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Double Trabecular Tantalum Cones as an Alternative to Additive Technologies for Revision Knee Arthroplasty (A Case Series)

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Abstract

Background. To compensate the extensive (AORI type III) bone defects, metal cones/ sleeves or massive allografts are used. In the absence of metaepiphyses, structural allografts or megaprostheses are usually used for tumor lesions of the bones. ***The aim of the study*** was to show the possibility of replacing extensive type III defects of the femur and tibia, covering the metaphysical and diaphyseal zones, with double tantalum cones. ***Materials and Methods.*** The study included 13 patients undergone revision knee arthroplasty in 2015–2019. During the surgery, the primary fixation of the femoral or tibial component was achieved by the tight fit diaphyseal cone placement. The additional fixation is carried out by cementing of the metaphyseal cone to the diaphyseal cone and the further osseointegration with the remaining bone of the metadiaphyseal zone. Fixation of the endoprosthesis component to the cones and to the bone is achived by use of the bone cement. ***Results.*** The short-term outcomes of this technique in revision knee arthroplasty were evaluated in all patients. The results were evaluated as good if the primary stable fixation and the correct endoprosthesis components placement were achieved, the limb support ability and the knee function were restored, and there were no complications in the immediate postoperative period. In a year, one patient developed a relapse of infection in the operated knee. The endoprosthesis was removed and followed by knee arthrodesis after sanitation of the infection focus. Functional and radiological results one year after surgery were studied in 4 patients. The average functional scores were: by KSS 81 (good) and by WOMAC — 25 points (also good). On the control radiographs, the position of the components remained correct and stable with osseointegration of the cones in the metaphyseal and diaphyseal areas of the femur and tibia. In the remaining 8 patients, the time after surgery was less than a year. Their follow-up yet continued. ***Conclusion.*** Thus, the tantalum cones technique is a reliable way to reconstruct extended metadiaphyseal defects in revision knee arthroplasty in the short-term prospect. The method can be considered as an alternative to megaprostheses, structural allografts, and individually made cones. But the long-term results of its application are still requiring further study.

Keywords: revision knee arthroplasty, bone defects compensation, tantalum cones.

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Introduction

The number of primary *total knee arthroplasties* (TKA) in the world annually increases by 6%, regardless of the economic situation [1]. Meanwhile, the number of revisions is also steadily growing. Currently, the revisions reaches 6 to 8% of the TKA [2, 3, 4]. By 2030 the predicted growth of the absolute number of revisions will amount to 600% [5].

One of the most difficult tasks of revision KA is the compensation of bone defects in the femoral and tibial condyles resulted from osteolysis, aseptic or septic loosening, and removal of implant components [6, 7].

The advantages and disadvantages of a wide range of available methods of the bone mass deficiency compensation of AORI type I and II defects in revision TKA (bone auto- and allografts, cement, metal modular constructions) are described in detail in domestic and foreign literature [8, 9, 10, 11, 12].

To compensate AORI type III defects, metal cones/sleeves, structural allografts, oncological or individually made implants are used [13, 14, 15, 16]. Until recently, for the defect spreading to the metadiaphyseal zone of the femur or tibia, only two of the above-mentioned techniques remained in the surgeon's arsenal, namely structural allografts and megaprostheses.

In recent years, two more methods of solving this problem have begun to be applied in clinical practice: the implantation of individual titanium augments made with additive technologies with 3D modeling, and the technique of joint application of the diaphyseal and metaphyseal tantalum cones.

Double cones have been used by many surgeons in the last 5 years to compensate extensive type III defects, spreading not only to the metaphysis, but also reaching the diaphysis of the femur or tibia. This technique consists in the placement of two trabecular tantalum cones (diaphyseal and metaphyseal) capable of osseointegration with the remaining bone to ensure reliable fixation of the femoral or tibial components in both zones [17, 18]. The main fixation of the femoral or tibial component is achieved due to the tight fit of the diaphyseal cone, while additional fixation is provided by cementing the metaphyseal cone to the diaphyseal cone with the expectation of further osseointegration of both cones with the remaining bone of the metadiaphyseal zone. The implant is fixed to the cones and bone using bone cement.

The goal of this study was to demonstrate, on the clinical examples, the ability of the double tantalum cones technique to serve as an alternative for oncological megaprostheses, massive structural allografts, and additive 3D technologies for the extensive type III defects extending to the femoral and tibial diaphysis.

Material and Methods

Patients

We used the technique of double tantalum cones to compensate extensive defects of the metadiaphysis of the femur and tibia in 13 revision TKA: the femoral were placed in 9 patients, and the tibial — in 4 patients (Table).

Table

Localization of the double tantalum cones

Indication for revision knee arthroplasty	Bone	
	femur	tibia
Two-step treatment for surgical site infection	4	3
Component or joint instability	3	–
Periprosthetic fractures	2	

In all cases, a revision endoprosthesis with the Rotating Hinge Knee (Zimmer Biomet, USA) was implanted.

Surgical technique

In the technique of double tantalum cones, the main fixation of the femoral or tibial component is achieved by the tight fit of the diaphyseal cone, while additional fixation is made by cementing the metaphyseal cone to the diaphyseal. The further osseointegration of both cones with the remaining bone of the metadiaphyseal zone is also expected. The fixation of the component to the cones and bone is carried out by using bone cement.

The diaphyseal cone, implanted into the medullary canal using the press-fit technique, significantly strengthens the mechanical durability of the weakened cortical bone. The subsequent osseointegration of the diaphyseal cone and the bone will maintain the stable fixation of the cemented intramedullary stem in the diaphyseal zone in the long term.

The metaphyseal cone, compensating for the deficiency of bone tissue in the metadiaphyseal zone, is reliably attached to the diaphyseal cone and the revision component with the bone cement. It should be in close contact with the remaining cancellous cortical bone of the metadiaphyseal region, since the subsequent osseointegration of the cone is aimed at the long-term preservation of stable fixation of the component and the cone. The normal level of the articular line, depending on the current situation, is achieved by traditional methods: the selection of an adequate size of the femoral component and distal/posterior metal femoral blocks or additional resection of the tibial plateau and/or the use of metal tibial blocks and/or the height of the polyethylene liner.

The results evaluation

To evaluate the radiological results of revisions using double tantalum cones, X-rays of the knee in frontal and lateral planes and full length standing X-rays were performed. On these X-rays, the axis of the limb and the level of the articular line, the lateral distal femoral angle and the medial proximal tibial angle, the correspondence of the endoprosthesis components to the anatomy of the knee, the correctness of their implantation and the absence of radiolucent lines around the endoprosthesis components and tantalum cones were evaluated. The functional results were assessed using the KSS and WOMAC score scales.

Results

The immediate outcomes of all the surgeries were good. The primary stable fixation and correct implantation of the endoprosthesis components were achieved (radiographically, the axis of the limb and the level of the articular line corresponded to normal values or were within the permissible deviations), satisfactory function of the knee and supporting ability of the limb were restored. There were no complications in the immediate postoperative period. One female patient developed a recurrence of knee infection one year after the surgery. This required the removal of the endoprosthesis, joint debridement, and arthrodesis. The functional and radiological results of revision TKA using the double tantalum cone technique a year after the operation were evaluated in 4 patients. The functional results averaged 81 (good) on the KSS scale and 25 points (good) on the WOMAC scale. On the control radiographs, the position of the components remained correct, stable, osseointegration of the cones occurred in the metaphyseal and diaphyseal zones of the femur and tibia. The remaining 8 patients with less than a year after the surgery are still being followed.

Case report

A 66-year-old female patient has been suffering from knee osteoarthritis for about

10 years. In 2015, she underwent the total TKA due to grade III knee osteoarthritis, varus deformity, flexion-extensor contracture and left knee instability. The endoprosthesis, stabilized in the frontal plane, was placed. The postoperative course was uncomplicated. A year after the surgery, the knee function was assessed as satisfactory. Two years later, she fell. As a result, the patient developed a periprosthetic fracture of the left femur in the metadiaphyseal zone with disconnection of the femoral component stem. The plaster immobilization was performed at the local outpatient clinic. Although, the fracture did not consolidate and the further femoral component instability had developed. In 2019, she was admitted at our Center, with the diagnosis of grade III osteoarthritis, condition after left TKA (2015), the left femur pseudarthrosis, the endoprosthesis components instability, disconnection between the intramedullary stem and the femoral component (Fig. 1).

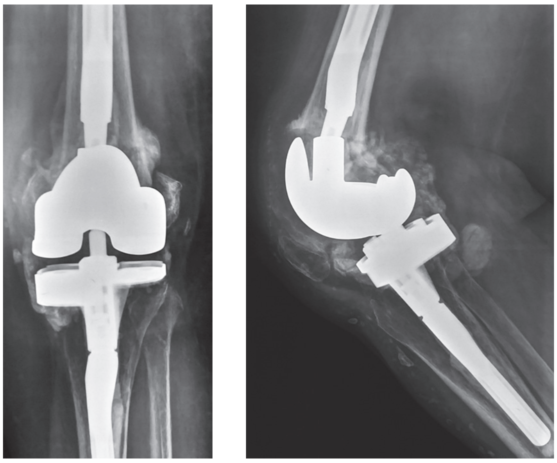

Fig. 1. The knee X-rays of the female patient. The left femur pseudoarthrosis, the endoprosthesis components instability, separation of the intramedullary stem from the femoral component.

The patient's condition on admission: she moved with support on crutches only within the premises, the limb was immobilized with a splint. The examination of the knee revealed diffuse pain in the joint and the lower third of the thigh on palpation, abnormal mobility of the fragments in the lower third of the thigh, the range of motion was 0/100°.

In the clinic, the revision left TKA was performed with a rotating hinge endoprosthesis. During the surgery, it was not possible to separate the femoral component from the femoral metaepiphysis. They were removed as a single block. Also, the fractured intramedullary stem of the femoral component and the stable tibial component were taken out. The removed metaepiphyseal part was represented by cortical bone firmly fixed to the femoral component with bone cement. The spongy bone was replaced by scar tissue (Fig. 2).

Extensive (AORI type III) bone defects of the femur and tibia formed after removal of the endoprosthesis components, bone cement, and scar tissue.

To compensate for the more damaged medial condyle, a metal modular block 10 mm high was used.

Fig. 2. The removed metaepiphyseal part of the femur and the femoral component of the endoprosthesis (a); broken intramedullary stem of the femoral component (b).

To compensate for the removed femoral metaepiphysis, the following manipulations were performed.

1. Using plastic approximate cones, the optimal size of the tantalum diaphyseal cone was selected. The lower third of the diaphyseal femur was processed. Then the above mentioned cone was placed into the femoral medullary canal using the press-fit technique (Fig. 3).

2. Using plastic approximate cones, the metaphyseal tantalum cone of the optimal was chosen. The cone allowed the femoral component to be maximally displaced distally and to be in contact with the remaining peripheral cancellous-cortical bone of the metaphyseal zone. To level the articular line and further lower the femoral component, two distal metal femoral blocks 10 mm high were used (posterior metal femoral blocks 10 mm high were used to reduce the space under the femoral component requiring filling with bone cement) (Fig. 4).

3. A femoral component with distal and posterior metal blocks, an intramedullary stem, and a metaphyseal tantalum cone was implanted. During implantation, bone cement was used to cover the stem to fix it to both cones and the femur, the contacting surface of the cones to connect them together, and the back surface of the femoral

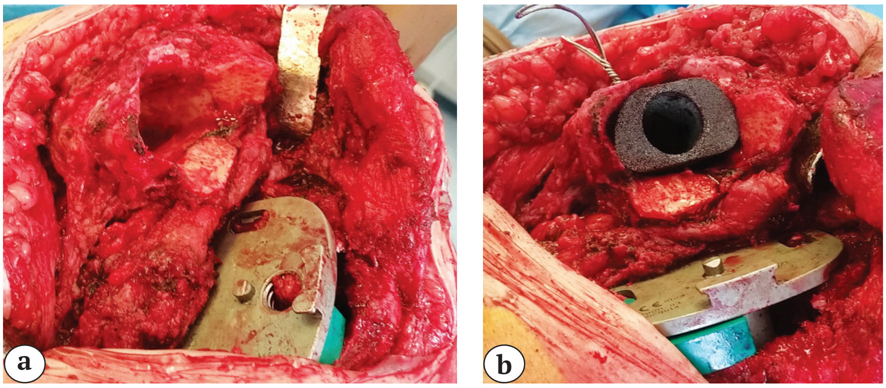

Fig. 3. After removal of the intramedullary endoprosthesis stem, bone cement and scar tissue, the metaphyseal zone is represented by the remains of the spongy-cortical bone on the external and posterior surfaces, an approximate tibial component is placed (a); diaphyseal tantalum cone is placed (b).

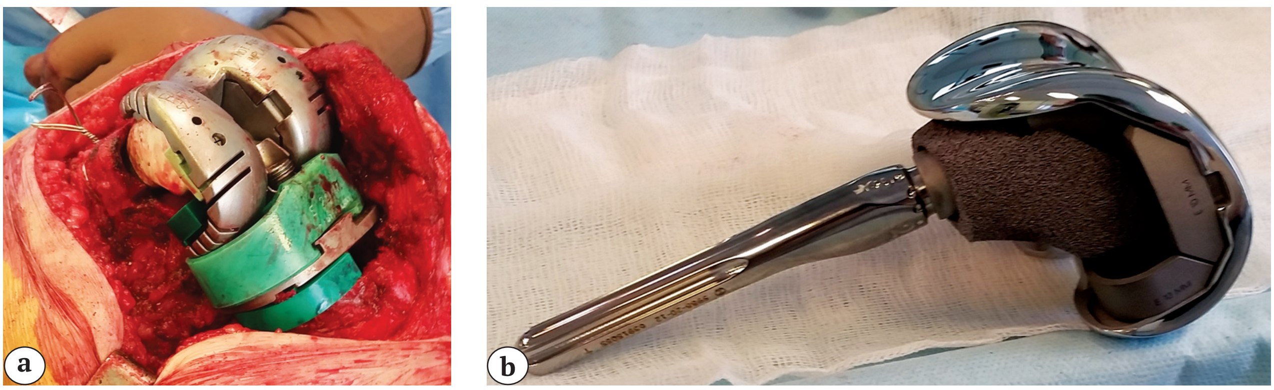

Fig. 4. An approximate femoral component was placed with a metaphyseal cone and modular distal and posterior blocks (a); a femoral component with metaphyseal tantalum cone and metal modular blocks before placement (b).

component with metal blocks to fix it to the metaphyseal cone. The metaphyseal cone in the zone of the contact with the remaining bone of the metaphysis was not cemented for subsequent osseointegration. The free medial surface of the cone was covered with cement to reduce roughness in contact with paraarticular soft tissues. The final assembly of the hinged endoprosthesis components was carried out (Fig. 5).

The early postoperative period was uncomplicated (Fig. 6).

The patient was discharged to continue rehabilitation at the local outpatient clinic. It was recommended that the patient should walk with support on crutches with dosed axial load on the limb for 3 months. At the control examination a year later, she walked with support on a cane. When the patient walked at a distance of 5 to 10 quarters, the pain in the knee was insignificant, the range of motion — 0 to 85°. The functional assessment of the joint on the KSS scale was 78 points (good), on the WOMAC — 27 points (good).

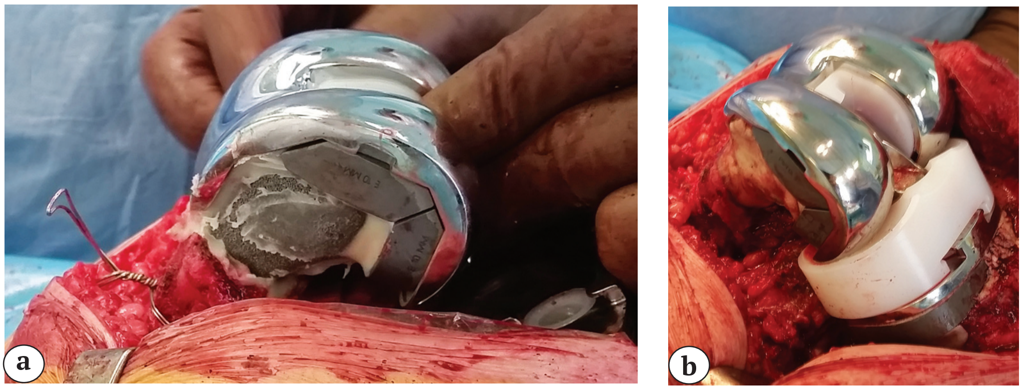

Fig. 5. A modular femoral component with metaphysical cone was placed (a); the definitive components of the endoprosthesis were placed (b).

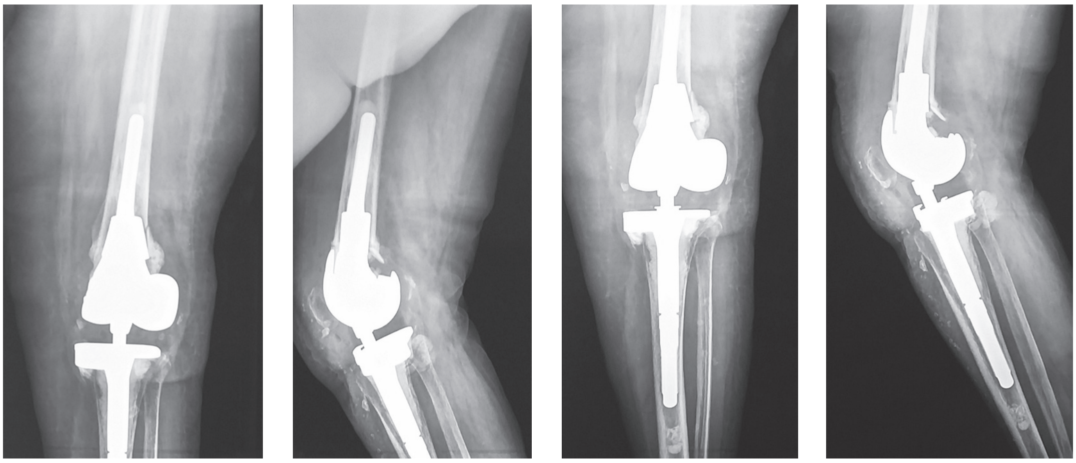

Fig. 6. Postoperative X-rays of female patient, 66 y.o. The femoral component was placed with diaphyseal and metaphyseaal cones, the position of the components and the level of the articular line are correct.

On control X-rays, the position of the components was correct, stable, the osseointegration of the cones in the metaphyseal and diaphyseal zones of the femur was visualized (Fig. 7).

For a better understanding of the essence of double tantalum cone in the compensation of extensive femoral and tibial defects in revision TKA, we would like to present two more clinical examples (Fig. 8, 9).

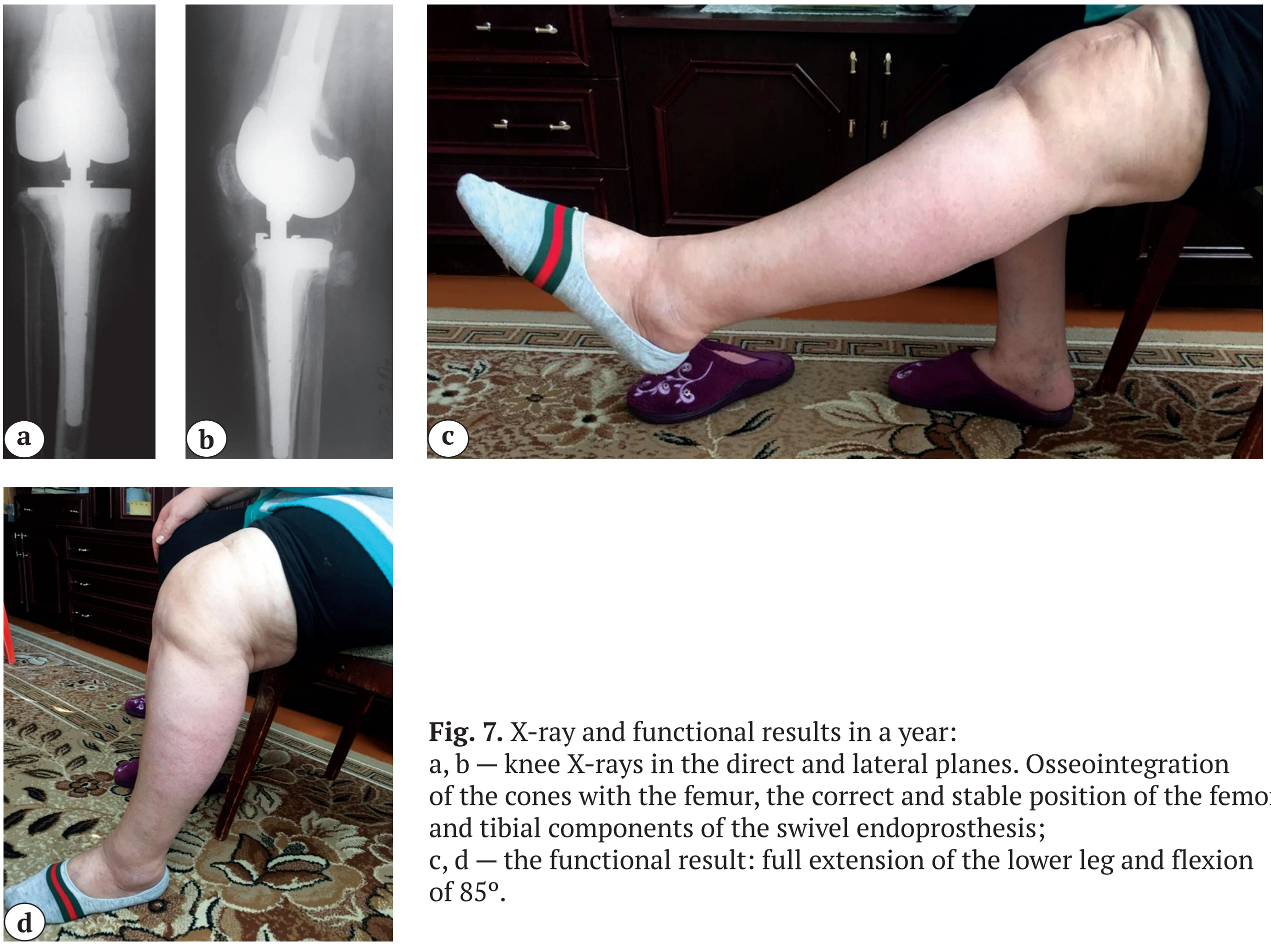

Fig. 7. X-ray and functional results in a year:
a, b — knee X-rays in the direct and lateral planes. Osseointegration of the cones with the femur, the correct and stable position of the femoral and tibial components of the swivel endoprosthesis;
c, d — the functional result: full extension of the lower leg and flexion of 85°.

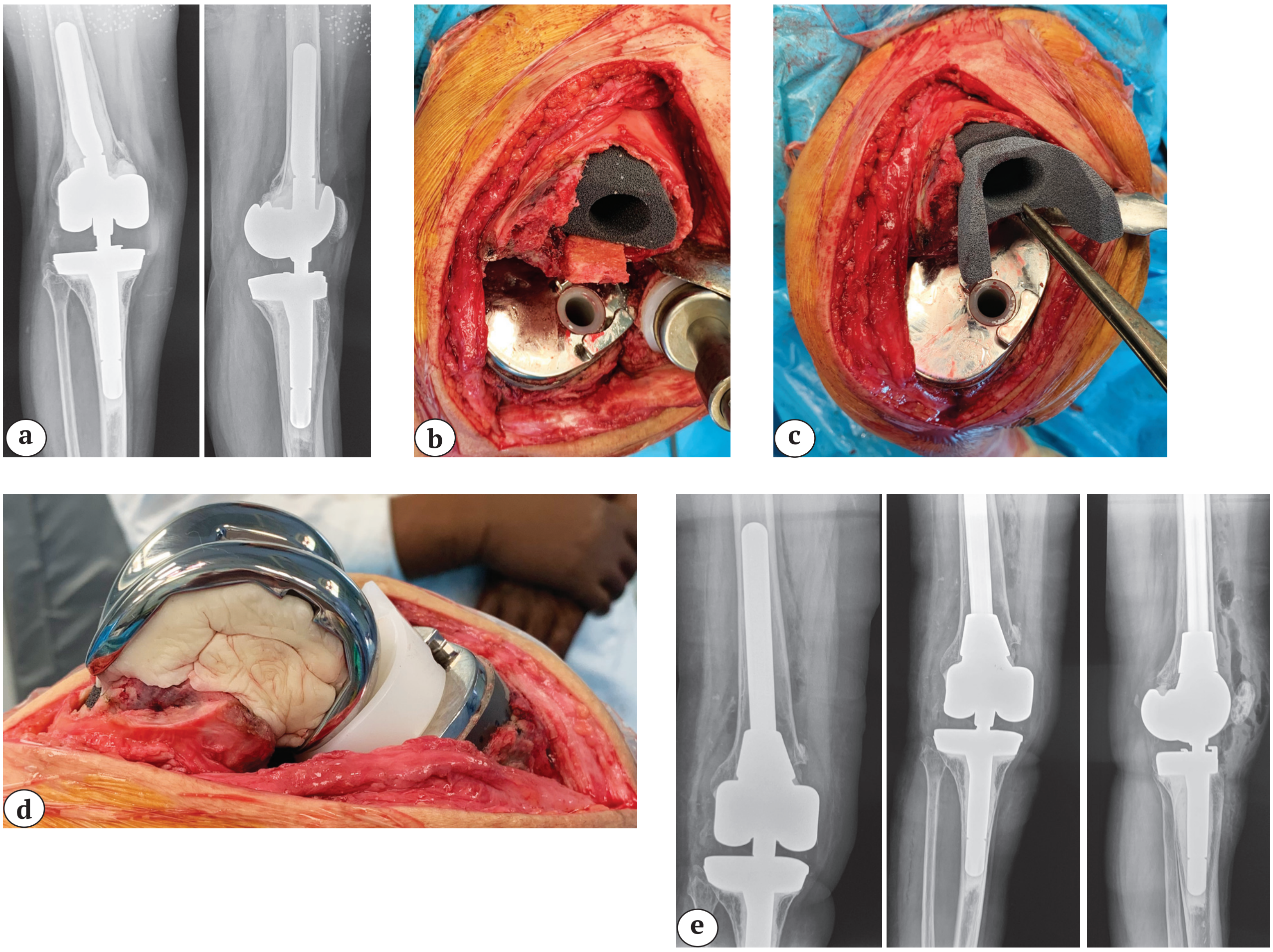

Fig. 8. A clinical example of the use of the double tantalum cone method for joint instability due to unbalanced
flexion and extension gaps after the swivel endoprosthesis placement:
a — preoperative X-rays;
b — intraoperative photo: a diaphyseal cone was placed and bone autoplasty of the posterior femoral wall was performed to increase the area of bone contact between the metaphyseal cone and the bone;
c — metaphyseal cone before placement;
d — the definitive components of the swivel endoprosthesis were placed (femoral component with metaphyseal cone);
e — postoperative X-rays.

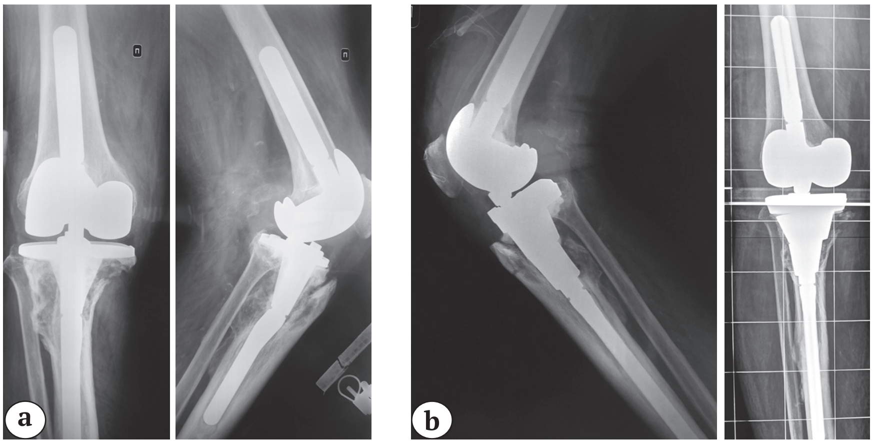

Fig. 9. A clinical example of the use of the double tantalum cones for revision knee arthroplasty due to the instability of endoprosthesis components and periprosthetic tibial fracture:
a — X-rays before the surgery; b — X-rays after the surgery.

Discussion

To compensate for extensive AORI type III defects by revision TKA, a number of interchangeable techniques are used in clinical practice. All of them have certain advantages and disadvantages [13, 14, 15, 16]. In accordance with the theory of zonal fixation by R. Morgan-Jones et al., to ensure a longevity of an endoprosthesis after revision TKA, each of the implanted components must have a tight fixation in at least two anatomical zones of the femur and tibia [19].

In type III bone defects, the epiphyseal zone is compromised by the main pathological process and cannot provide the stable fixation of the component in the long term.

Diaphyseal fixation is achieved by implantation of cementless or cemented intramedullary stems of various lengths and shapes [14, 20, 21]. In revision KA due to the long-term aseptic/septic instability of the components with intramedullary stems, after removal of the stems, cement and scar tissue from the medullary canal, the cortical bone becomes significantly thinner and loses its mechanical strength. A similar situation is observed after removal of static spacers reinforced with metal intramedullary rods. As a result, it is difficult to achieve any stable diaphyseal fixation of the revision component, which is necessary in accordance with the above-mentioned R. Morgan-Jones et al. theory [19].

In the 3rd zone, the metaphyseal, primary stable fixation and subsequent osseointegration of the revision components can be provided by coated metal bushings and tantalum porous cones [22, 23, 24, 25].

Bone grafting with femoral heads, cancellous cortical and structural allografts allows to compensate and partially restore lost bone, but it requires prolonged unloading of the limb for fusion and restructuring of the graft, as well as additional material costs for maintaining the allograft bank [8, 26, 27, 28].

In clinical practice, with extensive type III defects and replacement of revision systems with intramedullary stems, the epiphyseal fixation zone is absent, and the mechanical strength of the bone in the metaphyseal and diaphyseal zones is significantly reduced, and part of the cortical and cancellous bone is lost. The way out of this situation for a long time consisted in the removal of the remnants of the metaepiphyseal bone with part of the diaphysis and implantation of massive structural allografts with revision systems or the use of modular oncological megaprostheses [16, 20, 28, 29].

In recent years, some encouraging publications have appeared, indicating the successful application of additive technologies with 3D reconstruction, which makes it possible to produce an individual porous augment from titanium powder that optimally corresponds to the shape of the defect [30, 31, 32]. The use of this technique is limited by the need for coordinated joint work of a 3D modeling skills specialist with an operating surgeon to determine indications, manufacture an implant, and the correct endoprosthesis placement [31, 32].

A number of authors substantiated the possibility of using the double tantalum cone technique for extensive type III defects extending to the metaphyseal and diaphyseal zones [17, 18]. This technique provides the main fixation of the femoral or tibial component by tight fiting of the diaphyseal cone. The fixation of the component to the cones and bone is carried out with bone cement.

Additive technologies with 3D reconstruction and the double tantalum cone technique have been used in clinical practice for the last 5 years. Therefore, currently in the literature, there are only a few publications highlighting the technical features, advantages and disadvantages, immediate and short-term surgery outcomes, without comparing them with the results of other techniques [17, 18, 30, 31, 32].

The double tantalum cones technique makes it possible to compensate bone mass deficit, helps to achieve primary stable fixation of the endoprothesis components and to restore the normal level of the joint line even in case of extensive (AORI type III) defects, extending to the femoral and tibial metaphyseal and diaphyseal zones. Unlike bone allografting, it does not require any extra costs for maintaining the bone bank and allows the early axial load to the operated leg. Tantalum cones of various shapes and sizes can be used in a specific clinical situation during the revision surgery. In contrast to made by additive technologies with 3D reconstruction titanium augments, the tantalum cones don't require prolonged preoperative planning or individual manufactured components. Nevertheless, the presented technique requires a detailed clinical study in order to assess the mid- and long-term outcomes.

Publication Ethics

The patients gave their voluntary informed consent for the participation in this clinical study and publication of the results.

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Authors' contributions

T.A. Kulyaba — research conception and design, data interpretation and analysis, text preparation.

N.N. Kornilov — data interpretation and analysis, editing.

A.V. Kazemirskiy — collection and processing of the material, data interpretation and analysis.

G.Yu. Bovkis — text preparation, collection and processing of the material.

D.V. Stafeev — collection and processing of the material, data interpretation and analysis.

A.A. Cherny — collection and processing of the material.

I.I. Croitoru — collection and processing of the material.

A.I. Petukhov — collection and processing of the material.

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