Preoperative Planning in Primary Total Knee Arthroplasty

Abstract

Preoperative planning is of paramount importance in primary total knee arthroplasty. A thorough preoperative analysis helps the surgeon envision the operation, anticipate any potential issues, and minimize the risk of premature implant failure. Obtaining a thorough history is critical for appropriate patient selection. The physical examination should evaluate the integrity of the soft tissues, the neurovascular status, range of motion, limb deformity, and the status of the collateral ligaments to help determine the soft-tissue balancing and constraint strategy required. Standard radiographs, with a known magnification, should be obtained for preoperative total knee arthroplasty templating. Routine standing AP, lateral, and skyline radiographs of the knee can help the surgeon plan the bone cuts and tibial slope as well as the implant size and position at the time of surgery. In certain circumstances, such as severe coronal deformities, bone deficiencies, and/or extra-articular deformities, additional measures are frequently necessary to successfully reconstruct the knee. Constrained implants, metal augments, and bone graft must be part of the surgeon’s armamentarium.

Primary total knee arthroplasty (TKA) is an increasingly common procedure; the number of procedures performed in the last two decades has increased 162%. It is projected that the number of revisions in the United States will increase by 600% between 2005 and 2030. Although excellent functional outcomes and long-term survival rates have been reported, infection, instability, wear, osteolysis, mechanical loosening, and periprosthetic fracture are common causes of revision TKA. Many of these failure modes are related directly to the surgical technique and, therefore, are under the control of the surgeon.

Thorough preoperative planning is critical in optimizing implant position and soft-tissue balancing, which will minimize the probability of subsequent TKA failure and improve the surgical outcome. In addition, preoperative planning helps the surgeon to visualize the procedure and thereby appropriately counsel patients about potential surgical complications. Careful planning allows the surgeon to communicate with the surgical team preoperatively to ensure the availability of the required instrumentation and implants.

History and Physical Examination

Obtaining a thorough history is crucial for patient selection and for the evaluation of potential postoperative complications. Factors that should be considered include the preoperative diagnosis, patient age
and sex, characteristics of the knee pain, level of activity, functional limitations, involvement of other joints, mechanical symptoms, and previous treatment. The presence of comorbid conditions, smoking status, alcohol consumption, medications, and mental status should be assessed carefully to further guide preoperative evaluation and medical optimization. Active infection must be treated and resolved before surgery to prevent a postoperative infection. An assessment of the patient’s overall venous thromboembolism risk, including any history of previous deep vein thrombosis or pulmonary embolism, is recommended to optimize perioperative management. Evaluation of the patient’s social history can guide postoperative rehabilitation and discharge planning.

Dementia, diabetes mellitus, a body mass index >40, and renal and cerebrovascular diseases have been shown to be independent predictors for in-hospital mortality and postoperative complications after primary TKA. Therefore, the benefits of TKA should be weighed against such risks. Patients with neuromuscular conditions, such as Parkinson disease, are at high risk of instability following TKA and may benefit from specific implant options (eg, varus-valgus-constrained TKA, hinged knee components).

The patient’s gait should be assessed. In addition to observing the overall knee alignment, the surgeon should look for the presence of thrust and/or hyperextension during walking, which indicates ligamentous laxity. This indication may prompt the surgeon to consider a constrained knee design. An in-toeing or out-toeing gait may indicate preexisting rotational deformities. Hindfoot inspection also should be part of the examination because hindfoot valgus is not uncommon, and it tends to shift the mechanical axis of the lower extremity after TKA.

The presence of surgical scars should be noted during the skin examination because it can inform the decision of whether to use a standard midline surgical incision. When multiple previous incisions are encountered, it has traditionally been recommended that the most lateral incision be used and that at least 5 or 6 cm of skin bridging be provided between incisions to avoid postoperative skin complications. The presence of local signs of skin infection or adherence to the underlying bone also should be noted. Such findings necessitate further investigation and treatment before surgery.

Examination of preoperative knee range of motion (ROM) is essential. Although postoperative stiffness is multifactorial, preoperative ROM remains the most important predictor of postoperative motion. Identification of preoperative knee flexion contractures can help the surgeon plan an intraoperative strategy for correction.

Preoperative assessment of the collateral and cruciate ligaments is required to guide the strategy for soft tissue balancing and the selection of the implant. The integrity of the collateral ligaments is essential when performing TKA with an unconstrained or semiconstrained implant. Any fixed coronal deformity found on physical examination should be noted to allow for planning of intraoperative correction.

A thorough neurovascular examination also should be performed. The surgeon should note any signs of poor circulation, such as skin discoloration, atrophic nails, absent hair, or asymmetric or absent distal pulses. If any suspicion of peripheral arterial insufficiency is present, the ankle-brachial index should be determined. If the ankle-brachial index is <0.9, a preoperative vascular surgery consultation is warranted. Because patients with preexisting peripheral vascular disease are at high risk of arterial injuries and compromised blood flow during TKA, the surgeon should consider not using a tourniquet during the procedure or inflating it just at the time of cementing.

Finally, assessment of the ipsilateral hip and ankle joint and the contralateral limb should be performed to evaluate the involvement of these joints and the effects they may have on the patient’s postoperative mobility and rehabilitation. Ipsilateral hip arthritides can present as isolated knee pain and must be ruled out. Patients with a fixed flexion deformity on the contralateral knee may benefit from a shoe lift postoperatively. In cases of severe bilateral deformities, bilateral one-stage or two-stage TKAs should be planned.

### Imaging and Laboratory Testing

#### Plain Radiography

Standard radiographic evaluation for patients undergoing primary TKA includes a weight-bearing AP view of the knee, a lateral view of the knee, and a patellofemoral joint view, such as a skyline view. Although a full-length hip-to-ankle AP weight-bearing view is not performed routinely at some institutions, many authors feel that this view is useful for preoperative planning, especially in complex cases. The AP weight-bearing hip-to-ankle radiograph allows the surgeon to rule out extraarticular deformities, estimate the amount of coronal laxity, and plan the bone resection and the position of the femoral and tibial components with respect to the mechanical axis.

#### Radiographic Technique

The full-length hip-to-ankle AP weight-bearing view typically is taken with both knees in maximum...
extension and with the patient’s knees placed 18 inches apart. The rotational position of the lower extremity may influence the reliability of the measurements; therefore, it is important to have the patellae facing forward. The AP weight-bearing view of the knee typically is obtained with the x-ray beam focused at the knee joint and the patella, facing directly anteriorly. The true lateral view can be verified if no overlap is present between the medial and lateral femoral condyles. Finally, the tangential axial view of the patellofemoral joint is performed with the knee in 30° of flexion.

The surgeon must know the magnification of the radiographs to perform adequate conventional or digital radiographic templating. Adding a calibrated reference marker, such as a ball or coin at the level of the joint line, can increase the accuracy of the sizing of the tibial and femoral components during templating. Using this technique, preoperative planning accurately predicts the component size within one size larger or smaller 100% of the time for the tibia and 90% of the time for the femur.4

Knowing the expected implant size is beneficial for ensuring the availability of the implant, particularly if extreme sizes will be used.

**Radiographic Landmarks and Templating**

Before templating, the radiographs should be reviewed to confirm the diagnosis and ensure appropriate patient positioning to avoid inaccurate planning. The first step in radiographic templating is to draw a line on the full-length hip-to-ankle view that shows the overall mechanical alignment of the lower extremity (Figure 1, A). Varus or valgus malalignment and any extra-articular deformities should be noted. The tibiofemoral angle then is drawn to estimate the magnitude of a coronal deformity (Figure 1, B). Some authors use the hip-knee-ankle angle instead of the tibiofemoral angle to estimate the degree of the coronal deformity (Figure 1, C).

When an intramedullary distal femoral cutting jig is required, the femoral resection angle, which is the difference between the mechanical axis and the anatomic axis of the femur, can be used (Figure 2). This angle most commonly measures between 5° and 7° of valgus. In one report, however, Mullaji et al13 showed that this angle can vary from 3° to 11° of valgus. The authors suggested using an individualized femoral resection angle rather than a fixed resection angle, such as those measuring 5°, 6°, or 7°.

The tibial bone cut is perpendicular to the mechanical axis of the tibia. The amount of resection required usually is based on the combined thickness of the tibial component and the thinnest available polyethylene component thickness for the implant system being used, typically 10 mm. This amount of bone resection should be performed on the unaffected side of the tibial plateau or, if both sides are affected, from the level of the prearthritic tibial plateau (Figure 3).

The AP weight-bearing view of the knee is scrutinized to detect medial and/or lateral osteophytes and bone defects. The lateral knee view typically is used to detect posterior osteophytes and to measure the tibial slope and the patellar height (Figure 4). The skyline...
view of the patella is used to measure patellar shift and patellar tilt and to evaluate the extent of erosion of the patellofemoral joint (Figure 5). Chia et al\(^1\) showed that a preoperative lateral patellar shift \(\geq 3\) mm was an independent risk factor for patellar maltracking during TKA.

Lastly, the femoral and tibial component sizing is performed (Figure 6). The templating is dictated most commonly by the anterior-posterior dimensions of the femur and tibia. Various digital and acetate templating techniques have been investigated and shown to be effective and reliable, and they reduce surgical time and cost.\(^4,15\) In this step, the surgeon must carefully assess the implant location and anticipate any potential intraoperative adjustments, such as the resection of an osteophyte, to accurately estimate the implant location.

**Advanced Imaging**

CT or MRI is rarely indicated during planning for primary TKA. When the use of an extreme implant size is planned, CT can be invaluable in determining the size and whether a custom implant is required. A preoperative CT or MRI of the knee is obtained when patient-specific instrumentation and/or custom implants will be used.\(^16\)

**Laboratory Tests**

Routine preoperative laboratory testing, including a complete blood count and electrolyte levels, must be performed. Additional laboratory tests should be guided by the patient’s medical condition. Although having tight glycemic control with the goal of obtaining a hemoglobin (Hb) A1c (HbA1c) test result of \(\leq 7\%\) is desirable, Giori et al\(^17\) recently proposed that achieving a HbA1c level of \(\leq 8\%\) is acceptable to avoid substantial delays in performing the TKA. A low Hb level is an independent predictor for the need for a perioperative blood transfusion. The risk of transfusion is increased 3.7-fold for each 1 g/dL decrease in the Hb level below the threshold of 13 g/dL preoperatively.\(^18\) Various options are available to treat
a low preoperative Hb level, including iron supplementation, recombinant human erythropoietin administration, and tranexamic acid (ie, a antifibrinolytic agent) administered intraoperatively.

**Surgical Principles of Primary Total Knee Arthroplasty**

An understanding of implant designs used in primary TKA, as well as the technical principals of the procedure, is crucial to help the surgeon successfully reconstruct the knee (Table 1). Technical principles of TKA include restoration of neutral mechanical alignment, preservation of the joint line, restoration of coronal and sagittal balance, maintenance of patellar tracking, and restoration of the posterior tibial slope.

**Restoration of Neutral Mechanical Alignment**

Neutral mechanical alignment is achieved when the mechanical axis of the lower extremity passes through the center of the knee joint or when the anatomic axis of the lower extremities is $7^\circ \pm 1^\circ$ of valgus. Restoration of neutral knee alignment with TKA distributes the weight-bearing loads equally across the medial and lateral compartment of the knee joint, thereby minimizing the risk of implant wear and aseptic loosening. Achievement of a neutral anatomic alignment between $2.4^\circ$ and $7.2^\circ$ of valgus has been shown to substantially improve implant survival following primary TKA. To achieve mechanical alignment, the femoral and tibial cuts are made perpendicular to the mechanical axis, and soft-tissue releases correct any coronal deformity. Bellemans et al. questioned this concept and reported that a portion of the normal population does not have a neutral mechanical alignment at skeletal maturity, but rather has $\geq 3^\circ$ of varus. The authors termed this observation “constitutional varus.” The clinical disadvantages of restoring patients with constitutional varus to neutral alignment at the time of TKA are unknown. In the last decade, the concept of achieving a kinematically aligned knee has emerged and involves resection of the bone to restore the prearthritic state and anatomic angle while soft-tissue releases are performed to balance the knee.

**Preservation of the Joint Line**

The preservation or restoration of the anatomic position of the joint line is an important factor for a successful primary TKA. This measure can be achieved if bone cuts are so accurate that the amount of bone eroded preoperatively and the amount of bone resected at the time of TKA identically match the thickness of the prosthesis. Proximal elevation of the joint line leads to pseudopatella baja, which is associated with high contact forces at the patellofemoral joint and dysfunction of the extensor mechanism. Shifting the joint line distally can lead to patellar subluxation and retropatellar pain.

**Restoration of Coronal and Sagittal Balance**

Postoperative knee instability is a major cause of premature failure following primary TKA. This
outcome can be prevented with adequate preoperative assessment and careful intraoperative soft-tissue releases performed to achieve intraoperative stability throughout the ROM. Patients with coronal knee deformities typically have tight soft-tissue structures, such as ligaments, on the concave side of the deformity and stretched out soft-tissue structures on the convex side. A stepwise approach must be considered for soft-tissue releases when managing coronal deformities. It is recommended that osteophyte removal and all bone cuts should be performed first. A prosthetic trial or spacer blocks are then inserted to evaluate the medial and lateral gaps during flexion and extension. If the medial or lateral gaps are not balanced, then sequential soft-tissue releases should be performed. The soft-tissue releases should be performed with caution; overly zealous releases on the contracted side of the joint can lead to instability, and subsequent conversion to a constrained knee design might be required.

The aim of sagittal balance is to achieve equal flexion and extension gaps. Intraoperatively, these gaps can be achieved by soft-tissue releases, adjusting the tibial or femoral resections, or changing component size. It is important to correct a fixed flexion contracture because it can adversely influence functional outcomes after TKA. Although existing evidence shows that, in TKAs with a cruciate-retaining implant, residual flexion contracture may improve with time after surgery, it is imperative that all the necessary releases and osteophyte resections be addressed intraoperatively. This also has been shown to be required in patients with flexion contractures at the time of TKA performed with a posterior-stabilized (PS) implant.

### Maintenance of Patellar Tracking

Patellofemoral complications are responsible for approximately 8% of primary TKA failures. Alteration in knee kinematics, such as an increased Q angle (normal Q angle = 15°) and an imbalance of peri-patellar soft-tissue structures, can produce a laterally directed muscle vector that can lead to patellofemoral instability. Several factors influence the Q angle, including component malposition and limb malalignment. For example, internal rotation and medialization of the femoral or tibial components, as well as a femoral component positioned in >7° of valgus, can increase the Q angle during TKA. When patellar resurfacing is planned, improper patellar preparation, such as under-resection or an asymmetric patellar cut with a thick lateral facet, and lateralization of the patellar

### Table 1

<table>
<thead>
<tr>
<th>Implant Design (Example)</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Unconstrained knee (cruciate-retaining design; PCL is preserved)</td>
<td>Increased quadriceps muscle strength, lower shear forces at tibial component-host bone interface, preserved bone stock on the femoral side, improved stair climbing</td>
<td>Risk of postoperative PCL rupture, potential loss of femoral rollback with some current designs</td>
</tr>
<tr>
<td>Semiconstrained knee (posterior stabilized design; PCL is substituted)</td>
<td>Potential ease of ligament balancing, no need to correct a contracted PCL, suitable after patellectomy and for PCL-deficient knees, great versatility for different types of substantial knee deformities</td>
<td>Risk of cam-post impingement or dislocation, increased constraints in varus or valgus direction compared with cruciate-retaining knee design, risk of tibial post polyethylene wear from cam-post mechanism, risk of patellar clunk syndrome</td>
</tr>
<tr>
<td>Constrained knee (varus–valgus-constrained design, also known as condylar constrained knee)</td>
<td>Coronal stability in severe coronal bone deformities</td>
<td>Decreased femoral bone stock, potentially higher rate of aseptic loosening from increased constraint in younger and active patients, risk of tibial post polyethylene wear and/or fracture from cam-post mechanism</td>
</tr>
<tr>
<td>Highly constrained knee (rotating hinge design)</td>
<td>Highly constrained implants typically reserved for complex instability cases, when gaps are greater than the largest available polyethylene liner and/or for substantial bone loss</td>
<td>Potentially high rate of aseptic loosening from increased constraint, substantial reduction of bone stock</td>
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PCL = posterior cruciate ligament

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Figure 7

Algorithm demonstrating the key elements required for the clinical approach, choice of implant design, and techniques used during primary total knee arthroplasty. For radiographic templating, the hip-knee-ankle (HKA) angle or the tibiofemoral angle and the femoral resection angle should be measured on the full-length HKA weight-bearing AP radiograph to plan for the tibial and femoral resections. The tibial slope and patellar height should be measured on the patellofemoral view. CR = cruciate-retaining, MCL = medial collateral ligament, PS = posterior stabilized, RH = rotating hinge, TKA = total knee arthroplasty, VVC = varus–valgus constrained.
component also can increase the Q angle. Additionally, a patellar bone-prosthesis construct that is thicker than the native patella results in an increase in the lateral tilt and contributes to patellar maltracking.28

Restoration of Posterior Tibial Slope

The normal posterior slope angle (PSA) is highly variable, with a reported range of 5° to 15°.29 Although restoring the PSA should be considered when cutting the proximal tibia to optimize ROM, some authors recommend reducing the PSA in TKAs with PS knee implants to prevent cam-post impingement.9,19,29,30

Complex Primary Total Knee Arthroplasty

In complex cases, a specific implant design or surgical technique might be preferred over another. Several conditions, including severe coronal deformities and instability, extra-articular deformities, severe bone deficiency, and previous patellectomy, warrant careful preoperative consideration and selection of the optimal implant design and surgical technique. The surgeon must be aware of the various options available to manage such conditions during TKA to increase the likelihood of optimal outcomes (Figure 7).

Severe Coronal Deformities and Ligamentous Instability

Management of a coronal deformity requires a planned, stepwise approach to achieve a balanced knee intraoperatively. This approach includes removing the osteophytes, sequential soft-tissue balancing, and if necessary, adjusting the bone cuts. In the setting of severe varus deformity, however, the surgeon may not be able to achieve the desired intraoperative stability in rare instances and must anticipate the conversion to a constrained knee implant.31 Similarly, in knees with severe valgus alignment, intraoperative attempts should be made to balance the knee in flexion and extension before considering the use of a constrained implant. Several stepwise lateral releases and ligament balancing strategies can be used when a cruciate-retaining or PS implant is selected.32 However, when the medial collateral ligament (MCL) is extremely attenuated and extensive lateral releases have been performed, balancing the coronal plane may fail to correct the deformity and balance the knee. In addition, extensive lateral releases may result in flexion instability and/or a postoperative peroneal nerve palsy. This problem can be avoided by converting intraoperatively to a varus–valgus-constrained knee implant (Figure 8). Some authors prefer to use a PS knee implant with MCL advancement, repair, or reconstruction.32,33 However, these procedures have been criticized for their potentially adverse influence on the ligament’s isometricity.34 In a study on the use of lateral epicondylar osteotomy in TKA for rigid valgus deformities, Mullaji and Shetty35 reported no complications. In elderly and low-demand patients with severe valgus and MCL deficiency, the surgeon may consider performing a TKA with a constrained knee implant.32,36 Although some surgeons have expressed concern that TKAs with constrained implants will transfer stresses to the implant-bone interface, which can result in premature loosening, studies have shown that the survivorship of these implants is >96% at long-term follow-up.37 Nevertheless, surgeons should attempt to reconstruct the knee using nonconstrained knee implants and
be prepared preoperatively to ensure that constrained devices are readily available when the intraoperative assessment indicates that they are necessary.

Extra-articular Deformity

Previous osteotomies, metabolic bone disease, malunion of fractures, and bone tumors can lead to bowing or angulation of the femur or tibia. In the setting of extra-articular deformities in the coronal plane, the goal of TKA is to achieve a neutral mechanical alignment to optimize long-term results. However, the standard preoperative templating, bone incisions, and conventional instruments, such as an intramedullary guide, may be ineffective because of the bone deformity. Rotational and sagittal deformities also can add to the complexity of these cases.

Preoperatively, the surgeon can anticipate the impact of the deformity based on its distance from the knee joint. The closer the deformity is to the joint, the greater its impact on knee alignment. For example, if the apex of a femoral or tibial deformity is located at a distance corresponding to 25% of the length of the bone, the effect of the deformity will be twice that of a deformity located at a distance corresponding to 50% of the length of the bone. The magnitude of the deformity plays an equally important role in its management. The greater the deformity, the greater the impact on knee alignment.

Preoperative templating allows the surgeon to anticipate whether an intraoperative intra-articular compensatory correction is achievable or if an extra-articular corrective osteotomy is required (Figure 9). In general, an intra-articular compensatory correction can be achieved if the deformity is far from the joint and limited to <20° in the coronal plane on the femoral side and <30° on the tibial side. This technique might require extensive soft-tissue releases secondary to the asymmetric oblique cuts. Therefore, the surgeon should be prepared to reconstruct and/or advance the affected collateral ligament or convert to a constrained knee design. In contrast, if the deformity is severe and close to the joint or if preoperative templating indicates that the intra-articular bone resection will include the attachment sites of the MCL and/or lateral collateral ligament, an extra-articular corrective osteotomy (performed in a staged fashion or at the time of primary TKA) is recommended.

Although this technique is appealing and preserves ligamentous stability, it is associated with high rates of nonunion, infection, and arthrofibrosis.

Recent advances in computer-assisted navigation for TKA have expanded the indications for its use in patients with severe extra-articular deformities. Although computer-assisted surgery (CAS) has not been found to be superior to conventional techniques in routine TKA, Catani et al suggested that CAS has a definite advantage in patients with severe extra-articular deformities. The use of CAS can sometimes obviate the need for a...
corrective osteotomy or implant removal, thereby reducing the risk of complications.

**Bone Defects**

Bone defects on the tibial side commonly result from previous trauma, bone erosion from conditions such as inflammatory arthritis, and severe coronal deformities. Varus deformity typically is associated with medial tibial bone defects, whereas valgus deformity is associated with central-lateral defects. Preoperatively, the surgeon should determine the extent of the bone defect because management typically is based on its size (Figure 10). Dorr et al\(^4\) determined that any tibial bone defect that involves <50% of the tibial plateau or is <5 mm in depth can be filled with cement. For larger defects, management options include metal augments and autogenous bone grafts, with or without fixation. In one report, Berend et al\(^5\) used cement and screw fixation to manage large tibial bone defects and achieved low failure rates at 20-year follow-up.

Lee and Choi\(^6\) and Pagnano et al\(^7\) investigated the clinical outcome of using metal rectangular block augments at a minimum 5-year follow-up. The authors reported good to excellent results with no radiographic or clinical failures. In these studies, nonprogressive radiolucent lines were noted at the metal-cement interface; the significance of these findings on the long-term survivorship of the implant remains to be determined. Although biomechanical studies have shown that the tensile stress loads are reduced and that better stability and rigidity are achieved with metal block augments than with metal wedge augments,\(^8\) we are not aware of any clinical studies that demonstrate the superiority of one type of augment over another.

The use of autogenous bone graft to manage large tibial bone defects is another option, but variable success rates have been reported in the literature.\(^9,10\) Overall, metal augmentation is an attractive option for managing large bone defects. It provides immediate support and satisfactory load distribution with promising midterm results.\(^11,12\) Long-term data are required to confirm the durability of these implants, however. Autogenous bone grafting may be best for young patients, in whom restoration of the bone stock may be necessary for future surgeries.

**Previous Postpatellectomy**

Patients who have undergone a previous patellectomy lose their extension strength by 20% to 70%.\(^13\) In addition, in patients undergoing TKA, the loss of the patella decreases the stability of the knee and overloads the posterior cruciate ligament. The literature has shown that these patients achieve the best results when they undergo TKA with a PS knee implant.\(^14\) Nevertheless, even when a PS device is used, patients with a previous patellectomy have less favorable outcomes than those with a patella.\(^15\)

**Summary**

Preoperative planning is crucial in primary TKA. The application of conventional surgical principles during this procedure allows the surgeon to obtain reproducible results. A thorough preoperative history, physical examination, and radiographic templating can result in a precise plan that helps the surgeon successfully reconstruct the knee and anticipate potential complications.

**References**

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, reference 22 is a level I study. References 3, 7, and 13 are level II studies. References 4, 9, 11, 15, 23, 25, 26, 29, and 50 are level III studies. References 1, 2, 5, 12, 14, 17-21, 24, 28, 30, 33-37, 40-45, and 47-49 are level IV studies. References 6, 8, 10, 16, 27, 31, 32, 38, 39, and 46 are level V expert opinion.

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

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