of radiological, including radiometric indicators on the frequency of recurrent lumbar intervertebral disc herniations is relevant.

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RISK FACTORS OF RECURRENCE LUMBAR INTERVERTEBRAL DISC HERNIATION AFTER PRIMARY ENDOSCOPIC TRANSFORAMINAL DISCECTOMY. PART 1 (LITERATURE REVIEW)

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Osteoarthritis and geriatric syndromes: features of the relationship and management opportunities (literature review)

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Osteoarthritis (OA) is one of the leading age-associated musculoskeletal disorders, the prevalence of which is increasing due to population aging. The aim of this study is to analyze current literature data regarding the relation and management possibilities of OA and common geriatric syndromes. Methods. A systematic literature review was conducted using analytical methods across scientific databases such as PubMed, Web of Science, Scopus, and Google Scholar for the period 2019–2024. The search was performed using the keywords: "osteoarthritis," "sarcopenia," "sarcopenic obesity," "dysmobility," "malnutrition," and "undernutrition." Results. Typical geriatric syndromes (sarcopenia, sarcopenic obesity, dysmobility syndrome, and malnutrition) are the common phenomenons among OA patients. These conditions share common pathophysiological mechanisms that mutually aggravate each other's course. The analysis of current literature revealed a lack of comprehensive studies on the combination of OA with geriatric syndromes, especially in the Ukrainian scientific space. This article provides an overview and analysis of current scientific data regarding prevalence, risk factors, pathophysiological mechanisms, diagnostic features, clinical manifestations, as well as potential approaches to treatment, prevention, and rehabilitation of patients with OA in combination with the most common geriatric syndromes. Conclusions. The literature analysis demonstrated bidirectional interaction mechanisms between OA and other geriatric syndromes, highlighting the importance of developing effective strategies for early detection, prevention, and management of such patients within a multidisciplinary approach.

Остеоартрит (ОА) є одним із провідних вік-асоційованих захворювань опорно-рухової системи, поширеність якого зростає на фоні старіння населення. Мета. Проаналізувати сучасні літературні дані стосовно взаємозв'язку та можливостей менеджменту ОА та загальновідомих геріатричних синдромів. Методи. Систематичний огляд літературних джерел проведено з використанням інформаційного аналізу наукометричних баз даних PubMed, Web of Science, Scopus та Google Scholar за період 2019–2024 р. Пошук виконували за ключовими словами «остеоартрит», «саркопенія», «саркопенічне ожиріння», «дисмобільність», «недостатнє харчування», «мальнутриція». Результати. Типові геріатричні синдроми (саркопенія, саркопенічне ожиріння, синдром дисмобільності та мальнутриції) є поширеним явищем у хворих з ОА. Вони мають спільні патофізіологічні механізми, які взаємно посилюють перебіг одне одного. Аналіз сучасної літератури виявив недостатню кількість робіт щодо комплексного вивчення поєднання ОА з геріатричними синдромами, особливо в україномовному науковому просторі. У статті наведено огляд та аналіз актуальних наукових даних щодо поширеності, факторів ризику, патогенетичних механізмів виникнення, особливостей діагностики, клінічних проявів, а також потенційних підходів до лікування, профілактики та реабілітації хворих з ОА у поєднанні з розповсюдженими геріатричними синдромами. Висновки. Проведений аналіз літератури продемонстрував двонаправлені механізми взаємодії між ОА й геріатричними синдромами та підкреслив важливість розробки ефективних стратегій раннього виявлення, профілактики та ведення таких пацієнтів у межах мультидисциплінарного підходу. Ключові слова. Остеоартрит, саркопенія, саркопенічне ожиріння, синдром дисмобільності, синдром мальнутриції.

Keywords. Osteoarthritis, sarcopenia, sarcopenic obesity, dysmobility syndrome, malnutrition syndrome

Introduction

Osteoarthritis (OA) is one of the most common age-associated musculoskeletal diseases (MSD), the prevalence of which is constantly increasing, taking into account current trends in global population aging [1]. It affects every third person aged 65 years and older, with a higher incidence among women than men [2]. In European countries, the prevalence of symptomatic OA of the knee joints is from 5.4 to 29.8 %, OA of the hip joints from 0.9 to 9.7 % [3, 4].

Comorbidity is a widespread phenomenon in patients with OA, from 59 to 87 % of patients have at least one concomitant chronic disease, in particular, on average, a patient with OA has 2.6 concomitant diseases of moderate or severe compensation, and 31 % have 5 or more chronic diseases [2].

In older people, OA is often associated with a number of geriatric diseases and conditions, including sarcopenia (SP), sarcopenic obesity (SPO), dysmobility syndrome (DS), and malnutrition. They mutually worsen the overall health of a person, creating a vicious circle: OA causes a decrease or restriction of mobility, which contributes to the development of SP, SPO, and other syndromes, and they, in turn, aggravate OA symptoms, negatively affecting all aspects of daily life. For effective management of such patients, it is necessary to develop diagnostic algorithms that will allow detecting the combination of OA and concomitant geriatric conditions at an early stage. Understanding the relationships between them is key to developing a comprehensive approach to their diagnosis, treatment, and prevention. Unfortunately, the number of works on this issue, including in the Ukrainian-language literature, is limited.

Purpose: to analyze modern literary sources on the relationship and management options of osteoarthritis and common geriatric syndromes.

Material and Methods

An information analysis of literary data (meta-analyses, systematic reviews, experimental and clinical, including randomized controlled and cohort studies) was conducted using the scientific-metric databases PubMed, Web of Science, Scopus and Google Scholar for the period 2019–2024. Key works on the search topic published earlier were not excluded during the review. The search was conducted using the keywords “osteoarthritis”, “sarcopenia”, “sarcopenic obesity”, “dysmobility”, “inadequate nutrition”, “malnutrition”.

Osteoarthritis and sarcopenia

SP is a progressive generalized skeletal muscle disease associated with an increased risk of falls, fractures, impaired motor activity and a high mortality rate. SP leads to a decrease in muscle mass, in particular lean skeletal muscle mass, and muscle function (physical performance) [5].

Recently, the relationship between SP and OA has been actively studied, since both diseases have common development mechanisms and risk factors associated with aging. The frequency of SP among patients with OA according to various studies varies from 4.5 to 45.2 % and, accordingly, is twice as high compared to individuals without OA, and the presence of SP increases the risk of developing OA by 91 % [6–9].

The authors emphasize that SP develops more often in elderly people, especially among those with a history of falls or low physical activity. However, the question remains whether these are two separate and independent diseases that occur in individuals of the same age group or whether, on the contrary, they contribute to and potentiate the progression of each other [9, 12–16].

The main risk factors for the development of OA in individuals with SP are, in particular, age, reduced estrogen levels, and altered body mass index (BMI). On the other hand, decreased muscle strength is a major characteristic of SP and is considered one of the key risk factors for the development of OA. Muscle weakness reduces the stability of the knee joint and can accelerate the degeneration of articular cartilage. Studies in animal models have confirmed this relationship: experimental atrophy of muscles around the knee joint caused degenerative changes in articular cartilage [11, 17].

Irisin protein (IP) may play an important role in the development of SP and OA. It is a sensitive marker of muscle weakness and atrophy and may help predict the development of SP [13]. In 2016, it was first demonstrated that IP levels in synovial fluid and serum of patients with gonarthrosis negatively correlated with disease severity according to the radiological Kellgren-Lawrence criteria, indicating a possible relationship between IP concentration and OA progression. Further experimental studies confirmed that IP expression is reduced in the cartilage tissue of mice with knee OA after anterior cruciate ligament transection, while intra-articular injection of IP in mice resulted in a slowdown of destructive changes in the knee joint [15].

In addition, there are observations that demonstrate a link between IP and the development of SP. A Korean study of 715 individuals aged 18–90 years found that low IP levels were correlated with the presence of SP (males $r = 0.28$; females $r = 0.32$) and with

hand muscle strength measured by dynamometry (males r = 0.22; females r = 0.31) ($p < 0.01$ for all measures). The mean circulating IP level was significantly lower in the SP group compared with the control group, with no changes in body composition. In logistic regression models, the association between serum IP concentration and the presence of SP remained statistically significant even after adjustment for age, sex, and fat mass (FM) (odds ratio (OR) = 0.20; 95 % confidence interval (CI): 0.07–0.60; $p < 0.01$). The predictive values of IP levels for the diagnosis of SP were < 1.0 μg/mL for men and < 1.16 μg/mL for women (area under the operating characteristic curve, AUC) of 0.87 (95 % CI: 0.77–0.99; $p < 0.01$) for men and 0.68 (95 % CI: 0.55–0.81; $p < 0.01$) for women [16].

The mechanisms of action of IP in knee OA are realized through stimulation of chondrogenesis and inhibition of pro-inflammatory signaling pathways. In particular, IP promotes increased expression of cartilage anabolic genes (COL2A1, Aggrecan and SOX9), while simultaneously inhibiting the activity of JNK, p38 MAPK, NF-κB and AKT pathways, which reduces the production of matrix metalloproteinases (MMP-1, MMP-13), pro-inflammatory cytokines (IL-1, IL-6) and iNOS. In addition, IP is able to enhance chondrogenic differentiation by activating the Rap1/PI3K/AKT signaling cascade through the miR-125b-5p microRNA, which indicates its promising application in regenerative therapy of OA [17].

To date, other factors have been studied that significantly increase the risk of OA in patients with SP. In particular, these are smoking (OR = 1.54; 95 % CI: 1.21–1.95; $p < 0.05$), advanced age (> 75 years, OR = 10.6; 95 % CI: 3.7–30.2; $p < 0.05$), low income (OR = 5.4; 95 % CI: 1.4–21.4; $p < 0.05$), reduced Barthel index (< 90 points, OR = 11.0; 95 % CI: 3.5–34.5; $p < 0.05$), falls during the last 12 months (OR = 3.1; 95 % CI: 1.4–6.6; $p < 0.05$), malnutrition (OR = 3.5; 95 % CI: 1.3–9.3; $p < 0.05$), history of acute cerebrovascular accident (OR = 7.5; 95 % CI: 1.3–41.4; $p < 0.05$), vitamin D deficiency (OR = 9.4; 95 % CI: 1.1–82.5; $p < 0.05$) and presence of malignant neoplasms (OR = 4.8; 95 % CI: 1.2–19.5; $p < 0.05$). In contrast, higher education was associated with a reduced risk of SP (OR = 0.85; 95 % CI: 0.74–0.98; $p < 0.05$). Therefore, the analysis of these factors is important for the development of preventive strategies and timely diagnosis of OA in patients with SP [16, 21].

A causal relationship between SP and OA was confirmed by the Mendelian randomization (MR) method. It was proven that a decrease in appendicular fat-free mass (AFM) is associated with an increased risk of developing knee OA (OR = 1.32; 95 % CI: 1.22–1.43; p = 2.07×10–12) and hip OA (OR = 1.18; 95 % CI: 1.10–1.27; p = 2.05×10–6) in patients with SP. In a two-stage MR analysis, it was found that obesity (OB) plays an indirect role in reducing AFM and the development of knee OA (the proportion of the indirect effect is 5.9 %). It has also been found that walking pace is inversely correlated with the risk of developing OA, confirming the role of muscle mass and strength in preventing degenerative changes in the joints [12].

Another two-sample MR analysis confirmed that SP may have a causal effect on the development of OA through changes in muscle structure rather than through decreased muscle strength. However, the evidence for an effect of OA on the development of SP was not statistically significant (OR = 1.08; 95 % CI: 0.89–1.31; p = 0.46) [18]. At the same time, the results of another similar MR analysis established not only a reliable causal effect of SP on the development of OA (AM: HR = 1.10; 95 % CI: 1.05–1.16; handgrip dynamometry: HR = 0.82; 95 % CI: 0.71–0.95; walking speed: HR = 0.34; 95 % CI: 0.20–0.56), but also the effect of OA on the development of SP (AM β = –0.26; 95 % CI: –0.37–0.15; handgrip dynamometry β = –0.06; 95 % CI: –0.10–0.02; walking speed: β = –0.10; 95 % CI: –0.15–0.06) ($p < 0.05$ for all factors) [20].

A study based on data from the US National Health and Nutrition Examination Survey (NHANES) examined the causal relationship between OA and OA. Subgroup analysis showed that the positive association between OA and OA persisted among men and women (46–59 years) with normal BMI (18.5–24.9 kg/m²). MRI findings revealed a causal relationship between right and left hand grip strength and knee OA (OR = 0.67; 95% CI: 0.51–0.88; $p < 0.01$) and (OR = 0.79; 95% CI: 0.61–0.92; p = 0.04) [21].

In a retrospective study of patients undergoing elective knee osteotomy or total knee arthroplasty (TKA), the association between muscle mass (MM) loss and progression of knee OA was investigated. The authors found that the serum creatinine to cystatin C ratio, also known as the CP index, was significantly correlated with skeletal muscle mass. In addition, a positive association was found between the CP index and the functional activity scores of the Knee Society Score (Knee Society Score β = 0.37; p = 0.02), Knee injury and Osteoarthritis Outcome Score (KOOS), Activity of Daily Living Index (β = 0.42; $p < 0.01$), and Oxford Knee Score

(Oxford Knee Score, β = 0.42; p = 0.01). This observation emphasizes the role of reduced body MM for the functional activity of patients with knee OA, and the authors suggest using the above-mentioned index as a marker for determining MM loss in patients with gonarthrosis [10].

Some studies emphasize the role of chronic low-intensity inflammation as a common pathophysiological mechanism of the development of SP and OA. Increased levels of pro-inflammatory cytokines lead to an imbalance between protein synthesis and degradation in muscles and cartilage, which ultimately causes MM loss and cartilage destruction [15, 16].

In addition, a relationship has been established between a decrease in muscle strength and pain in the presence of OA. In a population-based cohort study involving 947 subjects (10.7 years of follow-up), it was found that higher muscle strength is associated with a decrease in pain intensity. Three different pain trajectories were identified: "minimal pain" (53 %), "mild pain" (34 %), and "moderate pain" (13 %). Higher lower limb and knee extensor muscle strength, as well as better muscle quality as measured by two-photon X-ray absorptiometry (DXA), were associated with a reduced risk of pain in the "mild pain" (relative risk (RR) = 0.95; 95 % CI: 0.92–0.98) and "moderate pain" (RR = 0.92; 95 % CI: 0.87–0.96; p < 0.01 for both groups) groups [22].

In another study examining body composition in patients with bilateral knee OA, skeletal muscle mass index (SMMI) was negatively correlated with the functional activity subscale of the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC-F) questionnaire (β = –0.16; 95 % CI: –0.66–0.03), and daily moderate-to-low intensity physical activity was negatively associated with bilateral knee pain (β = –0.80; 95 % CI: –0.10–0.01) [23]. Patients with OA had more severe knee pain and worse functional activity (p < 0.05). In the general group, FM was positively correlated with bilateral knee pain (β = 1.21; 95 % CI: 0.03–0.15), the pain subscale of the questionnaire (β = 0.25; 95 % CI: 0.23–1.22), and WOMAC functional activity (β = 0.28; 95 % CI: 0.35–1.29), as well as the 5-time sit-to-stand test (β = 0.19; 95 % CI: 0.03–0.42) [23]. Hip and knee OA are important predictors of high risk of falls [24–26]. The question arises whether the risk of falls increases in patients with SP and knee OA. The study by Iijima H. et al. [25] assessed the risk of falls in four groups: patients with isolated SP, isolated knee OA, a combination of SP and knee OA, and a control group (no SP or OA) in 291 individuals aged 60–90 years (78.7 % women). Patients with a combination of SP and knee OA had a 4.17-fold higher chance (95 % CI: 0.84–20.6) of recurrent falls (≥ 2 falls) than controls, while no statistically significant differences in the frequency of recurrent falls were found between the groups of patients with isolated SP and isolated knee OA [25]. According to existing studies, the presence of knee OA also affects balance and gait speed, with the results of the 6-minute walk test, sit-stand and stand-and-go tests showing lower performance compared to individuals without OA [24, 27, 28].

SP and OA are often found in patients with other chronic diseases, in particular, type 2 diabetes mellitus (T2DM). The study by S. Basat et al. [29] first revealed the relationship between SP and OA in elderly individuals with concomitant T2DM. Examination of patients included assessment of muscle function, body composition, inflammatory markers and the degree of joint damage. The group of patients with OA and T2DM demonstrated a significant decrease in MM, strength and functional capabilities compared to patients with T2DM without OA disorder. In particular, they observed a significant decrease in albumin and hemoglobin levels, as well as a decrease in shoulder and lower leg circumference.

Correlation analysis confirmed a negative relationship between MM and the severity of OA in patients with type 2 diabetes (r = –0.41; p < 0.05).

Unfortunately, therapeutic options for both OA and SP are limited. A randomized, double-blind, placebo-controlled trial in 124 subjects aged 50–70 years (38.7 % men) with knee OA and SP examined the effects of a high-protein plant-based dietary supplement (32 g) twice daily for 12 weeks. The results demonstrated that plant-based protein supplementation may improve symptoms of stage 1–2 knee OA in subjects with concomitant SP. After 12 weeks, patients receiving the aforementioned supplement showed a significant increase in MM, strength and physical performance, namely SMMI by 10 % (0.66 kg/m^2; 95 % CI: 0.45–0.86; p < 0.0001), muscle strength by handgrip dynamometry by 13.2% (2.83 kg; 95 % CI: 2.13–3.53; p < 0.0001) and physical performance by the Short Physical Performance Battery (SPPB) by 13.2 % (1.03; 95 % CI: 0.69–1.38, p < 0.0001). In addition, there was a 12 % improvement in the overall WOMAC score (3.95 points; 95 % CI: –5.02–2.89, p < 0.0001), as well as in the subscales of pain (by 20.6 %), stiffness (by 21.3 %), and daily activities (by 7.4 %). Quality of life in patients with OA and SP improved by 7.9 % as measured by the World Health Organization Quality of Life Brief Scale [30].

Nowadays, the search for potentially modifiable risk factors that may worsen symptoms or accelerate the progression of these two diseases is important. For example, the knowledge that muscle weakness is associated with knee pain and that exercises aimed at strengthening the quadriceps muscle improve the patient's overall condition by reducing pain intensity is valuable and useful [31].

Summarizing the results of current studies on the relationship between SP and OA, it should be noted that these two conditions share common risk factors and mechanisms for the development of SP, as a disease characterized by a decrease in MM and strength can contribute to the progression of OA by reducing the stability of joint structures and changing the biomechanics of movement. At the same time, pain, stiffness and mobility limitations, which are common symptoms of OA, can accelerate the development of SP by reducing physical activity. Such a bidirectional relationship progressively increases the level of disability among the elderly.

Osteoarthritis and sarcopenic obesity

SPO is a syndrome characterized by a simultaneous decrease in muscle strength and function, i. e. SPO combined with OA [32, 33]. In recent years, more and more studies have appeared in the scientific literature on this syndrome, as it is gaining relevance due to changes in nutrition and a decrease in the level of physical activity of the population. Although SPO and OA are separate diseases, they share common pathophysiological mechanisms and risk factors, including lifestyle characteristics, age-related and hormonal changes, and increased synthesis of pro-inflammatory cytokines and reactive oxygen species. In addition, these two conditions exacerbate the clinical manifestations and consequences of each other, which creates a vicious circle [34].

In the Ukrainian population aged 20–90 years, the frequency of SPO in women reaches 9.8 % and in men 9.6 % [32]. These figures are consistent with global data, where the prevalence varies from 0.8 to 22.3 % in women and from 1.3 to 15.4 % in men [34]. However, in patients with OA, the frequency of SPO is significantly higher and reaches 49.6 %, which is important to consider in the treatment and rehabilitation of patients [35].

A recent meta-analysis, which included 12 studies, found that low SMMI and SPO increase the risk of developing gonarthrosis by 1.36 and 1.78 times, respectively [36]. In addition, SPO is a factor that increases the risk of falls and fractures in elderly people with OA [37, 38].

A review by S. Balogun et al. [39] demonstrates that SPO is more frequently diagnosed in patients with bilateral knee OA compared with unilateral knee OA. In addition, patients with SPO complained of pain more often than patients with SP without OA, but the authors did not record a significant difference in pain intensity between patients with SPO and OA without SP.

The NHANES study [40] found that patients with SPO had a higher incidence of OA (23.4 %), as well as comorbidities such as hypertension (47.8 %) and type 2 diabetes (12.0 %) compared with patients regardless of the presence of SP and OA. In addition, they had increased serum levels of triglycerides (TG), cholesterol, glucose, urea, creatinine and uric acid. Multivariate analysis showed that the TG index can be used to predict the risk of OA in patients with SPO [40].

Recently, the association between OA, SPO and OA without SP in 4,362 postmenopausal women was analyzed. The authors found that SPO is associated with an increased risk of OA (61.49 vs. 41.54 % in individuals without SP and OB, $p < 0.001$) and more severe pain syndrome (39.11 vs. 27.55 %; $p < 0.001$). Patients with SPO had a 20% stronger association with OA and 11% more often complained of knee pain compared to individuals without musculoskeletal diseases. In addition, patients with SPO required joint replacement more often [41].

The increased need for TKA in individuals with SPO and OA is also demonstrated by the results of other studies [42]. In addition, unbalanced nutrition and insufficient nutrient intake are factors that contribute to the development of SP, physical weakness and can negatively affect the results of TKA. A retrospective cohort study of 587 subjects aged 60 years and older examined the effect of SPO and associated factors on the recovery of range of motion after total knee arthroplasty. Patients were divided into three groups: with SPO, OB and without it. Knee flexion range of motion was measured before and after SPO. Patients with OB and SPO had a higher probability of poor recovery compared with the group without OB (for both groups, $p < 0.001$). The SPO group had the highest risk of postoperative complications in the form of low range of motion (adjusted hazard ratio HR = 1.63; $p = 0.03$) [43].

There are currently several mechanisms linking OA and SPO. The first involves the interaction of inflammatory, biomechanical, and metabolic factors. The accumulation of adipose tissue around muscle leads to an increase in the concentration of pro-inflammatory cytokines, which, in turn, accelerate the loss of MM, which causes the development

of joint instability, increased pain, and progression of OA symptoms. Univariate logistic regression analysis revealed that SPO (OR = 6.68; 95 % CI: 4.70–9.49; p < 0.001) and TG index (OR = 1.46; 95 % CI: 1.34–1.59; p < 0.001) are significant independent factors for the development of OA. In addition, the analysis showed that older age (OR = 3.12; 95 % CI: 2.65–3.68, p < 0.001), female gender (OR = 1.87; 95 % CI: 1.58–2.20; p < 0.001), high BMI (OR = 1.04; 95 % CI: 1.02–1.06; p < 0.001), arterial hypertension (OR = 2.16; 95 % CI: 1.85–2.52; p < 0.001), type 2 diabetes (OR = 1.92; 95 % CI: 1.58–2.33; p < 0.001) and smoking at the time of examination (OR = 1.37; 95 % CI: 1.16–1.62; p < 0.001) were also significant risk factors for OA [40].

Literature data indicate that a decrease in AFM in combination with an increase in FM contributes to increased joint load, the development of chronic inflammation and degenerative-dystrophic changes in cartilage tissue. In a study by J. N. Chopp-Hurley et al. [44] analyzed the characteristics of nutrition and physical activity in individuals with different forms of OA and found that low physical activity and insufficient fiber intake were associated with an increased risk of OA, although they were not related to total body weight. Given that dietary interventions demonstrated a simultaneous decrease in both AFM and FM, the results emphasize the importance of analyzing body composition, not just body weight, to determine the effectiveness of diet and physical activity in OA. At the same time, intensive water exercises with resistance for OA reduced FM and contributed to the improvement of walking speed after a 4-month intervention period.

In summary, current literature data indicate that a decrease in MM combined with an increase in FM leads to increased load on the joints, the development of chronic inflammatory processes and acceleration of degenerative-dystrophic changes in cartilage tissue. The results obtained demonstrate that patients with SPO have more pronounced symptoms of OA, more often require TKA and recover worse after surgical intervention.

Osteoarthritis and Dysmobility Syndrome

DS is a condition that combines several factors that cause functional disorders and increase the risk of developing musculoskeletal complications, including: osteoporosis (OP), SP and SPO. This term was first proposed by Professor N. Binkley and colleagues in 2013, who defined DS as the presence of three or more of the following six criteria in a person: 1) bone mineral density (BMD) of the lumbar spine, femoral neck, or proximal femur ≤ –2.5 standard deviations; 2) BMI ≤ 7.26 kg/m² in men and 5.45 in women; 3) body fat content > 30% in men and > 40 in women; 4) walking speed < 1 m/s; 5) hand muscle strength (dynamometry) < 30 kg in men and < 20 in women; 6) the presence of one or more falls in the last 12 months. These criteria allow for a comprehensive assessment of the patient's condition and identify risks associated with DS. This approach is not new, the use of a combination of factors associated with adverse health outcomes is widely accepted in clinical practice, for example in the case of metabolic syndrome [38, 45, 46].

The prevalence of DS according to various authors ranges from 3.9 to 54.1 % [37, 46–48]. At the same time, it was found that this indicator is higher in urban populations compared to rural residents (31.6 vs. 27.9 %, respectively). A similar trend was recorded for comorbid pathology in the form of a combination of SP and DS (32.6 in the urban cohort vs. 28.4 % in the rural cohort) [49]. Risk factors for DS development include female gender, advanced age, history of falls and fractures, including osteoporotic fractures, SP, osteopenia and OP, presence of chronic diseases, OA, metabolic syndrome or its individual components (e. g., obesity, hypertension, dyslipidemia), low physical activity and excessive alcohol consumption. These factors may interact with each other, increasing the risk of developing DS and its associated complications [46, 48].

Insufficient physical activity is one of the pathogenic factors for the development of DS. Thus, a study involving 375 people aged 60–97 years found that insufficiently active people were approximately 2 times more likely to develop DS (95 % CI: 1.14–3.79; p < 0.05), regardless of BMI, smoking, and ethnicity [47].

In their study, N. Hong et al. [49] assessed jump power in residents of the USA and South Korea as a predictor of SP, DS, or their combination. The jump with the maximum height was selected for analysis with subsequent registration of its peak power (product of force and jump velocity) adjusted for the mass of the subjects (jump power to body weight ratio, W/kg). US participants were more likely to have elevated FM compared to South Korean participants (46.3 % vs. 19.5 %, p < 0.001), while the latter had worse gait speed (43.7 % vs. 11.9 %, p < 0.001) and PD (26.3 % vs. 42.1 %, p < 0.001). This analysis of age- and sex-matched individuals from the two cohorts suggests that jump power values of less than 19.0 W/kg in women and less than 23.8 in men can be used as international cutoffs for identifying individuals with SP and DS. Low power was associated

with an increased risk of developing SP (OR = 4.07), DS (OR = 4.32), or a combination of SP and DS (OR = 4.67, $p < 0.01$ for all measures) regardless of age, sex, height, and ethnicity.

In a study by M. M. Khaleghi et al. [48], which examined the relationship between the distribution of adipose tissue in different parts of the body and the likelihood of developing DS in 2,426 individuals over 60 years of age, it was found that FM and FM to AFM ratio were significantly associated with DS (OR = 1.04; 95 % CI: 1.02–1.05) and (OR = 3.42; 95 % CI: 1.95–5.99, respectively). The accumulation of FM within the trunk was also associated with the development of DS, but had a weaker relationship (OR = 1.02; 95 % CI: 1.00–1.03) and OR = 2.45; (95 % CI: 1.36–4.39, respectively). No statistically significant effect of smoking, excessive alcohol consumption, and the prevalence of chronic diseases on the development of DS was found, but the prevalence of DS was lower among married individuals ($p < 0.001$). In addition, it was proven that height, body weight, BMI, neck, waist, and hip circumferences were significantly lower in individuals with DS compared to individuals without DS. These patients also had a significant decrease in body MM, AFM, and BMD at the level of the lumbar spine and femur. In addition, individuals with DS demonstrated a low level of physical activity (82.6 % were sedentary compared to 69.5 % without DS), had lower physical performance (8.84 % vs. 9.97 %), lower walking speed (0.71 % vs. 1.0 m/s), and lower muscle strength measured by handgrip dynamometry (17.64 % vs. 27.62 kg). The results suggest that screening for body fat distribution in the elderly may be a valuable strategy for early diagnosis of DS and management aimed at preventing disability and improving their quality of life [48].

In their study, W. Sun et al. [37] found that the characteristics of the frequency body mass index (FBMI), which is calculated based on the calculation of the frequency of human body oscillations according to the three-dimensional gait analysis system and BMI of patients aged 60–90 years with DS, which is associated with bone quality, fracture risk, percentage of body fat, SMMI, hand muscle strength and walking speed, HR and 95 % CI for FBMI in the groups without DS and DS were 0.82 (0.74–0.90), respectively. According to the results of ROC analysis, FBMI had a prognostic value for differentiating individuals without DS from patients with DS (AUC = 0.67; $p < 0.05$), with an optimal threshold for prediction of 16.04 (sensitivity = 0.48, specificity = 0.77).

To date, research results demonstrate that the accumulation of adipose tissue (especially in the lower extremities and trunk) and low physical activity are associated with an increased risk of DS in elderly people with OA, thereby increasing pain and mobility limitations. On the other hand, OA promotes the development of muscle atrophy, which in turn accelerates the progression of DS.

Given this, the diagnosis and treatment of DS are important for the prevention of falls and fractures, especially among older people. Preventive measures may include muscle-strengthening exercises, weight control, treatment of OP and other strategies aimed at improving mobility and reducing the risk of injury.

Osteoarthritis and Malnutrition Syndrome

Malnutrition syndrome (MS) is a broad concept that combines both nutrient deficiencies and excesses or imbalances in the intake of proteins, vitamins and trace elements. The prevalence of MS among patients with musculoskeletal diseases varies between 9–39 %, while the average rate among hospitalized patients is 20–50 %. In patients with OA, the frequency of MS is up to 69.5 % [50], while one in five patients does not receive enough nutrients to meet their energy and protein needs. The prevalence of MS increases with age, as well as with an increase in the frequency of comorbid conditions, including OA and SP [51, 52]. MS is correlated with an increased risk of SP, increasing its chances by almost 3 times (OR = 2.99; 95 % CI: 2.40–3.72) [6].

MS is an independent risk factor that negatively affects the clinical outcomes of treatment of somatic and surgical pathologies, reduces the quality of life, disrupts the functional state of the body and limits the autonomy of patients. It is also a reliable and modifiable predictor of postoperative complications and adverse outcomes in orthopedic practice. MS is a well-known cause of increased length of hospital stay and mortality [50–52].

A review of the literature demonstrates a variety of approaches to the diagnosis and confirmation of MS, including anthropometric (mid-upper arm and lower leg circumference, BMI), laboratory (white blood cell count, hemoglobin, total protein, albumin, transferrin) parameters, and standardized nutritional status assessment scales [50, 53, 54]. Each of the above items is scored on a scale from 0 to 3, with age > 70 years considered an additional risk factor (+1 point). A total score ≥ 3 indicates an increased risk of MS. An albumin concentration < 3.5 g/dL is often considered a key marker of MS and has been defined as the “gold standard” in some studies. [50, 53].

In elderly patients, protein deficiency causes a decrease in the level of insulin-like growth factor 1 (IGF-1), the main anabolic regulator of cartilage

homeostasis, which contributes to the development of OA. In an experimental study in rats, the effect of an isocaloric low-protein diet (ILPD) on cartilage and subchondral bone was studied. Morphometric parameters of trabecular and cortical subchondral bone, thickness of hyaline and calcified cartilage, and proteoglycan content were analyzed using micro-computed tomography. After 2 months of the study, a decrease in IGF-1 levels by 18 % ($p < 0.001$) was observed in the ILPD group. The mass of trabecular subchondral bone decreased by 10 % ($p < 0.01$), and the thickness of the cortical plate of the subchondral bone of the medial condyle was reduced by 12 % ($p < 0.05$). A deterioration in the biomechanical properties of hyaline cartilage (strength, elasticity, and work energy) was found, which decreased by 47, 58, and 41 %, respectively ($p < 0.01$). No changes in the content of proteoglycans were recorded. This pattern of cartilage degradation is similar to that observed in the early stages of OA [55].

It is known that MS worsens the course of OA and slows down recovery after surgical interventions for TKA. In particular, insufficient protein intake (less than 1.2–1.5 g/kg body weight) and low energy value of the diet (less than 27–30 kcal/kg body weight) correlate with lower indicators of motor activity of patients according to the results of the Hip disability and osteoarthritis outcome score (HOOS) questionnaire and the short-form health survey (SF-12) after hip arthroplasty, and adherence to the Mediterranean diet is associated with better functional status of joints and higher hemoglobin values ($p < 0.05$) [56].

According to the results of systematic reviews and meta-analyses, in patients with MS who underwent TKA, including for knee or hip OA, an overall increase in the number of complications by 93 % was observed, including: an increase in the duration of hospital stay (according to different authors from 0.3 to 1.7 days), repeated hospitalizations, an increased risk of postoperative complications, in particular sepsis (OR = 2.13; 95 % CI: 1.29–3.51; $p = 0.03$) and acute postoperative infections (OR = 5.9; 95 % CI: 1.32–26.06; $p = 0.02$) [50, 57, 58] The analyzed sources indicate the presence of a close relationship between MS and OA. Insufficient protein in the diet, as well as its reduced calorie content, increases the risk of SP by more than 30 %, which, in turn, accelerates the progression of OA by reducing MM. Patients with a combination of OA and MS have been shown to have slower recovery after surgical interventions and a higher risk of complications. Given these common pathophysiological mechanisms, the need for an integrated approach to the diagnosis, treatment and prevention of MS and OA is important.

Conclusions

OA is a serious medical and social problem that worsens the quality of life of patients, affecting not only the condition of the joints, but is also closely related to other geriatric syndromes, such as SP, SPO, DS and MS. A decrease in muscle mass together with an increase in adipose tissue contributes to the acceleration of degenerative changes in cartilage tissue, the progression of inflammation and impaired biomechanics of movement. Insufficient physical activity and unhealthy diet increase the risk of developing SP, DS and MS, which, in turn, complicate the course of OA. The literature analysis demonstrated bidirectional mechanisms of interaction between these conditions, which emphasizes the importance of early diagnosis and a multidisciplinary approach to the combination of geriatric syndromes.

Conflict of interest. The authors declare no conflict of interest.

Prospects for further research. Conducting prospective cohort studies to determine the frequency of sarcopenia, sarcopenic obesity, dysmobility syndrome and malnutrition in the Ukrainian population both in isolation and in combination with osteoarthritis of various localizations. In addition, the task of developing and validating comprehensive screening algorithms that combine clinical assessment of OA symptoms with the detection of signs of the above-mentioned geriatric syndromes is relevant.

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OSTEOARTHRITIS AND GERIATRIC SYNDROMES: FEATURES OF THE RELATIONSHIP AND MANAGEMENT OPPORTUNITIES
(LITERATURE REVIEW)

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CHRONICLE

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Current issues of modern traumatology and orthopedics

On 11 April 2025, a scientific and practical conference "Current Issues of Modern Traumatology and Orthopedics" was held in Zaporizhzhia, organized by the Zaporizhzhia State Medical and Pharmaceutical University together with the NGO "Zaporizhzhya Regional Association of Orthopedists and Traumatologists".

Professor Maxim Leonidovich Golovakha, head of the NGO "Zaporizhzhya Regional Association of Orthopedists and Traumatologists", opened the conference, emphasizing the importance of exchanging experience in today's challenging conditions.

Oleg Anatolyovich Kostogryz (Kyiv), in his presentation titled "Meniscal suture," provided participants with an overview of current knowledge regarding meniscal anatomy, characteristics of meniscal injuries, as well as suture techniques and their efficacy.

The features of assessing the daily functioning of people with pathologies of the musculoskeletal system were highlighted by Bondaruk Dmitry Oleksandrovych (Dnipro). He investigated the methods of analyzing the functional state of patients with musculoskeletal injuries, taking into account changes in the expert assessment of functioning.

Andriy Oleksandrovych Mametiev (Dnipro) shared an interesting experience. In his report "Reconstructive and restorative surgery of the hand", he outlined the features of performing such operations on the hand in case of combat injuries.

Maksym Oleksandrovych Kozhemyaka (Zaporizhzhya) reported on "A comprehensive approach to pharmacological support of patients with injuries and diseases of the musculoskeletal system", and also considered modern pharmacological strategies for supporting such patients.

Figure. Presenters

Yevhen Mykhailovych Boyko (Zaporizhzhya) shared his experience of replacing bone defects in case of combat injuries. He presented interesting information on the tactics and practical application of various methods of replacing bone defects.

Denys Oleksandrovych Herman (Zaporizhzhya) analyzed the features of the diagnosis and treatment of tourniquet syndrome in his report.

During the presentations, a lively discussion continued, during which the participants exchanged views on the above methods and their application in modern conditions. Professor M. L. Golovakha thanked all those present for their activity and contribution to the development of traumatology (Figure).

The conference became an important platform for professional dialogue, exchange of experience and improvement of approaches to the treatment of traumatological and orthopedic pathologies. The participants noted the high relevance of the topic, especially in the context of working with combat injuries. We would like to express our gratitude to all speakers and listeners for their active participation and fruitful work.

M. L. Golovakha

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To the 100th anniversary of Professor Yuri Yuliyovych Kollontai — memory of the teacher (1925-2025)

8 May 2025 marks the 100th anniversary of the birth of Yuriy Yuliyovych Kolontai, an orthopedic traumatologist, an outstanding scientist, the founder of the Ukrainian school of hand surgery and tendon alloplasty, a laureate of the State Prize of Ukraine, an Honored Inventor of Ukraine, Honorary Chairman of the Dnipropetrovsk Regional Association of Traumatologists and Orthopedists, Head of the Department of Orthopedics and Traumatology of the Dnipropetrovsk Medical Academy (1970–1990), a veteran of World War II, awarded 7 government awards.

Yuriy Yuliyovych was born on 8 May 1925 in the village of Solone, Dnipropetrovsk region, in the family of a doctor and began his career in August 1941, working as a medical orderly in an evacuation hospital. In February 1943 he was drafted into the army and, after graduating from the artillery school, he participated in numerous combat operations. At the age of 19, he became a holder of the Order of the Red Star. In 1951, after graduating from the Dnipropetrovsk Medical Institute (DMI), he was sent to Professor M. I. Sytenko Kharkiv Research Institute of Orthopedics and Traumatology, where, under the leadership of Professor M. P. Novachenko, he went from clinical resident to senior research fellow, chief physician. In 1957, he successfully defended his Candidate thesis “Congenital injuries of the brachial plexus in newborns”.

In August 1962, Yu. Yu. Kolontai was elected to the position of Associate Professor of the Department of Traumatology, Orthopedics and Military Field Surgery of the Military Medical Institute, its head, and later he was re-elected for 20 years.

Significant surgical activity, perseverance and determination allowed him to solve a number of problems of orthopedic and traumatological practice and summarize his experience in the doctoral dissertation “Tendon Homoplasty” (1968).

The professor was a scientist with a wide scientific range, published more than 240 scientific papers of great theoretical and practical significance, 40 patents for inventions and 47 rationalization proposals.

In 1983, the monograph “Open Hand Injuries’ was published under the editorship of Kolontai, and in 1997 “Surgery of Hand Injuries”. These are the first and most detailed manuals on this problem in Ukraine.

On the initiative and with the personal participation of Yuriy Yuliyovych, in 1982 an interregional center, the first specialized department of hand surgery in Ukraine was opened in Dnipropetrovsk. Thanks to his perseverance, an interregional center for tissue preparation and conservation was opened. The professor paid constant and significant attention to the preparation of scientific change, under his leadership 3 doctoral and 10 candidate theses were defended at the department.

Time passes inexorably, but the work, creative ideas and scientific achievements of Yuriy Yuliyovych continue to live, because he managed to form a powerful scientific school, develop traditions, unite his like-minded students into a friendly team that honorably carries and creatively develops the ideas of the teacher.

Every year on May days, according to a long-standing tradition, numerous students, colleagues, and patients of Yuriy Yuliyevich Kolontai gather at the cemetery to honor the bright memory of a man who left a piece of his soul, love, and devotion to the profession in everyone.

ANNIVERSARIES

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Oleksandr Yevgenijovych Loskutov

26 May 2025 marks the 75th anniversary of his birth and 52 years of medical, scientific, pedagogical and public activity of the Head of the Department of Traumatology and Orthopedics of Dnipropetrovsk State Medical University, Academician of the National Academy of Medical Sciences of Ukraine, Doctor of Medical Sciences, Professor, Honored Worker of Science and Technology of Ukraine, Laureate of the State Prize of Ukraine Oleksandr Yevheniyovych Loskutov.

O. E. Loskutov was born on 26 May 1950 in the city of Dnipropetrovsk. Following his graduation from Dnipropetrovsk Medical Institute (now Dnipropetrovsk State Medical University) in 1973, he began his career as a traumatologist. Since 1976, his subsequent scientific, pedagogical, clinical, and public service work has been affiliated with Dnipropetrovsk State Medical University, where he has served as a teacher, associate professor, professor, and, since 1991, as the head of the Department of Traumatology and Orthopedics.

The range of scientific and practical problems of Oleksandr Yevheniyovych was and remains very wide. His candidate's thesis (1982) addressed the subject of multiple fractures and dislocation fractures of foot bones. In his doctoral thesis (1991), he explored treatment approaches for complications and outcomes related to injuries of the supracalcaneal joint. He proposed various methods and technologies of reconstructive, restorative and stabilizing operations of this localization. Truly pioneering is the clinical and biomechanical substantiation of the design of the supracalcaneal joint endoprosthesis that he conducted, which allowed for the first time in world practice to perform its successful cementless endoprosthesis. Addressing the challenges associated with endoprosthesis of this joint established the foundation for subsequent advancements in endoprosthesis for joints in other anatomical locations. On the initiative of Loskutov, based on I. I. Mechnikov Regional Clinical Hospital (Dnipro) in 1991, the first in Ukraine specialized endoprosthetic clinic was opened, and in 1996, a basic course was founded, which trained more than 350 orthopedists from different regions of Ukraine. Having enormous working capacity and a wide range of scientific interests and ideas, Oleksandr Yevheniyovych developed and proposed a series of devices for transosseous osteosynthesis in hand and foot disorders, improved and substantiated original reconstructive and restorative operations in musculoskeletal system defects.

For over four decades, the honouree has been dedicated to advancing the field of domestic endoprosthetics. He is the author of the national program of Ukraine for hip joint endoprosthetic repair, developed and implemented various designs of modular endoprosthetics of the hip, shoulder, elbow joints, hand and foot into industrial production and wide clinical practice. Thanks to these developments, Ukraine became the 8th country in the world to have mastered the production of its own endoprostheses. For his significant contribution to the development of the problem of endoprosthesis, Oleksandr Yevheniyovych was awarded the State Prize of Ukraine in 1996, and in 1998 the title of Honored Worker of Science and Technology of Ukraine. For his significant contribution to the development of the integration of medicine and technical sciences, in 2009, O. Ye. Loskutov was elected Honorary Doctor of the Oles Honchar DNU, and in 2010 Deputy Chairman of the Council of the Dnieper Scientific Center of the NAS of Ukraine. In 2012, Oleksandr Yevheniyovych was a corresponding member, and in 2016 an academician of the NAMS of Ukraine. Oleksandr Yevheniyovych does a lot of public work as a member of the Presidium of the Association of Orthopedists and Traumatologists of Ukraine

and chairman of the Dnipropetrovsk Regional Society of Orthopedists and Traumatologists.

O. Ye. Loskutov is a well-known scientist, a highly qualified orthopedic traumatologist, who possesses a wide arsenal of modern conservative and surgical methods of treating patients with diseases and injuries of the musculoskeletal system. He has personally performed over 15,000 operations of the greatest complexity. Professor O. Ye. Loskutov's international recognition includes his 2008 election as an honorary corresponding member of Germany's Society of Orthopedics and Orthopedic Surgery, as well as honorary professorships at several domestic and foreign universities.

Thanks to his international authority, in 2009 Ukraine was the first of the post-Soviet countries to be elected to the European Federation of National Associations of Orthopedics and Traumatology (EFORT), and O. Ye. Loskutov was elected as a National Delegate to this organization. O. Ye. Loskutov is a highly qualified teacher-educator of orthopedic and traumatology specialists, including those from different countries of the world (Palestine, Jordan, Lebanon, Syria, India, Nigeria, Angola, Sudan, China).

The jubilant is the author of 646 scientific papers, 11 monographs and 39 patents for invention, 22 copyright certificates. Under his leadership, 3 doctoral and 22 candidate theses were completed.

The military operations in the east of our country became a huge tragedy and a serious test for all of Ukraine. The staff of the Department and Clinic of Orthopedics and Traumatology of I. I. Mechnikov Regional Hospital, headed by Academician O. Ye. Loskutov, was involved in providing assistance to patients from the combat zone. The department staff, doctors of the clinic, interns, clinical residents formed 11 mobile traumatology teams to provide assistance to the wounded, centers were formed in Kyiv, Pavlograd, Dnipro, Novomoskovsk. Over the years, the hospital has provided assistance to more than 3,000 wounded, and the orthopedics clinic has operated on more than 700 patients. Starting from May 2014, on the initiative of the academician, together with related and military specialists, numerous scientific and practical conferences on the organization of assistance in the event of combat injuries have been organized and held. Also, Loskutov and the department staff developed standards for material support of assistance in the event of gunshot fractures and other combat injuries of the limbs, introduced tactics of VAC-therapy, organ-preserving and reconstructive-restorative operations.

On his initiative in May 2014 the teaching of military field surgery was resumed at the department for 5th-year students and a series of lectures was given for practicing physicians and interns on the topic of combat and mine-explosive trauma.

The beginning of full-scale aggression in February 2022 was a turning point in the daily work of Oleksandr Yevheniyovych. Since then, all his professional and public activities have been aimed at finding ways to provide and improve assistance to affected citizens and soldiers of the Armed Forces of Ukraine. In the period 2022–2023, he personally participated in the organization and escort of humanitarian convoys from Germany, Austria, and Poland. Previously, the academician carried out active work to involve public organizations of partner countries with the participation of our orthopedic colleagues.

In mid-2023, despite the difficult logistical conditions, Academician O. Ye. Loskutov organized a complete change in the location of the main base of the Department of Traumatology and Orthopedics. In a short time, it received a new face on the basis of the University Hospital of the DSMU. A new infrastructure of the department was built, the logistical base was updated, and educational facilities were renovated.

Without slowing down, at the same time Loskutov continues his active practical activities. He performs surgical interventions, consults military and civilian citizens, establishes and maintains contacts with foreign colleagues. One of the areas of this work was implemented in the organization of technical and methodological support of the prosthetic plant in Dnipropetrovsk region. In close cooperation with the employees of this enterprise, the stages of production of modern limb prostheses were established.

By the example of his daily work, his experience, Oleksandr Yevheniyovych inspires the young generation of interns, future orthopedic traumatologists of Ukraine.

The Department of Traumatology and Orthopedics, the staff of the university hospital, colleagues and students are proud to have worked side by side with Oleksandr Yevheniyovych Loskutov for many years, a scientist whose scientific ideas are continued in the research of his students and followers. We sincerely congratulate the jubilant, wishing him good health, creative inspiration, and inexhaustible energy for new scientific research and victories for the benefit of our flourishing Ukraine!

Association of Orthopedic Traumatologists of Ukraine
Dnipropetrovsk Regional Association of Orthopedic Traumatologists
Staff of the Department of Traumatology and Orthopedics, Dnipropetrovsk State Medical University