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Total Knee Arthroplasty in Patients with Extra-articular Deformities

(Challenges, Techniques, and Outcomes)

Abstract

Performing total knee arthroplasty (TKA) in patients with extra-articular deformities presents complex and significant surgical challenges that can have both direct and indirect impacts on treatment outcomes. These deformities often require more meticulous planning and tailored surgical strategies to maintain biomechanical alignment of the joint and ensure optimal patient function. Among these strategies are intra-articular corrections and extra-articular osteotomies, with the choice depending on the specific characteristics of the patient and the severity of the deformity. In this context, advanced technologies such as computer-assisted surgery and robotic systems have emerged as innovative tools that enhance accuracy in surgical planning and execution, minimize the risk of surgical errors, and facilitate improved clinical outcomes. This article provides a comprehensive review of current best practices and emerging trends in managing TKA for patients with extra-articular deformities, while also emphasizing the importance of multidisciplinary preoperative planning, advanced imaging assessment, and patient-specific risk evaluation. It further discusses structured decision-making algorithms to guide the selection of appropriate corrective techniques, with careful attention to soft-tissue balance, implant positioning, and long-term stability. Collectively, these considerations aim to optimize functional outcomes, reduce complications, and improve implant longevity in this challenging patient population.

Keywords: Total knee arthroplasty, Knee, Osteotomy, outcomes

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Introduction

Total knee arthroplasty (TKA) is a widely practiced procedure that effectively addresses end-stage knee osteoarthritis and similar debilitating conditions. The main objectives of TKA are to alleviate pain, improve mobility, and restore quality of life.[1, 2] However, the procedure becomes significantly more complex when patients present with extra-articular deformities.[3] These deformities, which occur outside the joint itself, can complicate knee alignment, soft tissue balancing, and overall surgical planning, making standard techniques less predictable. Such deformities may stem from trauma, congenital malformations, previous fractures with malunion, metabolic bone diseases, or even long-standing osteoarthritis leading to compensatory changes in the surrounding structures.[4, 5] Correctly addressing these deformities is essential, as neglecting them during TKA can lead to prolonged pain, impaired function, joint instability, and increased stress on the prosthetic components. These factors may compromise patient satisfaction, accelerate implant wear, and increase the risk of early failure, potentially necessitating revision surgery.[6] Furthermore, the presence of multiplanar deformities may alter the mechanical axis of the lower limb, requiring precise preoperative assessment to determine whether intra-articular correction alone is sufficient or if combined extra-articular procedures are warranted. Careful evaluation of limb alignment, bone stock, and soft tissue integrity is therefore critical to achieving balanced reconstruction and durable implant fixation. This article reviews the current treatment algorithms and approaches for managing extra-articular deformities, including radiographic evaluation, surgical planning, implant selection, the role of computer-assisted navigation, and the multidisciplinary approach required to optimize patient outcomes and ensure long-term prosthetic survival.

Etiology of Extra-articular Deformities

Extra-articular deformities of the femur and tibia can result from several factors, including congenital anomalies, metabolic bone diseases, posttraumatic malunions, and previous surgeries.[7, 8] Among the most common causes are malunions, leading to altered alignment and abnormal mechanical stress across the knee.[9, 10] These malunions can disrupt normal knee function and increase the risk of developing knee osteoarthritis.[11, 12] Although some studies have questioned the direct link between femoral malunions and knee osteoarthritis, it is generally accepted that the severity of the deformity plays a significant role in the progression of osteoarthritis.[13-18]

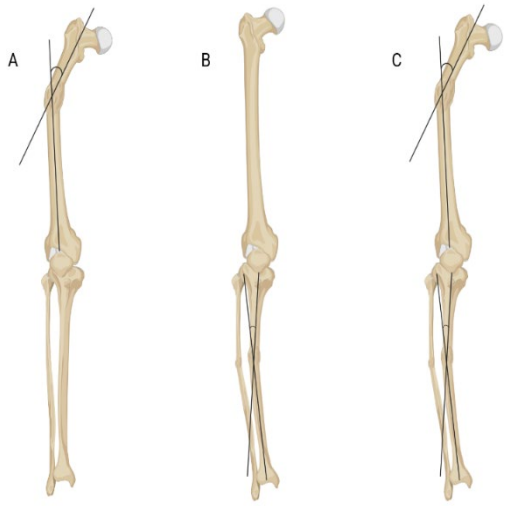

Figure 1: Different locations of deformities for considering extra-articular osteotomy. Deformity in femur (A), deformity in tibia (B), combined femoral and tibial deformities (C).

Additionally, metabolic bone diseases such as osteogenesis imperfecta, Paget's disease, and rickets can contribute to structural bone changes that lead to deformities, often resulting in weakened bone quality and joint instability.[18, 19] When treating patients with such conditions, of bone fragility, they may complicate the surgical approach and require special handling during the procedure.

Classification

The extra articular deformities can be classified based on their anatomical location (femoral, tibial, or combined), direction (varus, valgus, flexion, extension, or rotational), and severity.[10] The severity of the deformity is typically measured in degrees of angulation or millimeters of translation from the normal anatomical axis. Femoral deformities are often categorized as varus or valgus in the coronal plane, and flexion or extension in the sagittal plane. Tibial deformities may be described as varus, valgus, or rotational. Combined deformities involving both the femur and tibia present additional complexity and may require more extensive surgical planning and intervention (figure 1).[3, 20]

Preoperative Evaluation and Planning

Thorough preoperative evaluation is essential for successful outcomes in TKA with extra-articular deformities. This evaluation begins with a comprehensive patient history, focusing on the etiology of the deformity, previous treatments or surgeries, and the patient's functional limitations and expectations.[21-24]

Physical examination should assess the patient's gait, range of motion, ligamentous stability, and neurovascular status. The examiner should note any leg length discrepancies, rotational abnormalities, or fixed flexion deformities. A careful evaluation of the soft tissues, including skin quality and previous surgical scars, is crucial for surgical planning.[14, 18, 22]

Imaging studies play a critical role in the assessment of extra-articular deformities. Standard radiographs, including weight-bearing lateral and coronal views of the knee, provide initial information about joint space narrowing, osteophyte formation, and bone quality.[9, 25] However, for patients with extra-articular deformities, full-length lower extremity radiographs are essential. These images, often referred to as hip-to-ankle or long-leg films, allow for accurate measurement of the mechanical and anatomical axes of the lower limb, as well as the assessment of the overall limb alignment.[7, 20, 26]

Advanced imaging modalities such as computed tomography (CT) and magnetic resonance imaging (MRI) may be necessary in complex cases. CT scans can provide detailed information about bone geometry and rotational alignment, which is particularly useful in cases of rotational deformities or when planning corrective osteotomies. MRI can offer additional information about soft tissue structures, including ligaments and muscles, which may be affected by long-standing deformities.[5, 20]

In some cases, three-dimensional printing technology may be used to create patient-specific models or cutting guides, enhancing the precision of the surgical procedure.[27, 28]

Coronal Plane Deformities

Preoperative planning for TKA in patients with extra-articular deformities in the coronal plane begins by determining the degree of deformity and its impact on knee alignment. In cases where the deformity is mild and the CORA (center of rotation of angulation) is located farther from the joint, intra-articular corrections can often be achieved.[29-31] If the deformity is more severe or the CORA is closer to the knee joint, osteotomy may be required to fully correct the alignment before proceeding with TKA.[20, 26, 32] Additionally, surgeons must assess the involvement of the collateral ligament insertions to ensure the cuts made during TKA will not disrupt ligamentous integrity.[20, 31, 32]

Table 1: Correction of different extraarticular deformities based on locations in TKA

Deformity Location	Deformity Type	Acceptable Angle for Intra-articular Correction	Recommended Correction Method for Larger Angles
Femur	Coronal plane	Up to 20°	>20°: Extra-articular osteotomy
Femur	Sagittal plane	Up to 15°	>15°: Extra-articular osteotomy
Tibia	Coronal plane	Up to 30°	>30°: Extra-articular osteotomy
Tibia	Sagittal plane	Up to 10°	>10°: Extra-articular osteotomy
Combined femoral and tibial	Coronal plane	Up to 35° total	>35°: Consider staged correction
Rotational deformity	Axial plane	Up to 15°	>15°: Extra-articular derotational osteotomy

For deformities that exceed 20 degrees in the femur or 30 degrees in the tibia, extra-articular osteotomy should be considered (table 1). In these cases, correction must be achieved before TKA, as intra-articular adjustments alone will not restore proper knee function. The magnitude of deformity and its proximity to the joint must be carefully assessed using preoperative templating and measurements from radiographic images.[20, 26, 29-32]

Sagittal Plane Deformities

Sagittal plane deformities, such as flexion or extension malalignments, tend to be more tolerable during TKA than coronal plane deformities. Studies suggest that intra-articular correction is feasible for sagittal plane deformities up to 10 degrees of flexion (procurvatum) or 20 degrees of extension (recurvatum). Larger deformities, particularly those greater than 20 degrees, typically require a corrective osteotomy prior to TKA (table 1).[33]

In cases of recurvatum, which involves hyperextension of the knee, TKA can generally restore alignment without risk of femoral notching. However, procurvatum deformities, which cause excessive flexion, pose a higher risk of femoral notching during correction.[33] For combined coronal and sagittal deformities, more complex solutions such as hexapod frames, which allow gradual correction in multiple planes, can be employed.[34]

Rotational Deformities

Rotational deformities, often overlooked in TKA, can significantly impact the alignment and function of the knee joint. These deformities are often diagnosed through clinical evaluation of gait and examination of foot progression angles. Subtle rotational abnormalities may also be indicated by patellar subluxation on plain radiographs. When suspected, cross-sectional imaging, typically a CT scan, is essential for assessing femoral version and confirming the degree of rotational deformity.[35]

Correcting rotational deformities during TKA can be challenging, as the procedure allows for only minimal correction of axial malalignments. Therefore, correction of significant rotational deformities is generally best performed in a staged procedure before TKA. This approach reduces complications, such as excessive femoral notching or improper alignment during surgery, and ensures optimal outcomes.[33]

Limb-Length Discrepancy

Limb-length discrepancies (LLD) are common in patients with extra-articular deformities. In these cases, the affected limb is often shorter. Major LLD (10 mm or more) must be addressed before or during TKA. Surgical options include using intramedullary lengthening nails (ILNs) to simultaneously correct both deformity and limb-length discrepancies, although these devices can cause varus or valgus deformities depending on the nail's stiffness and the patient's bone structure. Preoperative planning should carefully assess the required correction angles and the

expected outcomes of the lengthening procedure. A successful limb-lengthening procedure can greatly improve patient outcomes by restoring functional limb length and correcting the mechanical axis.[20]

Surgical Techniques and Considerations

The surgical approach to TKA in patients with extra-articular deformities depends on the nature and severity of the deformity, as well as the surgeon's experience and preference. The primary goal is to achieve a stable, well-aligned knee with balanced soft tissues and appropriate implant positioning.[36, 37]

Correction types

Intra-articular Correction

For mild to moderate extra-articular deformities or when the deformity is distant from the joint, correction can often be achieved through intra-articular techniques alone.[36] Indications for intra-articular correction typically include:
a) Sagittal deformities up to 20°;
b) Femoral coronal deformities up to 15-20°;
c) Tibial coronal deformities up to 30° [6,36,38].

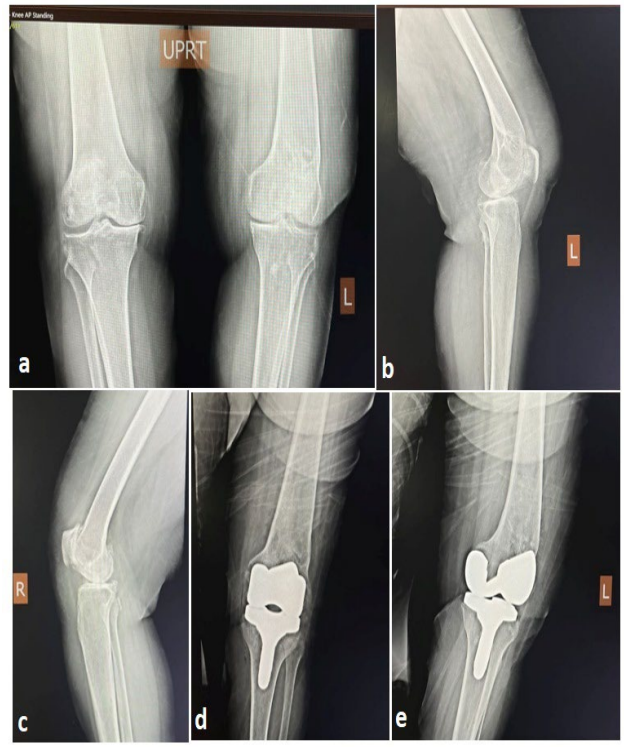

Figure 2: Intra-Articular Correction of Moderate Extra-Articular Deformity During Total Knee Arthroplasty

This approach involves careful bone resection and soft tissue balancing within the knee joint itself. The principle is to create rectangular flexion and extension gaps that are equal and symmetrical, which may require asymmetric bone cuts and selective soft tissue releases.[36] In cases of varus deformity, for example, this might involve a more conservative cut on the medial tibial plateau combined with a lateral soft tissue release (figure 2). Conversely, valgus deformities may require lateral femoral condyle under-resection and medial advanced soft tissue releases.[37] The key is to achieve a balance between bony alignment and soft tissue tension.[36]
Advantages of intra-articular correction include:[36]
- Being less invasive compared to osteotomy;
- Single-stage procedure;
- Avoids complications associated with osteotomies.
Limitations:[36, 39, 40]
- Not suitable for severe deformities;
- May require extensive soft tissue releases;
Risk of ligament imbalance.
A 61-year-old female with moderate left knee deformity underwent TKA. (**a** through **c**) The preoperative deformities were within thresholds suitable for intra-articular correction (≤20° sagittal, ≤15–20° femoral coronal, or ≤30° tibial coronal). (**d** and **e**) Postoperative images reveal successful mechanical axis restoration using selective bone resections and soft tissue balancing, with symmetrical and rectangular flexion-extension gaps achieved, eliminating the need for osteotomy.

Extra-articular Correction

For more severe deformities, or when intra-articular correction would compromise the collateral ligaments or lead to excessive bone resection, extra-articular correction may be necessary.[36,39] This typically involves an osteotomy of the femur or tibia to correct the deformity before or during the TKA procedure. Femoral osteotomies can be performed at various levels, depending on the location and nature of the deformity. Distal femoral osteotomies are common for correcting varus or valgus deformities near the knee joint, while more proximal osteotomies may be required for deformities closer to the hip. Tibial osteotomies are typically performed in the proximal tibia and can address varus, valgus, or rotational deformities.[36] Osteotomies can be performed as a staged procedure or simultaneously with the TKA. The decision between staged and simultaneous procedures depends on several factors, including the severity of the deformity, the complexity of the required correction, and the surgeon's experience.[33,36]

Staged procedures allow for healing of the osteotomy site before TKA but require two separate surgeries.[33] Simultaneous procedures can be more challenging but offer the advantage of a single surgical intervention and recovery period.[36]

Advantages:[36]

- Allows for true correction of severe deformities;
- Can reproduce native knee laxity and overall lower limb axis;
- Suitable for deformities close to the joint.

Disadvantages:[36]

- More invasive procedure;
- Higher risk of complications;
- May require staged approach.

Implant Selection and Positioning

Proper implant selection is crucial in TKA with extra-articular deformities.[37, 41] While standard implants may be sufficient in some cases, others may require more constrained designs or the use of augments and stem extensions.[39, 41] The level of constraint should be carefully considered, balancing the need for stability with the preservation of bone stock and the potential for future revisions. Implant positioning in the presence of extra-articular deformities can be challenging. The goal is to achieve overall limb alignment while respecting the joint line and ensuring proper patellofemoral tracking.[39] This may involve compromises between anatomical and mechanical alignment principles, particularly in cases where full correction of the extra-articular deformity is not feasible or desirable.[41, 42]

In cases of severe deformity or poor bone quality, the use of stemmed implants and augments may be necessary.[29, 41] Stems can provide additional stability by extending the fixation into the diaphysis of the bone. Augments, such as metal blocks or wedges, can help address bone defects and achieve proper alignment without excessive bone resection.[41]

Neurovascular Protection

When performing surgery on patients with extra-articular deformities, especially those requiring osteotomies, there is an increased risk of injury to neurovascular structures.[34, 43] The peroneal nerve, in particular, is vulnerable when significant bone cuts are made in the tibia or femur. Preoperative assessment of the neurovascular structures is crucial to mitigate risks during surgery. Surgeons must be prepared for potential complications such as nerve palsy, particularly if large or rapid deformity corrections are required.[43]

When correcting multi-planar deformities, external fixators like hexapod frames are beneficial because they allow for gradual correction, which helps avoid acute soft tissue tension and reduces the risk of nerve injury. Close postoperative monitoring is essential, and patients should be thoroughly educated about the risks of nerve damage and the signs of complications.[34]

Infection Risk

Infection remains a major concern for patients undergoing TKA, particularly in those who have had previous surgical procedures such as osteotomies or external fixators. The use of external fixators increases the risk of infection at pin sites, which may extend to the joint or underlying bone. Therefore, a meticulous preoperative infection workup is essential, including inflammatory markers and joint aspiration when necessary.[36]

In cases where a previous implant is present, surgeons must carefully assess for any signs of deep infection before proceeding with arthroplasty. Preventive measures, such as antibiotics, should be used appropriately.[3]

Computer-assisted and Robotic-assisted TKA

Advanced technologies such as computer navigation and robotic-assisted surgery have shown promise in improving accuracy and precision in TKA, particularly in cases of extra-articular deformity. These technologies can aid in achieving more precise bone cuts, optimizing implant positioning, and balancing soft tissues. Computer navigation systems provide real-time feedback on limb alignment and component positioning, allowing for intraoperative adjustments.[4, 30, 35, 44-47] Robotic-assisted systems offer the additional advantage of haptic feedback and can execute precise bone cuts based on preoperative planning.[48-50] While these technologies show potential benefits, they also have limitations, including increased operative time, learning curve, and cost. Their role in TKA for extra-articular deformities continues to evolve, and long-term outcome studies are needed to fully establish their efficacy.

Management of Specific Deformities

Femoral Deformities

Femoral deformities can present in various planes and often require a combination of techniques for correction.[43] Varus and valgus deformities in the coronal plane may be addressed through careful intra-articular bone resection and soft tissue balancing if mild to moderate.[6] More severe deformities may require femoral osteotomy, either distal or proximal, depending on the apex of the deformity. The functional impact of a deformity on limb alignment is determined more by its location than its angular magnitude. Midshaft deformities, for instance, alter the mechanical axis by approximately 50%, highlighting the importance of both level and severity in surgical planning (figure 3).[39]

A 69-year-old man with a pronounced extra-articular deformity of the right proximal femur underwent TKA. (**a** through **d**) Preoperative imaging revealed marked varus malalignment originating in the upper femur, situated well above the knee joint. Given the deformity's location, its influence on the overall mechanical axis was diminishing distally, making it amenable to intra-articular correction during TKA. (**e** and **f**) Postoperative radiographs confirmed successful realignment of the limb and secure placement of the prosthetic components, all achieved in a single-stage surgical intervention.

Rotational deformities of the femur can significantly affect patellofemoral mechanics and overall knee kinematics. Correction of these deformities often requires a rotational osteotomy, which can be performed at the distal femur or more proximally. The amount of correction needed should be carefully planned preoperatively using CT scans to assess femoral anteversion.[46]

Flexion or extension deformities in the sagittal plane can be particularly challenging. Mild flexion deformities can often be addressed through careful soft tissue releases and appropriate bone resection. However, severe Tibial deformities are commonly encountered in the coronal plane as varus or valgus angulation. Mild to moderate deformities can often be corrected through intra-articular techniques, including asymmetric bone resection and soft tissue balancing.[38, 51]

More severe deformities may require a proximal tibial osteotomy, which can be performed simultaneously with the TKA or as a staged procedure.[52, 53] Rotational deformities of the tibia can affect patellar tracking and overall knee function. Correction of significant tibial torsion typically requires a rotational osteotomy, which is often performed at the supramalleolar level to avoid compromising the proximal tibia for implant fixation.[54]

Anterior or posterior bowing of the tibia in the sagittal plane can affect implant positioning and overall limb alignment. In some cases, this may necessitate the use of offset stem extensions or even tibial osteotomy to achieve proper alignment and implant fit.[52] fixed flexion deformities may require more extensive soft tissue releases or even femoral osteotomy to achieve full extension.[3]

Tibial Deformities

Tibial deformities are commonly encountered in the coronal plane as varus or valgus angulation. Mild to moderate deformities can often be corrected through intra-articular techniques, including asymmetric bone resection and soft tissue balancing.[38, 51] More severe deformities may require a proximal tibial osteotomy, which can be performed simultaneously with the TKA or as a staged procedure.[52, 53]

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Combined Deformities

Patients with combined femoral and tibial deformities present the greatest challenge in TKA.[20] These cases require careful preoperative planning to determine the optimal correction strategy.[39] In some instances, correction of one deformity (e.g., femoral) may sufficiently improve overall limb alignment, obviating the need for correction of the other (e.g., tibial).[20] However, in severe cases, both femoral and tibial corrections may be necessary.[55, 56]

The sequence of correction in combined deformities is crucial. Generally, the more proximal deformity is addressed first, as this can influence the alignment of

the more distal segments.[49] However, the specific approach should be tailored to each patient's unique anatomy and functional needs.[39]

In cases of multi-planar deformities, the use of hexapod external fixators for gradual correction prior to TKA may be considered. This approach allows for precise correction of complex deformities and can be particularly useful in cases where acute correction would put neurovascular structures at risk.[34]

Postoperative Management and Rehabilitation

Postoperative management of patients undergoing TKA with correction of extra-articular deformities follows many of the same principles as standard TKA, with some important considerations.[5] Pain management is crucial, and multimodal analgesia protocols are typically employed to facilitate early mobilization and rehabilitation.[36, 46]

Early mobilization is encouraged to prevent stiffness and promote muscle strength and joint function. However, in cases where osteotomies have been performed, weight-bearing restrictions may be necessary to allow for bone healing. The specific rehabilitation protocol should be tailored to the individual patient, taking into account the nature of the deformity correction and any additional procedures performed.

Physical therapy plays a vital role in the recovery process. Initial focus is on regaining range of motion, particularly in cases where significant soft tissue releases or osteotomies have been performed. As healing progresses, emphasis shifts to strengthening exercises and gait training. Patients with long-standing deformities may require extended rehabilitation to overcome ingrained movement patterns and optimize their new biomechanical alignment.[37]

Long-term follow-up is essential for patients who have undergone TKA with correction of extra-articular deformities. Regular clinical and radiographic assessments are necessary to monitor implant position, bone healing (in cases of osteotomy), and overall limb alignment.[57] Any signs of instability, malalignment, or implant loosening should be promptly addressed to prevent more serious complications.[36]

Outcomes and Complications

Outcomes of TKA in patients with extra-articular deformities can be highly satisfactory when appropriate surgical techniques are employed.[39, 47] Many studies have reported significant improvements in pain, function, and quality of life following these procedures.[41, 51, 58-61] However, it's important to note that outcomes may be more variable compared to primary TKA in patients without extra-articular deformities, and patient expectations should be managed accordingly.[45, 61, 62]
Functional outcomes, as measured by range of motion and standardized knee scores, generally show substantial improvement postoperatively.[63, 64] However, patients with severe preoperative deformities or those requiring extensive soft tissue releases may experience more limited gains in range of motion.[29, 30, 65] Patient-reported outcome measures typically demonstrate high levels of satisfaction, particularly in terms of pain relief and improved mobility.[20, 48, 65]

Figure 3: Intra-Articular Correction of Extra-Articular Femoral Deformity During Total Knee Arthroplasty

Radiographic outcomes focus on the achievement and maintenance of proper limb alignment and implant positioning. While perfect mechanical alignment may not always be achievable or desirable in cases of severe extra-articular deformity, the goal is to optimize overall limb function and implant longevity.

Complications following TKA with correction of extra-articular deformities can be more frequent and severe compared to standard TKA. These may include:
- Infection: The risk of infection may be increased due to longer operative times and more extensive soft tissue dissection.[54, 56]
- Instability: Achieving proper soft tissue balance can be challenging in the presence of extra-articular deformities, potentially leading to instability.[54, 62]
- Periprosthetic fracture: Patients with poor bone quality or those undergoing simultaneous osteotomy may be at increased risk of periprosthetic fracture.[66, 67]
- Neurovascular injuries: Correction of severe deformities can put neurovascular structures at risk, particularly in cases of long-standing valgus deformities where the peroneal nerve may be vulnerable.[6, 68, 69]
- Implant failure: Suboptimal implant positioning or persistent abnormal biomechanical forces may lead to early implant loosening or failure.[4, 44]
- Recurrence of deformity: In some cases, particularly with incomplete correction or in patients with underlying metabolic bone diseases, there may be a risk of deformity recurrence over time.[55, 70]
Careful preoperative planning, meticulous surgical technique, and vigilant postoperative management are essential to minimize these risks and optimize outcomes.

Future Directions in TKA for Extra-Articular Deformities

The field of TKA for extra-articular deformities is evolving rapidly with advancements in surgical techniques and technologies. One promising development is the continued integration of kinematic alignment approaches, which seek to restore the patient's native knee kinematics rather than simply aiming for standard mechanical alignment. These methods may improve functional outcomes, particularly in patients with complex deformities.

Further research into the use of 3D modeling and patient-specific instrumentation for preoperative planning could lead to more personalized surgical approaches, optimizing the alignment and reducing complications. Additionally, the role of artificial intelligence (AI) in surgery is expanding. AI algorithms may assist in preoperative planning by analyzing large datasets, predicting surgical outcomes, and refining the accuracy of implant positioning.[4, 71] These advances hold promise for reducing surgical errors and improving long-term outcomes.

Summary

The management of extra-articular deformities in TKA requires careful planning, advanced imaging, and a multidisciplinary approach. Proper preoperative evaluation using full-length radiographs and other imaging techniques helps determine the appropriate surgical approach. Surgeons must be prepared to perform intra-articular corrections or extra-articular osteotomies based on the severity and location of the deformities. Advances in technology, such as computer-assisted navigation and robotic systems, have the potential to improve surgical precision and outcomes, although their implementation is currently limited by cost and training requirements.
Postoperative complications, including residual malalignment, ligament imbalance, and nerve injury, must be carefully managed. Preventive measures, such as preoperative neurovascular assessments and infection controls, are essential to minimize risks. As the field continues to evolve, new innovations in personalized implants and AI-driven preoperative planning may further enhance the management of extra-articular deformities in TKA, ultimately leading to better patient outcomes.

Conflict of interest

The authors declare they don't have any conflict of interest.

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