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Case Report

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Total Knee Arthroplasty Using Hinge Joints

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ABSTRACT This article discusses some of the considerations in planning a revision total knee arthroplasty (RTKA). Total knee arthroplasty (TKA) involves replacing all parts of the knee joint to restore functionality and function. TKA is one of the most common and reliable surgical treatments for knee disorders. However, some patients require revision total knee arthroplasty (RTKA) after TKA for a variety of reasons, including mechanical wear, implant loosening, subsidence, infection, instability, periprosthetic fracture, and stiffness. Unfortunately, the overall outcome of RTKA is not as satisfactory as that of primary TKA due to many factors, including success rates and risk factors. Our approach to improving RTKA outcomes includes the use of linked, rotating-hinge revision prostheses, as well as the treatment of patients with metaphyseal bone loss. In preoperative planning of RTKA, we use the classification of bone defects, options for restoring the joint line, which allows for individual selection of the type (kind) and components of a modular revision endoprosthesis. A clinical example also allows for substantiation of the choice of the type (kind) of endoprosthesis, namely a revision endoprosthesis with a rotating hinge.

Keywords: bone defects, metaphyseal bone loss, revision knee arthroplasty, bone cement

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AORI — Anderson Orthopaedic Research Institute
RTKA — revision total knee arthroplasty
TKR — total knee replacement
WOMAC — Western Ontario and McMaster University Osteoarthritis Index

Infectious complications in the knee joint area, as well as after knee arthroplasty, are a major health problem. Their frequency is 0.5–5% of all knee joint interventions [1]. Risk factors include the patient's age and health, weight, integrity of the anatomical structures of the joint, characteristics of the infectious process, the endoprosthesis model used, features of the surgical technique of re-endoprosthetics, patient compliance, and much more [2].

Revision total knee arthroplasty (RTKA) can be one- or two-stage [3]. Each type of technique has its own indications and contraindications [4]. One-stage RTKA is indicated when the probability of success is high: there are no cultured microorganisms or the obtained microflora is sensitive to most antibiotics [5].

Two-stage RTKA includes the use of a spacer impregnated with antimicrobial chemotherapeutic agents at the first stage of treatment, which is placed in the patient for a period of 2 to 6 months. Today, both ready-made factory-made spacers and intraoperatively manufactured cemented methyl methacrylate spacers are used [6]. After the staged use of the spacer, conservative treatment and relief of the inflammatory process, but not earlier than 3–6 months later, the second stage of treatment is carried out - implantation of a revision knee joint endoprosthesis [7].

The main complications of RTKA after using various spacers are the development of arthrofibrosis of the knee joint, with greater or lesser proliferation of connective tissue, loss of bone tissue, loss of anatomical landmarks, loss of the ligamentous apparatus, difficulty in restoring the original joint line, soft tissue balance [8]. At the same time, unfortunately, there is insufficient medical continuity, since the primary knee joint endoprosthesis is installed in one institution, treatment of infectious complications and installation of the spacer occur in another institution, and subsequent revision prosthetics - in a third [9].

When planning the revision surgery, total knee arthroplasty (TKA), we used the AORI classification of bone defects (Anderson Orthopaedic Research Institute, 2006) and joint line restoration options for the correct selection of revision prosthesis components [10–12].

AORI CLASSIFICATION OF BONE DEFECTS (2006)

The current AORI classification of bone defects (Table 1) was offered by the Anderson Orthopedic Research Institute in 2006. This classification takes into account bone defects of the femur and tibia after primary knee arthroplasty, which are divided depending on the type, depth and location of the defect.

Table 1

Management For classifications AORI defects

Type of defect	Identification of features	Treatment
F1/ T1	No subsidence of components or osteolysis; no cancellous defects in the peripheral areas; cancellous bone that will support the implant; defects can be filled with a small amount of bone graft granules or cement; normal joint line present Femur - Complete Condylar Profile Tibia - the component above the head of the fibula and the entire metaphyseal segment	Without augments (more than 4 mm), structural grafts or cement filler (more than 1 cm). No rod components are used
F2/ T2	Cancellous bone cannot support the implant; cancellous defects may require bone grafts; the component used requires augmentation to restore the joint line; osteolysis may be more extensive than shown on radiographs Femur - reduced condylar profile Tibia - the component is at or below the apex of the fibular head and the tibial prominence is reduced	The joint line is restored with an augmented component (more than 4 mm), autograft or allograft particles, or cement filler (more than 1 cm). Rod components can be used
F3 / T3	Marked migration of components; knee instability; metaphyseal insufficiency Femur - loss of collateral ligament attachments to one or both condyles; severe condylar bone loss due to osteolysis or comminuted supracondylar fracture	A structural graft, augment, or cement, or hinge component used to reconstruct the condyle or plateau. Rod components must be used

It should be noted that the AORI classification considers only those defects that arise after removal of the prosthetic components. Defects are assessed on preoperative radiographs and the classification can be subsequently modified intraoperatively. The femoral epicondyles, posterior femoral condyles and the position of the patella relative to the joint line can be used as landmarks to differentiate complex

femoral defects. The fibular head and tibial tuberosity should also be used as landmarks for those tibial defects that are difficult to assess. The following definitions of the defect type are the basis of this classification:

Type 1 Defect (intact metaphyseal bone): mild bone defects that do not compromise the stability of the component.

Type 2 Defect (Metaphyseal Bone Failure): Loss of cancellous bone requiring filling with cement, augment, or bone graft to restore a reasonable joint line level. Type 2 bone defects may occur in one femoral condyle or tibial plateau (2A) , or in both condyles or plateaus (2B).

Type 3 Defect (Insufficient Metaphyseal Segment): Bone loss that compromises a large portion of the condyle or plateau. These defects are usually associated with insufficiency of the collateral or patellar ligaments and usually require bone grafts or custom implants.

As always, in any classification, some cases are borderline. To classify them, it is necessary to evaluate both the postoperative radiographs and the surgical treatment performed.

Bone defects are also possible in the patella, but these cases were excluded from the AORI classification of bone defects because they do not influence the choice of methods in revision surgery, bone grafting and special revision components are not used for their treatment - with rare exceptions.

Femoral bone defect F1

Preoperative radiographs of the Type 1 femur demonstrate a properly aligned component with no evidence of femoral osteolysis.

They also do not show a significant migration component, there should have been a good joint line level. Minor superficial defects from the remains of cement plugs were treated with partial bone graft or cement. Table 1 summarizes the features and methods of treatment of the F1 defect.

Postoperative radiographs of the Type 1 femur show a relatively normal joint line level with the patella 1 cm proximal to the tibial plateau. The femoral condyles appear intact on the anteroposterior radiograph; the posterior condylar offset is preserved on the lateral radiograph. The proximal tip of the posterior condyle of the component should match the proximal end of the patient's posterior femoral condyle. Further bone loss may also occur after implant removal.

Femoral bone defect F2

F2 femoral bone defect is characterized by osteolysis or significant proximal migration of the femoral component. Radiographs may show implant subsidence with circumferential radiolucency. In addition, loss of distance from the epicondyles to the implant margin will be evident on anteroposterior radiographs. Femoral osteolysis should not extend beyond the epicondyles.

In some F2 defects, the normal relationship of the femoral component to the femoral shaft may be altered (6-degree valgus deviation). The implant subsides with angular migration into an incorrect varus or valgus position relative to the anatomical axis of the femur.

Defects F2A: one condyle

2A femoral defect may involve either condyle. The cancellous bone of the involved condyle may have been damaged by osteolysis or iatrogenically if an incorrect distal angulation of the femoral bone was made during the primary arthroplasty. The bone of the opposite femoral condyle is relatively intact with a normal joint line level.

2A femur is the presence of unilateral elevation of the joint line with preservation of bone in the contralateral condyle for implant fixation. The presence of small bone defects in the contralateral condyle does not change the classification of a Type 2A defect as long as the contralateral condyle maintains a relatively normal joint line level.

Reconstruction of an F2A defect using a primary implant is rare. In most cases, a modular augment is used to re-establish a normal joint line. In some circumstances, the treatment technique for an F2A defect must include partial restoration of the joint line. This may be necessary to correct a large preoperative flexion contracture. An F2A defect is converted to an F2B defect when the contralateral condyle is resected at a more proximal level. When the joint line is elevated, a smaller femoral component size is needed to re-establish flexion-extension balance. Postoperative radiographs of a

properly repaired F2A defect should show the augmented condyle or the restored condyle. An anteroposterior radiograph may demonstrate a more proximal level of condyle resection. However, augmentation may not always be visible on the lateral radiograph if there is a carter box of a posteriorly stabilized or linked implant.

Defect F2B: both condyles

2B femoral defect is identical to the 2A defect but involves both femoral condyles. The damaged metaphyseal bone requires restoration with cement, augments, or bone grafts to achieve an acceptable joint line level. In the anteroposterior radiograph of a Type 2B subsided femoral component, the distance from the distal edge of the component to the epicondyles is reduced.

If the epicondyles are flattened by component migration, the defect is an F3 level. Osteolysis may be seen on the anteroposterior radiograph between the component and the metaphyseal rim. Additionally, the patella baja may be present on the lateral radiograph. Due to proximal glenoid migration, the posterior condyle of the prosthetic component may have migrated superior to the patient's remaining posterior femoral condyle. Use of large amounts of cement proximal to the femoral component usually results in an F2B classification. Often, both femoral condyles must be augmented distally and posteriorly with modular augments to restore a normal glenoid level. The cement mantle is sometimes reinforced with cancellous bone screws. An F2B defect should always be reconstructed with a revision component and nail. Some F2B defects require glenoid elevation to restore adequate knee motion. This is true for a tight knee with a flexion contracture of more than 20 degrees.

Postoperative radiographs of an F2B defect demonstrate either an elevated joint line without major bone defects or a normal joint line that has been restored with augments, bone graft, or thick cement mantle under the component. The metaphyseal segment of the femur will appear shortened or replaced by a femoral component of increased thickness. Bone grafts will be difficult to discern if the graft is tightly adherent to the patient's bone. The patella may be level with or below the superior aspect of the tibial component, indicating elevated joint line.

Defect F3

Type 3 femoral defects have extensive structural bone loss, including most of one or both femoral condyles. See Table 1 to identify the features of F3 defects.

Preoperative radiographs of F3 defects demonstrate osteolysis and marked migration to the level of the epicondyles. When the femur migrates, the epicondyles are near the component. Although the severity of osteolysis is not always obvious on radiographs, the surgeon should anticipate that osteolysis may be much more severe than expected. Osteolysis typically appears as a defect in the cancellous bone adjacent to the implant. Osteolysis often appears at the margins of the femoral component and is accompanied by a sclerotic or scalloped border. Often, lytic osteolytic lesions are seen in areas where the femoral component is not anchored to the patient's bone. The most aggressive lytic osteolytic lesions may not have a radiographic sclerotic border. Loosening of a hinged, custom, or revision component often results in an F 3 defect. These component designs often have a rod that migrates within the femoral canal. A significant amount of bone was removed during placement of these components. In these cases, the metaphyseal segment of the femur is shortened.

Surgical reconstruction of a type F3 defect is a salvage procedure requiring restoration of the metaphyseal bone with a massive structural allograft or a custom femoral component. Extensive bone loss may involve one or both condyles. A varus-valgus tethered implant or preservation and reattachment of one or both collateral ligaments may be required. A femoral canal-filling stem is then required. Achieving rotational stability of the femoral component may require total femoral canal cementation or use of an allograft.

Postoperative radiographs of a type 3 femur defect demonstrate restoration of the distal femoral metaphysis and, in some cases, the diaphysis. All hinch or hinge constructs are considered type F3 by default because they replace the metaphyseal segment and connect adjacent components and

compartments. Because of the differential bone density, delineation of the allograft from the patient's adjacent bone is obviously straightforward. Ideal reconstruction of an F3 defect involves restoration of the normal joint line against a minimally thick polyethylene liner.

Tibial bone defect T1

The same principles used in classifying femoral defects apply to tibial bone deficiencies. In the tibial compartment, implant loosening is more common. Often, the tibial component subsides in a varus position, creating a bone defect in the medial plateau. The Type 1 tibia has the same identifying features as the F1 femoral defect (see Table 1). Preoperative radiographs show a properly aligned tibial component without significant implant subsidence or tibial osteolysis. The proximal tibia is superior to the fibular head. For T1 defects, a standard tibial component is recommended because the patient's appropriate cancellous bone is preserved.

Postoperative radiographs also confirm that the bones and contours of the tibial metaphysis were preserved above the fibular head. Standard components with a total component thickness (metal + polyethylene) of less than 20 mm are usually used.

Tibial bone defect T2

T2 defect is often caused by loosening of the tibial component and secondary subsidence of the tibia, usually in a varus position. A circular radiolucent line forms between the cementum and the bone as the component subsides. The distance between the fibular head and the component is decreased. A lateral radiograph is useful for measuring this distance. The radiographic appearance of osteolysis is variable radiolucency below the component (see Table 1 for tibial defects).

T2A defect: one plateau

2A defect usually results from loosening of the tibial component and its subsidence into a varus position. The tibial component rarely subsides into a valgus position, even in genu valgus. Preoperative radiographs often show lucencies of varying shapes below the tibial component. In the contralateral tibial plateau, bone is present at a relatively normal joint line level. Type T2A defects may also be present with aseptic loosening of the unicondylar tibial component.

Surgical treatment of the T2A defect involves the use of a modular component with a nail along with a small autograft, allograft, or augment. It is important to avoid converting the T2A defect to a T2B defect by resecting more tibial plateau bone at a more distal level. In this case, when an iatrogenic T2B defect is created, a thicker tibial component will be required.

T2B defect: both plateaus

Type 2B defects involve the entire tibial plateau. Radiographic appearance of T2B defects demonstrates damage to the metaphyseal segment of the tibia by component subsidence, osteolysis, or both. The damage may extend to the level of the fibular head but should not involve extensive bone destruction below that level.

metaphysis should be reduced but still present. Osteolytic lesions should have sharp margins with some cancellous bone to allow cement to bind during reconstruction. Surgical treatment of T2B defects typically involves the use of a modular long-shaft tibial component and reconstruction of the tibial plateau with bone graft, augments, or a thickened tibial component. A wedge-shaped augment will be adequate to treat a T2B defect if bone loss is predominantly on one side of the plateau. If structural bone graft was used, canal - filling rods are required.

of the defect is often used for T2B reconstructions. Reinforcement with cancellous screws can provide a stronger construct than cement alone. The most challenging technique for reconstruction of type 2 and type 3 tibial defects is achieved by the proper use of cement and allograft. The advantage of using allograft is the recreation of a cancellous bone bed for cemented connection to the patient's bone. In fact, structural allografts have shown long-term efficacy in knee revision surgeries.

Radiographs after repair of T2B defects show restored joint line level using tibial augments, cement, or allograft. The augment may be a thickened revision component, step augment, or angled augment under the modular component. Bone graft may be used in addition to the augment. If the joint line level has not been restored, the

plateau of the tibial component will be at or below the level of the fibular head.

Tibial bone defect T3

A Type 3 tibial defect usually results from severe tibial instability caused by aseptic loosening and implant migration. Osteolysis or periprosthetic fracture may contribute to the development of a Type 3 defect. In a Type 3 defect, there is an extended lesion of the cancellous bone of the proximal tibia. The fibular head may be preserved and located superior to the proximal tibia. Channel-filling stems are necessary to stabilize the modular component. In severe cases, the metaphyseal tibia is completely absent. Therefore, large structural allografts are necessary to restore the proximal tibia, fix the components, and establish a normal joint line.

Preoperative radiographic appearance of the T3 defect shows severe migration, instability, and destruction of the proximal tibia metaphysis. Both the attachment sites of the patellar ligament and the attachment points of the collateral ligaments are often affected due to the large amount of bone loss. Patella alta and involvement of the extensor mechanism may be present.

Massive structural allografts or custom tibial components are indicated for reconstruction of the T3 procymbal defect. Cemented canal-filling stems will aid rotational stability. Varus-valgus-limited implants, collateral ligament replantation, and extensor mechanism reconstruction may be used for reconstruction of the T3 procymbal defect.

Postoperative radiographic appearance of a T3 defect demonstrates a restored metaphyseal segment of the proximal tibia.

If the classification of bone defects is applied correctly, the method of reconstruction used should be adequate for each category of defect.

When planning RTKA, we also used the classification of joint line restoration options according to M. Innocenti (2013) for the correct selection and installation of revision endoprosthesis components [13, 14] (Table 2).

In RTEK, joint line elevation is a common phenomenon associated with poorer clinical and functional outcome [15–17]. The basis for this evidence lies in the difficulty of balancing the flexion-extension gap, which in most cases leads to proximization of the distal femur to compensate for the increased flexion space. One solution to avoid joint line elevation is to use a larger femoral component; however, a larger component has a wider mediolateral diameter, which may lead to the formation of a soft tissue impingement effect on the prosthesis [18].

Table 2

Variants of joint line restoration (M. Innocenti et al., 2013)

Option 1	Use of a larger femoral component
Option 2	Use of a standard size femoral component. Posterior displacement of the femoral component
Option 3	Use of a standard size femoral component. Posterior displacement of the femoral component using a cemented stem
4th option	Use of a standard size femoral component. Posterior displacement of the femoral component using a cementless stem and offset sleeve

For RTKA we used a rotating hinge-linked TKA (RH-TKA) system [19].

RH-TKA system with a rotating hinge was developed to provide the orthopaedic surgeon with additional options related to revision knee arthroplasty. The RH-TKA is a limited rotation knee prosthesis. The prosthesis is designed to provide approximately 10° of internal/external rotation in each direction. Rotation is locked by the tibial bearing at full extension. Due to the pin design , the prosthesis has the ability to lengthen, i.e. distract, up to 30 mm between the femoral and tibial components. In extreme flexion, the femoral component can move away from the tibial bearing, which compensates for the sagittal leverage forces acting on the prosthesis stem in these situations.

The implants are available in five sizes (2, 4, 6, 8 and 10). In addition to size 2, the sizes can be combined with the next size, one size larger or smaller. The RH-TKA system allows the use of metal augments, cemented and cementless, straight or offset rods, metaphyseal cones. The compatibility of the modular RH-TKA with the monolithic RH-TKA allows (if necessary) to combine the components of the prostheses during surgery.

Clinical example

Patient Yu., 56 years old, was treated in the orthopedic department with the diagnosis "Contracture of the left knee joint. Purulent gonitis of the left knee joint. Condition after installation of a spacer of the left knee joint."

Upon admission, she complained of pain, swelling, hyperemia in the area of the left knee joint, subfebrile increase in body temperature up to 37.5°C, deformation and impaired support ability of the left lower limb.

The patient's medical history shows that she was repeatedly hospitalized in the district clinical hospital, where, according to the patient, 5 arthroscopy of the left lower limb was performed between 2016 and 2018. During the arthroscopy on 06.2018, drainage was installed and antibiotic therapy was administered. After the last hospitalization, the above complaints continued to manifest with periodic intensity.

In 2019, a diagnosis of "Gonitis of the left knee joint" was made and a knee joint resection was performed with the installation of an antibacterial spacer.

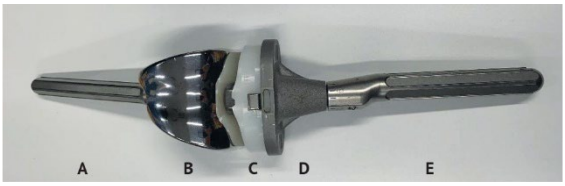

Fig. 1. Modular RH-TKA system with a rotating hinge: A, E - extension rods; B - femoral component; C - liner; D - tibial component

On examination: the walking function is impaired. The patient moves by unloading the lower limb. The contours of the left knee joint are deformed. Palpation of the knee joint area is painless. There is a limitation of active and passive movements in the joint due to excessive tension of the collateral ligaments.

Range of motion: extension - 5°, flexion - 85°. Functional assessment of the left knee joint according to the WOMAC scale (Western Ontario and McMaster University Osteoarthritis Index) - 47 56. Muscle hypotrophy of the left lower limb is noted. No signs of vascular or neurological pathology were detected.

Infection was excluded by laboratory biochemical, immunological and microbiological studies. After multiple negative knee cultures, negative biochemical and immunological blood tests for C -reactive protein and interleukin-6, revision knee replacement was recommended.

During preoperative planning, the valgus angle was measured and the condition of the ligamentous apparatus was checked. The bone defect according to the AORI classification was assessed as F3/T3 based on the results of radiographic and, subsequently, intraoperative studies (Fig. 2).

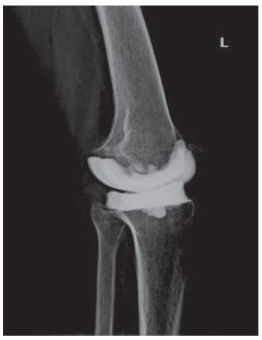

Fig. 2. Preoperative radiograph

Restoration of the joint line was planned as option 1 according to M. Innocenti - using a larger femoral component.

Indications for the use of the RH-TKA endoprosthesis with a rotating hinge were the presence of F3/T3 bone defects, ligament instability, and severe imbalance in the flexion and extension gaps.

On 26.02.2020, revision endoprosthetics was performed with spacer removal and installation of a revision modular knee endoprosthesis of the RH-TKA type (Fig. 3). Modular RH-TKA system with a rotating hinge. Modular components, femoral augments and canal-filling stems were used. The operation was performed using standard bone cement with an antibiotic. The choice of the endoprosthesis model was also carried out taking into account the pronounced metaphyseal bone loss F3/T3 (bilateral bone loss, including most of one or both femoral condyles and damage to the tibia metaphysis below the head of the fibula) according to the AORI classification.

The postoperative radiographic picture demonstrates the restoration of the distal metaphysis of the femur and the metaphyseal segment of the proximal tibia and the joint line.

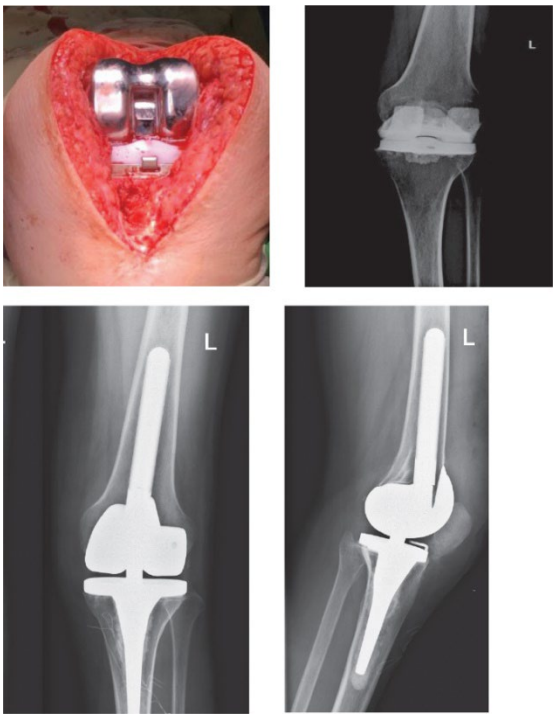

Fig. 3. Results of installation of the RH-TKA modular system with a rotating hinge

Postoperative observation after 3 years. The weight-bearing ability of the limb was restored. Functional assessment of the knee joint according to the WOMAC scale is 81. At the control examination: the patient moves independently without additional support. No recurrence of inflammation has been noted during the entire observation period from the moment of the revision surgery to the present time.

CONCLU5.SION

We believe that with the increasing number of patients with severe deformities and bone defects, rotating hinged knee prostheses will play an increasingly important role. However, there are insufficient and inconsistent data regarding the indications for use and subsequent clinical outcome for this type of knee implant. Some authors consider them exclusively as revision prostheses and, to a lesser extent, as prostheses for primary implantation due to the increased risk of loosening compared to uncoupled prostheses. Nevertheless, there is agreement regarding the indications for rotating hinged knee prostheses to solve problems such as severe bone loss, flexion-extension gap imbalance, severe ligamentous instability of the knee joint, and large varus and valgus deformities. In preoperative planning of revision knee arthroplasty, the AORI bone defect classification (2006) or Innocenti joint line reconstruction options (2013) can be used.

Hommel et al. reported promising clinical results with the use of hinged knee prostheses. The study was conducted in 62 patients (62 knees), with a mean follow-up of 6.8 ± 2.2 years (range, 2.8–11.7 years), 15 men and 47 women. The mean age at follow-up was 74.1 ± 9.9 years, the mean body mass index was 30.2 ± 5.2 kg/m ^{2}. The cumulative survival rate for the hinged knee prosthesis system with revision for any reason was 99.2% (95% confidence interval (CI), 94.5–99.9) at 5 years and 89.4% (95% CI, 68.8–96.7) at 10 years. All patients surveyed stated that they were satisfied with the implanted knee prosthesis, with a mean pain score of 1.7±2.0 on the visual analog scale for pain. No radiographic evidence of implant loosening or migration was detected [20].

Therefore, if knee stability cannot be achieved with a standard primary endoprosthesis, the use of a rotating hinged knee prosthesis is justified. Careful patient selection and a gentle implantation technique are prerequisites for achieving a good postoperative result and a high degree of patient satisfaction. Further prospective studies comparing the used designs of rotating hinged knee prostheses with different degrees of coupling are needed to clarify the long-term clinical results.

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