Review Article

Management of Extra-articular Deformity in the Setting of Total Knee Arthroplasty

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Abstract

Extra-articular deformities of the femur and tibia in conjunction with advanced knee osteoarthritis pose unique challenges for the arthroplasty surgeon. Careful preoperative planning is needed to evaluate both the intra- and extra-articular deformities and to determine the best route to total knee arthroplasty. An intra-articular compensatory correction can typically be performed if the extra-articular deformity is distant from the joint or if preoperative templating shows that bony cuts do not interfere with ligamentous attachments. Staged osteotomy followed by arthroplasty is beneficial in severe cases in which bony cuts are excessive or would interfere with soft-tissue structures and in cases with leg-length discrepancy. Osteotomies can be performed percutaneously and fixed with intramedullary nails, external fixators, or plate and screw constructs. Ligamentous laxity after correction and risk of peroneal nerve injury are increased in extra-articular deformity cases and must be considered during the knee arthroplasty procedure with increased implant constraint and patient counseling, respectively. Computer-assisted navigation has an emerging role in total knee arthroplasty in patients with extra-articular deformity.

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More than 700,000 total knee arthroplasties (TKAs) are performed annually in the United States.[1] Although correction of intra-articular pathology is a mainstay of TKA, less has been published on the evaluation and management of extra-articular deformity in the setting of TKA. An extra-articular deformity may be a result of previous trauma or skeletal developmental abnormalities and may increase the risk of knee osteoarthritis.[2] Thus, orthopaedic surgeons should be aware of the diagnosis and treatment algorithms for extra-articular deformity in the setting of TKA. Performing a TKA without addressing underlying extra-articular malalignment may place the patient at risk of ongoing pain and early implant failure.[3] The purpose of this article is to present treatment algorithms for the management of extra-articular deformity in either the femur or tibia and in the coronal, sagittal, or axial plane and to review the radiographic imaging, surgical planning, and multidisciplinary approach necessary to optimize clinical outcomes and minimize arthroplasty failure.

Causes of Extra-articular Deformity of the Femur and Tibia and Its Association With Knee Osteoarthritis

Causes of extra-articular deformity of the femur and tibia are numerous and can lead to varying degrees of deformity. Specific causes include metabolic bone diseases, congenital abnormalities, posttraumatic malunion, and previous osteotomies.[4] Fracture malunion of the femur and/or tibia, one of the most common causes of extra-articular deformities around the knee,[5] may cause altered knee kinematics and asymmetric compartmental forces related to the deformity and resultant mechanical axis deviation (MAD) that may lead to early degenerative changes in the knee joint.[6,7] However, the direct link between fracture malunion and knee osteoarthritis has been questioned because a study of femoral shaft malunions with more than 20 years of follow-up did not find an association between femur malunion and knee osteoarthritis.[8] The severity of the deformity, not the malunion itself, is likely the most important determinant of overall knee function and risk of osteoarthritis progression. In a study of 237 patients with knee osteoarthritis, Sharma et al[2] noted that more than 5° of varus or valgus deformity had a five times greater risk of osteoarthritis progression over an 18-month period compared with neutral controls. In addition, they found that the magnitude of mechanical malalignment correlated with a decline in physical function and increase in osteoarthritis. These longitudinal studies demonstrating increasing osteoarthritis progression, particularly with mechanical deformities greater than 5°, suggest that untreated fracture malunions may require TKA at a higher rate than normal controls. For this reason, it is likely that joint arthroplasty surgeons will encounter patients with extra-articular deformities and end-stage osteoarthritis necessitating TKA, and appropriate management of these deformities at the time of TKA is critical to a successful clinical outcome.

Another cause of extra-articular deformity about the knee is congenital or metabolic bone diseases.[5] These include osteogenesis imperfecta, causing a bony bowing or thinning deformity, Blount disease, causing varus deformity of the proximal tibia and distal femur, and hereditary hypophosphatemia or hyperparathyroidism, which lead to worsened bone quality and a variety of deformities. Tumors, both benign and malignant, are another cause of extra-articular deformity. Tumors themselves, and the medications used in the management of tumors, can lead to worsened bone quality and deformity and should be treated in consultation with a tumor surgeon. Finally, Paget disease of bone occurs from a disorganized bony deposition that causes the bone to become sclerotic and thickened. Associated deformities include distal femoral valgus and anterior bowing of the tibia. Patients with Paget disease are also at risk of increased blood loss during surgery, and advanced planning should be done for these patients before they undergo TKA.[5]

Radiographic Evaluation

Long leg hip-to-ankle radiographs in the AP and lateral planes are essential for accurate preoperative planning and assessment of an extra-articular deformity. Alghamdi et al[9] noted that more than 50% of extra-articular deformities of the tibia are not detected on short films of the knee. We routinely obtain full-length radiographs for all TKA patients to evaluate the deformity and allow for appropriate preoperative planning.[10] Although positioning can be difficult in cases of severe deformity, every attempt should be made to position the patient in an anatomic fashion. Correlation should be made between the physical examination and the positioning of the radiographic images. Several measurements are made on the calibrated full-length standing radiographs to evaluate the location and extent of deformity (Table 1).

Coronal Plane Measurements

In the coronal plane, the MAD is used to evaluate for varus or valgus deformity. The lateral distal femoral angle (LDFA) and the medial proximal tibial angle (MPTA) determine whether the deformity is originating from the femur, the tibia, or both. The joint line convergence angle indicates the amount of deformity coming from within the joint. The center of rotation of angulation (CORA) is useful to determine the distance of the deformity from the joint and can be used if osteotomy planning is being considered.

Sagittal and Axial Plane Measurements

The posterior distal femoral angle and the posterior proximal tibial angle are the primary measurements used to evaluate the degree of deformity in the sagittal plane.

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Table 1

Radiographic Measurements for Preoperative Assessment of Deformity[11]

Measurement	Description	Normal Range	Clinical Significance
Coronal plane measurements			
MAD	Measured by drawing a line from the center of the femoral head to the center of the ankle and drawing a second line from the center of the tibial spines to meet the first line	0-8 mm medial	Any line that is drawn laterally is considered a valgus deformity, and any line greater than 8 mm medial is considered a varus deformity
LDFA	Angle between a line from the center of the hip to the center of the knee and a second line connecting the femoral condyles	85°-90°	Angle outside of normal range indicates deformity originating from the femur
MPTA	Angle between a line down the shaft of the tibia and a line across the top of the tibial condyles	85°-90°	Angle outside of normal range indicates deformity originating from the tibia
JLCA	Angle between a line drawn across the tibial condyles and a line across the femoral condyles	0°-2°	Angle greater than normal range indicates deformity originating from inside the joint, either from cartilage loss or ligamentous instability
Sagittal plane measurements			
PDFA	Angle between the sagittal distal femoral joint line and the mid-diaphyseal line of the femur	79-83	Angle outside of the normal range indicates a sagittal plane deformity of the femur
PPTA	Angle between the sagittal tibial joint line and the mid-diaphyseal line of the tibia	77-84	Angle outside of the normal range indicates a sagittal plane deformity of the tibia
Axial plane measurements			
LLD	Distance measured from the top of the femoral head to the center of the ankle joint on each limb	NA	Any discrepancy should be noted and accounted for in the correction of the deformity
Deformity measurements			
CORA	Location where the anatomic axes of the bone proximal to the deformity and distal to the deformity meet	NA	Often used as the basis for where to plan the osteotomy if corrective surgery is being considered

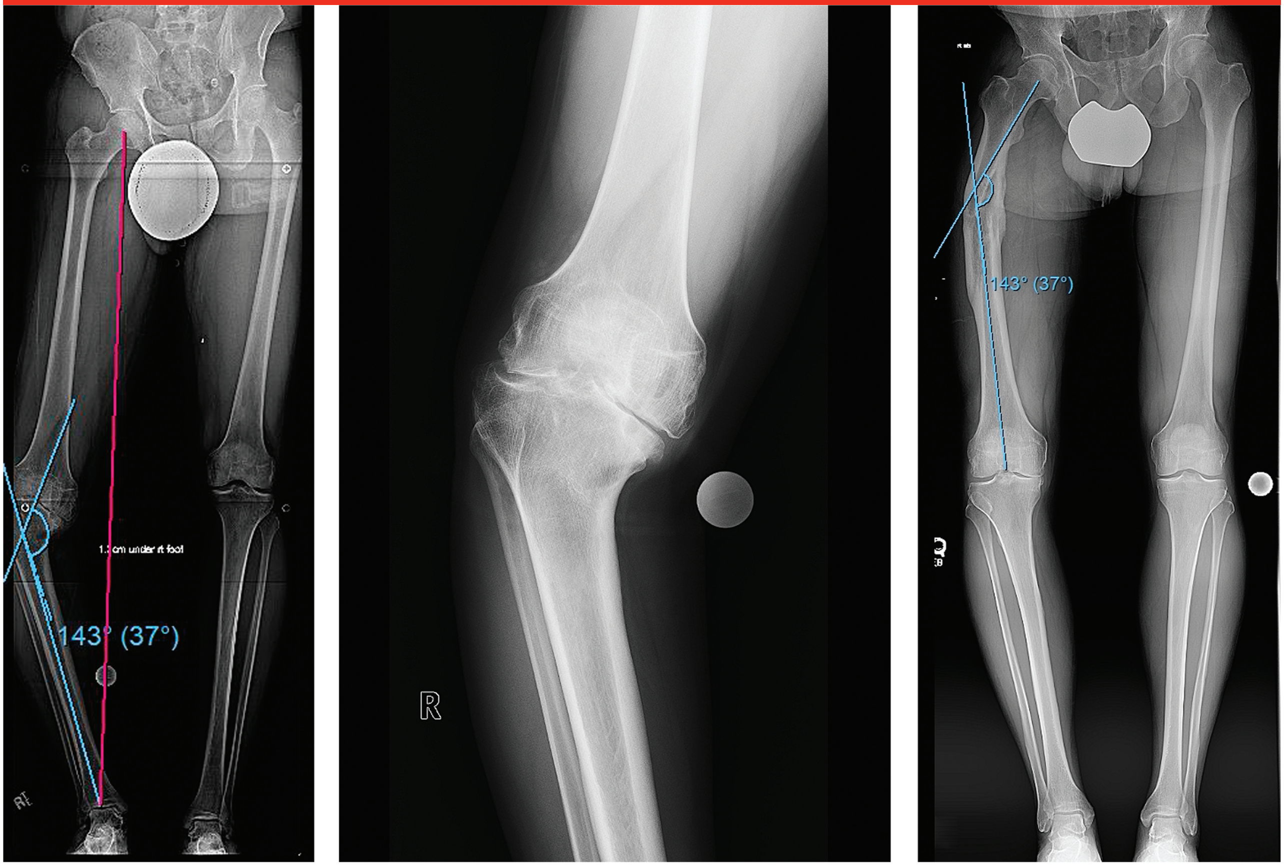
CORA = center of rotation of angulation, JLCA = joint line convergence angle, LDFA = lateral distal femoral angle, LLD = limb-length discrepancy, MAD = mechanical axis deviation, MPTA = medial proximal tibial angle, NA = not applicable, PDFA = posterior distal femoral angle, PPTA = posterior proximal tibial angle

Measurements should be made preoperatively, and any deviation from the normal range should be considered in preoperative planning. The CORA can also be determined and used to determine osteotomy planning in the sagittal plane. For axial plane malalignment, a CT scan can also be used to determine femoral version[12] and should be obtained in cases of concern for axial malalignment.

Leg-Length Measurements

Limb-length discrepancy (LLD) should also be measured and considered in planning for TKA, but the patient should be advised that an LLD may persist after TKA. Radiographically, standing full-length radiographs are an accurate and reproducible method for evaluating LLD. The true, or structural, limb-length difference is the distance from the top of the femoral head to the center of the ankle joint on each limb. Separate measurements of the femur and the tibia can be useful in determining the source of the structural LLD. Functional measurement of LLD can be performed from the umbilicus to the medial malleolus.[13,14] A clinical measurement of a patient's functional LLD can be performed by placing blocks of varying heights under the shorter

Figure 1



A B C

Radiographs demonstrating the effects of deformity near and far from the knee joint. **A**, A large deformity near the knee joint has a severe effect on angulation at the knee joint. Anatomic axes and mechanical axis are shown. Severe deviation of the mechanical axis is noted. **B**, View of the same patient's knee showing the tibial deformity. **C**, A deformity of the same magnitude further away from the knee joint has less of an effect on angulation at the knee joint.

limb until the patient feels leg lengths to be equal.[13]

Preoperative Templating for Total Knee Arthroplasty With Extra-articular Deformity

Preoperative planning for TKA in cases of extra-articular deformity in the femur, tibia, or both should include (1) the magnitude (in degrees) of the extra-articular deformity and (2) the location of the deformity (CORA) in relation to the knee joint. The location of the CORA determines surgical treatment because as the CORA moves further away from the knee joint, its effect on overall mechanical alignment decreases and the deformity becomes easier to address with TKA alone.[4] For example, a deformity of the same magnitude just a few centimeters from the knee joint may require a substantial correction, whereas a larger deformity farther away from the knee joint may have a minimal effect on bone resections and balancing of the TKA (Figure 1). Wolff et al[4] used geometric calculations to show that the magnitude of deformity increases linearly as it gets closer to the joint. They showed that for the same 20° extra-articular deformity, with every 10% of overall femur or tibia length that the deformity moved closer to the joint, an additional 2° of overall limb malalignment would be present.[4] Furthermore, LDFA and MPTA measurements should be analyzed as further deviations from normal measurements and should be incorporated into the preoperative planning for the correction.

Preoperative Planning for Total Knee Arthroplasty: The Coronal Plane

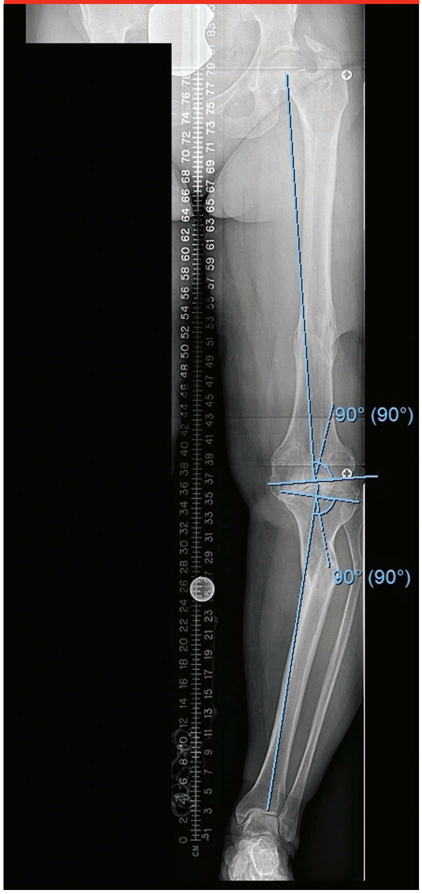
A key component of preoperative planning in the coronal plane is determining the location of distal femoral and proximal tibial bone cuts in relation to the insertion sites of the collateral ligaments because this will determine whether the correction is achievable with TKA alone or if osteotomies are needed before TKA. Previous studies have reported that an intra-articular compensatory correction can usually be achieved with TKA if the extra-articular deformity is <20° in the coronal plane on the femoral side or <30° on the tibial side when the CORA is located outside the metaphyseal region.[11,15-17] For deformities of greater severity or deformities close to the joint, an extra-articular osteotomy may be needed to achieve a well-aligned TKA. Femoral-sided deformities are less well tolerated than tibial deformities in the coronal plane because a corrective cut of the distal femur will change the balance of the knee only in extension, whereas a corrective cut on the tibial side will change the balance of the knee equally in flexion and extension.[18] Therefore, intra-articular correction of an extra-articular femoral-sided deformity may lead to an unbalanced knee due to flexion-extension gap imbalance. As previously mentioned, the threshold for performing an isolated intra-articular compensatory correction with a TKA is based on angular severity, CORA distance from the joint line, and concomitant sagittal plane deformity. As angular severity increases and CORA is in close proximity, the extent of soft-tissue releases necessary to achieve a well-balanced knee increases along with the need for either an unlinked constrained or linked constrained (hinge) device.[19]

Wang and Wang[16] described another simple methodology to determine whether the coronal plane malalignment is correctable with TKA alone or if osteotomies are needed. The mechanical axis of the femur is drawn first from the center of the femoral head to the center of the femoral notch. A second line is then drawn perpendicular to the mechanical axis line at the proposed level of the femoral resection. If the perpendicular line (proposed femoral bone resection) passes distal to the insertions of the collateral ligaments (on average 25 mm proximal to the joint line), an intra-articular correction is feasible. If the proposed femoral bone resection compromises the collateral ligament insertion, an extra-articular correction must be performed before TKA (Figure 2). For the tibia, a line is drawn from the center of the talus up the shaft of the tibia in the distal fragment of the deformed bone. Wang and Wang reported that if this line passes through the top of the tibial plateau, correction with primary arthroplasty is feasible. However, larger tibial corrections may require bone grafting, extensive releases, and constrained implants. If the tibial bone resection is too radical or not possible with conventional implants, a corrective tibial osteotomy should be performed before arthroplasty.[16,18,20] It is often helpful to draw a line perpendicular to the mechanical axis to estimate the exact tibial resection that will be performed.

Wang and Wang[16] applied their coronal plane planning methodology to a series of 15 patients with fracture malunions causing extra-articular deformity of the femur or tibia. Preoperative planning predicted that an intra-articular correction would be possible. In the case series, the mean preoperative femoral deformity was 15° in the coronal plane and 8° in the sagittal plane. The mean tibial deformity was 19° in the coronal plane. All patients underwent primary TKA, and the mean postoperative mechanical axis angle was 0.3° varus. They reported a mean Knee Society Score improvement from 22.3 to 91.7 at a mean of 38 months postoperatively and no complications in the patient cohort.

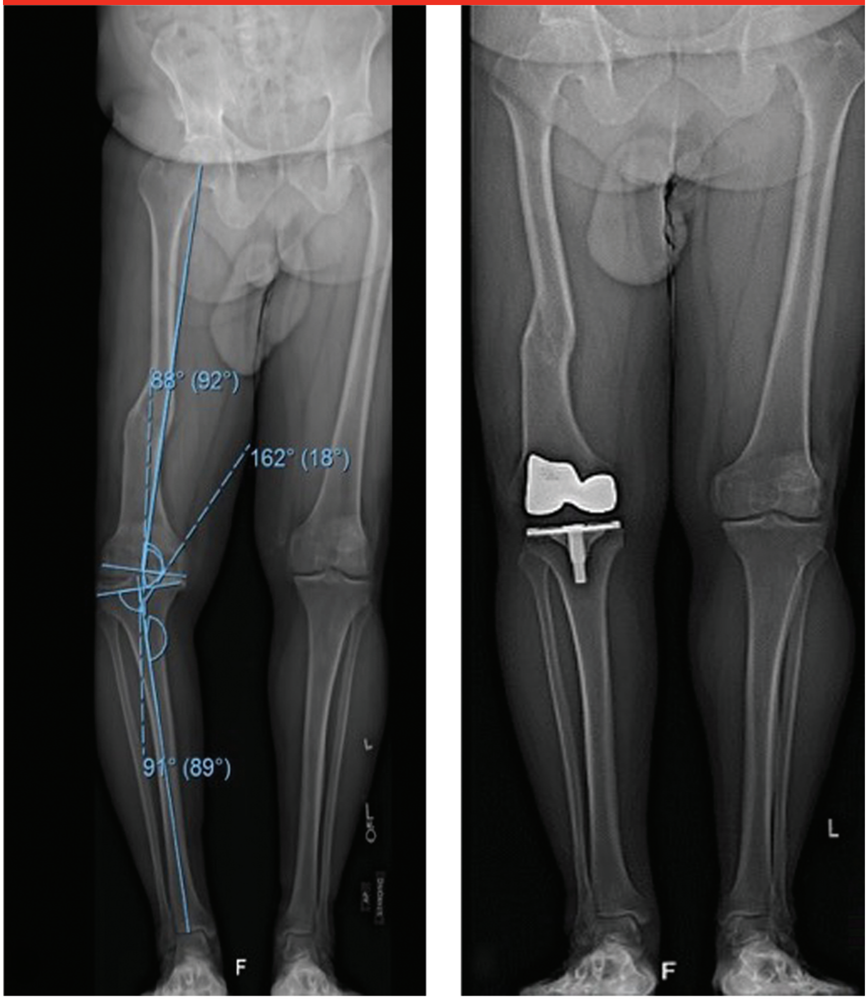
Preoperative planning should also include an assessment of stem or keel fit on the tibia and stem fit on the femur. Implants should be chosen preoperatively and if stemmed implants are being used, this must be included as part of the preoperative template. In cases in which intra-articular correction can be

Figure 2



Radiograph of a 50-year-old woman with previous trauma to left lower extremity demonstrating preoperative templating bony cuts for correction of extra-articular deformity. Ninety-degree cuts are drawn on the tibia and femur to template for TKA. Preoperative planning shows an acceptable distal femoral cut. On the tibial side, if a 10 mm cut is taken from the lateral side, a large medial defect would be present. If a 90° cut was made with a 2 mm taken off the medial side, the lateral tibial cut would be excessive. Options in this case include corrective osteotomy versus cutting 10 mm of bone from the lateral side and filling the large medial defect with graft, cement, or augment. In this case, the authors would favor a corrective tibial osteotomy, followed by primary TKA, without the need for augmenting the defect. TKA = total knee arthroplasty

Figure 3



A **B**

Radiographs of a 59-year-old man, who presented with right knee pain after a femoral fracture 40 years prior, demonstrating femoral recurvatum deformity (**A**). Computer navigation (Orthoalign) was used for alignment of the femoral cutting guide. Neutral alignment was obtained in both the coronal and sagittal planes using standard primary TKR implants (**B**).

achieved but stems or keels will not fit because of an extra-articular deformity, consideration should be given to either switching implants or performing a corrective osteotomy before TKA to avoid complications intraoperatively.

Preoperative Planning for Total Knee Arthroplasty: Sagittal Plane

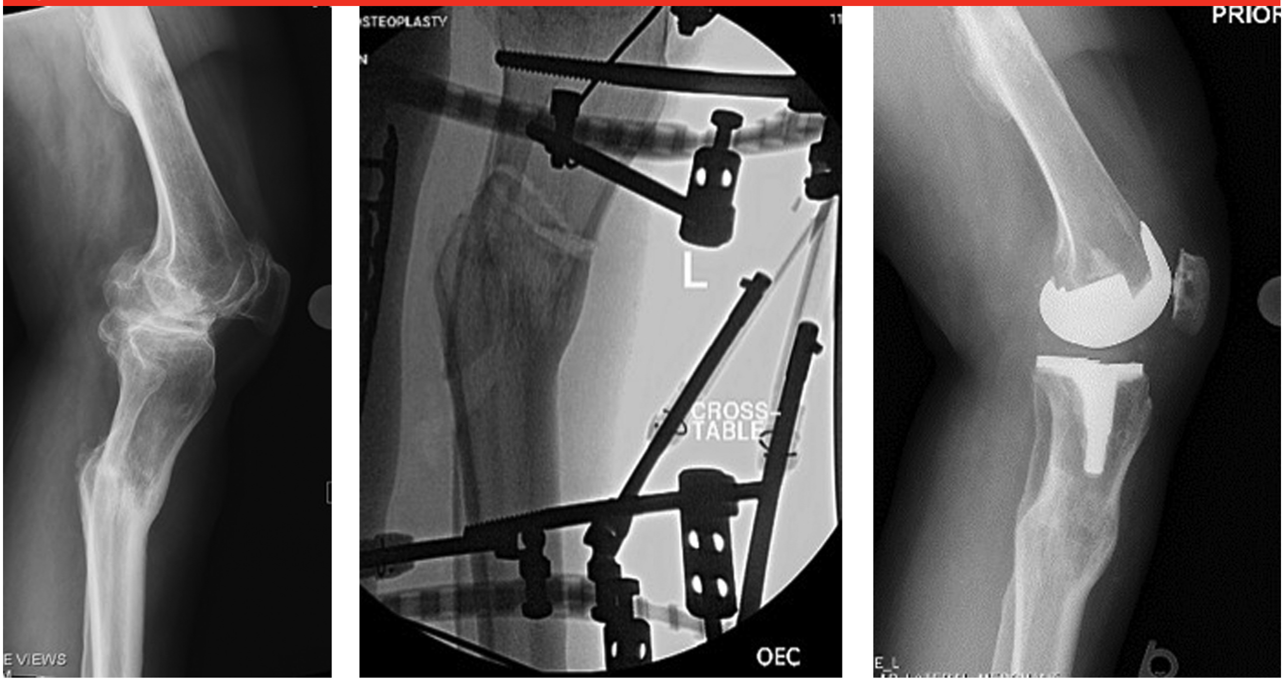
Sagittal plane deformity is typically better tolerated than coronal plane deformity in the setting of patients undergoing TKA.[19,21] The literature is limited on this topic, but previous studies have reported that an intra-articular correction with TKA is feasible if a procurvatum deformity is less than 10° or a recurvatum deformity less than 20°.[19] Tolerance of recurvatum deformity is greater than that of procurvatum deformity because of the risk of femoral notching with a procurvatum extra-articular deformity. In recurvuatum, it is possible to correct a larger sagittal deformity with a TKR without notching the anterior femoral cortex (Figure 3). Other authors have reported the successful intra-articular correction of sagittal plane deformity of up to 15° for either recurvatum or procurvatum.[21] Although no absolute degree of sagittal malalignment exists, generally guidelines suggest that when the sagittal deformity (either procurvatum or recurvatum) is greater than 20°, an osteotomy should be performed before TKA. In the setting of a sagittal deformity that is combined with a coronal plane deformity, hexapod frames are a useful tool that can be used to gradually correct the deformity in multiple planes[22,23] (Figure 4).

Preoperative Planning for Total Knee Arthroplasty: Rotational Deformity

Preoperative awareness and planning for an axial plane deformity is also important for a successful outcome of TKA. Rotational deformity may be evaluated clinically during examination of a patient's gait by assessing for asymmetry in foot progression angle between the normal and malaligned limb.[24] Hip range of motion, particularly internal and external rotation, should be assessed, and significant differences between the normal and affected side should raise suspicion for rotation abnormalities involving the hip. Plain radiographs may demonstrate subluxation of the patella in the trochlea groove, which may also indicate a rotational abnormality. Any rotational abnormality noted on examination of plain radiographs should be further evaluated with cross-sectional imaging, typically a CT version study of the lower extremity.

Unfortunately, TKA allows for minimal correction of rotational deformity. Wang et al[21] reported in a series of patients undergoing TKA

Figure 4



A B C

Radiographs of a 50-year-old woman, who sustained multiple fractures when she was a pedestrian struck by a motor vehicle 30 years before presentation, demonstrating tibial varus and recurvatum deformities. She incurred a malunion of the left proximal tibial shaft. She reported pain and knee stiffness. The radiographs demonstrated 29° of recurvatum deformity extra-articularly and 22° of tibial varus deformity (**A**). To correct both the varus and recurvatum deformities, an osteotomy was performed and a hexapod frame was used, acting as a virtual hinge, with gradual adjustments made to correct the deformity (**B**). She was in the frame for a total of 3 months, initially making the daily adjustments and then allowing for consolidation of the bony regenerate. She was staged to total knee arthroplasty 2.5 years after frame removal using primary components (**C**).

with a history of femoral fracture malunion and severe internal rotation of the femur leading to unavoidable notching of the anterior-lateral femoral cortex during the TKA. They recommended the use of a wedge cancellous bone graft in the notched area in these cases. With femoral malunion and excessive external rotation of the distal femur, no special challenges were encountered at the time of TKA.[21] Rotational deformities are a challenging issue facing the arthroplasty surgeon. We do not recommend attempting to correct a rotational deformity at the time of TKA. Instead, the senior authors prefer to correct any rotational deformity in a separate staged procedure before TKA to avoid complications during the arthroplasty procedure.

Preoperative Planning for Total Knee Arthroplasty: Limb-Length Discrepancy

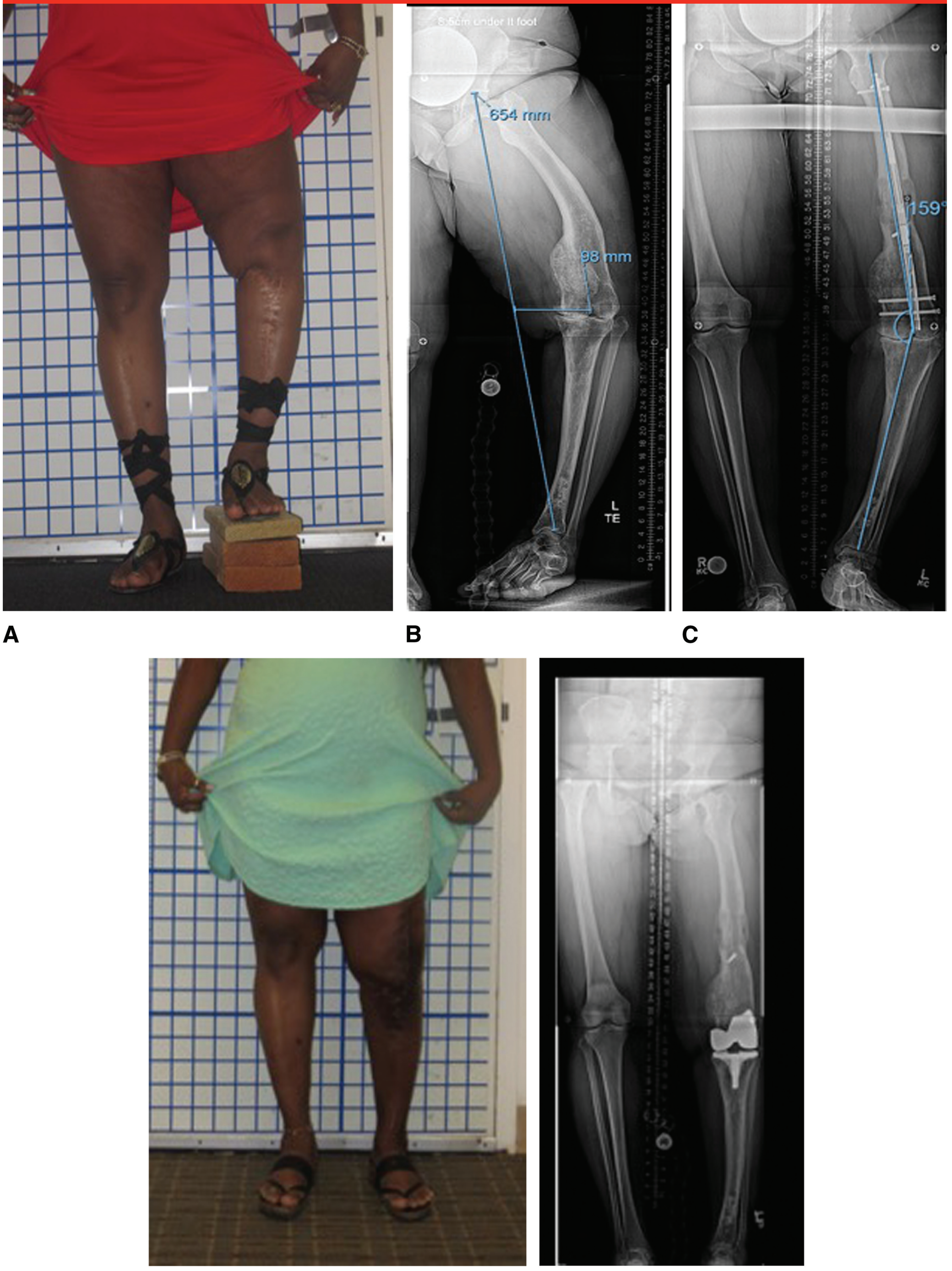
Extra-articular deformity in patients seeking TKA can also be associated with an LLD, usually shortening of the affected limb. In cases of both LLD and deformity, intramedullary internal lengthening nails (ILNs) can simultaneously correct both problems[25-28] (Figure 5). When using an ILN before or simultaneously with a TKA, the surgeon must be aware of the deformities that ILNs can create as they lengthen. Thinner-diameter ILNs have a tendency to bend into varus, whereas stiffer nails are more likely to create a valgus deformity as they lengthen along the anatomic axis. Blocking screws are especially useful for allowing for correction of coronal or sagittal deformity with ILNs. Care must be taken to avoid impingement of blocking screws onto the ILN that will prevent the nail from lengthening appropriately.[29]

Kim et al[30] reported the effect of uncorrected leg-length discrepancy on the outcome of TKA. They found that a postoperative LLD of >15 mm was associated with markedly lower scores on both the Knee Society functional score and the ascending stairs parameter of the WOMAC score. However, no difference was found in patient satisfaction results.

Treatment Principles for Correction of Extra-articular Deformity

The surgical treatment options for correction of an extra-articular deformity

Figure 5



A B C D E

Photographs and radiographs showing femoral varus deformity and LLD. A 51-year-old woman with a history of unknown metabolic disease presented with knee pain, bilateral hip pain, and back pain progressing since childhood. She felt comfortable with a 12.5-cm block under her left leg to compensate for her LLD (**A**). Preoperative planning showed a mechanical axis deviation of 98 mm medial and an overall alignment with 35° of varus deformity along with a procurvatum deformity of 26° (**B**). A retrograde intramedullary lengthening nail was used to correct the limb length, varus, and procurvatum deformity. Lengthening was performed on the magnetic intramedullary lengthening nail at a rate of approximately 1 mm daily (**C**). She was staged to a TKA with a constrained polyethylene insert one year later with removal of the retrograde nail at the time of surgery (**D**). Postoperative clinical photograph and standing alignment radiograph showing correction of the deformity (**E**). LLD = limb-length discrepancy, TKA = total knee arthroplasty include (1) primary TKA, (2) simultaneous corrective osteotomy and TKA, and (3) staged corrective osteotomy and delayed TKA. In cases in which an osteotomy is deemed necessary, the decision must be made between either a staged or simultaneous osteotomy before TKA. Regardless of whether the osteotomy is staged or simultaneous, the objective is to restore the mechanical alignment of the femur and tibia to accommodate the arthroplasty implant and to do this using the least possible radical bone resection, soft-tissue releases, and reduce the need for constrained implants.

There are pros and cons to both the staged approach and the simultaneous approach for correcting extra-articular deformity for TKA. A staged osteotomy allows for greater surgical flexibility for optimizing deformity correction because no concern exists with regard to interfering with immediate TKA. If necessary, plates and screws can be used and later removed as needed. In addition, the osteotomy is given the opportunity for full healing without the risk of cement intrusion from TKA. In addition, correction of underlying malalignment improves knee kinematics, and symptoms may be alleviated, possibly delaying the need for TKA. The authors find this to be more common in preoperative mechanical valgus deformities. Lonner et al[31] reported 11 knees with extra-articular deformity (10 fracture nonunions and one patient with hypophosphatemic rickets) who underwent a simultaneous femoral osteotomy followed by TKA in the same surgical setting. Although they reported significant improvements in the Knee Society Score (KSS) outcomes, the complication rate was 45% and included one osteotomy nonunion, two manipulations under anesthesia for stiffness, one acute pulmonary embolism, and one case of symptomatic implant requiring removal.[31]

Although it is the authors' preference to use a staged approach when an osteotomy is deemed necessary, there are also benefits to a simultaneous approach. If the surgeon is adept at both osteotomy and arthroplasty and performs both simultaneously, the patient only undergoes one surgical procedure and one recovery period. However, the recovery may be longer and more difficult than the two recoveries after a staged approach. Furthermore, in a simultaneous approach, surgeons should be cognizant of blood loss management and management of cement during implantation of the total knee because cement may be prone to extrude through the osteotomy site.

Comparing risks and benefits of the staged versus simultaneous approach, we generally prefer a staged osteotomy followed by subsequent arthroplasty with potential removal of osteotomy implant as needed.

Surgical Technique and Implant Choice for Extra-articular Osteotomy Correction

Multiple surgical techniques and methods of fixation have been used for osteotomy correction including intramedullary nails, plate and screw constructs, or hexapod external frames.[32] Internal lengthening intramedullary nails can be particularly useful if there is both an angular deformity and an LLD. Distal femoral and proximal tibial plates can be used and are frequently removed before or at the time of the arthroplasty procedure (Figure 6).

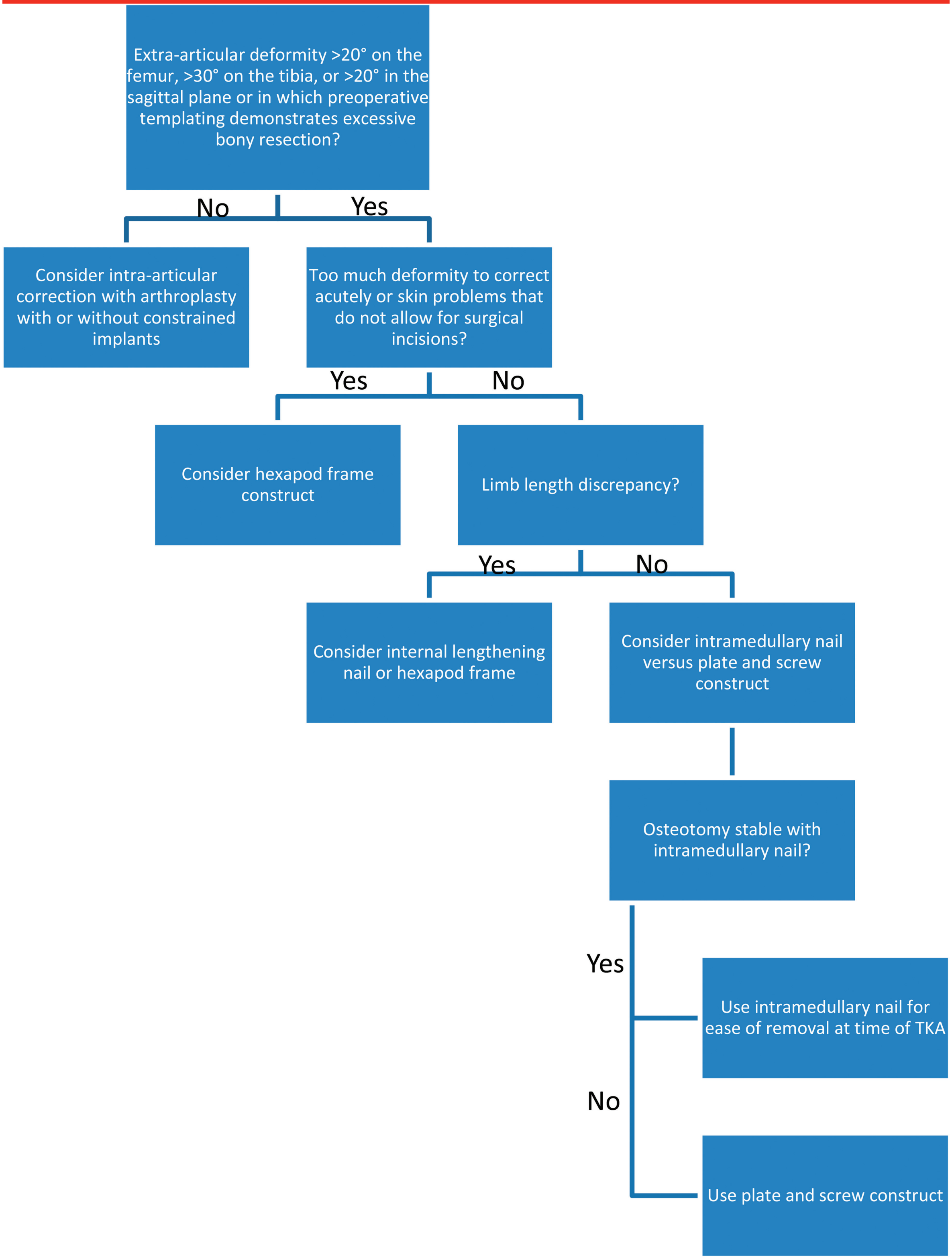
External fixation devices such as the hexapod frame can also be used for deformity correction with osteotomy. Benefits of this fixation method for deformity correcting osteotomies include gradual correction and control in multiple planes. Gradual correction is beneficial for minimizing peroneal nerve injury, which may be seen with acute angular correction.[33] Disadvantages of hexapod frames include patient discomfort and risk of pin-site infection. Deep osteomyelitis has been reported in up to 4% of patients undergoing external fixation, which is particularly concerning in patients requiring arthroplasty.[34] In staged cases in which the osteotomy implant is removed either shortly before or in the same setting as the TKA, stemmed arthroplasty implants may be used to bypass the osteotomy site and stress risers created after implant removal.[35]

In patients with extra-articular deforming in whom a subsequent TKA is expected, osteotomy should focus on correcting the femur and tibia to their respective anatomic and mechanical axes, rather than perfecting the overall alignment of the entire limb. If an acute correction is feasible, intramedullary nails are preferred because they may easily be removed at the time of TKA. Antegrade femoral nails are optimal because they can be left in place, and computer navigation or patient-specific cutting guides are used instead of an intramedullary guide. In cases in which gradual correction is needed, external fixators are used. Surgeons must be aware of previous incisions and consider the future TKA incision when performing the deformity correction. A complete correction of axial plane deformity is also performed at the time of osteotomy because TKA allows for minimal correction in the axial plane.

Special Considerations in Total Knee Arthroplasty Associated With Extra-articular Deformity

Computer-assisted navigation provides some valuable features when managing an extra-articular deformity at the time of TKA, especially in the setting of a previous implant.

Figure 6



Algorithm demonstrating suggested management of severe osteoarthritis of the knee in the setting of extra-articular deformity.

Benefits of computer-assisted, robotic, or patient-specific cutting guides include avoiding the use of an intramedullary femoral alignment rod and more reliable access to the mechanical axis without the use of fluoroscopy.[36-39] Catani et al[36] reported the use of an image-free navigation system (Stryker Navigation) in a series of 20 patients with an extra-articular deformity secondary to remote femur or tibia fracture. Computer-assisted navigation was used to identify the center of the femoral head, and the proximal tibia cut was also aligned with the mechanical axis of the tibia using navigation. The authors demonstrated an improvement from a mean preoperative alignment of 10.4° ± 8.3° varus to a mean postoperative alignment of 0.8° ± 1.2° varus and an improvement in the KSS from 48.4 to 91.4. In addition, they reported no complications in this more complex cohort.[36] The use of computer technologies for extra-articular deformity is a rapidly evolving field, and additional studies are needed to define their role in the management of extra-articular deformity.

In cases of complex extra-articular deformity, the surgeon must also be aware of certain complications that are more prone to arise and must counsel the patient appropriately. In a case series of 12 patients with extra-articular deformity secondary to skeletal dysplasia who were undergoing TKA, Kim et al[33] reported that 3/12 required customized implants, 5/12 required constrained polyethylene inserts, and 2/12 experienced transient peroneal nerve palsies. In our experience, for cases of particularly severe multiplanar deformities, staged osteotomy and a gradual correction using a hexapod frame is a useful tool that allows for accommodation of soft tissues and neurovascular structures to correction of the deformity.

Furthermore, infection is a concern in patients with retained implant who are undergoing TKA. Cross et al[40] reported a 5% infection rate in a small series of patients undergoing conversion from high tibial osteotomy to TKA. Higher infection rates have been reported with the use of hexapod frames,[34,41] so when using these devices before TKA, surgeons should ensure that patients are free of any evidence of deep or superficial infection before proceeding with arthroplasty with inflammatory markers and joint aspiration if elevated.

Ligamentous contractures and laxity may be present in the knee in cases of extra-articular deformity.[4] Surgeons performing TKA in the setting of extra-articular deformity should be prepared to perform ligamentous releases and use constrained implants as needed.

Summary

Preoperative full-length standing hip-to-ankle radiographs are necessary for preoperative assessment of extra-articular deformity in the setting of TKA. Measurements including MAD, LDFA, MPTA, posterior proximal tibial angle, posterior distal femoral angle, JLOA, and CORA should be made to distinguish between intra-articular and extra-articular deformity and to plan for the correction. Preoperative templating should be used to assess bony cuts that will be needed for intra-articular correction. In cases of severe deformity in which TKA alone is not possible, there are numerous advantages to staging the osteotomy rather than performing a simultaneous osteotomy correction and then arthroplasty in the same surgical setting. It is important to consider that ligamentous laxity is associated with extra-articular deformity, and constrained implants should be available and used appropriately. Special care should be taken to protect neurovascular structures, especially the peroneal nerve, in cases in which a large deformity correction is performed, and patients should be educated preoperatively of this increased risk. A thorough preoperative neurovascular examination and appropriate studies to document the status of the neurovascular structures may be indicated. Hexapod frames may be used for gradual correction to protect neurovascular structures. In addition, an increasing role exists for computer navigation both for managing femoral malunions at the time of TKA and for performing TKA after deformity correction.

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References printed in **bold type** are those published within the past 5 years.

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