Preoperative Planning for Primary Total Hip Arthroplasty

Abstract

Preoperative planning is of paramount importance in obtaining reproducible results in modern hip arthroplasty. Planning helps the surgeon visualize the operation after careful review of the clinical and radiographic findings. A standardized radiograph with a known magnification should be used for templating. The cup template should be placed relative to the ilioischial line, the teardrop, and the superolateral acetabular margin, so that the removal of the supportive subchondral bone is minimal and the center of rotation of the hip is restored. When acetabular abnormalities are encountered, additional measures are necessary to optimize cup coverage and minimize the risk of malposition. Templating the femoral side for cemented and cementless implants should aim to optimize limb length and femoral offset, thereby improving the biomechanics of the hip joint. Meticulous preoperative planning allows the surgeon to perform the procedure expeditiously and precisely, anticipate potential intraoperative complications, and achieve reproducible results.

Since the introduction of modern hip arthroplasty, hip prostheses have consistently relieved pain and improved function.1 Advancements in implant design, materials, surgical technique, and anesthesia have increased durability of the arthroplasty and decreased the prevalence of complications. However, component malposition leading to excessive wear or dislocation, fixation failure, limb-length discrepancy, and dislocation remain important concerns. Dislocation may be related to component orientation, soft-tissue tension, or failure to restore hip biomechanics. Mechanical failure is also multifactorial and dependent on materials, design,2 surface finish,3,4 position, and bone quality, as well as biologic response to wear debris.5 Many of these factors are under the control of the surgeon; thus, a thorough preoperative plan may mitigate the likelihood that any of these factors will contribute to arthroplasty failure.6

The step-by-step process of a hip replacement should begin before the operation after careful review of the clinical and radiographic findings. This review should result in an exact preoperative plan that will guide surgery to achieve optimal, reproducible results.6-10

Besides improving precision during surgery, preoperative planning forces the surgeon to think in the three dimensions demanded during surgery. Preoperative planning also
allows the surgical team to prepare the instrumentation required for each operation, have the proper inventory of implants available, and predict complications and needs that may arise during surgery.

**History and Physical Examination**

The medical history and current medical status of the patient should be considered during preoperative planning in order to choose implant fixation, implant designs, and surgical approaches. The following also should be considered: the patient’s age, sex, preoperative diagnosis, level of activity, and mental status; involvement of other joints; conditions precluding the use of crutches or walker; medical problems; and the patient’s expectations from the surgery and life expectancy.

Patients at high risk for dislocation because of neuromuscular problems, substance abuse, or other reasons may benefit from particular surgical approaches or specific implant characteristics (eg, larger femoral head diameter) that optimize hip stability. Constrained cups may rarely be considered for patients at a very high risk for dislocation.

The preoperative examination should include assessment of the patient’s gait and hip range of motion, as well as evaluation of the ipsilateral knee, lumbosacral spine, and fixed or functional deformities. Both the actual and functional limb-length discrepancy should be established. The actual limb-length discrepancy is determined by measuring the distance between the anterosuperior iliac spine and the medial malleolus. The functional limb-length discrepancy is what the patient perceives while in a standing position; it can be determined by placing blocks under the affected side until the patient feels the limbs’ length to be “equal.”

The most common cause for functional limb-length discrepancy is either flexion and/or abduction contracture.14

When there is a difference between the actual and functional limb length, pelvic obliquity may be evaluated by comparing the level of both hemipelvises with the patient standing and sitting. Suprapelvic obliquity, in association with scoliosis or degenerative disease of the lumbosacral spine, persists in the seated position. Conversely, pelvic and infrapelvic obliquity resolves in the same position. Intrinsic pelvic abnormalities resulting in obliquity include loss of bone or cartilage as a result of arthritis, necrosis, or infection, and fractures of the pelvic ring resulting in deformity. In addition, the surgeon should be aware of infrapelvic obliquity resulting from limb-length discrepancy related to the following: previous fracture of the limb, congenital hemihypertrophy, sequela of poliomyelitis, and undisclosed prior trauma affecting epiphyseal growth. In these cases, there is a difference between the predicted limb-length discrepancy seen in hip radiographic findings and the clinical picture. When suprapelvic or infrapelvic obliquity exists, equalizing the functional leg length often provides the patient improved gait and increased comfort, provided the stability of the arthroplasty is not jeopardized.

**Radiographic Technique**

A standardized radiographic evaluation of the hip usually includes an anteroposterior (AP) view of the pelvis centered over the pubic symphysis. Such a radiographic evaluation will also include AP and true lateral views of the affected hip, which will depict a lateral view of the femur as well as of the acetabulum.

The AP views are obtained with the patient lying supine on the table with the hips in 10° to 15° of internal rotation. This allows a true AP view of the femoral neck, which has a normal anteversion of 10° to 15°. If the radiographs are obtained with the hips externally rotated, the true femoral offset will be underestimated. If there is tilt or rotation of the pelvis with the patient lying supine, lumbosacral spine pathology or hip contracture should be suspected.

For adequate preoperative planning, the surgeon needs to know the magnification of the hip radiographs. Assuming that the x-ray tube is at a distance of 1 meter from the tabletop, and that the film is placed in a tray 5 cm below the table, the radiograph magnification will be approximately 20% ± 6% (2 SDs).15 Magnification is directly proportional to the distance between the pelvis and the film; therefore, increased magnification should be expected in obese patients and, conversely, less magnification in thin patients.

For patients in whom absolute precision is required (eg, a candidate for a custom prosthesis), a magnification marker can be taped to the patient’s skin at the level of the greater trochanter.16 The magnification marker consists of a Plexiglas tube with two lead spheres embedded at an exact distance of 100 mm. A coin with a known diameter can also be used as a magnification marker.

**Radiographic Review**

Before templating, the radiographs should be reviewed to confirm the diagnosis and eliminate the possibility of limb or pelvis malpositioning that might mislead the surgeon in planning, as well as to allow consideration of anatomic challenges that might be confronted intraoperatively. Pelvic rotation is suggested by the absence of superimposition of the center of the sacrum and coccyx on the pubic symphysis and asymmetry of the obturator foramina.17 In the presence of lumbosacral hyperlordosis resulting from hip flexion contracture, the AP view of the pelvis resembles an inlet view, and the acetabular landmarks may not be accurately visualized for templating. Rotation of the upper femur...
can be assessed by the relative visualization of the lesser and greater trochanters. An increased visualization of the lesser trochanter implies external rotation of the hip, and, conversely, a hidden lesser trochanter suggests internal rotation.

The AP view of the pelvis is useful to assess limb-length discrepancy, the contralateral hip, and the lower lumbar spine, which can cause fixed pelvic obliquity. Occasionally, abduction or adduction contractures of the hip can be identified. The lateral view of the femur can help in planning the location of the proximal femoral opening in proximity of the piriformis fossa18 (Figure 1). A too anterior or posterior femoral opening point can lead to eccentric reaming and concomitant femoral shaft perforation or fracture and to a noncircumferential cement mantle.18

The shape of the femur and acetabulum, as well as the trabecular pattern, should be examined to confirm the diagnosis and to choose between implant designs and fixation. In patients with posttraumatic deformities, Paget’s disease, previous osteotomies, or fibrous dysplasia, the upper femur can be deformed or angulated, making stem insertion difficult.

The bone quality and geometry of the upper femur can be assessed using the radiographic indexes proposed by Singh et al19 and Dorr et al.20 Analysis of the morphology of the upper femur helps some surgeons decide between cemented or cementless femoral implants.

**Determining Radiographic Landmarks and Templating**

Templating should follow the steps of surgery: acetabular side first, followed by the femoral side. The measured distances and implant sizes should be recorded following a preestablished order so that the surgical team understands and follows the plan throughout the surgery.

The first step in templating is to draw a horizontal reference line through the base of both teardrops. The teardrops are the most accurate anatomic landmarks in relation to the bony acetabulum because they are located close to the center of rotation of the hip joints.21,22 Alternative horizontal reference lines can be drawn through the most distal aspect of the sacroiliac joints and through the most distal aspect of the ischial tuberosities. However, the farther away from the center of the hip joint that anatomic structures lie, the more potential error is introduced by pelvic rotation. Several key radiographic landmarks, which can be visualized during acetabular exposure, should be marked before cup templating: the base of the teardrop, the ilioischial line, and the superolateral margin of the acetabulum (Figure 2, A).

**Acetabular Templating**

Correct orientation of the acetabular cup is essential for the stability of the arthroplasty.23-25 The cup should be sized so that when the template is placed with the cup at 40° ± 10° of abduction, the medial border approximates the ilioischial line and the cup has adequate lateral bone coverage, with minimal removal of the supportive subchondral bone (Figure 2, B). Some surgeons plan to place the inferior border of the cup level with the inferior teardrop line; others think this measure...
necessitates more acetabular bone removal than is necessary. In cemented cups, templating should allow for a uniform cement mantle of 2 to 3 mm. If the lateral coverage of the cup is not complete, the uncovered area should be measured and reproduced during surgery—with the trial and definitive component—to ensure adequate inclination.

With the acetabular template in place, the center of rotation should be marked on the radiographs (Figure 2, B). The templated center of rotation may be compared with the contralateral center to determine whether they are at the same vertical distance from the reference line and the same horizontal distance from the teardrop. Any difference may be recorded to compensate limb length and offset during femoral templating.

Arthritic cysts located in the acetabular roof may be outlined on the radiographs and grafted during surgery or used as anchoring holes for cemented fixation. Note should be made of acetabular osteophytes to be removed prior to cup insertion.

**Protrusio Acetabuli**

The acetabular cup should be templated in an anatomic position lateral to the teardrop and Köhler’s line, with peripheral rim contact. The width of the medial particulate bone graft required to fill the defective and protruded medial wall can be measured (Figure 3, B). During surgery, reaming should be sufficient to obtain adequate peripheral support, but it should not extend to the full depth of the protruded medial wall. Proper placement of the cup improves soft-tissue tension and decreases the possibility of femoral impingement with the pelvis.

**Lateralized Acetabulum**

Medial osteophytes frequently are present in patients with hypertrophic osteoarthritis and lateral subluxation of the femoral head. The extent of the medial osteophyte should be noted preoperatively. At surgery, the acetabulum should be reamed until the pulvinar, ligamentum teres, cotyloid notch, and transverse acetabular ligament are clearly visualized. Failure to adequately assess and remove and ream the medial osteophyte can lead to implantation of the cup in a lateralized position, often resulting in insufficient coverage, suboptimal fixation, and compromised biomechanics (Figure 4). It also can jeopardize an adequate enhanced soft-tissue repair when a posterolateral approach is used.12

**Dysplastic Acetabulum**

In patients with dysplastic hips, insufficient acetabular coverage and superolateral migration of the femo-
Femoral Templating and Restoration of Limb Length

The aims of femoral templating are to achieve an implant with adequate alignment and fixation within the femoral canal to restore femoral offset and to optimize limb length.

Preoperative limb-length discrepancy attributable to hip anatomy can be determined by measuring the perpendicular distance from the proximal corner of the lesser trochanter to the reference line. The radiographic discrepancy should be compared with that measured during the clinical examination. The amount of limb-length change produced by the operation will be the vertical distance between the center of rotation of the femoral component and the center of rotation of the acetabular component (Figure 6). When the femoral center of rotation on templating is superior to that of the acetabular component, the limb will be lengthened; in contrast, when the femoral center is inferior to the acetabular center, the limb will be shortened accordingly.

A line perpendicular to the femoral shaft at the level of the tip of the greater trochanter is frequently used to determine the desired level of the femoral head’s center of rotation. This measurement is inaccurate,
However, because this relationship varies considerably with the neck-shaft angle. In patients with coxa valga, the center of rotation is located above the tip of the greater trochanter; in patients with coxa vara or coxa brevis, the center of rotation is located below the tip of the greater trochanter.

After determining the desired height of the prosthetic head, the stem’s size should be chosen, depending on the planned fixation mode. For a cementless, proximally fitted stem, optimal contact between the lateral and medial endosteal cortex of the proximal femur should be achieved. In fully porous-coated stems, optimal endosteal contact in the diaphysis is necessary. For cemented fixation, the stem should allow for a 2-mm circumferential cement mantle, which usually is marked on the template.6

While centered within the femoral canal, the femoral template is displaced proximally or distally to reproduce the altitude for equalization of limb length [Figure 6]. The entrance in the piriformis fossa can be marked on the radiograph following the axis of the stem in the AP and lateral views (Figures 1 and 6). This entrance point can help the surgeon center the canal finder when starting femoral preparation.6

The stem’s femoral offset should approximately restore the offset of the normal hip. If the center of rotation of the prosthetic head lies medial to that of the cup on templating, the reconstruction will produce an increased offset. If the center of the femoral head lies lateral to the center of the acetabulum, a decreased offset will be produced. In a severely arthritic hip that is externally rotated on radiographs, templating will underestimate the femoral offset. In these circumstances, optimal stem offset may be determined by templating the contralateral, normal side. In the presence of severe bilateral arthritis and an external rotation contracture, the patient’s offset may be determined intraoperatively—after hip dislocation and before neck osteotomy—by measuring the distance from the center of rotation of the head to the tip of the greater trochanter. The templated stem size and offset should be recorded in the plan. Templating usually should aim for the midrange of neck lengths to allow adjustment to a shorter or longer modular head during surgery.

Once the planned position and offset of the stem are chosen, the new center of rotation of the prosthetic head, and the angle and level of the neck osteotomy, should be marked [Figure 6]. At this point, measurements may be obtained using the template’s magnified ruler. The distance from the proximal corner of the lesser trochanter to the center of rotation of the head can be corroborated by comparison with the altitude of the tip of the greater trochanter (6).

If the hip is short, the limb-length discrepancy (1) should be added proximally to the center of rotation of the cup (CR) to determine the altitude of the center of rotation of the prosthetic femoral head (H). After that, superimposing the stem template in the adequate intramedullary position will allow marking of the location of the proximal femoral entrance in relation to the greater trochanter (2). Two distances are measured from the proximal corner of the lesser trochanter: to the center of the head (3) and to the neck cut (4). The width of the calcar at the neck cut will guide the proximal valgus-varus orientation of the stem (5). The altitude of the prosthetic head can be corroborated by comparison with the altitude of the tip of the greater trochanter (6).

Figure 6

If the hip is short, the limb-length discrepancy (1) should be added proximally to the center of rotation of the cup (CR) to determine the altitude of the center of rotation of the prosthetic femoral head (H). After that, superimposing the stem template in the adequate intramedullary position will allow marking of the location of the proximal femoral entrance in relation to the greater trochanter (2). Two distances are measured from the proximal corner of the lesser trochanter: to the center of the head (3) and to the neck cut (4). The width of the calcar at the neck cut will guide the proximal valgus-varus orientation of the stem (5). The altitude of the prosthetic head can be corroborated by comparison with the altitude of the tip of the greater trochanter (6).
Utility and Accuracy of Preoperative Templating

Only a few studies have assessed the usefulness and accuracy of preoperative planning. Eggli et al. evaluated the efficacy of preoperative planning in achieving the new center of rotation, restoring limb length, and choosing the cup and stem size in 100 consecutive primary total hip replacements performed by one experienced surgeon. The authors reported 90% agreement in the cup size and 92% agreement in the cemented stem size. The mean absolute difference between the planned and actual position of the center of rotation of the hip was 2.5 ± 1.1 mm vertically and 4.4 ± 2.1 mm horizontally. The mean postoperative limb length difference was 3 ± 1 mm clinically and 2 ± 1 mm radiologically. More than 80% of difficulties encountered during surgery were anticipated during preoperative planning, including the need for trochanteric osteotomy, acetabular autografts and allografts, acetabular reinforcement rings, and resection of osteophytes.

Evaluating 110 hybrid and cementless primary total hip replacements, Knight and Atwater reported agreement with the preoperative plan in the cup size in 62% of cases, in the cemented stem size in 78% of cases, and in the cementless stem size in 42% of cases. Undersizing of cementless stems relative to the preoperative plan occurred in 50% of cases. The accuracy of templating increases with the surgeon’s experience. Carter et al. reported that a senior orthopaedic surgeon was able to predict the size of a cementless stem in 95% of cases, compared with predictions of 82% and 88% for second- and fourth-year residents, respectively. In our experience, acetabular and femoral components for cemented and hybrid total hip arthroplasties can be predicted within ± one size in 99.2% of cases with careful templating.

Several sources of error can affect the accuracy of the preoperative plan. As mentioned, radiographic magnification depends on the patient’s body habitus. In the very thin patient, the magnification will be less (approximately 15%), and in the very obese patient, the magnification will be greater (approximately 25%). The longest distance measured during the templating process is that from the proximal corner of the lesser trochanter to the center of rotation of the prosthetic head, which helps estimate limb-length change. Because it is the longest distance measured, it is the measurement most affected by variability in radiographic magnification.

Measurements from the proximal corner of the lesser trochanter are affected by anatomic variability because some patients have a less prominent lesser trochanter with ill-defined corners. The surgeon also can use the vertical distance between the templated prosthetic head and the tip of the greater trochanter to estimate limb length intraoperatively and to guide the depth of insertion of the femoral component (Figure 6).

Adapting Preoperative Planning to the Intraoperative Findings

Although surgical planning has a high predictive value in achieving the goals stated, occasionally the surgical scenario will not match the preoperative plan. For example, implanting a cup of a different diameter will modify the center of rotation and limb length if adjustments in the plan are not made. Likewise, modifying femoral implant size may change the prosthetic neck length and offset.

Furthermore, the surgeon should not rely solely on the preoperative plan for choosing stem size. The tactile feedback during broaching and reaming provides important clues for selecting the size, particularly for cementless fixation, and for minimizing the risk of fracture during broaching or implant impaction. Careful recognition of the compliance and strength of the bone during preparation is as important as the preoperative plan.

Following reduction of the trial prosthesis, meticulous examination of the range of motion should be made, and osteophytes, which limit the safe range of motion, should be excised. If the leg length is adequate but the soft-tissue tension is poor, some stem designs will allow increasing the offset without increasing limb length. If soft-tissue tension and stability are still not restored by these means, a slight increase of limb length may be considered. Older patients perceive lengthening and shortening of the operated leg less than do young patients.

In patients with bilateral degenerative hip disease undergoing unilateral surgery, the plan and execution of the first hip should be recorded, including intraoperative changes, so that it can be reproduced during the surgery on the contralateral side.

Summary

Preoperative planning is an essential part of modern total hip arthroplasty. Information obtained during the initial survey, physical and radiographic examination, and templating can result in a precise plan to help the surgeon anticipate potential intraoperative complications. Preoperative planning also can help the surgeon perform the procedure expeditiously as well as achieve reproducible, desired results.

References

Evidence-based Medicine: The studies referenced represent primarily level III (retrospective cohort studies) and level IV case series and level V expert opinion. There were no level I, randomized controlled studies referenced.
Preoperative Planning for Primary Total Hip Arthroplasty


