http://dx.doi.org/10.35630/2199-885X/2021/11/1.14

ENDOPROSTHETIC REPLACEMENT IN PATIENTS WITH TUMORS OF BONES AND JOINTS: REVISION SURGERY

Received 29 December 2020;
Received in revised form 20 January 2021;
Accepted 22 January 2021

***Volodymyr Protsenko*[1]✉, *Oleksandr Burianov*[2], *Obada Bishtawi*[2], *Yevgen Solonitsyn*[2]**

[1] *Institute of Traumatology and Orthopedics of the NAMS Ukraine, Kyiv*
[2] *Bogomolets National Medical University, Kyiv, Ukraine*

✉ *ip15@ukr.net*

ABSTRACT — The article analyzes complications after individual oncological endoprosthesis replacement in tumor lesions of bones and joints, which led to repeated endoprosthesis replacement. After operations of endoprosthesis replacement of bones and joints with tumor lesions, the following complications were observed: periprosthetic infection — 7.4%, aseptic instability of the stem of endoprosthesis —13.1%, destruction of the endoprosthesis structure - 2.3%, wear of polyethylene inserts — 1.7%. Revision endoprosthesis replacement due to complications after endoprosthesis replacement of bones and joints for tumors was performed in 38 (21.7%) cases. Repeated endoprosthesis replacement of knee joint was performed in 22 cases, repeated endoprosthesis replacement of hip joint was performed in 6 cases, repeated endoprosthesis replacement of elbow joint was performed in 4 cases, repeated endoprosthesis replacement of shoulder joint was performed in 3 cases, repeated endoprosthesis replacement of tibial shaft was performed in 2 cases, repeated endoprosthesis replacement of ankle joint was performed in 1 case. The factors that led to complications and repeated endoprosthesis replacement were presented. In case of an infectious complication, it was recommended to install a metal-on-cement *spacer*, followed by repeated endoprosthesis replacement; in case of aseptic instability of the stem of endoprosthesis, repeated endoprosthesis replacement was performed with replacement of only one (loose) component of the endoprosthesis using a long intramedullary nail or replacement of the entire endoprosthesis; in case of the destruction of endoprosthesis structure, the repeated endoprosthesis replacement of the joint was effected with replacement of the entire endoprosthesis structure; when the polyethylene inserts were worn out, the repeated endoprosthesis replacement was performed with the replacement of the polyethylene inserts. After repeated endoprosthesis replacement, repeated revision operations were performed in 10 (26.3%) cases.

KEYWORDS — endoprosthetic replacement of bones and joints, complications, periprosthetic infection, aseptic loosening of the stem of endoprosthesis, destruction of the endoprosthesis structure, wear of polyethylene inserts, repeated endoprosthesis replacement.

INTRODUCTION

Over the past 30–40 years, the progress of onco-orthopedics has allowed to perform organ-sparing operations on the extremities in cases of bone tumors in most circumstances. Nowadays, in 90% of patients with bone tumors, the standard of organ-sparing surgery represents endoprosthesis replacement of joints and bones, which became possible due to the improvement of endoprosthesis replacement systems and surgical techniques of reparative surgery. Endoprosthesis reconstruction in patients with malignant tumors and bony spread improves the quality of life and allows timely giving of chemotherapy treatment cycles [1].

According to the references, this has been facilitated by the success of combined and complex treatment of malignant bone tumors [2, 3, 4]. As a result of endoprosthesis replacement, the development of various complications is possible, which leads to repeated operations in the scope of a revision endoprosthetic replacement. According to various authors, reoperations were performed in 13.68–50% of cases after joint endoprosthesis replacement for bone tumors [4, 5].

Depending on the model of the endoprosthesis, the reasons for revision endoprosthesis replacement included: deep infection in 7.3–17% of cases, aseptic instability in 1–12% of cases, destruction of the endoprosthesis structure in 1.5–10.6% of cases, wear of polyethylene components of the endoprosthesis in 3.1–35.6% of cases. Infectious complications after endoprosthetic reconstruction in oncology patients according to the current information range from 5% to 66% [6, 9, 18]. According to some researchers [7], in general, in reparative surgery on the extremities in patients with bone tumors, infectious complications amounted to 32%, 17% of these patients underwent amputations. According to Myers et al. [18] out of 32 patients with endoprosthesis bed infection, 7 patients underwent primary amputation, and 25 patients underwent a two-stage reoperation, of which 8 patients eventually underwent amputation. According to Capanna et al. [9] in 5% of cases, patients who underwent endoprosthesis replacement were subjected to repeated endoprosthesis replacement. Subsequent analysis revealed that 6% of patients had recurrent infections of the endoprosthesis bed and, accordingly, these patients were subjected to repeated endoprosthesis replacement.

Instability of the stem of endoprosthesis is the second frequent complication of endoprosthesis replacement of bones and joints. In almost half of the cases (44–47%) the cause of the revision operation is the mechanical instability of the implant stem [4, 8, 10]. According to the references, aseptic instability of oncological endoprostheses occurred in 6–27% of cases with a follow-up period of 1 to 15 years [19, 20]. Therefore, complications that occur after bone and joint endoprosthesis replacement performed in bone tumors are a factor that determines the prognosis of survival of endoprostheses and may represent indications for revision endoprosthetic replacement. In turn, revision endoprosthetic replacement has a much higher complication rate than primary endoprosthesis replacement. The need for re-intervention after revision replacement occurs within 5 years in 20–56% of cases [4, 11]. The risk of repeated endoprosthetic replacement according to Myers et al. [18] is 12% amounts to 32% in five years after surgery, 25% to 61% in 10 years, and 30% to 75% in 15 years.

In this article, we analyze the results of joint and bone endoprosthesis replacement in tumor lesions and provide data on the reasons that led to repeated endoprosthesis replacement in this category of patients.

MATHERIALS AND METHODS

During the period from 2009 to 2020, 175 operations of endoprosthesis replacement of bone and joint in cases of bone tumors were performed at the clinic of Institute of Traumatology and Orthopedics of the NAMS Ukraine, Kyiv. Among the patients, there were 96 women (54.9%) and 79 men (45.1%). The mean age of patients was 39.6 ± 1.3 years. Different models of endoprostheses were used: individual oncological endoprostheses, produced by Inmed (Ukraine) in 112 cases, by Beznoska (the Czech Republic) in 5 cases, by Zimmer (USA) in 4 cases, by Prospon (the Czech Republic) in 1 case, and individual modular oncological endoprostheses produced by V. Link (Germany) in 37 cases, by Stryker (USA) in 15 cases, by Implantcast (Germany) in 1 case. The indications for endoprosthetic replacement were: giant cell tumor — 56 cases, osteogenic sarcoma — 47, chondrosarcoma — 27, metastatic tumors — 18, bone fibrosarcoma — 9, giant-cell sarcoma — 6, lymphosarcoma — 3, malignant fibrous histiocytoma of bone — 2, myeloma – 2; adamantinoma — 2, Ewing's sarcoma — 2, fibrous histiocytoma of bone — 1.

Endoprosthetic reconstruction of the knee joint, after resection of the distal femur with a tumor, occurred in 64 (36.6%) patients; of the knee joint, after resection of the proximal tibia, occured in 31 (17.7%) patients; of hip joint, after resection of the proximal femur occured in 24 (13.7%) patients; of shoulder joint, after resection of the proximal humerus, was performed in 24 (13.7%) patients; of elbow joint, after resection of the distal humerus or proximal humerus, was performed in 13 (7.4%) patients; of ankle joint, after resection of the distal tibia, was performed in 6 (3.4%) patients, of humeral diaphysis was performed in 5 (2.9%) patients, of tibial shaft was performed in 4 (2.3%) patients, of femoral shaft was performed in 3 (1.7%) patients, of radial shaft was performed in 1 (0.6%) patient.

Before endoprosthesis replacement, a comprehensive examination of patients was performed, which included both general clinical studies (studies of values of blood, urine, ECG, ultrasound of internal organs, etc.), and X-ray radiological methods of examination. X-ray examination allowed to reveal a tumor of the skeleton, the length of the bone lesion, the malignant invasion in the soft tissues surrounding the bone. Computed tomography allowed to determine the degree of bone destruction, the condition of the bone medullary canal and tumor extension in it. Functional magnetic resonance tomography allowed to assess the soft tissue component of the tumor, the condition of the muscle envelope. Angiography was used to determine the source of blood supply to the tumor, the connection with the great vessels. With the help of osteoscintigraphy tumor lesions in other parts of the skeleton were revealed. Positron emission tomography was used to detect distant metastases in bone and visceral organs.

The morphological examination of the tumor, of course, was the main criterion for examining the patient. The technique of trepan or open tumor biopsy was used to obtain material for histological examination. The scope of surgery consisted of resection of the joint segment or bone segment with an *en block* tumor and replacement of the bone defect with an individual oncological or individual modular oncological endoprosthesis. The functional result of the operated limb was calculated according to the MSTS scale (Musculo-Sceletal Tumor Staging /System/). Quality of life was determined by the EORTC-QLQ-C30 questionnaire. The 10-year survival of endoprostheses was studied using the Kaplan-Meier multiple estimation method. Survival in patients was also assessed by the Kaplan-Meier method.

OBTAINED RESULTS

As a result of endoprosthetic replacement for bone and joint tumors, the following complications were revealed: after resection of the distal femur and knee joint endoprosthesis replacement (64 patients):

aseptic instability of the stem of endoprosthesis occured in 11 (17.2%) patients (Fig. 1), periprosthetic infection occured in 5 (7.8%) patients, destruction of the endoprosthesis structure occured in 2 (3.1%) patients, wear of polyethylene inserts occured in 1 (1.6%) patient.

After resection of the proximal tibia and endoprosthetic replacement of knee joint (31 patients) the following complications were revealed: periprosthetic infection was observed in 4 (12.9%) patients, aseptic instability of the stem of endoprosthesis was observed in 2 (6.5%) patients, destruction of the endoprosthesis structure was observed in 1 (3.2%) patient.

After resection of the proximal femur and endoprosthetic replacement of hip joint (24 patients) the following complications were revealed: aseptic instability of the stem of endoprosthesis was observed in 3 (12.5%) patients, wear of polyethylene inserts was observed in 2 (8.3%) patients, periprosthetic infection was observed in 1 (4.2%) patient (Fig. 2).

After resection of the proximal humerus and endoprosthesis replacement of the shoulder joint (24 patients) the following complications were revealed: aseptic instability of the stem of endoprosthesis was observed in 2 (8.4%) patients (Fig. 3), perirothic infection was observed in 1 (4.2%) patient. After resection of the distal humerus or proximal ulna and elbow joint endoprosthesis replacement (13 patients) the following complications were revealed: aseptic instability of the stem of endoprosthesis was observed in 2 (15.4%) patients, periprosthetic infection was observed in 1 (7.7%) patient, destruction of the endoprosthesis structure was observed in 1 (7.7%) patient. After resection of the distal tibia and ankle joint endoprosthesis replacement (6 patients) the following complications were revealed: aseptic instability of the stem of endoprosthesis was observed in 1 (16.7%) patient, periprosthetic infection was observed in 1 (16.7%) patient. After resection of the tibial shaft and endoprosthesis replacement of the bone defect (4 patients) the following complication was revealed: aseptic instability of stem of the implant was observed in 2 (50%) patients. According to our observations, overweight, which was observed in 9 (30%) cases, and increased patient activity in the post-surgery period, which was observed in 6 (20%) cases, were the main causes of aseptic instability of the stem of endoprosthesis, destruction of the endoprosthesis structure, and destruction of polyethylene inserts. In cases of periprosthetic infection the following measures were taken: non-surgical treatment with application of dialysis and administrations of antibiotics and antiseptics into a joint cavity in combination with systemic antibiotic therapy in 4 patients, surgical sanitation of an endoprosthesis bed in an amount of excision of necrotic and infected tissues with removal of the endoprosthesis and subsequent repeated endoprosthesis replacement after reduction of the infection process (two-stage repeated endoprosthesis replacement) in 7 patients, limb amputation in 1 patient. In case of instability of the stem of endoprosthesis, repeated endoprosthesis replacement was performed in 25 patients, including replacement of the stem of endoprosthesis with a longer one in 17 patients. In case of destruction of the endoprosthesis structure, repeated endoprosthesis replacement with replacement of all the structure of an endoprosthesis in 5 patients was carried out. In case of wear (destruction) of polyethylene inserts, repeated endoprosthesis replacement with replacement of inserts in 3 patients was executed. Repeated endoprosthesis replacement of a knee joint in patients with a tumor of the distal femur was performed in 17 patients, repeated endoprosthesis replacement of a knee joint in patients with a tumor of the proximal tibia was performed in 5 patients, repeated endoprosthesis replacement of a hip joint was performed in 6 patients, repeated endoprosthesis replacement of a shoulder joint was performed in 3 patients, repeated endoprosthesis replacement of an elbow joint was performed in 4 patients, repeated endoprosthesis replacement of an ankle joint was performed in 1 patient, repeated endoprosthesis replacement of tibial shaft was performed in 2 patients. The functional outcome of the operated limb (according to the MSTS scale) amounted to: 75–85% after knee joint endoprosthesis replacement, 70–80% after hip joint endoprosthesis replacement, 65–70% after shoulder joint endoprosthesis replacement, 75–80% after elbow joint endoprosthesis replacement, 70–72% after ankle joint endoprosthesis replacement, 85–90% after femoral shaft endoprosthesis replacement, 80–85% after tibial shaft endoprosthesis replacement, 85–95% after the endoprosthesis replacement of diaphysis of humerus, 96% after the endoprosthesis replacement of diaphysis of ulnar bone.

The functional outcome of the operated limb (according to the MSTS scale) amounted to: 70–80% after knee joint repeated endoprosthesis replacement, 65–75% after hip joint repeated endoprosthesis replacement, 60–65% after shoulder joint repeated endoprosthesis replacement, 70–75% after elbow joint repeated endoprosthesis replacement, 65–67% after ankle joint repeated endoprosthesis replacement, 80–85% after femoral shaft repeated endoprosthesis replacement, 75–80% after tibial shaft repeated endoprosthesis replacement, 80–90% after the repeated endoprosthesis replacement of diaphysis of humerus, 85% after the repeated endoprosthesis replacement of diaphysis of ulnar bone.

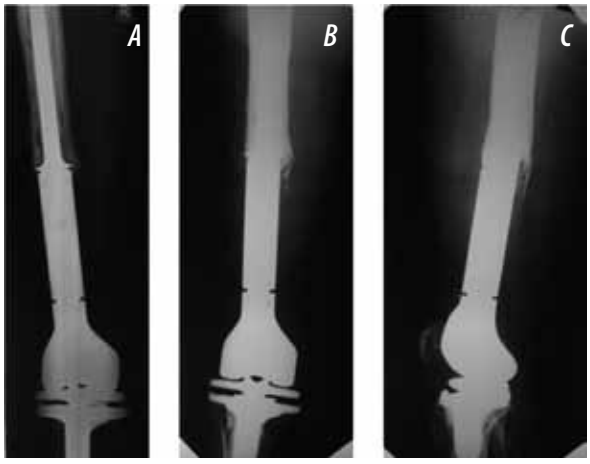

Fig. 1. *A — photoprint of the radiograph of the patient G. — aseptic loosening of the stem of knee joint endoprosthesis, produced by Stryker; B, C — photoprints of radiographs of the patient G. — a state after repeated endoprosthesis replacement of a knee joint*

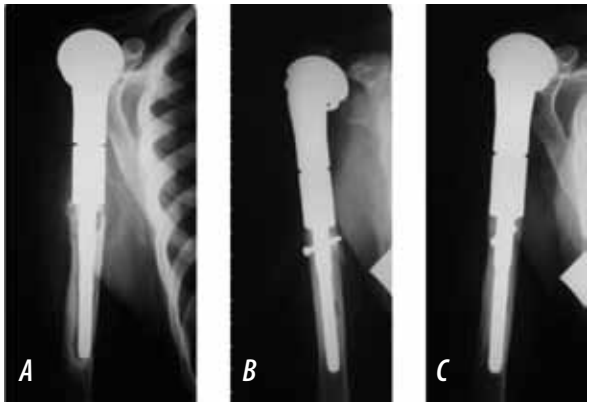

Fig. 3. *A — photoprint of the radiograph of the patient S. — aseptic loosening of the stem of endoprosthesis of the shoulder joint, produced by Inmed; B, C - photoprints of radiographs of the patient S. — a state after repeated endoprosthesis replacement of the shoulder joint with the installation of a anti-rotation screw*

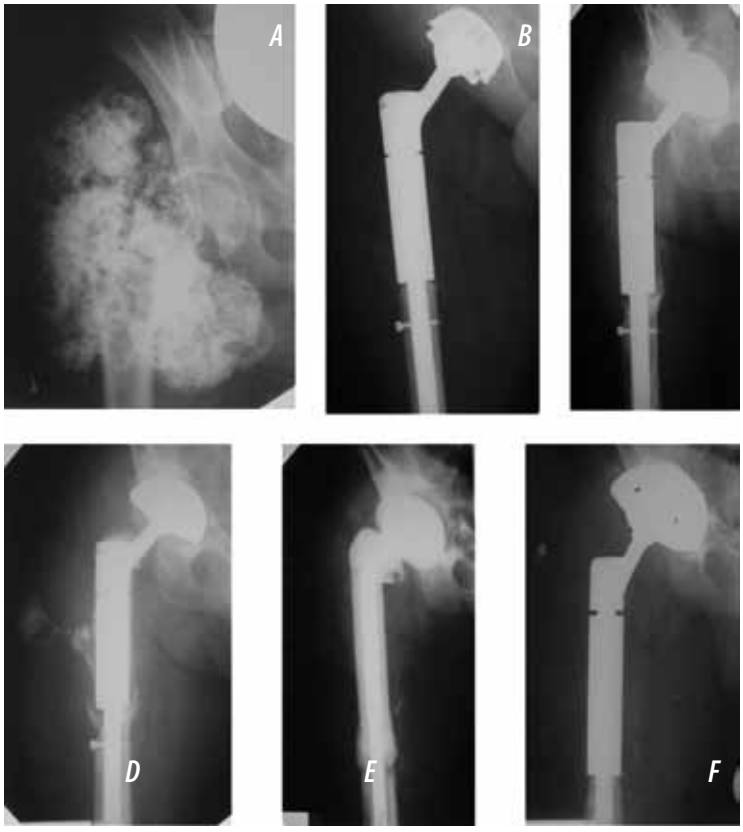

Fig. 2. *A — photoprint of the radiograph of the patient S. — primary chondrosarcoma of the proximal part of right femur; B — photoprint of the radiograph of the patient S. — a state after resection of the proximal femur with a tumor and hip endoprosthesis replacement with an endoprosthesis, produced by Inmed; C — photoprint of the radiograph of the patient S. — a state after repeated endoprosthesis replacement with replacement of the metallopolymer hip joint cup due to loosening of the cup; D — photoprint of the radiograph of the patient S. — periprosthetic infection with fistulous tract; E — photoprint of the radiograph of the patient S. — a state after removal of the endoprosthesis and installation of a metal-on-cement spacer; F — photoprint of the radiograph of the patient S. — a state after repeated endoprosthesis replacement*

The quality of life in patients (EORTC-QLQ-C30 questionnaire) before endoprosthesis replacement amounted to 20–40 points, after endoprosthesis replacement it amounted to 75–80 points, and after repeated endoprosthesis replacement it amounted to 65–75 points. The 10-year survival of the most frequently used endoprostheses in our sampling, calculated by the Kaplan-Meier method, amounted to 75% for Inmed (Ukraine) endoprostheses (70-80%), and 83% for V.Link endoprostheses (Germany) (80–90%), 92% for endoprostheses "Stryker" (USA) (85–95%), taking into account the totality of all revisions.

The overall three-year survival of operated and treated patients amounted to 68.2 ± 2.4%, and the overall five-year survival of operated and treated patients amounted to 51.8 ± 3.2%.

RESULTS AND DISCUSSION

Revision endoprosthesis replacement due to complications after bone and joint endoprosthesis replacement was performed by us in 38/175 (21.7%) cases. After repeated endoprosthesis replacement, repeated revision operations were performed in 10/38 (26.3%) cases.

According to the results, occurrence rate of instability of the stem of endoprosthesis during hip

endoprosthesis replacement was 12.5%, and according to the references, the occurrence rate of instability of the stem of endoprosthesis in patients, who undergone endoprosthesis replacement of the proximal femur ranged from 2.2 to 24.5%, i.e. our indicator was consistent with the data of other researchers [12].

Occurrence rate of instability of the stem of endoprosthesis in endoprosthesis replacement of the distal femur in our study was 17.2%, according to the references it is 6–14%, and in some studies — up to 27% [12], which is also consistents with our results.

Occurrence rate of instability of the stem of endoprosthesis during endoprosthesis replacement of the proximal tibia in our study was 6.5%, and according to the references it ranged from 6 to 27% [19, 20], and in some studies up to 31% [12], which practically coincides with our results.

According to our data, destruction of the endoprosthesis structure ranged from 3.2% to 7.7%, depending on the applied model of the endoprosthesis and the location of the endoprosthesis replacement. Destruction of the endoprosthesis structure (fracture of the stems of endoprosthesis) according to some researchers [13] was observed in 1.8% of cases, according to other researchers [9] in total of 95 cases of endoprosthetic replacement in 6 (6.3%) cases there was a fracture of the stems of endoprosthesis, and according to Myers et al. [18] fracture of the endoprosthesis structure occurred in 2% of cases, respectively, all patients underwent repeated endoprosthesis replacement.

In our study, the occurrence rate of destruction of polyethylene inserts was observed in 1.6% of cases in knee joint endoprosthesis replacement, and in 8.3% in hip endoprosthesis replacement. According to the references [9], destruction of polyethylene inserts amounted to up to 41%, of which in 30% of cases repeated endoprosthesis replacement was performed, and in some studies [5] it ranged from 3.1% to 35.6%. Myers et al. [18] in total of 194 cases of endoprosthesis replacement there are 36 (18.6%) patients with a destruction of polyethylene inserts. It should also be noted that of the 36 patients, who undergone repeated endoprosthesis replacement, in 16 cases a repeated destruction of inserts was reported.

Infectious complications that led to repeated endoprosthesis replacement in our study ranged from 4.2 to 16.7%, and based on the references, infectious complications amounted to 7.2% [16].

After endoprosthesis replacement of the shoulder joint, the complications in our study included the following: aseptic instability of the stem of endoprosthesis in 2 (8.4%) patients, periprosthetic infection in 1 (4.2%) patient. In the references [15], the authors analyze 60 cases of endoprosthesis replacement of shoulder joint, where complications amounted to 32%, repeated endoprosthesis replacement because of aseptic instability was performed in 2 patients (3%), because of infection of the endoprosthesis bed it was performed in 2 (3%) patients, because of shoulder joint instability it was performed in 6 (10%) patients, 3 patients underwent amputation due to tumor recurrence. According to the authors [14] complications of endoprosthesis replacement of the shoulder joint were observed in 60% of cases, including fractures of the endoprosthesis in 7 patients and infectious complications in the bed of the endoprosthesis in 3 patients, repeated endoprosthesis replacement was performed in 10 patients.

The distal part of the humerus was affected in 1% of cases of tumor lesions of the skeleton.

According to our studies, during endoprosthesis replacement of elbow joint in 13 patients, aseptic instability of the stem of endoprosthesis was observed in 2 (15.4%) patients, periprosthetic infection was observed in 1 (7.7%) patient, destruction of the endoprosthesis structure was observed in 1 (7.7%) patient.

The authors [17] report the experience of performing endoprosthesis replacement of the distal humerus in 18 patients, where aseptic instability of the endoprosthesis was observed in 3 (16.6%) patients, local tumor recurrence was observed in 2 (11%) patients, periprosthetic infection was observed in 2 (11%) patients, radial nerve neuritis was observed in 1 (5.5%) patient, fracture of the endoprosthesis structure was observed in 1 (5.5%) patient, due to complications repeated endoprosthesis replacement was performed in 4 cases.

Survival of the endoprosthesis amounted to 78% during monitoring of up to 4.5 years. According to our study, in endoprosthesis replacement of the ankle joint (6 patients), aseptic instability of the stem of endoprosthesis was observed in 1 (16.7%) patient, periprosthetic infection was observed in 1 (16.7%) patient, and according to the references [21], of 9 patients operated for tumors of the distal tibia, complication in the form of periprosthetic infection was observed in 2 (22.2%) patients.

The authors [22] report that out of 280 knee joint endoprosthesis replacement operations for tumor lesions of the distal femur, 52 (18.6%) repeated endoprosthesis replacement operations were performed in this area, of which they were performed in 8 (2.9%) cases due to infection of the endoprosthesis bed, and in 44 (15.7%) cases they were performed due to instability.

According to our studies, during resection of the distal femur and knee joint endoprosthesis replace-

ment, aseptic instability of the stem of endoprosthesis was observed in 11 (17.2%) patients, periprosthetic infection was observed in 5 (7.8%) patients, which is slightly higher than in the above authors. According to the references [22], of 117 primary knee joint endoprosthesis replacement in patients with proximal tibial tumor, repeated endoprosthesis replacement was performed in 32 (27.3%) cases, due to periprosthetic infection repeated endoprosthesis replacement was performed in 13 (11.1%) cases, due to aseptic instability repeated endoprosthesis replacement was performed in 19 (16.2%) cases. According to our data, after resection of the proximal tibia and knee joint endoprosthesis replacement, periprosthetic infection was observed in 4 (12.9%) patients, aseptic instability of the stem of endoprosthesis was observed in 2 (6.5%) patients, which is slightly higher regarding peripheral infection, and much lower regarding aseptic instability of the stem of endoprosthesis. Some researchers [22] report that repeated endoprosthesis replacement was performed in 6 (7.1%) cases out of 84 primary hip endoprosthesis replacement, due to periprosthetic infection in 3 (3.6%) cases, and due to aseptic instability repeated endoprosthesis replacement was performed in 3 (3.6%) cases.

According to our study, after resection of the proximal femur and hip endoprosthesis replacement, aseptic instability of the stem of endoprosthesis was observed in 3 (12.5%) patients, periprosthetic infection was observed in 1 (4.2%) patient, which is higher than the values, provided by the above authors.

In the references [22] the results were reported of 81 endoprosthesis replacement of the shoulder joint, where repeated endoprosthesis replacement was performed in 4 (4.9%) cases, of which due to aseptic instability — in 2 (2.45%) cases, and due to periprosthetic infection — in 2 (2,45%) cases.

According to our study, after resection of the proximal humerus and shoulder joint endoprosthesis replacement, aseptic instability of the stem of endoprosthesis was observed in 2 (8.4%) patients, and periprosthetic infection was observed in 1 (4.2%) patient, which is also higher than these researchers reported. Thus, after comparing the results obtained by us and the results of other researchers, we can conclude that some complications after primary endoprosthesis replacement in our study are more numerous, due to the use of imperfect model of endoprosthesis or violation of the technique of endoprosthesis replacement.

FINDINGS

1. Revision endoprosthesis replacement due to complications after bone and joint endoprosthesis replacement for tumors was performed in 38 (21.7%) cases.

2. Repeated endoprosthesis replacement due to periprosthetic infection was performed in 7.4% of cases, due to aseptic instability of the stem of endoprosthesis it was performed in 13.1% of cases, due to destruction of the endoprosthesis structure it was performed in 2.3% of cases, due to wear of polyethylene inserts it was performed in 1.7% of cases.

3. Repeated endoprosthesis replacement was required 1.2 times more often than after primary endoprosthesis replacement and amounted to 26.3%.

4. The overweight of the patient which was observed in 9 (30%) cases, and increased patient activity in the postoperative period, which was observed in 6 (20%) cases, were the main cause of aseptic instability of the stem of endoprosthesis, and of destruction of the endoprosthesis structure, and of destruction of polyethylene inserts.

REFERENCES

1. **Smolle MA, Andreou D, Tunn PU, Leithner A.** Advances in tumour endoprostheses: a systematic review. EFORT Open Rev. 2019 Jul 2;4(7):445–459. PMID: 31423328; PMCID: PMC6667979. https://doi.org/10.1302/2058-5241.4.180081

2. **Aliev M., Sokolovsky V., Sushentsov E., Amiraslanov A., Nisichenko D.V.** Endoprosthetic replacement at tumors of long bones // Europ. J. Surg. Oncol. – 2004. – Vol.30. – №2. – P. 171. (In Russ).

3. **Eckardt JJ, Kabo JM, Kelly CM, Ward WG Sr, Cannon CP.** Endoprosthetic reconstructions for bone metastases. Clin Orthop Relat Res. 2003 Oct;(415 Suppl): S254–62. PMID: 14600617. 10.1097/01.blo.0000093044.56370.94

4. **Andreou D, Hardes J, Gosheger G, Henrichs MP, Nottrott M, Streitbürger A.** Die interdisziplinäre Diagnostik und Therapie von Knochensarkomen der Extremitäten und des Rumpfes [Interdisciplinary diagnostic and treatment of bone sarcomas of the extremities and trunk]. Handchir Mikrochir Plast Chir. 2015 Apr;47(2):90–9. German. doi: 10.1055/s-0034-1396853. Epub 2015 Apr 21. PMID: 25897578.

5. **Bruns J, Delling G, Gruber H, Lohmann CH, Habermann CR.** Cementless fixation of megaprostheses using a conical fluted stem in the treatment of bone tumours. J Bone Joint Surg Br. 2007 Aug;89(8):1084–7. doi: 10.1302/0301-620X.89B8.19236. PMID: 17785750.

6. **Lenze U, Knebel C, Lenze F, Consalvo S, Lazic I, Breden S, Rechl H, von Eisenhart-Rothe R.** Endoprothetischer Totalersatz von Femur, Humerus und Tibia [Total endoprosthetic replacement of femur, humerus and tibia]. Orthopade. 2019 Jul;48(7):555–562. German. PMID: 31190111. https://doi.org/10.1007/s00132-019-03762-1

7. **Ottaviani G, Robert RS, Huh WW, Jaffe N.** Functional, psychosocial and professional outcomes in

long-term survivors of lower-extremity osteosarcomas: amputation versus limb salvage. Cancer Treat Res. 2009; 152:421–36. PMID: 20213405. https://doi.org/10.1007/978-1-4419-0284-9_23

8. **Wirganowicz PZ, Eckardt JJ, Dorey FJ, Eilber FR, Kabo JM.** Etiology and results of tumor endoprosthesis revision surgery in 64 patients. Clin Orthop Relat Res. 1999 Jan;(358):64–74. PMID: 9973977.

9. **Griffin AM, Parsons JA, Davis AM, Bell RS, Wunder JS.** Uncemented tumor endoprostheses at the knee: root causes of failure. Clin Orthop Relat Res. 2005 Sep; 438:71–9. PMID: 16131872. DOI: 10.1097/01.blo.0000180050.27961.8a

10. **Ashwood N, Witt JD, Hallam PJ, Cobb JP.** Analysis of the referral pattern to a supraregional bone and soft tissue tumour service. Ann R Coll Surg Engl. 2003 Jul;85(4):272–6. PMID: 12855033; PMCID: PMC1964394. doi: 10.1308/003588403766275015

11. **Pala E, Trovarelli G, Calabrò T, Angelini A, Abati CN, Ruggieri P.** Survival of modern knee tumor megaprostheses: failures, functional results, and a comparative statistical analysis. Clin Orthop Relat Res. 2015 Mar;473(3):891–9. PMID: 24874116; PMCID: PMC4317408. DOI: 10.1007/s11999-014-3699-2

12. **Baranetsky A.L.** Aseptic instability of oncological prostheses of the hip and knee joints. // diss. Cand. honey. sciences. – M., – 2002., P.108. (In Russ).

13. **Unwin PS, Cannon SR, Grimer RJ, Kemp HB, Sneath RS, Walker PS.** Aseptic loosening in cemented custom-made prosthetic replacements for bone tumours of the lower limb. J Bone Joint Surg Br. 1996 Jan;78(1):5–13. PMID: 8898118.

14. **Jones CW, Shatrov J, Jagiello JM, Millington S, Hong A, Boyle R, Stalley PD.** Clinical, functional and radiological outcomes of extracorporeal irradiation in limb salvage surgery for bone tumours. Bone Joint J. 2017 Dec;99-B(12):1681–1688. PMID: 29212693. https://doi.org/10.1302/0301-620X.99B12.BJJ-2016-0462.R2

15. **Asavamongkolkul A, Eckardt JJ, Eilber FR, Dorey FJ, Ward WG, Kelly CM, Wirganowicz PZ, Kabo JM.** Endoprosthetic reconstruction for malignant upper extremity tumors. Clin Orthop Relat Res. 1999 Mar;(360):207–20. doi: 10.1097/00003086-199903000-00025. PMID: 10101327.

16. **Persson U, Persson M, Malchau H.** The economics of preventing revisions in total hip replacement. Acta Orthop Scand. 1999 Apr;70(2):163–9. doi: 10.3109/17453679909011256. PMID: 10366918.

17. **Hanna SA, David LA, Aston WJ, Gikas PD, Blunn GW, Cannon SR, Briggs TW.** Endoprosthetic replacement of the distal humerus following resection of bone tumours. J Bone Joint Surg Br. 2007 Nov;89(11):1498–503. PMID: 17998189. https://doi.org/10.1302/0301-620X.89B11.19577

18. **Myers GJ, Abudu AT, Carter SR, Tillman RM, Grimer RJ.** The long-term results of endoprosthetic replacement of the proximal tibia for bone tumours. J Bone Joint Surg Br. 2007 Dec;89(12):1632–7. PMID: 18057365. https://doi.org/10.1302/0301-620X.89B12.19481

19. **Gerrand CH, Currie D, Grigoris P, Reid R, Hamblen DL.** Prosthetic reconstruction of the femur for primary bone sarcoma. Int Orthop. 1999;23(5):286–90. PMID: 10653296; PMCID: PMC3619753. DOI: 10.1007/s002640050373

20. **Yang Q, Li J, Yang Z, Li X, Li Z.** Limb sparing surgery for bone tumours of the shoulder girdle: the oncological and functional results. Int Orthop. 2010 Aug;34(6):869–75. Epub 2009 Aug 23. PMID: 19701633; PMCID: PMC2989017. doi: 10.1007/s00264-009-0857-3

21. **Karpenko V.Yu., Bukharov A.V., Kurilchik A.A., Yadrina A.V., Ivanova M.V., Derzhavin V.A.** Endoprosthetic replacement for distal extremity tumors. P.A. Herzen journal of oncology. 2017;6(5):31–36. https://doi.org/10.17116/onkolog20176531-36. (In Russ).

22. **Babalaev Almazbek Altynbaevych.** Reendoproshetics after organ-safe operations in patients with bone tumors: dissertation of a candidate of medical sciences: 14.01.12. Place of defense: State Institution "Russian Cancer Research Center, Russian Academy of Medical Sciences". – Moscow, 2013. – 97 p. (In Russ).