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Efficacy Evaluation of Primary Oncological Knee Arthroplasty in Patients with Tumor Involvement of the Distal Femur

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Abstract

The aim of the study was to determine the factors influencing functional outcomes and the likelihood of mechanical and infectious complications in patients with tumor involvement of the distal femur who underwent primary oncological knee arthroplasty.

Methods. We analyzed the treatment results of 227 patients who underwent primary oncological knee arthroplasty for tumor involvement of the distal femur between 2003 and 2018. Functional outcomes were assessed using the MSTS scale at the 12-month follow-up, while mechanical and infectious complications were evaluated according to the ISOLS classification. We also examined the factors affecting these outcomes.

Results. Various types of complications occurred after an average period of 70.5 months in 70 (30.8%) patients: infection (type IV) — 16 cases (7.1%); prosthesis failure (type III) — 13 (5.7%); instability of prosthetic components (type II) — 41 (18.1%). Active drainage did not affect the risk of infectious complications but significantly reduced postoperative hospital stay ($p<0.001$). Patients weighing more than 90 kg had a statistically significant increase in the risk of construct failure ($p = 0.044$). The use of rotating platform prostheses significantly reduced the risk of component failure ($p = 0.016$). When anatomical femoral stems and rotating platform prostheses were used, there was a significant reduction in the risks of component instability ($p<0.001$). The type of fixation did not increase the risk of mechanical complications ($p = 0.860$). Utilization of a thin cement mantle decreased the risk of prosthesis instability by 5.1 times compared to standard cementation techniques, with statistically significant differences in odds ratios. The median function of the knee joint, as measured by the MSTS scale, was 80%. Patients operated through the subvastus approach demonstrated the best joint function ($p<0.001$). At the 60-month follow-up, overall prosthesis survival rates ranged from 80 to 100%. However, at 125 months, the leading prostheses were Stryker (92.9%), MUTARS (71.8%), and Biomet (69.1%).

Conclusions. Rotating-hinge endoprostheses showed optimal performance in reducing the risks of mechanical complications and increasing a construct lifespan. It is essential to use anatomically shaped stems when installing the femoral component. The choice of fixation method does not influence survival rate or stability of the component. It does, however, allow surgeons to take an individualized approach based on the patient's weight, age, and bone condition. The medial subvastus approach offers the most favorable conditions for restoring knee joint function.

Keywords: oncological knee arthroplasty, cemented fixation, cementless fixation, fixed hinge, rotating hinge, surgical approach.

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Оценка эффективности первичного онкологического эндопротезирования коленного сустава при опухолевом поражении дистального отдела бедренной кости

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Реферат

Цель исследования — определить факторы, влияющие на функциональные результаты и вероятность механических и инфекционных осложнений у пациентов с опухолевым поражением дистального отдела бедренной кости, перенесших первичное онкологическое эндопротезирование коленного сустава.

Материал и методы. Выполнен ретроспективный анализ результатов лечения 227 пациентов, которым в период с 2003 по 2018 г. проводилось первичное онкологическое эндопротезирование коленного сустава по поводу опухолевого поражения дистального отдела бедренной кости. Оценивали функциональные результаты по шкале MSTS через 12 мес., механические и инфекционные осложнения по классификации ISOLS, а также факторы, оказывающие на них влияние.

Результаты. Различные виды осложнений со средним сроком их развития 70,5 мес. были выявлены у 70 (30,8%) пациентов: инфекция (тип IV) — 16 (7,1%); разрушение эндопротеза (тип III) — 13 (5,7%); нестабильность компонентов эндопротеза (тип II) — 41 (18,1%). Использование активного дренирования не повлияло на риск развития инфекционных осложнений, но позволило уменьшить послеоперационный койко-день (p<0,001). При весе пациента более 90 кг повышались риски разрушения конструкции (p = 0,044). Использование эндопротезов с ротационной платформой снижало риски разрушения компонентов эндопротеза (p = 0,016). При использовании анатомических бедренных ножек и протезов с ротационной платформой отмечалось значимое снижение рисков формирования нестабильности компонентов (p<0,001). Вид фиксации компонентов не влиял на частоту механических осложнений (p = 0,860). Использование тонкой цементной мантии позволило снизить в 5,1 раза риски развития нестабильности эндопротеза по сравнению со стандартной техникой цементирования, различия шансов были статистически значимыми. Медиана функции коленного сустава по шкале MSTS составила 80%. Наилучшую функцию сустава продемонстрировали пациенты, прооперированные из внутреннего доступа subvastus (p<0,001). На сроке наблюдения 60 мес. общая выживаемость эндопротезов варьировалась от 80 до 100%. Спустя 125 мес. явными лидерами были эндопротезы фирм Stryker (92,9%), MUTARS (71,8%) и Biomet (69,1%).

Заключение. Наименьшие риски механических осложнений и повышение сроков выживаемости конструкции наблюдались при имплантации эндопротезов с наличием ротации в шарнирном механизме. Обязательным правилом установки бедренного компонента следует считать использование ножек анатомической формы. Выбор вида фиксации компонента не влияет на его выживаемость и стабильность, но является опцией, которая дает возможность хирургу осуществлять индивидуальный подход в зависимости от веса, возраста и состояния кости пациента. Наиболее благоприятные условия для восстановления функции коленного сустава обеспечивает использование медиального доступа subvastus.

Ключевые слова: онкологическое эндопротезирование коленного сустава, цементная фиксация, бесцементная фиксация, ротационный шарнир, фиксированный шарнир, хирургический доступ.

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INTRODUCTION

Oncological arthroplasty is the primary surgical method for treating bone tumors of the knee joint. This approach not only allows for tumor removal but also restores joint function and limb weight-bearing capacity [1, 2].

In the early stages of orthopedic oncology, the increasing number of arthroplasties was accompanied by a high rate of oncological complications, as well as challenges related to implant quality, the lack of understanding its optimal design, and the absence of a proven implantation technique. These factors naturally led to a high rate of various complications and controversial functional outcomes [2, 3].

Alongside advances in systemic and pharmacological cancer therapy, the development of new technologies and materials used in modern prostheses has significantly improved the effectiveness and safety of this method [4, 5, 6].

The active development of oncological arthroplasty has led to key advancements in this field, including the implementation of modular systems, the possibility of both cemented and cementless fixation, variations in the length, shape, curvature, and surface texture of the stems, and the refinement of the different types of hinge mechanisms from fully constrained hinge designs to modern rotating prostheses that allow for knee joint rotation, as well as the development of patient-specific components using 3D printing. All these innovations have been developed to increase prosthesis survival and functional outcomes [1, 7, 8, 9].

Among the advantages of the prostheses with a rotating-hinge mechanism are their improved anatomical compatibility, prevention of component instability by lowering the stress at the bone-implant interface, and the relatively low rate of mechanical complications associated with prosthetic failure. Some authors report statistically significantly better functional outcomes in patients who received rotating knee prostheses. However, multi-center studies and meta-analyses generally do not reveal statistically significant differences in prosthetic survival based on the presence of rotating platforms, while fully constrained prostheses are often more cost-effective [4, 10, 11, 12, 13].

The comparison of different fixation methods and their impact on mechanical complication rates and prosthetic survival has shown that, when proper cementation techniques are followed, the rate of complications related to prosthetic instability is comparable to that of cementless fixation. However, many authors note that cementless fixation offers better 10-year survival rates (cemented: 45-75%, cementless: 65-90%) [14, 15, 16, 17, 18].

As the survival rate of oncological knee prostheses has increased, long-term operational characteristics have become more apparent. E. Carlisle et al. have highlighted weak points in prosthetic design that have become evident during extended follow-up. One of such drawbacks is the fracture of GMRS cementless stems with a diameter of 11 mm or less. Consequently, for patients with narrow femoral canals, the authors recommend cemented fixation with a minimal cement mantle thickness as an alternative [19].

The optimal cement mantle thickness for diaphyseal fixation components (stems) remains an open question. Excessive cement mantles are objectively considered a significant risk factor for the instability of oncological knee prosthesis [9]. Many prosthetic manufacturers recommend a thickness of 2-3 mm as a standard, which most surgeons strive to follow. However, Y. Numata et al., in their study on the so-called "French paradox", suggest that an ultrathin cement mantle (≤1 mm) can achieve good prosthetic survival outcomes [20].

Even a stable, structurally intact prosthesis cannot ensure good knee joint function if the patient has a limited range of motion or quadriceps muscle atrophy. These factors inevitably lead to gait disturbances, lameness, increased mechanical stress on the prosthesis, and ultimately reduced implant survival [21].

Despite the growing number of publications on oncological knee prostheses, study results vary significantly. The choice between cemented and cementless fixation, the effectiveness of rotating-hinge mechanisms, and strategies for optimizing postoperative functional recovery still remain relevant questions [22, 23, 24, 25].

To address these issues, we conducted a retrospective study focusing on patients with tumors of the distal femur, as this patient group is at the highest risk for mechanical complications, particularly aseptic prosthetic loosening and failure.

The aim of the study was to identify factors influencing functional outcomes and the probability of mechanical and infectious complications in patients with distal femoral tumors who had undergone primary oncological knee arthroplasty.

METHODS

During 2000-2024 more than 500 primary oncological knee arthroplasties have been performed at our center. Given the long observation period and incomplete data on each patient necessary for study group formation, we established the following *inclusion criteria*:

– patients who underwent operation for the bone tumor of the distal femur (primary benign and malignant tumors, secondary bone metastases);

– a minimum follow-up period of 60 months after the initial surgical treatment;

– availability of complete clinical data necessary for study objectives (diagnosis, prosthesis type, surgical approach, fixation method, and functional outcomes).

Exclusion criteria:

– patients with oncological disease progression in the form of local recurrences or metastatic spread, as the evaluation of these complications was outside the scope of the study;

– patients operated with the use of non-standard techniques or patient-specific prostheses from unknown manufacturers (Vorontsov method with the use of a molded cemented articulating spacer, revision constrained knee prostheses using massive structural allografts);

– patients who received short femoral stems (<10 cm).

We identified five patients with severe knee extension contractures (range of motion limited to 10-20°), classified as Type I complications according to the ISOLS classification [26]. These contractures were caused by improper tibial component positioning or violation of rehabilitation protocols due to individual circumstances. All five patients subsequently underwent revision procedures, including arthrotomy and debridement or tibial tuberosity osteotomy with its proximal transposition. Since these cases showed no correlation between negative outcomes and prosthetic design and were too few for statistical analysis, they were excluded from the study.

A total of 227 patients who underwent primary oncological knee arthroplasty for distal femoral tumors between 2003 and 2018 were included in the retrospective study.

The following parameters were analyzed:

– functional outcomes based on the MSTS score at 12 months [27];

– mechanical and infectious complications according to the ISOLS classification (Type I – soft tissue failure; Type II – aseptic loosening; Type III – structural failure; Type IV – periprosthetic infection; Type V – tumor progression with contamination of prosthesis) [26];

– factors influencing complications: surgical approach, resection extent, patient weight, use of drains, prosthesis model, fixation type, presence of rotating platform, stem shape and diameter.

Knee arthroplasty was performed for various tumor types: 51 cases (22.5%) involved primary malignant neoplasms, 162 cases (71.4%) involved locally aggressive benign tumors, and 14 cases (6.2%) involved secondary metastatic lesions.

Among patients included, 50.2% (n = 114) were female and 49.8% (n = 113) were male. The median follow-up period was 79 months [67.5-99.5], (min – 12, max – 176).

Categorical variables describing the study group are presented in Table 1, while quantitative variables are presented in Table 2.

Patients with cemented fixation components (168 cases, 74%) were divided into two groups based on cementing technique. An ultrathin cement mantle (≤1 mm) was used in 91 cases (54.2%), while the standard technique (2-3 mm mantle) was applied in 77 cases (45.8%). The impact of cement mantle thickness on complication rates and prosthetic survival was assessed.

To evaluate the effect of drains on the risk of infection, a group of 133 patients with rotating-hinge prostheses was analyzed: 48 cases (36.1%) had no active drainage, with only joint aspiration performed, 85 cases (63.9%) had drains left in place for 2-5 days postoperatively.

Table 1

Descriptive statistics for categorical variables of the study group

Variable	Category	Absolute	%	95% CI
Stem shape	Anatomical	183	80.6	74.9-85.5
	Straight	44	19.4	14.5-25.1
Type of fixation	Cementless	59	26.0	20.4-32.2
	Cemented	168	74.0	67.8-79.6
Rotating platform	Absence	67	70.5	64.1-76.3
	Presence	160	29.5	23.7-35.9
Approach	Lateral	62	27.3	21.6-33.6
	Medial parapatellar	94	41.4	34.9-48.1
	Medial subvastus	71	31.3	25.3-37.7

Table 2

Descriptive statistics for quantitative variables of the study group

Variable	Me	Q_1-Q_3	n	min	max
Age, years	45.00	36.00-56.00	227	19.00	82.00
Weight, kg	79.00	72.50-88.00	227	45.00	110.00
Resection extent, cm	14.00	12.00-15.00	227	7.00	28.00
Stem diameter, mm	14.00	13.00-15.00	227	10.00	17.00
Onset time of complications, months	70.50	42.00-93.75	70	12.00	144.00
Postoperative length of hospital stay, d	10	7.00-12.00	133	5	18

When assessing functional outcomes, the type of surgical approach was taken into account: lateral – 62 (27.3%), internal parapatellar – 94 (41.4%), and medial subvastus – 71 (31.3%). Additionally, the limitation of active extension and the range of motion in the knee joint were evaluated.

The following oncological prosthetic systems were implanted: Biomet OSS (121 cases, 53.3%), LINC (20 cases, 8.8%), MUTARS (29 cases, 12.8%), ProSpon (1 case, 0.4%), Stryker (37 cases, 16.3%), and Phoenix (19 cases, 8.4%).

Statistical analysis

Statistical analysis was performed using the Windows OS and the Microsoft Excel and StatTech 4.7.2 (StatTech, Russia) software.

For descriptive statistics, data were presented as percentages. In all groups, the median (Me) was used as the measure of central tendency, while the lower (Q_1) and upper (Q_3) quartiles [25-75% interquartile range] were used as the measure of dispersion. Categorical data were described with absolute values and percentage proportions; 95% confidence intervals (95% CI) for proportions were calculated using the Clopper-Pearson method. The comparison of two groups by a quantitative variable with a non-normal distribution was performed using the Mann-Whitney U test. The comparison of the frequency characteristics of qualitative variables was conducted using nonparametric methods: the χ^2 test, Yates' χ^2 test, and Fisher's exact test. A predictive model describing the dependence of a quantitative variable on factors was developed using linear regression. The direction and strength of the correlation between two quantitative variables were assessed using Spearman's rank correlation coefficient (for non-normally distributed data). Survival analysis was conducted using the Kaplan-Meier estimator. Statistical significance was set at $p<0.05$. To ensure completeness of description and ease of interpretation and comparison, quantitative indicators across different study subgroups were presented in the form of box-and-whisker plots.

RESULTS

Various types of complications, with an average onset time of 70.5 months, were identified in 70 patients (30.8%). Depending on the type of complication, they were distributed as follows: infection (Type IV) – 16 cases (7.1%), with a median onset time of 20.5 months; prosthetic failure (Type III) – 13 cases (5.7%), Me = 71 months; and prosthesis instability (Type II) – 41 cases (18.1%), Me = 84 months.

The analysis of the probability of developing infectious complications did not reveal any significant associations with an oncological diagnosis (p = 0.399), patient age (p = 0.36), resection extent (p = 0.106), the presence of drainage (p = 1.000), prosthesis fixation type (p = 1.000), or the presence of a rotating platform (p = 0.361). The only factor that showed a statistically significant influence on the occurrence of infectious complications was patient weight (p = 0.017).

To assess the discriminatory ability of weight as the predictor of complications, a ROC analysis was performed, with the resulting curve shown in Figure 1.

The analysis of model sensitivity and specificity is presented in Figure 2.

Weight was a statistically significant predictor of infectious complications (AUC = 0.682; 95% CI: 0.531-0.832, p = 0.017). The cut-off point for weight corresponding to the highest Youden index was 81 kg. Infectious complications were predicted for patients with a weight equal to or greater than this threshold. The sensitivity and specificity of the resulting predictive model were 81.2% and 57.3%, respectively.

Although the use of active drainage did not affect the risk of infectious complications, it significantly reduced the postoperative length of hospital stay (p<0.001, Mann-Whitney U test) (Figure 3).

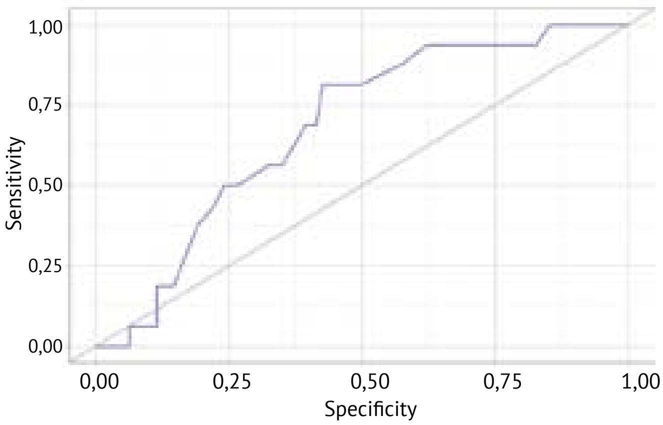

Figure 1. ROC curve characterizing the discriminatory ability of weight in predicting the risks of infectious complications

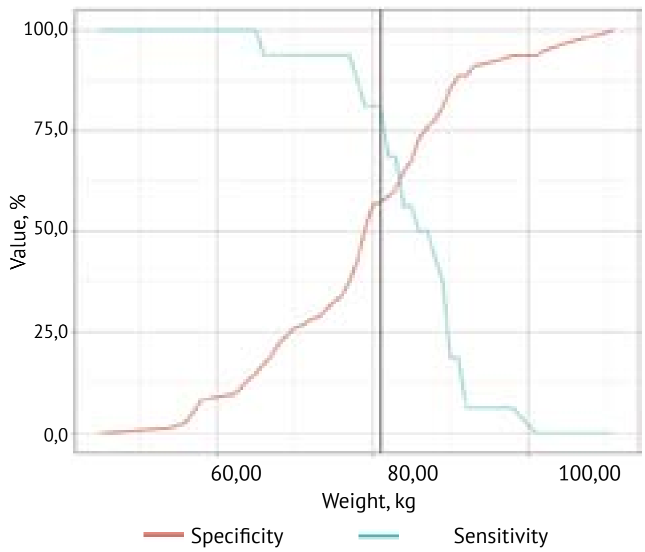

Figure 2. Dependence of sensitivity and specificity of the model on threshold values of estimated probability for complication development

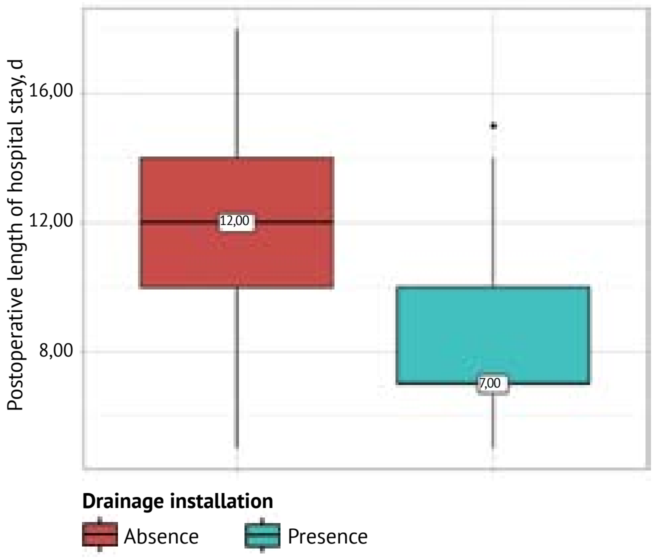

Figure 3. Postoperative length of hospital stay depending on the installation of active drainage

All patients with deep periprosthetic infection underwent two-stage revision knee arthroplasty.

Type III complications, according to the ISOLS classification, included stem fractures in 3 cases and hinge mechanism failure in 10 cases. No bone fractures unrelated to prosthetic component instability were observed in the study group. All cases of bone perforation by prosthetic components were classified as Type II complications.

We analyzed the influence of quantitative and categorical factors on the probability of developing Type III complications. The results are presented in Tables 3 and 4.

According to the obtained data, the risk of complications related to structural failure showed a statistically significant association with patient weight ($p = 0.044$). However, no statistically significant differences were found when comparing the extent of resection and stem diameter ($p = 0.613$ and $p = 0.085$, respectively) (both Mann-Whitney U test).

ROC analysis was performed to assess the discriminatory ability of weight as the predictor of complications, with the resulting curve shown in Figure 4.

Weight was a statistically significant predictor of Type III complications (AUC = 0.668; 95% CI: 0.501-0.834, $p = 0.044$). The cut-off point for weight corresponding to the highest Youden index was 90 kg. Complications of this type were predicted for patients with a weight equal to or greater than this threshold. The sensitivity and specificity of the predictive model were 46.2% and 85.4%, respectively.

Based on the obtained data, the use of prostheses with a rotating platform significantly reduced the risk of prosthetic component failure ($p = 0.016$), whereas the type of fixation did not show statistically significant differences ($p = 0.743$) (Fisher's exact test).

We also analyzed the factors influencing the development of complications associated with component instability (Type II) (Tables 5 and 6).

Table 3

Influence of quantitative factors on the probability of developing Type III complications

Factor	Category	Complications			p
		Me	Q_1-Q_3	n	
Weight, kg	Absence	78.00	69.00-86.00	157	0.044*
	Presence	87.00	74.00-98.00	13	
Resection extent, cm	Absence	14.00	12.00-15.00	157	0.613
	Presence	15.00	10.00-15.00	13	
Stem diameter, mm	Absence	14.00	13.00-15.00	157	0.085
	Presence	14.00	14.00-15.00	13	

* — differences are statistically significant (p<0.05).

Table 4

Influence of categorical factors on the probability of developing Type III complications

Factor	Category	Complications, n (%)		p
		absence	presence	
Rotating platform	Presence	123 (95.3)	6 (4.7)	0.016*
	Absence	34 (82.9)	7 (17.1)	
Type of fixation	Cementless	40 (90.9)	4 (9.1)	0.743
	Cemented	117 (92.9)	9 (7.1)	

* — differences are statistically significant (p<0.05).

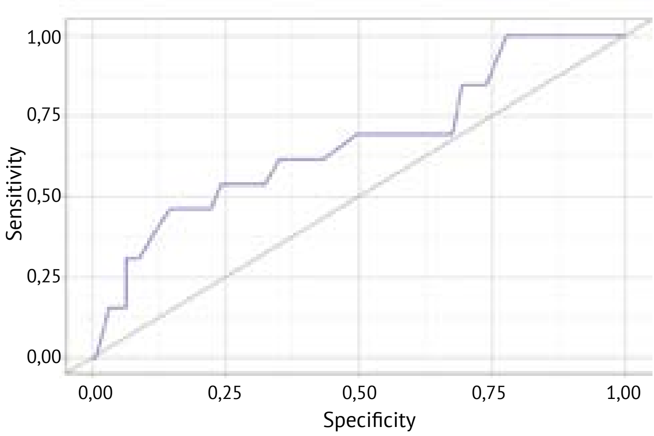

Figure 4. ROC curve characterizing the discriminatory ability of weight in predicting type III complications

Drawing from the presented data, statistically significant differences were observed when anatomical femoral stems and prostheses with a rotating platform were used, both of which reduced the risk of component instability (p<0.001, p<0.001, respectively) (Fisher's exact test, Pearson's χ^2 test). The use of cemented versus cementless fixation did not show statistically significant differences (p = 0.860) (Pearson's χ^2 test).

According to the presented table, statistically significant differences were found when analyzing stem diameter (p<0.001) (Mann-Whitney U test). However, patient weight and the extent of resection did not show statistically significant differences in relation to the presence or absence of Type II complications (p = 0.108, p = 0.657, respectively) (both Mann-Whitney U test).

ROC analysis was performed to assess the discriminatory ability of stem diameter as a predictor of complications, with the resulting curve shown in Figure 5.

Stem diameter was a statistically significant predictor of knee prosthesis instability (AUC = 0.836; 95% CI: 0.778-0.894, p<0.001). The cut-off point for stem diameter corresponding to the highest Youden index was 13 mm. Complications were predicted for stem diameters below this value. The sensitivity and specificity of the resulting predictive model were 65.9% and 98.1%, respectively.

Table 5

Influence of categorical factors on the probability of developing Type II complications

Factor	Category	Complications, n (%)		p
		absence	presence	
Stem shape	Anatomical	154 (92.8)	12 (7.2)	<0.001*
	Straight	3 (9.4)	29 (90.6)	
Rotating platform	Presence	123 (86.0)	20 (14.0)	<0.001*
	Absence	34 (61.8)	21 (38.2)	
Type of fixation	Cementless	40 (78.4)	11 (21.6)	0.860
	Cemented	117 (79.6)	30 (20.4)	

* — differences are statistically significant (p<0.05).

Table 6

Influence of quantitative factors on the probability of developing Type II complications

Factor	Category	Complications			p
		Me	Q_1-Q_3	n	
Weight, kg	Absence	78.00	69.00-86.00	157	0.108
	Presence	83.00	73.00-91.00	41	
Resection extent, cm	Absence	14.00	12.00-15.00	157	0.657
	Presence	14.00	14.00-15.00	41	
Stem diameter, mm	Absence	14.00	13.00-15.00	157	<0.001*
	Presence	12.00	12.00-13.00	41	

* — differences are statistically significant (p<0.05).

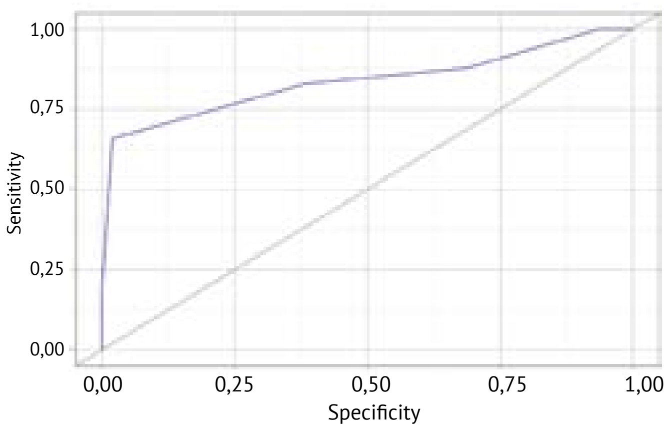

Figure 5. ROC curve characterizing the discriminatory influence of stem diameter on predicting prosthesis instability

To determine the optimal cementing technique for the femoral component, we analyzed the risk of instability based on the use of an ultrathin cement mantle (Figure 6). According to the obtained data, statistically significant differences were identified (p<0.001) (Pearson's χ^2 test).

The odds of complications in the group of patients using the thin mantle technique were 5.1 times lower compared to the group where the standard cementing technique was used. The differences in odds were statistically significant (OR = 0.196; 95% CI: 0.080-0.480).

The median value of knee joint function, assessed using the MSTS questionnaire at 12 months post-surgery, was 80% [76.7-86.7] (min – 67.7%; max – 96.7%). The median range of motion was 90° [90-110] (min – 35°, max – 120°). The limitation of active extension was observed in 61 patients (26.9%).

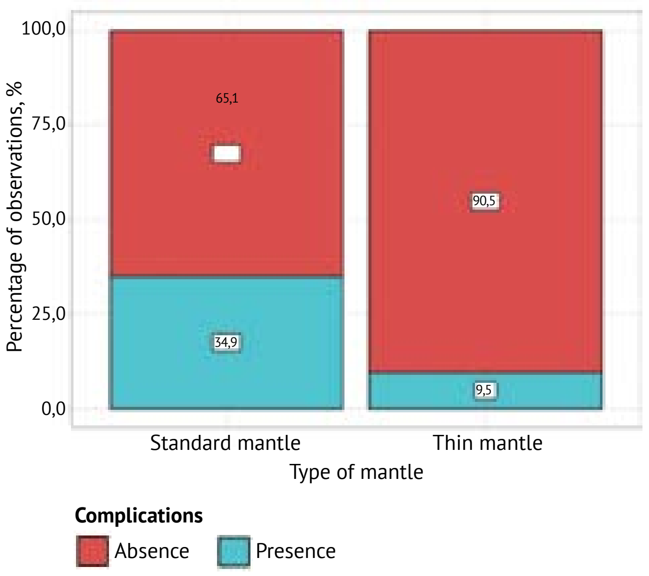

Figure 6. Proportion of type II complications depending on the cement mantle thickness

We analyzed the impact of limited active extension on knee joint function using the MSTS questionnaire (Figure 7). The limitation of active extension significantly reduced knee joint function (p<0.001) (Mann-Whitney U test).

The correlation analysis of the relationship between joint function and range of motion revealed a significant positive correlation. According to our data, for every 1° increase in range of motion, joint function improved by 0.257%. The obtained model explains 34.9% of the observed variance (Figure 8).

When comparing joint function based on the surgical approach, statistically significant differences were found (p<0.001) (Kruskal-Wallis test). The best joint function was observed in patients who underwent operation using the medial subvastus approach (p<0.001). However, it is worth noting that the lateral approach also had a statistically significantly better effect on joint function compared to the medial parapatellar approach (p<0.001) (Figure 9).

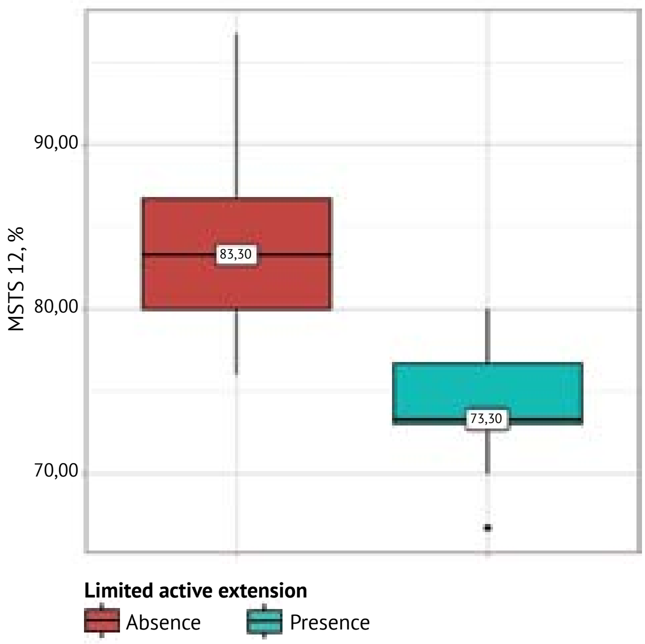

Figure 7. Joint function scores on the MSTS scale depending on the presence of limited active extension

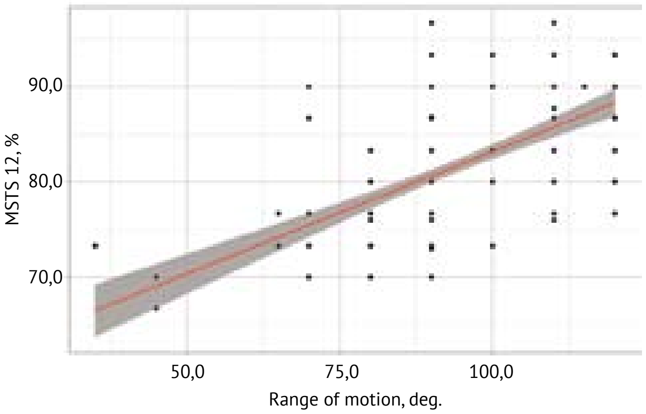

Figure 8. Regression function graph showing the dependence of MSTS scale function on the range of motion at 12 months postop

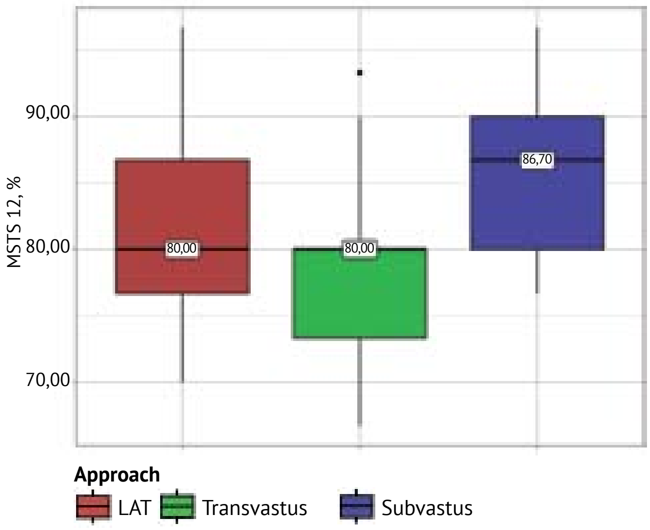

Figure 9. Joint function scores on the MSTS scale depending on the surgical approach

We also identified significant differences when evaluating the impact of the surgical approach on the limitation of active extension and range of motion (Figures 10 and 11).

The use of the medial subvastus approach statistically significantly reduced the probability of the limitation of active extension in the operated knee (p<0.001) (Pearson's χ^2 test).

When assessing the range of motion based on the surgical approach, statistically significant differences were found (p = 0.006) (Kruskal-Wallis test).

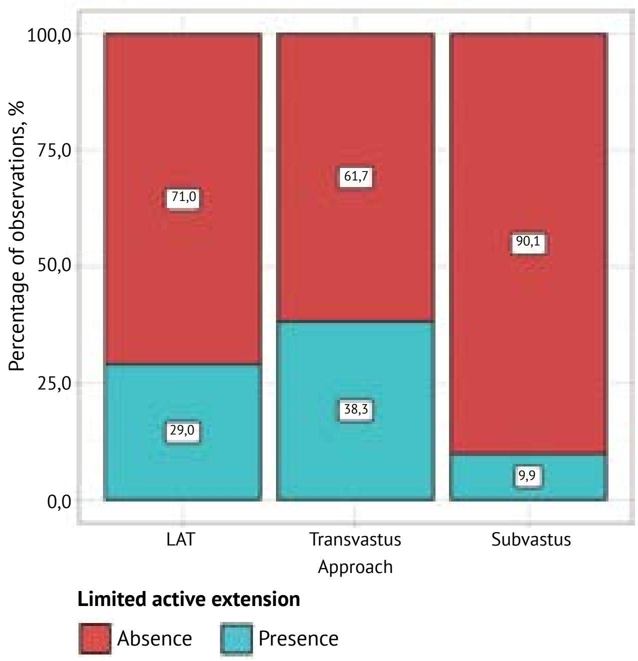

Figure 10. Limitation of active extension depending on the surgical approach

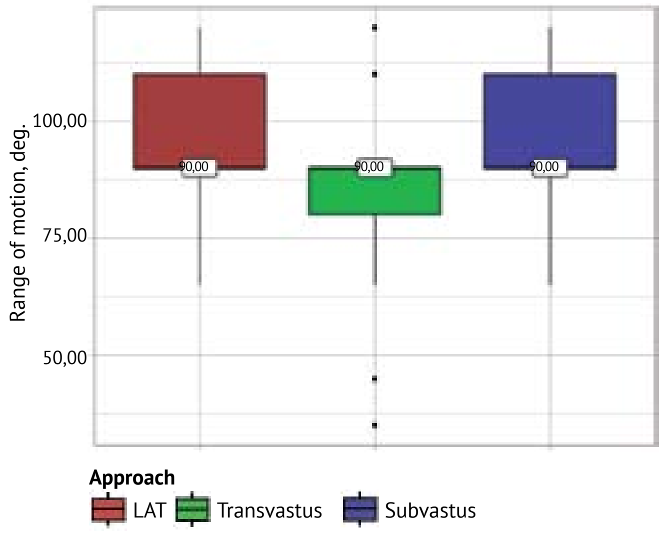

Figure 11. Range of motion depending on the surgical approach

Both the lateral and medial subvastus approaches were more favorable for preserving knee joint range of motion compared to the medial parapatellar approach. However, no statistically significant differences were found between the lateral and medial subvastus approaches (p = 0.952) (Mann-Whitney U test).

An interesting observation was that when performing a comparative analysis of the impact of the lateral and medial subvastus approaches on functional outcomes and the limitation of active extension in the group of patients who underwent surgery with prostheses without a rotating platform, no statistically significant differences were found between the two approaches (p = 0.620) (Mann-Whitney U test) (p = 0.398, respectively) (Fisher's exact test).

The results obtained from the assessment of implant survival based on the presence of a rotating platform, fixation type, and prosthesis model are presented in Figures 12, 13, and 14.

Differences in overall survival, assessed using the likelihood ratio test, were statistically significant (p<0.001).

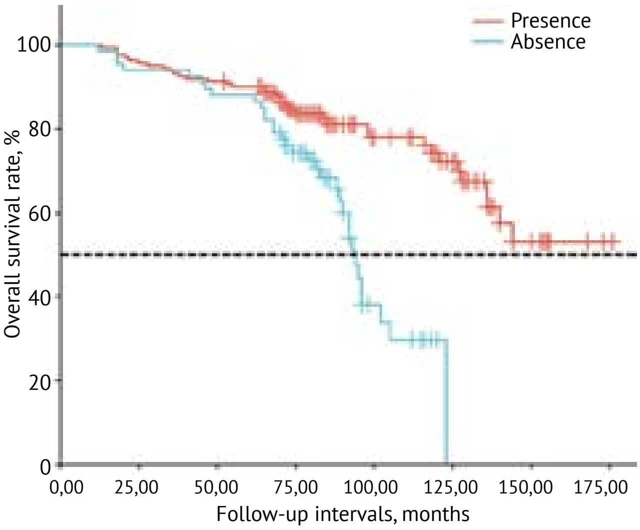

Figure 12. Overall survival curve of endoprostheses depending on the presence of a rotating platform

When evaluating the relationship between overall prosthesis survival and the studied factors using Cox regression, the following proportional hazards model was obtained:

$$h_i(t) = h_0(t) \times \exp(1.092 \times X),$$

where $h_i(t)$ is the predicted instantaneous risk of complication for the *i*-th observation (in %), $h_0(t)$ is the baseline instantaneous risk of complication for a given time t, X represents the absence of rotating platform.

The risk of complications in patients who underwent operation with prostheses without rotating platform was 2.982 times higher (p<0.001).

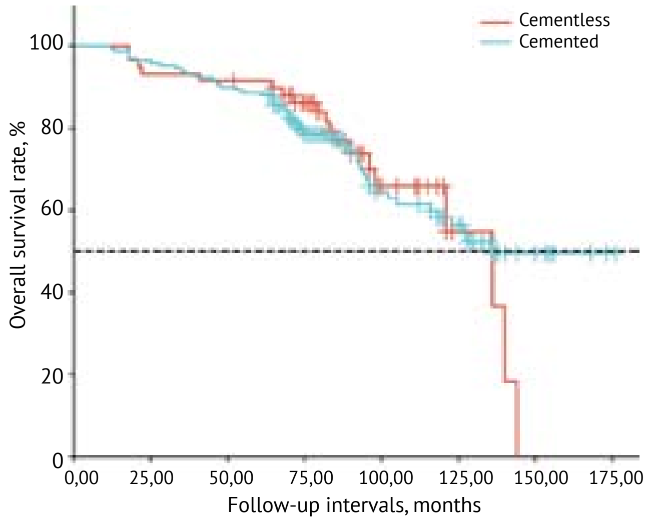

Figure 13. Overall survival curve of endoprostheses depending on the type of fixation (cemented, cementless)

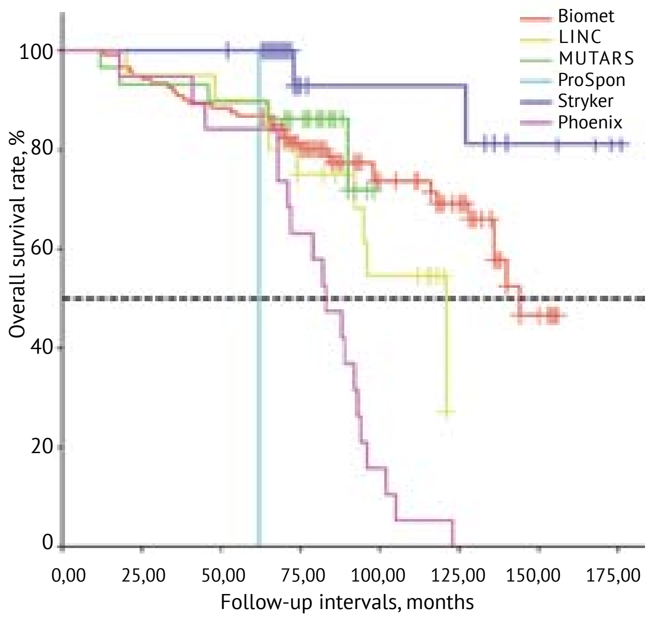

Figure 14. Overall survival curve depending on the manufacturer of endoprosthesis

The analysis showed that the median prosthesis survival time was 136.00 months from the start of observation in both the cementless and cemented fixation groups (95% CI: 98.00-144.00 months and 95% CI: 116.00–∞ months, respectively). No statistically significant differences were found.

All prostheses demonstrated good survival rates at 60 months, ranging from 80 to 100%.

However, at 125 months, the clear leaders were the prostheses from the companies Stryker (92.9%), MUTARS (71.8%), and Biomet (69.1%).

DISCUSSION

According to our data, patient weight had a statistically significant impact on the risk of periprosthetic infections and component failure. A critical threshold was identified at a body weight exceeding 90 kg, which is consistent with the findings of other authors [9]. Therefore, patients should be advised to control their weight in the postoperative period. The use of oncological knee prostheses with a rotating platform in the hinge mechanism significantly influenced several important parameters. We identified a statistically significant reduction in the incidence of Type II ($p<0.001$) and Type III ($p = 0.016$) complications. Additionally, this factor positively affected prosthesis survival ($p<0.001$). Similar results were obtained in a study by G.J. Myers et al. However, in their research, the authors compared the impact of different hinge mechanisms on implant stability and survival using hybrid fixation prostheses, emphasizing this aspect in their conclusions [11]. Such implants were not used in our study.

A noteworthy feature of the Biomet OSS rotating platform is the absence of a bumper preventing hyperextension in the knee joint, which results in increased load on the anterior section of the mobile-bearing insert. Consequently, this leads to accelerated wear, negatively impacting long-term prosthesis survival, its 10-year survival rate, while only slightly lower, was still inferior to that of a modern system without a rotating platform (MUTARS – 71.8% vs Biomet – 69.1%). Similar complications, including bumper (polyethylene bushing) failure in the rotating mechanism of the Zimmer Segmental implant, were noted by I. Barrientos-Ruiz et al., who observed this problem in three patients at mid-term follow-up. Clinically, this presented as excessive knee extension and functional impairment [28].

Based on our results, in addition to the presence of rotating-hinge mechanism, the shape and diameter of the femoral stem significantly influenced prosthesis stability. The implantation of anatomically shaped stems with a diameter greater than 13 mm substantially reduced the risk of Type II complications according to the ISOLS classification. Findings similar to ours were reported by P. Piakong et al., who observed no aseptic loosening in patients with cemented stems of at least 13 mm in diameter, provided the bone resorption area at the component interface did not exceed 20% of the contact surface [25]. However, it is worth noting the study by A.V. Sokolovsky et al., which analyzed data from 1.292 patients and found no correlation between early or late aseptic loosening after primary and revision arthroplasty and stem diameter [9].

An analysis of the impact of the type of fixation (cemented vs cementless) on complication risk showed no statistically significant differences for Type II ($p = 0.860$) or Type III ($p = 0.743$) complications according to the ISOLS classification. Fixation type also did not affect prosthesis survival. These findings are consistent with results from other studies [14, 15, 22].

At the same time, our proposed cementing technique using a thin mantle significantly reduced the risk of prosthesis instability compared to the standard technique ($p<0.001$). The most critical factor in this regard is the pressure exerted by the stem on the cement during insertion into the canal. Thus, the thinner the planned mantle, the greater the pressure on the cement, enhancing its integration into the bone and ensuring even distribution. One more key factor is the safe polymerization temperature, as lower temperatures reduce the risk of osteonecrosis. J.P. Little et al. reported that with a cement mantle thickness of up to 1 mm, the maximum temperature reached only 32.7°C [29].

As expected, limited active knee extension and reduced range of motion significantly affected functional outcomes. We identified a correlation between these limitations and the surgical approach used. The most favorable approach for achieving optimal functional recovery was the medial subvastus approach ($p<0.001$). However, our findings showed no statistically significant difference in functional outcomes between the lateral and medial subvastus approaches in patients with non-rotating platform prostheses, suggesting that both approaches can be effectively used in clinical practice if the prosthesis is appropriately selected. This is particularly important for cases where preoperative biopsy was performed via the lateral approach.

Limitations

The limitation of our retrospective study was the uneven distribution of patients across the groups based on the prosthetic models used. This was due to the inability of a single center to collect data on all implant designs used. Nevertheless, the substantial total number of cases, extended follow-up duration, and completeness of the data, which allowed for an assessment of key aspects such as hinge mechanisms, fixation methods, and surgical techniques, enabled us to address the primary research questions.

CONCLUSIONS

Based on the results of this retrospective study, prostheses with rotating-hinge mechanisms demonstrated optimal performance in terms of reducing mechanical complication risks and extending implant survival. The use of anatomically shaped femoral stems should be considered a mandatory principle of implantation. The choice of fixation method does not impact implant survival or stability but rather serves as an option that allows surgeons to tailor their approach according to the patient's weight, age, and bone condition. The medial subvastus approach provides the best conditions for knee function restoration.

A promising direction for future research in this field is fostering collaboration among leading specialists in our country and performing multicenter studies. Such efforts would facilitate the accumulation of a larger database on the survival and performance characteristics of modern prosthetic models. Based on this knowledge and experience, the development and production of a domestically manufactured oncological knee prosthesis may become feasible.

DISCLAIMERS

Author contribution

Mikailov I.M. — study concept and design, statistical data processing, drafting the manuscript.

Tikhilov R.M. — scientific guidance, editing the manuscript.

Grigoriev P.V. — data analysis and interpretation, editing the manuscript.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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Consent for publication. Not required.

REFERENCES

1. Pala E., Trovarelli G., Angelini A., Maraldi M., Berizzi A., Ruggieri P. Megaprosthesis of the knee in tumor and revision surgery. *Acta Biomed.* 2017;88(2S):129-138. doi: 10.23750/abm.v88i2-S.6523.
2. Heisel C., Kinkel S., Bernd L., Ewerbeck V. Megaprostheses for the treatment of malignant bone tumours of the lower limbs. *Int Orthop.* 2006;30(6):452-457. doi: 10.1007/s00264-006-0207-7.
3. Sokolovskii V.A., Sokolovskii A.V., Tararykova A.A., Fedorova A.V., Bludov A.B. Long-term oncological results of patients with primary and metastatic tumors of the musculoskeletal system who underwent arthroplasty. *Bone and soft tissue sarcomas, tumors of the skin*. 2022;14(4):33-44. (In Russian). doi: 10.17650/2782-3687-2022-14-4-33-44.
4. Pala E., Henderson E.R., Calabrò T., Angelini A., Abati C.N., Trovarelli G. et al. Survival of current production tumor endoprostheses: complications, functional results, and a comparative statistical analysis. *J Surg Oncol.* 2013;108(6):403-408. doi: 10.1002/jso.23414.
5. Henderson E.R., Groundland J.S., Pala E., Dennis J.A., Wooten R., Cheong D. et al. Failure mode classification for tumor endoprostheses: retrospective review of five institutions and a literature review. *J Bone Joint Surg Am.* 2011;93(5):418-429. doi: 10.2106/JBJS.J.00834.
6. Capanna R., Scoccianti G., Frenos F., Vilardi A., Beltrami G., Campanacci D.A. What was the survival of megaprostheses in lower limb reconstructions after tumor resections? *Clin Orthop Relat Res.* 2015;473(3): 820-830. doi: 10.1007/s11999-014-3736-1.
7. Kurilchik A.A., Ivanov V.E., Starodubtsev A.L., Zubarev A.L., Aliev M.D. Types of surgery for cancer treatment using 3D-printed implants. *Bone and soft tissue sarcomas, tumors of the skin*. 2022;14(3):11-19. (In Russian). doi: 10.17650/2219-4614-2022-14-3-11-19.
8. Agaev D.K., Sushentcov E.A., Sofronov D.I., Valiev A.K., Musaev E.R., Khaylenko V.A. et al. The use of computer modeling and 3D-technologies in oncoorthopedia. Literature review. *Bone and soft tissue sarcomas, tumors of the skin*. 2019;11(4):5-16. (In Russian).
9. Sokolovskii A.V., Sokolovskii V.A., Bludov A.B., Fedorova A.V., Agaev D.K., Valiev A.K. Long-term results and modern principles of prevention and treatment patients with endoprosthesis aseptic instability in oncology. *Bone and soft tissue sarcomas, tumors of the skin*. 2022;14(1):11-24. (In Russian). doi: 10.17650/2782-3687-2022-14-1-11-24.

10. Ruggieri P., Mavrogenis A.F., Pala E., Abdel-Mota'al M., Mercuri M. Long term results of fixed-hinge megaprostheses in limb salvage for malignancy. *Knee*. 2012;19(5):543-549. doi: 10.1016/j.knee.2011.08.003.
11. Myers G.J., Abudu A.T., Carter S.R., Tillman R.M., Grimer R.J. Endoprosthetic replacement of the distal femur for bone tumours: long-term results. *J Bone Joint Surg Br*. 2007;89(4):521-526. doi: 10.1302/0301-620X.89B4.18631.
12. Bus M.P., van de Sande M.A., Fiocco M., Schaap G.R., Bramer J.A., Dijkstra P.D. What Are the Long-term Results of MUTARS® Modular Endoprostheses for Reconstruction of Tumor Resection of the Distal Femur and Proximal Tibia? *Clin Orthop Relat Res*. 2017;475(3):708-718. doi: 10.1007/s11999-015-4644-8.
13. Gosheger G., Gebert C., Ahrens H., Streitbuerger A., Winkelmann W., Hardes J. Endoprosthetic reconstruction in 250 patients with sarcoma. *Clin Orthop Relat Res*. 2006;450:164-171. doi: 10.1097/01.blo.0000223978.36831.39.
14. Pala E., Trovarelli G., Calabrò T., Angelini A., Abati C.N., Ruggieri P. Survival of modern knee tumor megaprostheses: failures, functional results, and a comparative statistical analysis. *Clin Orthop Relat Res*. 2015;473(3):891-899. doi: 10.1007/s11999-014-3699-2.
15. Darwich A., Jovanovic A., Dally F.J., Abd El Hai A., Baumgärtner T., Assaf E. et al. Cemented versus Cementless Stem Fixation in Revision Total Knee Arthroplasty: A Systematic Review and Meta-Analysis. *Antibiotics (Basel)*. 2023;12(11):1633. doi: 10.3390/antibiotics12111633.
16. Wang C., Pfitzner T., von Roth P., Mayr H.O., Sostheim M., Hube R. Fixation of stem in revision of total knee arthroplasty: cemented versus cementless – a meta-analysis. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(10):3200-3211. doi: 10.1007/s00167-015-3820-4.
17. Piakong P., Kiatisevi P., Yau R., Trovarelli G., Lam Y.L., Joyce D. et al. What Is the 10-year Survivorship of Cemented Distal Femoral Endoprostheses for Tumor Reconstructions and What Radiographic Features Are Associated with Survival? *Clin Orthop Relat Res*. 2020;478(11):2573-2581. doi: 10.1097/CORR.0000000000001336.
18. Geiger E.J., Arnold M.T., Hart C.M., Greig D., Trikha R., Sekimura T. et al. What Is the Long-term Survivorship of Primary and Revision Cemented Distal Femoral Replacements for Limb Salvage of Patients With Sarcoma? *Clin Orthop Relat Res*. 2023;481(3):460-471. doi: 10.1097/CORR.0000000000002333.
19. Carlisle E., Steadman P., Lowe M., Rowell P., Sommerville S. What Factors Are Associated With Stem Breakage in Distal Femoral Endoprosthetic Replacements Undertaken for Primary Bone Tumors? *Clin Orthop Relat Res*. 2023;481(11):2214-2220. doi: 10.1097/CORR.0000000000002746.
20. Numata Y., Kaneuji A., Kerboull L., Takahashi E., Ichiseki T., Fukui K. et al. Biomechanical behaviour of a French femoral component with thin cement mantle: The 'French paradox' may not be a paradox after all. *Bone Joint Res*. 2018;7(7):485-493. doi: 10.1302/2046-3758.77.BJR-2017-0288.R2.
21. Jover-Jorge N., González-Rojo P., Amaya-Valero J.V., Baixuali-García F., Calva-Ceinós C., Angulo-Sánchez M.Á. et al. Evaluating functional outcomes and quality of life in musculoskeletal tumor patients with distal femoral megaprostheses: a case-control study. *World J Surg Oncol*. 2024;22(1):341. doi: 10.1186/s12957-024-03627-8.
22. Pala E., Mavrogenis A.F., Angelini A., Henderson E.R., Douglas Letson G., Ruggieri P. Cemented versus cementless endoprostheses for lower limb salvage surgery. *J BUON*. 2013;18(2):496-503.
23. Li Y., Sun Y., Shan H.C., Niu X.H. Comparative Analysis of Early Follow-up of Biologic Fixation and Cemented Stem Fixation for Femoral Tumor Prosthesis. *Orthop Surg*. 2019;11(3):451-459. doi: 10.1111/os.12483.
24. Zhang C., Hu J., Zhu K., Cai T., Ma X. Survival, complications and functional outcomes of cemented megaprostheses for high-grade osteosarcoma around the knee. *Int Orthop*. 2018;42(4):927-938. doi: 10.1007/s00264-018-3770-9.
25. Piakong P., Kiatisevi P., Yau R., Trovarelli G., Lam Y.L., Joyce D. et al. What Is the 10-year Survivorship of Cemented Distal Femoral Endoprostheses for Tumor Reconstructions and What Radiographic Features Are Associated with Survival? *Clin Orthop Relat Res*. 2020;478(11):2573-2581. doi: 10.1097/CORR.0000000000001336.
26. Enneking W.F., Dunham W., Gebhardt M.C., Malawer M., Pritchard D.J. A system for the functional evaluation of reconstructive procedures after surgical treatment of tumors of the musculoskeletal system. *Clin Orthop Relat Res*. 1993;(286):241-246.
27. Henderson E.R., O'Connor M.I., Ruggieri P., Windhager R., Funovics P.T., Gibbons C.L. et al. Classification of failure of limb salvage after reconstructive surgery for bone tumours: a modified system Including biological and expandable reconstructions. *Bone Joint J*. 2014;96-B(11):1436-1440. doi: 10.1302/0301-620X.96B11.34747.
28. Barrientos-Ruiz I., Ortiz-Cruz E.J., Peleteiro-Pensado M., Merino-Rueda R. Early Mechanical Failure of a Tumoral Endoprosthesic Rotating Hinge in the Knee: Does Bumper Wear Contribute to Hyperextension Failure? *Clin Orthop Relat Res*. 2019;477(12):2718-2725. doi: 10.1097/CORR.0000000000000949.
29. Little J.P., Gray H.A., Murray D.W., Beard D.J., Gill H.S. Thermal effects of cement mantle thickness for hip resurfacing. *J Arthroplasty*. 2008;23(3):454-458. doi: 10.1016/j.arth.2007.02.015.

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