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Revision Total Knee Arthroplasty

Revizijska operacija totalne endoproteze kolena

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Abstract

Primary total knee arthroplasty (pTKA) is an effective surgical procedure, with increasing volume driven by an ageing global population, expanding indications, and younger, more active patients becoming candidates for such treatment. Consequently, the rate of revision TKA (rTKA) is also projected to increase in the following decades. Revision surgery should be based on understanding the causes of pTKA failure, extensive pre-operative imaging and planning, evaluation of bone loss, an adequate surgical approach, and the availability of different implant options with possible grafts for managing bone defects. The most common indications for rTKA are aseptic loosening, periprosthetic joint infection, instability, and component wear. Bone loss frequently presents a challenge in rTKA; therefore, understanding its etiology and properly classifying it is crucial for a successful outcome. The Anderson Orthopaedic Research Institute (AORI) classification and the Morgan-Jones / Zonal classification of bone loss are the two most used classifications for assessing bone loss in pre-operative planning stage. Different methods for managing bone loss include cement augmentation, bone grafting, metal augmentation, stemmed implants with offset adaptors, and metaphyseal sleeves or cones. If the bone loss is too extensive for reconstruction, a megaprosthesis must be used. Available implants for rTKA can be classified relative to their constraint into four groups: unconstrained, minimally constrained, semi-constrained, and high-constrained. This article reviews the current evidence and outlines key principles for implant selection in revision knee arthroplasty.

Izvleček

Primarna vstavitev totalne kolenske endoproteze (TEP) je učinkovit poseg. Zaradi starajoče se populacije v svetu ter vse številčnejših indikacij in vse več mlajših in bolj aktivnih kandidatov za posege se opravlja vse pogosteje. Zato pričakujemo v prihodnjih desetletjih tudi porast števila opravljenih revizijskih operacij. Uspeh revizijske operacije temelji na razumevanju vzroka za neuspeh primarne vstavitve TEP, obsežnih radioloških preiskavah pred operacijo in računalniškem planiranju posega, ustreznem kirurškem pristopu, ki omogoča zadostno preglednost, ter dostopnem naboru različnih revizijskih

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Ključne besede: kirurgija kolena; revizijska operacija totalne endoproteze kolena; klasifikacija defektov kostnine; klasifikacija Morgan-Jones; klasifikacija AORI; mehanizmi obvladovanja defektov kostnine

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implantov in graftov za rekonstrukcijo nastalih kostnih defektov. Med najpogostejše indikacije za revizijsko operacijo sodijo aseptično omajanje, periprotetična okužba sklepa, nestabilnost in obraba komponent. Kostni defekti, ki ostanejo po odstranitvi komponent, so pomemben izziv za rekonstrukcijo. Zato sta razumevanje njihovega nastanka in pravilna klasifikacija ključnega pomena za uspešen izid operacije. Klasifikacija Anderson Orthopaedic Research Institute (AORI) in Morgan-Jonesova oz. conalna klasifikacija sta 2 najpogosteje uporabljeni klasifikaciji za oceno kostnega defekta med načrtovanjem revizijskega posega. V okvir različnih metod za obvladovanje kostnih defektov sodijo cementni poviški, kostni presadki, kovinski distančniki, implantati z deblom in kompenzatorjem odmika ter metafizni stožci in tulci. Če je kostni defekt preobsežen za rekonstrukcijo, je potrebno uporabiti megaendoprotezo oziroma tumorsko endoprotezo. Revizijske implantate oz. endoproteze se lahko glede na stopnjo omejitve gibanja v sklepu (*angl.* konstraint) razdeli v 4 skupine: neomejene, minimalno omejene, delno omejene in visoko omejene. Ta članek povzema pregled sodobne znanstvene literature in predstavi ključna načela za izbiro vsadka pri revizijski artroplastiki kolena.

1 Introduction

Primary total knee arthroplasty (pTKA) is an effective treatment for advanced and end-stage knee arthritis, providing patients with both pain relief and good functional outcomes. The number of pTKAs has been steadily increasing over recent decades due to the ageing global population, expanding indications, and the growing number of younger, more active patients eligible for the procedure. Consequently, the number of revision TKAs (rTKA) has also risen. Population-level analyses from OECD and selected non-OECD countries show annual increases in pTKAs of approximately 5–6%, with the greatest growth in patients younger than 65 years. This demographic shift is expected to result in a disproportionate long-term increase in rTKAs, given the finite lifespan of implants and rising lifetime revision risk (1). The American Joint Replacement Registry predicts that by 2030, the number of pTKAs will increase by 673% and rTKAs by 306%, based on procedure volumes between 2005 and 2012 (2). While global trends indicate rising TKA volumes, similar patterns are seen in Slovenia. In 2016, the demand for pTKAs in the Slovenian population was projected to peak around 2045 at approximately 2,900 procedures (3). However, the National Arthroplasty Registry of Slovenia already reports higher-than-expected increases: the number of primary TKAs rose from 2,834 in 2019 to 3,558 in 2023 (a 28% increase), while revisions increased from 222 to 314 cases (a 37% rise) (4). Historically, polyethylene wear, infection, aseptic loosening, and patellar failure were the principal causes for failure of pTKA. Due to improvements in implant design and manufacturing, polyethylene quality, surgical technique, and infection-reduction methods, these causes were supplemented by mechanical loosening and infection as the main causes of failure in modern pTKAs. It is important to understand that revision TKA is not merely a simple repetition of the primary procedure, but a demanding surgery, requiring detailed pre-operative imaging and planning, including an evaluation of bone loss, an appropriate surgical approach, availability of different implant options, and grafts for adequate management of bone defect and effective post-operative rehabilitation. Over the past 10–15 years, a wide range of new TKA implants, both primary and revision, have been introduced to the market. During the same period, the incidence of rTKA has continued to rise. As these procedures are complex and not routinely performed, it is often necessary to order the appropriate implant in advance and to ensure the availability of all required implant types and components during surgery. This article reviews current evidence and provides guidance on the principles that should inform implant selection in rTKA.

2 Indications for rTKA

The British Orthopaedic Association (BOA) published guidance on the management of patients with problematic TKAs, in which the surgically correctable causes of pTKA failure were summed up in an acronym "SPECIFIC" (5):

- Stiffness and Soft tissue problems (wound breakdown, synovitis, impingement, hemarthrosis, arthrofibrosis)
- Patellar / component malPosition
- Extensor mechanism dysfunction
- Component loosening
- Infection
- Fracture
- Instability
- Component wear / breakage

These indications are also listed in The National Joint Registry of England and Wales (NJR), which shows that 35.0% of revisions are caused by aseptic loosening, 23.0% by periprosthetic joint infection (PJI), 20,0% by component wear, and 14,0% by instability. A study done by Delanois et al, using data from the Nationwide Inpatient Sample (NIS) database, showed that the most common causes for rTKA in the United States from 2009 to 2013 were PJI and aseptic loosening, accounting for 20.4% and 20.3% respectively, followed by instability at 7.5% and wear at 2.6% (2). The National Arthroplasty Registry of Slovenia identified periprosthetic joint infection as the leading cause of rTKA from 2019 to 2023, followed by loosening. More precisely, PJI accounted for 30.8% of cases, loosening for 22.6%, instability, malalignment, and limited range of motion (ROM) for 11.1%, and pain for 7.2% (4). An important shift in failure mechanisms occurred with improvements in polyethylene manufacturing processes. Previously, polyethylene wear and subsequent osteolysis were prevalent causes of rTKA, but the introduction of highly crosslinked polyethylene (HXLPE), additionally stabilized with vitamin E, and improved packaging, which reduces oxidation, made polyethylene spacers more resistant to wear (6). Unicompartmental knee arthroplasty (UKA) has also shown a positive correlation to revision rates, with overall revision rates of UKA compared to TKA being 2.29 times higher in clinical studies and 1.96 times higher in registers. Component malpositioning, improper post-operative limb alignment, and surgeon volume were shown to increase UKA revision rates, with leading indications being aseptic loosening (36.0%), osteoarthritis progression (20.0%), and pain (14.0%) (7).

3 Preoperative evaluation and imaging

3.1 Physical examination

Typical symptoms that may lead to subsequent rTKA include pain since the index procedure or new-onset pain, which may indicate chronic or acute infection, respectively (8), or pain exacerbated by weight-bearing due to mechanical etiologies (8). Stiffness and instability, particularly in stair navigation, level ambulation, or rising from a seated position, might also be present (9). Physical examination primarily evaluates gait abnormalities (e.g., stiff-legged gait or incomplete extension during the stance phase). It also examines active and passive range-of-motion limitations. Signs of inflammation, such as effusion, warmth, or skin changes, may differentiate infection from complex regional pain syndrome (CRPS) (10). Ligamentous stability testing and patellar tracking evaluation are essential for identifying component malalignment, excessive stiffness, or soft-tissue balancing insufficiency (8,9).

3.2 Laboratory studies

Preoperative laboratory tests should primarily focus on ruling out infection. Complete blood count (CBC), sedimentation rate (SR), and C-reactive protein (CRP) measurements are indicated (8). CBC focuses mainly on assessing hemoglobin levels to evaluate the risk of post-operative anemia and transfusion needs (11). Furthermore, white blood cell (WBC) count may be useful for screening for infection (12). Additional tests for infection, including CRP and SR, are crucial for reliably excluding infection or other inflammation (8,12). Aspiration of the knee can be performed to rule out infection using cell count, eubacterial PCR, and bacterial cultivation (8).

Normal prothrombin time (PT) and a standardized INR (international normalized ratio) value might be necessary in patients with either prothrombotic or bleeding states before proceeding with the operation. They are used to evaluate blood clotting and identify potential coagulopathy-related complications during and/or after surgery (11).

3.3 Imaging

A combination of several distinct radiographic methods is utilized to properly evaluate different endoprosthetic parameters. These play a crucial role in determining the cause and possible solutions of patients' clinical problems. Each of these methods has its own advantages and disadvantages, which will be discussed.

3.3.1 X-RAY

Standard preoperative radiographic planning for TKA includes serial anteroposterior (AP) and lateral radiographic images (8). Imaging may provide an assessment of bone loss, visualization of the medullary canal, and estimation of the appropriate stem size and length (10). Weight-bearing radiographs help evaluate any signs of uneven wear on the knee joint. The axial-skyline view is used to evaluate the patellar trackings within the knee (8). Leg length radiographs in the standing position are taken to estimate the overall knee alignment and the longitudinal mechanical axis of the lower limb. Furthermore, an AP radiograph of the pelvis can be used to rule out any potential hip-related issues with referred pain (8). Although radiographs are useful, inexpensive, and relatively reliable, they may not be able to fully capture the extent of bone defects. Up to 46% of knees with small areas of bone necrosis (< 5 mm) cannot be diagnosed preoperatively with radiographs alone (10).

3.3.2 CT and MRI

CT, according to the Berger protocol, is commonly used to assess postoperative rotational positioning of knee arthroplasty components in symptomatic patients with TKA (14). The femoral version can be used to evaluatie femoral vs. tibial component rotation relative to the femoral neck (8). However, the ranges of optimal positioning for both femoral and tibial component rotation are very wide and difficult to standardize due to the high variability in "natural" knee alignment between individuals with healthy knees. MRI may be used to assess soft tissues and neurovascular structures around the TKA, but special sequences and advanced imaging techniques (e.g., metal artifact reduction sequence [MARS]) must be used to minimize the distortions and artifacts caused by metal implants (10,13,14).

3.3.3 Bone scan and SPECT/CT

Bone scintigraphy (= bone scan) plays a limited but specific role in preoperative assessments for revision total knee arthroplasty (TKA), as it is a 2-dimensional bone tracer uptake study (commonly Tc-99m-methylene diphosphonate) combined with the 3-dimensional SPECT/CT. While bone scans may be positive for up to two years after pTKA, the same result could indicate endoprosthetic loosening, infection, or stress fractures (8,12,13). Conversely, a negative bone scan reliably excludes component loosening (8). Diffuse uptake patterns may suggest complex regional pain syndrome (CRPS), where surgical treatment is usually contraindicated. The main disadvantage, however, is the method's inability to differentiate between etiologies of inflammation (13,14). Single-photon emission computed tomography with CT (SPECT/CT) combines the anatomic CT planes with functional information from bone tracer uptake. This can assess causes of pain in noninfected, painful knees. Bone tracer uptake may be used to diagnose endoprosthetic loosening, patellofemoral overloading, malalignment, and subchondral stress. Furthermore, SPECT/CT has a sensitivity of up to 96% and specificity of up to 100% for the detection of tibial and femoral loosening, as well as patellofemoral osteoarthritis. It offers better detail than other imaging, as it can detect functional alterations that might not be visible on radiographs or MRI. SPECT/CT relates the bone tracer uptake patterns to the location of the endoprosthetic component (13,14).

4 Surgical approaches

Proper skin assessment, essential in rTKA, includes inspecting prior surgical scars and evaluating the mobility of the layers superficial to the fascia, which may be scarred from previous surgical procedures. Transverse scars should be crossed as close to the right angle as possible (60° or more), and short scars (less than 1.5cm) can be dismissed. Whenever possible, previous incisions should be reused, preferably the most lateral incision, in order to avoid compromising the blood supply to lateral skin flaps. They should be elevated as a thick, singular layer to preserve the microvascular plexus (15). In cases involving multiple incisions or extensive scarring, a plastic surgeon should be consulted to optimise incision design and potential muscle flap procedures, such as tissue expansion, local rotational flaps, gastrocnemius muscle flaps, and free flaps. The anteromedial parapatellar approach is the standard approach in rTKA, providing excellent exposure for component removal and reconstruction. Initial steps include parapatellar capsulotomy, dissection of the medial structures of the proximal tibia, and sometimes deep MCL release. Additional procedures, such as releasing intraarticular adhesions, performing a wide synovectomy in the suprapatellar area and the medial and lateral gutters, further improve exposure and, by releasing the lateral retinaculum and lateral patellar facetectomy, further improve patellar mobility. External rotation of the tibia during the surgical procedure can reduce tension on the extensor mechanism and help lateral patellar subluxation without the need for eversion, which carries a risk of patellar tendon injury (16).

4.1 Component removal

Component removal begins with the removal of the polyethylene spacer, using a retractor or similar instrument to pry it out, thereby releasing joint tension and improving exposure. The post of hinged spacers can be cut first, aiding removal. The extraction of the femoral component involves using a reciprocating saw from the medial and lateral side, and osteotomes to undermine the posterior condyles and posterior chamfer, while avoiding damage to the underlying bone stock and soft tissues. For stemmed primary or revision implants, additional anterior femoral cortex osteotomies may be necessary, e.g., creating a cortical window to remove residual cement. Tibial component removal also requires careful use of the reciprocating saw to avoid damaging surrounding tissue, with the cuts running in the anteroposterior direction, parallel to the keel. A blunt impactor is later used to pound out the tibial component. Removal of cones, sleeves, and stems during multiple revision surgeries is particularly challenging due to bone ingrowth and often requires the use of a universal stem extractor. If modular implants with cones or stems are present, components should be disconnected first (17).

4.2 Extensile approaches

Extensile approaches are rarely needed but may be indicated in complex cases requiring greater exposure, for example, when a fibrotic quadriceps mechanism and shortened patella tendon are present, or extreme bone defects necessitating extensive distal femoral reconstruction with megaendoprostheses, in which case a lateral approach to the distal femur is preferred. Tibial tubercle osteotomy (TTO) is indicated to supplement the lateral parapatellar approach, to correct patella baja and to avoid impingement in flexion, in case of severe knee ankylosis, or to access a well-fixed tibial component via an anterior cortical window. This technique involves longitudinal medial osteotomy while preserving the periosteum laterally and secure refixation using K-wires or medullary screws. If stable refixation is achieved, flexion limitation may only be necessary during stair navigation and during extended leg raises for 4 weeks postoperatively (18). The quadriceps snip approach, a less invasive option, offers improved exposure without postoperative immobilization, but the technique is rarely used nowadaysbecause newer surgical guidelines disfavour patellar eversion. V-Y quadricepsplasty provides extensile exposure and possible lengthening of the extensor mechanism but carries risks, including extensor mechanism lag and compromised healing. In rare cases, femoral peel techniques and quadriceps muscle lifting via subperiosteal dissection of the distal femur can be employed for severely ankylosed knees (17,18). These techniques must be carefully indicated and performed sparingly to optimize patient outcomes and reduce soft-tissue complications.

5 Mechanisms of bone loss

Given that bone loss management is one of the most important challenges in revision TKA, it is important to understand the etiology and mechanisms underlying it.

5.1 Stress shielding

Stress shielding occurs when an implant reduces mechanical load onthe surrounding bone, leading to bone loss and reduced bone density in the "shielded" region. This can be explained by Wolff's law and Frost's mechanostat hypothesis, which state that bone remodels in response to mechanical stress (19). In TKA, the bone beneath the tibial or femoral component can become osteopenic if the implant offloads force onto the diaphysis, bypassing the epiphyseal and metaphyseal regions. Stiffer implants, for example, those with cobalt-chrome tibial baseplates, were found to cause greater stress shielding than all-polyethylene tibial baseplates, which have greater elastic properties (20). While it is true that stemmed endoprostheses offer better implant stability by resisting shear forces and tibial lift-off, they often worsen stress shielding. The load transferred by the stem extension can bypass critical regions of the bone, leading to decreased bone density and increasing the risk of the implant displacement and periprosthetic fractures (21).

5.2 Aseptic loosening, wear, and osteolysis

Mechanical loosening, also called aseptic loosening, results from excessive loading of the bearing surfaces, often worsened by misaligned components, endoprosthesis instability, and patellar maltracking (6). These issues generate particulate wear, which triggers an inflammatory response by activating macrophages that release chemokines, cytokines, and prostaglandins. At the bone-implant contact, osteoclasts are activated, leading to bone resorption. Moreover, pseudo-synovial and granulomatous tissues produce fluid within the joint space, increasing hydrodynamic pressure. Elevated pressure damages the spongy peri-implant bone, causing osteocyte death and debonding at the implant or cement surface (22). Wear was historically one of the leading causes of rTKA (18), but improved polyethylene and metal component design, improved alignment options, including mechanical, kinematic, and anatomical alignment, improvements in tibial insert locking mechanisms, and reductions in backslide have reduced this problem (23). The polyethylene manufacturing process has evolved to include highly cross-linked PEs (HXLPEs) and additives such as vitamin E, which provide greater wear resistance. Metal debris from the femoral or tibial component can elicit a similar inflammatory response, which, when combined with polyethylene debris, accelerates wear-induced osteolysis (24). Because wear and loosening frequently coexist, evaluating implants during surgery is important to determine the optimal revision strategy. For example, changing only the polyethylene spacer was shown to be an effective solution for resolving insert wear alone (24).

Figure 1: A complicated revision case due to infection. The primary implant (A,B) was removed and a custom-made articulating spacer loaded with vancomycin (C, D) was implanted for 6 weeks in the I. stage. In the II. stage, Medacta revision system (E,F) was implanted (revision femoral component with a long press-fit stem and distal metal block augments, rotating hinge insert, revision tibial component with a long press-fit stem coupled with an offset adaptor).
Source: Department of Orthopaedic Surgery, Novo mesto General Hospital.

5.3 Infection

Both endoprosthetic joint infection (PJI) and its treatment in the process of rTKA result in significant bone loss. During the active stage of infection, bone loss occurs due to direct toxin-mediated damage from bacteria and the subsequent inflammatory and immune response. Bacterial toxins and enzymes contribute to enzymatic degradation, fibrinolytic activation, vascular damage, and bone necrosis. The immune response then triggers the release of antibodies and cytokines, which activate the osteoclasts that perform bone resorption (25). A thorough, systematic debridement of infected and necrotic tissue during revision surgery is necessary to maximize treatment effectiveness. While more loosely fixed cemented implants may be easier to remove, infected cases often require complete removal of the cement mantle, which leads to significant bone loss. The extraction of ingrown uncemented implants at the bone-implant interface can also result in additional bone damage (17). Two-stage revision procedures often use cement spacers, which deliver high concentrations of local antibiotics while preserving joint space and tension on surrounding tissues (Figure 1). Bone loss might occur due to spacer sinking into soft bone, erosion at the bone-spacer interface from shearing, disuse osteopenia and an immune response to wear particulates. Articulating spacers helped mitigate these potential complications by allowing partial weight-bearing and joint flexion (26). The technique of custom-made articulating spacer (CUMARS), initially developed for hip arthroplasty, involves loosely cementing definitive implants that match macroscopic bone architecture. Its advantages include improved function, retained soft-tissue tension, and better patient tolerance between stages of the revision process. In frail or low-demand patients, CUMARS can serve as a definitive treatment, but bone loss may still occur during the second stage, when the latter is necessary, due to spacer removal and additional debridement (27).

6 Classifications of bone loss

The classification of bone loss in TKA is a critical step in pre-operative planning, as it guides the surgeon's choice of reconstruction methods and implants. Initially assessed on pre-operative radiographs and definitively confirmed intra-operatively after component removal and debridement of the osteolytic areas, bone loss is evaluated based on its size, location, depth, and whether an intact peripheral cortical rim remains to contain the defect and support revision components later on. The Anderson Orthopaedic Research Institute (AORI) classification, which has become the most widely adopted system globally, categorizes defects separately for the tibia and femur ("T" or "F"), into three grades (Figure 2). Type I defects involve only minor bone loss at the implant interface without compromising metaphyseal support. Type II defects, which may be further subdivided into IIa (involving one femoral condyle or one side of the tibial plateau) and IIb (involving both condyles or both sides), feature metaphyseal bone damage that requires adjuncts such as cement reinforcement, bone grafting, or metal augmentation to restore the joint line. They can be either contained, indicating central bone loss with an undisturbed cortical rim surrounding it, or uncontained, when a defect in the cortical rim is present. Type III defects involve extensive metaphyseal deficiency, often with ligament detachment and require structural allografts or custom-made implants with extended intramedullary stems (28). Additionally, the zonal classification described by Morgan-Jones et al. defines three anatomical zones (epiphysis, metaphysis, and diaphysis) and recommends achieving stable fixation in at least two zones (29). This assessment affects lower limb alignment, implant selection, and rTKA constraint selection.

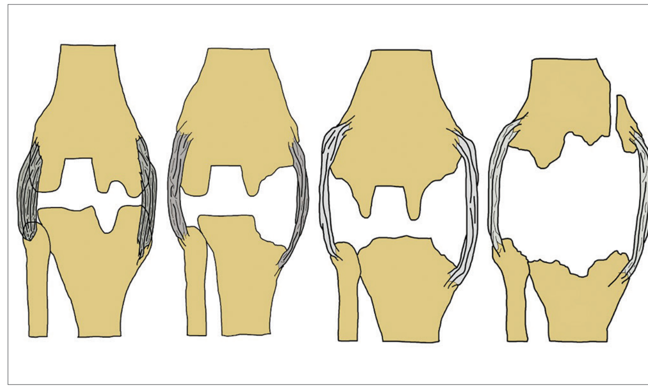

Figure 2: AORI classification (from left to right: Type I, Type II A, Type II B, Type III).
Source: Image is from authors' own archive.

7 Mechanisms for managing bone loss

A number of mechanisms and methodologies for the management of bone loss in rTKA have been proposed: cement, bone graft, metal augments, metaphyseal fit implants (cones and sleeves), and endoprostheses with various degrees of constraint and various tibial inserts, which can be coupled with a stem extension and offset adaptor (Figure 3). If the bone loss is too extensive for reconstruction, a megaprosthesis must be used.

7.1 Cement

Cement is widely available, cost-effective, highly adaptable to the dimensions and shapes of a bone defect, and can deliver antibiotics locally. It is most commonly used for peripheral epiphyseal defects (AORI type I). However, it has a modulus of elasticity much lower than bone; therefore, it may underperform when subjected to shear forces and performs well under compression. Additionally, it carries the risk of thermal necrosis of the nearby bone, which can lead to osteonecrosis and compromised implant stability. Further possible downsides include stress shielding of the surrounding bone because of incomplete load transfer, which reduces its long-term survival (6,30). Cement is recommended only for defects thinner than 5 mm, but can also be combined with screw fixation for treating more extensive AORI type 1 and type 2a defects. This approach has excellent reported outcomes, with no failures in a 13-year follow-up period. However, the use of cement is not advised for defects thicker than 5-8 mm or in patients with poor bone quality (30).

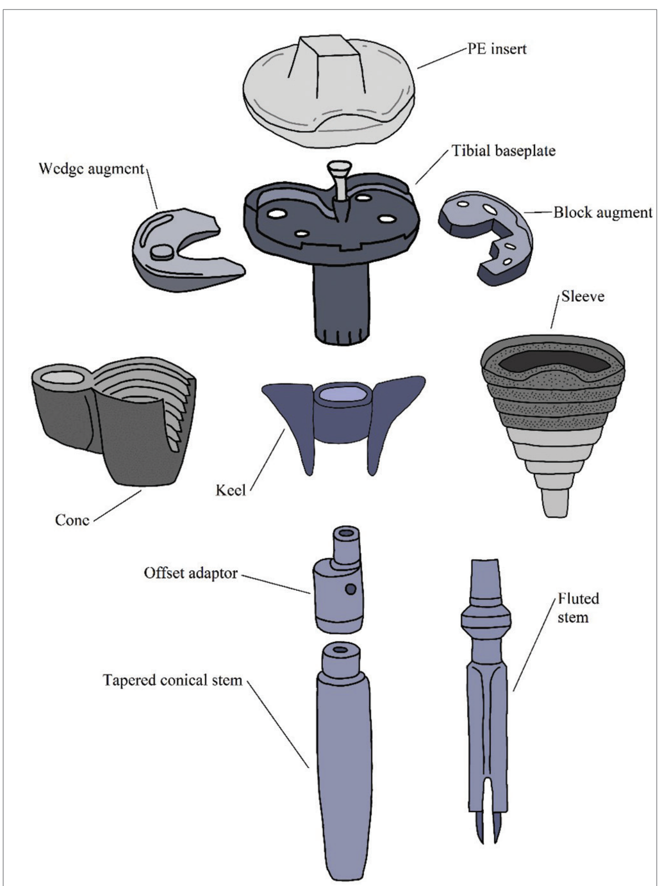

Figure 3: An overview of different tibial revision components available today.
Source: Image is from authors' own archive.

7.2 Bone grafts

Bone grafting can involve either an autograft or an allograft. The general advantages of autografts include easy availability, low cost (compared to custom implants), bone stock restoration, the opportunity to attach collateral ligaments, and intraoperative flexibility. Autografts are typically harvested from the distal femur, iliac crest, or the contralateral tibia and are considered the gold standard due to their osteogenic, osteoinductive, and osteoconductive properties. However, donor site complications, including delayed wound healing, blood loss, chronic pain, and infection, present their downsides. Allografts avoid these donor-site issues but pose risks, such as reduced strength from gamma radiation sterilization, which can lead to graft collapse and fracture, immune rejection, graft resorption, delayed union, and disease transmission. In addition, they are difficult to obtain and represent a considerable logistical challenge. For revisions involving infection, bone grafting is generally unsuitable. Impaction grafting, usually applied to AORI type 1 to type 2 tibial and femoral defects, can use either type of graft with or without mesh for containment, and involves morselization of bone. If an autograft is included, the osteoinductive properties of the final graft are markedly improved. This method is technically complex, time-consuming, and requires careful preparation of both graft and host bone (18,31). Bulk structural allografts are another option for large and uncontained defects, e.g., AORI types 2 and 3, when more than 50% of the tibial hemisphere or a femoral condyle is absent. Femoral head allografts are typically trimmed of fibrous tissue and cortical bone, treated with pulse lavage, and secured with screws into the recipient knee. As many healthy host bone and soft-tissue attachments as possible must be preserved, and the contact must be well prepared. If possible, retaining the patient's epicondyles and integrating them with the graft is advantageous. Directly attaching collateral ligaments to the allograft is not advisable because of the risk of ligamentous insufficiency. Since bone ingrowth is not possible at the endoprosthesis–graft interface, the endoprosthesis components have to be fixed by cement. Contraindications include active infection, neuropathic arthropathy, metabolic bone disorders, immunosuppression, and areas of radiation-induced necrosis. These may lead to graft nonunion, collapse following bone resorption, and implant instability (6,31). Survivorship of bulk structural grafts varies among studies, with the average of 70% at 1 and 10 years, because revascularization and host integration are often absent. For massive segmental bone loss, i.e., an AORI type III defect, the technique of structural allograft-prosthesis composite was used in selected cases in the past but is rarely nowadays (6,18,31).

7.3 Augments

Metal augments are available as blocks or wedges, in symmetric or asymmetric shapes, and are designed to replace mild to moderate metaphyseal bone defects up to 20 mm thick. They are indicated for defects where cement augmentation alone is not suitable, either because of defect thickness or an uneven shape. Metal augments are usually made from solid titanium-aluminum-vanadium alloy, have a blasted surface, can be adapted to the dimensions of the defect, and can be attached with cement or screws. Blocks are generally increased in 5 mm increments, with a total thickness usually not exceeding 15 mm (32). Reconstruction of bone defects using augments is crucial to avoid joint-line deviations, insufficient posterior condyle offset, undersized femoral components, and patellofemoral overstuffing. On the other hand, their placement may require additional resection of healthy bone. Other risks include stress shielding, fretting, and wear debris, which can negatively affect long-term outcomes (33). Augmentation with blocks offers many biomechanical advantages over wedges, including improved stress distribution, greater resistance to compression, and reduced deformation. While augmentation with wedges may be more bone-sparing, studies report higher failure rates. They are also prone to increased shear forces, which lead to loosening and tibial implant migration. A study on medial tibial block augmentation showed that it performs comparably to augmentation in varus knees without bone defects in terms of knee scores and survival rates over 3- to 6-year follow-ups (33).

7.4 Metaphyseal sleeves and cones

Metaphyseal sleeves and cones are used to fill larger metaphyseal bone defects when the cortical bone remains relatively preserved, as metal augments are less effective in such scenarios (32). Metaphyseal (zone 2) fixation is crucial for a stable long-term implant fixation, as it avoids stress shielding related to diaphyseal-only (zone 1) fixation. Fixation nearer to the joint line also provides a better restoration of the joint line and better axial stability (18). While sleeves provide both fixation and augmentation, cones are primarily augmentation components. The latter are typically made from tantalum or titanium and have an ultra-porous outer structure, which encourages osseointegration and enables uncemented implantation. However, internal fixation between the cone and the revision implant is attained by cement. The cone material has a Young's elastic modulus similar to that of cancellous bone, which helps with load transfer and minimizes stress shielding. Functionally, cones act as metaphyseally anchored metallic bone grafts, and any remaining space between the cone and host bone is filled with bone graft or substitute. Despite their high osseointegrative properties, cones can be challenging to remove and may lead to even more extensive bone loss in cases such as infection (32,34). Long-term studies report 75% survivorship over a minimum 10-year follow-up, with failure due to aseptic loosening (15.6%) and infection (9.4%) (34). In contrast, metaphyseal sleeves are made from titanium alloy with an external porous layer of titanium beads or microfragments. Their stepped design ensures maximal bone contact. Compaction broaches, which are sequentially increased in size until rotational stability is reached, are used to prepare the bone for their press-fit implantation. In this way, bone ingrowth is further promoted by Wolff's law (35). The sleeve's interior is smoothly polished and tapered, allowing the stem extension to achieve Morse fixation. Indications for sleeves include bone defects requiring extended fixation from zone 1 to zones 2 or 3, large defects unsuitable for metal augmentation, and constructs needing multiple extension and flexion gap corrections. However, challenges include malalignment, loosening, and intraoperative fractures. Sleeves have good reported survival rates, with a revision rate as low as 2.5% over 4.8 years. Both sleeves and cones have advantages over traditional bone grafting, avoiding problems such as graft resorption, disease transmission, and size mismatches (34,35).

7.5 Stem extensions and offset adaptors

Stem extensions distribute the load and protect the remaining bone by bridging defects in the metaphysis and diaphysis and offloading stress to healthy bone. They are recommended when there is insufficient bone to support the implant, when increased constraint is required, and when correction of femoral hyperextension is needed. They are divided into metaphyseal-engaging stems (MESs) and diaphyseal-engaging (press-fit) stems (DESs). MESs are shorter (30–75mm), made from cobalt-chromium alloy, and cemented in full length, which means they fit the shape of the metaphysis without needing an offset adaptor, but they pose a risk of significant bone loss (36). DESs are longer (75mm +), made from titanium alloy, and are cemented in the proximal section and press-fit in the distal section. In this way, they ensure Zone 3 (diaphyseal) fixation. Downsides include stress shielding, periprosthetic fractures, end-of-stem pain, and higher costs. Determining the appropriate stem length and diameter remains a topic of debate. Longer stems reduce micromotion at the endoprosthesis-bone interface they increase stress shielding beyond 60 mm. Consequently, titanium alloy stems less than 40 mm are often preferred to avoid stress shielding (37). Another difference is diameter: MESs typically have a predetermined diameter, whereas DESs require intraoperative measurement for a press-fit in the medullary canal (36,37). Stem extensions are often coupled with a Z-shaped connector between the tibial/femoral component and the stem extension, called an offset adaptor. The offset refers to the distance between the metaphyseal center and the diaphyseal axis. The use of an offset adaptor helps optimize coverage of the metaphyseal bone while ensuring that the stem extension is properly engaged in the medullary canal. In this way, Zone 1 to Zone 3 fixation is linked, and the risk of malalignment in the coronal or sagittal plane is minimized. An offset adaptor is especially advised for AORI IIa bone defects, where it helps ensure maximal bone-component contact and minimizes overhang and soft-tissue irritation (37).

7.6 Tibial inserts

Polyethylene (PE) spacers are the most frequently worn and failed components in pTKA, making the choice of spacer very important for the outcome of rTKA (6). The design modifications to the intercondylar box and PE post influence the range of valgus/varus movement, lateral translation, rotational stability, and femoral lift-off. The PE spacer and the bearing surface of the femoral component interact in a rolling, sliding, and rotational manner, making wear resistance requirements even stricter for rTKA than for pTKA. Despite this, there have not been many advances in PE's material properties. The primary material used for inserts remains ultrahigh-molecular-weight polyethylene (UHMWPE) (38). Recent innovations, including second-generation HXLPE with vitamin E stabilization and α-tocopherol-modified UHMWPE, promise improved resistance to wear, oxidation, and delamination. PE spacer thickness also influences survival. A minimum thickness of 10 mm is recommended, as wear increases threefold for every 1 mm reduction. Additionally, thicker inserts (over 10 mm) are essential for preserving a physiological joint line of 10–12 mm, particularly since the cruciate ligaments are often sacrificed. Although thicker inserts can help fill bone defects and reduce instability, they also entail greater sliding distances and a higher risk of backside wear (39).

7.7 Endoprosthesis constraint grading

Constraint in TKA endoprosthesis design limits movement in specific directions (anteroposterior and/or mediolateral) and depends on the particular coupling mechanism between the femoral and the tibial component of rTKA (40). The choice of constraint mechanism (Figure 4) is based on the state of collateral

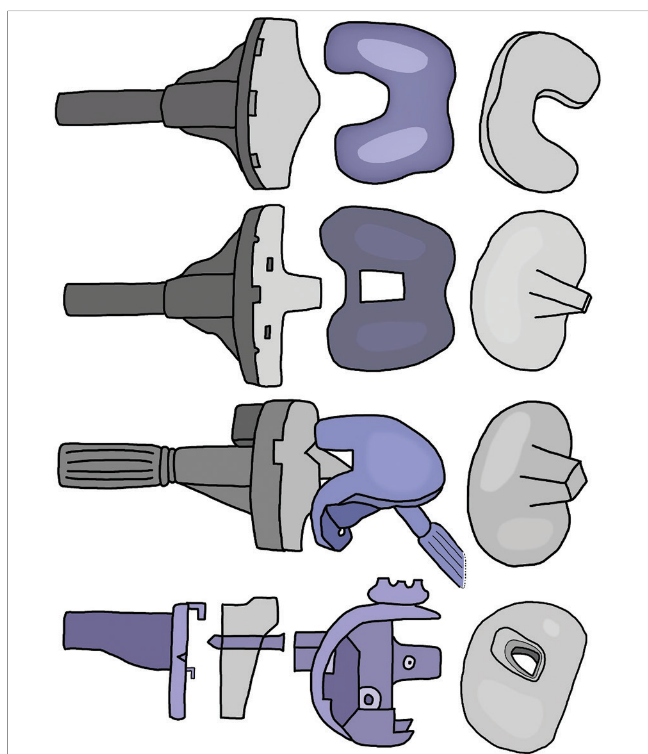

Figure 4: Different constraint mechanisms (from left to right): cruciate-retaining, posterior-stabilized, varus–valgus constrained, and rotating hinge endoprostheses.
Source: Image is from authors' own archive.

ligaments and posterior capsule, which directly influence stability. The more intact and functional the ligaments or the capsule, the less constraint is needed (18). Stability is also linked to the quality of the remaining bone stock, as significant bone loss can compromise the fixation of peripheral stabilizers. However, when components are malpositioned or loosen, the flexion and extension gaps become imbalanced, creating a state of "pseudo-instability." In such cases, since the soft-tissue envelope remains intact, revision of the components can restore proper alignment and balance flexion and extension gaps without the need for more-constrained implants (18,41). Unconstrained endoprostheses, which include bicruciate-retaining designs, unicompartmental knee arthroplasty (UKA), and cruciate-retaining endoprostheses (CR), are rarely used in revisions (18,40). Minimally constrained endoprostheses, such as posterior-stabilized designs (PS), ultracongruent articulations, and third-condylar models, can be used when the posterior cruciate ligament (PCL) is absent but collateral ligaments remain functional. While minimally constrained designs might work for isolated polyethylene spacer changes, more extensive ligament or bone damage often requires a more constrained endoprosthesis. Semiconstrained designs, such as varus-valgus-constrained (VVC) or condylar-constrained knee endoprostheses (CCK), are constrained, unlinked implants. These include a taller and wider central post on the spacer that fits into the femoral cam, increasing stability. A VVC endoprosthesis is used when an imbalance in the medial-lateral direction remains after soft tissue release or when the difference between the medial and lateral compartment gaps exceeds 3–5 mm (42). Highly constrained endoprostheses include fixed-hinge knees and rotating-hinge knees (RHKs) and are used when an additional anti-recurvatum mechanism is needed. Fixed-hinge knees were associated with high loosening rates, especially in young, active patients, and are rarely used nowadays (6,42). Modern RHK designs, however, include a rotating mechanism that allows the tibial component to pivot around the femoral component. Indications for RHKs include extensive bone loss, damaging collateral ligament attachment (AORI type 3), complete ligament insufficiency, severe varus and valgus deformities coupled with flexion contractures or hyperextension, and advanced-stage arthrosis caused by neuromuscular diseases. While more constrained endoprostheses improve stability, they can also increase stress at the endoprosthesis-bone interface, which leads to fretting and faster loosening. Therefore, the least constraining implant that can achieve the desired stability should be used (40).

7.8 Megaprosthesis

A megaprosthesis is used when bone loss is irreparable and replaces the entire proximal tibia or distal femur (6). The primary benefit is preserving the limb and joint movement. However, these implants have some major limitations, including high rates of soft tissue failure, infections, suboptimal function, implant complications, and periprosthetic fractures. They were initially developed for use in en-bloc tumour resection cases. Their use has now expanded to highly comminuted intra-articular fractures of the distal femur and proximal tibia, where reconstruction with ORIF is not ideal, and as a salvage option in rTKA. As the incidence of periprosthetic and interprosthetic fractures rises, internal fixation with screws, plates, or intramedullary nails is usually attempted first, but it often fails due to poor bone stock. In this case, distal femoral or proximal tibial replacement with a megaprosthesis yields outcomes comparable to ORIF (43). Data on the survival rates of megaprostheses in rTKA is limited. Infection rates for megaprostheses differ significantly based on their use. While studies of oncological cases report infection rates of around 15%, rTKA surgeries show substantially lower rates at 9.1% (44). Two complementary intraoperative strategies have emerged to reduce PJIs in megaprosthetic and complex orthopaedic reconstructions: the defensive antibacterial coating (DAC®) hydrogel and silver-coated implants. DAC® is a biodegradable coating of hyaluronic acid and poly-D,L-lactide that forms a temporary barrier on implant surfaces, reducing bacterial adhesion and enabling local antibiotic delivery to target early biofilm formation. Clinical studies show that DAC® lowers infection rates from 5.3% in controls to 0.7%, and preclinical models demonstrate that, when combined with antibiotics, it can reduce bacterial load by up to 99.9% and is fully absorbed within 72 hours, providing protection during the highest-risk postoperative period (45). Silver-coated implants provide a continuous antimicrobial surface through a thin silver layer, inhibiting bacterial colonization and biofilm formation without altering standard surgical techniques or implant integration. Pooled clinical data indicate that silver coatings reduce PJI rates from 13.4% to 9.2% in primary procedures and from 29.2% to 13.7% in revision settings, with low systemic absorption and rare local argyria, offering durable protection against infection (46).

8 Conclusion

Revision total knee arthroplasty is a complex operation that demands thorough planning, precise surgical technique, and a solid understanding of how to recognize and manage bone loss. As the number of primary TKAs continues to rise worldwide, the need for revision procedures will grow as well, making evidence-based revision surgery increasingly important. Classifying bone defects accurately with systems such as AORI and Morgan-Jones helps guide surgeons with implant selection and reconstruction. At the same time, the wide range of available options allows them to adapt treatment to each case. The aim of revision TKA is to restore stability, alignment, and function while reducing the risk of complications. Achieving this requires not only the right implants and reconstruction techniques but also individualized assessment and good perioperative care. While future innovations may further improve outcomes, success today continues to depend on applying evidence-based principles, tailoring surgery to each patient, and counselling them realistically, as revision outcomes are generally less predictable than primary TKA outcomes.

Conflict of interest

None declared.

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