Leg-Length Discrepancy After Total Hip Arthroplasty

Abstract
Leg-length discrepancy after total hip arthroplasty can pose a substantial problem for the orthopaedic surgeon. Such discrepancy has been associated with complications including nerve palsy, low back pain, and abnormal gait. Careful preoperative measurement and assessment, as well as preoperative and postoperative patient education, are important factors in achieving an acceptable result. However, after total hip arthroplasty, equal leg length should not be guaranteed. Rather, the patient should be given a realistic assessment of what can reasonably be expected.

The objectives of total hip arthroplasty (THA) include pain relief, improved mobility and stability of the hip, normal mechanics of the hip joint, and, when possible, equality of leg length. In general, obtaining pain relief and improving stability take precedence over restoring equal leg length. However, leg lengthening may be required to provide a stable hip joint after reconstruction arthroplasty.

Data published by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) provide an account of the types of medical errors that occur in hospitals in the United States.1 In his presidential address to the American Academy of Orthopaedic Surgeons, James Hern- don, MD, remarked on the 19 major events described by the JCAHO that deserve watchfulness; 6 are relevant to orthopaedic surgery.2 Included among these are patient falls and leg-length issues; the latter account for 4.7% of medical errors.

Nerve injury is the most serious complication associated with leg-length inequality.14 In a review of 23 THAs complicated by peroneal and sciatic nerve palsy, Edwards et al15 noted an average lengthening of 2.7 cm [range, 1.9 to 3.7 cm] for peroneal palsy and 4.4 cm [range, 4.0 to 5.1 cm] for sciatic palsy. In a case report describing acute sciatic and femoral neuritis following THA, Mihalko et al7 described a patient who, following a leg lengthening of 2.5 cm, reported pain without motor or sensory deficit; the patient also had abnormal electromyography and nerve conduction velocities. Pritchett16 reported on 19 patients who had severe neurologic deficit and persistent dysesthetic pain fol-
following THAs in which limb lengthening of 1.3 to 4.1 cm was performed. After evaluating factors that influence nerve repair, Smith concluded that nerve lengthening of as much as 15% to 20% of the resting length was safe. However, for hip arthroplasty, the specific degree of length that can be gained without risking nerve palsy remains undefined. Although surgeons generally agree that progressively greater lengthening is associated with greater risk to the nerve, no consensus exists regarding a safe threshold for lengthening. Some sciatic nerve problems that occur in the presence of leg-length inequality are not directly related to the leg lengthening.

Most patients with minor leg-length discrepancy after THA have few symptoms, and most patients with moderate leg-length discrepancy have readily manageable symptoms. However, a minority of patients, mostly those with marked limb-length discrepancy, may have substantial disability as a result of pain or functional impairment. Common symptoms include pain, paresthesias, and instability of gait.

Gurney et al evaluated the effects of an artificial limb-length discrepancy on gait economy and lower extremity muscle activity in older adults. They found that with 2 to 4 cm of limb-length discrepancy, there was a significant ($P < 0.0005$) increase in oxygen consumption. With 3 and 4 cm of limb-length discrepancy, there was a significant ($P = 0.001$ and $P < 0.005$, respectively) increase in heart rate and significant ($P = 0.001$ and $P < 0.005$, respectively) quadriceps activity in the longer limb. With a 4-cm limb-length discrepancy, there was a significant ($P < 0.003$) increase in plantar flexor activity in the shorter limb. The authors concluded that in older adults, limb-length discrepancy of between 2 and 3 cm is the critical point with regard to the effects on most physiologic parameters. Elderly patients with substantial pulmonary, cardiac, or neuromuscular disease may have difficulty walking with a limb-length discrepancy as small as 2 cm.

Bhave et al reported that a limb-length discrepancy creates an asymmetry in the ground reaction force and that surgical lengthening of the short limb to within 1 cm of the contralateral limb reduced the asymmetry to less than a significant level. Vink and Huson reported a notable increase in the electromyographic activity of the erector spinae muscles only when the leg-length discrepancy was $\geq 3$ cm.

To prevent postoperative leg-length discrepancy and its attendant problems, it is important to understand the various components of leg-length assessment related to THA, including preoperative planning, intraoperative measurement, and postoperative management. With minimally invasive techniques and smaller incisions, the need for accurate placement of implants is heightened. Computer-assisted surgery may play a role in accurately determining such placement.

**Preoperative Planning**

**Patient History**

The patient’s perceived leg-length discrepancy is a very important aspect of the preoperative history. It is useful to ask patients specifically whether their legs feel equal and whether they use a shoe lift. A patient’s legs often are of unequal length before surgery. Ranawat and Rodriguez noted a high prevalence of asymptomatic leg-length inequality in the general population. Muscle contracture frequently is a cause of apparent discrepancy. A history of scoliosis, poliomyelitis, developmental dysplasia of the hip, degenerative disk disease of the lumbar or thoracic spine, or lumbar surgery, including spinal fusion, is important and may have an effect on leg length and the subsequent development of symptoms.

**Physical Examination**

An abduction, adduction, or flexion contracture should be assessed and quantified because of the potential influence on perceived length. A flexion contracture can lead to overestimating shortening, and an abduction contracture can increase perceived length. Next, the pelvis should be leveled by placing a series of blocks under the shorter limb. Finally, the true and apparent limb lengths are measured.

The true limb length is determined by measuring the length of the femur and implants. The apparent limb length is determined by adding the effect of soft-tissue contractures and pelvic obliquity. Most discrepancies are a combination of true and apparent differences. Because functional limb length is the result of a complex interaction of the lengths of bones, implants, soft-tissue contractures, and pelvic obliquities, no single measure adequately conveys all of this information.

The apparent leg length can be measured from the umbilicus to the medial malleolus. This technique provides a simple measure of the functional length; however, it does not assess the effect of soft-tissue contractures and pelvic obliquity. This measurement also can be influenced by the position of the limb and the pelvis. The true leg length is measured from the anterior superior iliac spine to the medial malleolus. This is arguably the most reliable clinical measure of limb length; however, the technique requires precise identification of landmarks, which may be difficult, particularly in obese individuals. True leg-length measurement also is subject to variation because of changes in the position of limbs and pelvis and because of soft-tissue contractures.

The physical examination should include an assessment of spinal deformity and iliac crest symmetry. True leg-length differences may result in a compensatory scoliosis, which may be resolved by placing an
appropriate lift beneath the shorter limb. Conversely, when contrac-
tures of the hip and knee cause a
fixed pelvic obliquity, placing a lift
beneath the shorter limb will not re-
solve the pelvic obliquity. Balancing
by using wooden blocks provides
easy assessment of functional leg-
length discrepancy in a reproducible
fashion; however, this method does
not adequately separate the effects of
soft-tissue contractures and fixed
pelvic obliquity.

Of particular concern is the pa-
tient who presents with a leg-length
discrepancy in which one leg is per-
ceived to be longer than the other al-
though the actual leg lengths are
equal. Common causes of such a per-
ceived “long leg” include scoliosis,
fixed pelvic tilt, and contralateral leg
deformity. Less commonly seen is an
abduction contracture in which the
true leg lengths are equal even
though the apparent leg length is
longer on the side of the contracture.

Patient Education and
Informed Consent

How a patient reacts to perceived
leg-length inequality is associated
with his or her discussion with the
surgeon, who can reassure the patient
that most inequalities have little im-
portance. Patients retain little preop-
erative information about risks and
expectations, no matter how carefully
presented preoperatively; they re-
member more of the information pro-
vided about potential benefits.

During the preoperative discus-
sion, the surgeon should establish
the expectation that equal leg
lengths is not a guarantee after
surgery. Chronic shortening and tis-
sue scarring may make residual
shortening unavoidable at surgery.
Conversely, some individuals with
excessive laxity may require length-
ening to ensure adequate hip stabil-
ity. However, studies have reported
that, even after appropriate patient
education was provided and consent
given, approximately one half of pa-
tients with lengthened legs did not
recall that this possibility had been
communicated to them. Additionally, patients whose affected
side is longer preoperatively should
be warned that further lengthening
may occur as a result of surgery and
that deliberate shortening may not
be feasible.

Radiographic Assessment

Preoperative radiographs are help-
ful in assessing true leg-length dis-
crepancy; included should be an an-
teroposterior view of the pelvis with
both femurs internally rotated ap-
proximately 20° (Figure 1). External
rotation of the hip, which often oc-
curs in association with degenera-
tion, gives the false appearance of
decreased femoral offset. This false
appearance can contribute to under-
estimating the offset and neck
length required to restore hip stabili-
ty and optimal biomechanics.

An appropriately rotated hip shows
the anterior and posterior aspects of
the greater trochanter to be in align-
ment and does not show the entire
lesser trochanter in profile. In patients
with unilateral disease, the anteropos-
terior pelvic view should have appro-
priate rotation on the contralateral
side. When an external rotation con-
tracture prevents appropriate internal
rotation in the supine position, plac-
ing the patient prone may correct the
radiographic appearance.

Determining radiographic leg
length can be difficult in a patient
undergoing revision THA, particu-
larly when significant metaphyseal
and/or diaphyseal bony deficiency
exists as a result of the previous ar-
throplasty. Attempts should be
made to identify radiographic land-
marks on the deficient side that can
be identified at surgery and used in-
traoperatively to help reapproximate
the appropriate leg length.

Preoperative Templating

Templating is useful for predict-
ing limb lengths. With acrylic tem-

---

Figure 1

As an estimate of leg-length discrepancy radiographically, a reference line is drawn
through the bottom of the obturator foramina. On each side, the distance from the
lesser trochanter landmark to the reference line is measured. The difference
between the two is the radiographic leg-length discrepancy. The tip of the greater
trochanter may be used as an alternative reference mark in conjunction with the
lines through the obturator foramina.
plates, the surgeon is able to predict the approximate change in limb length by noting the relationship of various implant landmarks, such as the hip center and its relationship to fixed bony landmarks (eg, the tear drop, the lesser trochanter). The surgeon also can note how these landmarks change with acetabular and femoral implants of various size.

The templates are designed to fit the internally rotated anteroposterior view of the femur. Ideally the ipsilateral side, when available, should be templated first to determine the potential correct sizes for both the acetabular and femoral components. It is important to remember that radiographs typically are magnified up to 20%.

**Acetabular Templating**

Preoperative acetabular templating is performed with the following goals in mind. First, the acetabular shell should make bone contact at the subchondral plate. The lateral opening should approximate 40° ± 5°. Finally, in most cases, the tear drop should coincide with the inferomedial corner of the acetabular component. Placing the acetabular template in this position establishes the new center of rotation of the THA (Figure 2). Placement of the acetabular component as close as possible to the templated position is important because doing so defines the hip center and directly influences leg length.

**Femoral Templating**

When templating the femoral side of the acetabular socket, there are three main goals: optimally size the femoral component, maintain offset, and optimize limb lengths. With appropriately aligned, internally rotated femoral views, the surgeon should be able to determine whether an adequate offset can be achieved with the implants being considered. One method to create a larger offset is to make a lower neck cut and use a longer neck. Another strategy to obtain a larger offset is the use of lateralized femoral components. The advantage of using lateralized femoral components is that offset can more readily be restored without lengthening the limb.

Trochanteric advancement can improve soft-tissue tension without increasing leg length. Disadvantages to using this method, however, include the risk of trochanteric bursitis, nonunion, increased operating time, and the potential need for tension-band wire removal.

The use of templates is the first step in obtaining acceptable clinical results with regard to leg length. However, such use should be combined with a reliable intraoperative method to obtain optimal length.

**Intraoperative Leg-Length Measurement**

**Application of Preoperative Templating Intraoperatively**

Because determining limb length intraoperatively relies on identifying anatomic landmarks, patient positioning is important to ensure proper orientation of these landmarks. Before draping, with the patient in the position that will be evaluated intraoperatively, the baseline limb length is assessed with respect to the contralateral limb. It is also helpful to check that landmarks on the contralateral extremity can be palpated intraoperatively through the drapes.

The accuracy of preoperative femoral templating relates in part to the location of landmarks from which to measure the level of the femoral neck resection during surgery. Although the lesser trochanter is commonly used, its sloping superior surface blends with the inferior femoral neck and therefore may not always provide a definitive landmark, either on radiographs or intraoperatively. In a series of 100 consecutive hip surgeries in which the authors measured from the lesser trochanter and used digitized radiographs and a special software program, Eggli et al found that the actual to the planned...
level of neck resection varied by as much as 7 mm.

Woolson and Harris32 measured from the top of the femoral head to the level of the neck resection, a practical method when the femoral head is not deformed and the preoperative leg-length difference is minimal. Woolson et al33 used this technique and radiographically determined postoperative leg-length discrepancy for a consecutive series of 351 patients (408 hips) who underwent bilateral or unilateral primary THA. Ninety-seven percent of the patients had a postoperative leg-length discrepancy of <1 cm. The average discrepancy for these patients was 1 mm.

Knight and Atwater34 conducted a prospective study of 110 consecutive primary THAs in which surgeons recorded the preoperative plan that was used to determine implant size; implant sizing was correctly predicted from the plan for 62% of acetabular cups (69 of 110) and for 78% of cemented stems (43 of 55); however, correct sizing was predicted from the plan in only 42% of cementless stems (23 of 55).

Surgeons stray from the template plan for cases in which implants of different size or offset are used, the femoral neck resection is not made where intended preoperatively, the neck cut is modified to provide better implant fit, or a tight press-fit femoral component fails to fully seat. A further variable is the difficulty of predicting the actual superior and medial extent of acetabular reaming.

Intraoperative Radiographs

An intraoperative radiograph can be taken with trial components in place and radiographic landmarks measured, as in revision surgery templating. When possible, both hips should be clearly visible on the film. However, metallic patient positioners that can obscure landmarks may need to be removed during film exposure, making intraoperative magnification hard to assess and accurate positioning difficult.

Intraoperative Measurements

As noted, proper patient positioning and identification of baseline landmarks are important. The greater trochanter may be used as an intraoperative landmark for leg-length measurement.35 However, the center of the femoral head does not always coincide with the superior tip of the greater trochanter.36

Several intraoperative methods to measure for implants use one or more reference pins driven into the pelvis. Measurements are made from the pin to a mark on the greater trochanter. The leg should be placed in the same position during each measurement.

Mihalko et al7 used a method in which a large unicortical fragment screw is placed above the superior rim of the acetabulum. The screwdriver is placed in the hex-headed screw, as the baseline limb length, the distance is measured from the shaft of the screwdriver to a mark made with the cautery at the vastus tubercle on the lateral aspect of the greater trochanter. After the implantation of the prosthetic trial components, a check is made to ensure the appropriate limb length.

McGee and Scott37 used a method in which a Steinmann pin is driven into the pelvis 1.5 to 2 cm superior to the acetabulum and bent into a U. A mark is made at the point where the free end of the U contacts the greater trochanter. The pin is swiveled out of the operative field and returned during measurements, with each measurement obtained with the legs in a reproducible position. Restoring the mark to the tip of the pin restores the preoperative length, and suitable adjustments are then made from that reference point. The tip of the pin is used to reference hip offset.

Because a standard Steinmann pin may be too short in obese patients, other measuring pins have been recommended.38,39 One option is to use two Steinmann pins, one in the pelvis and the other in the greater trochanter. The distance between the two is measured before dislocating the hip and during trial measurements. However, a trochanteric pin, which is removed and replaced in its track during measurements, may be unreliable.38

A variety of measuring calipers has been described in which one end articulates with a pin, pins, or spikes anchored into the pelvis, while a stylus at the other end references off a mark on the greater trochanter.40

Another device combines a spirit level with the two-pin method to eliminate variations in the abduction/adduction position of the leg during measurements. Bose41 reported its use in 117 operations; by using the device, the leg was lengthened >12 mm in 5% of hips, compared with 31% lengthening without the device.

Other devices also can measure offset with the use of a vertical caliper. In the lateral decubitus position, the horizontal distance between the tip of the stylus and the marked point on the femur represents the change in leg length, whereas the vertical distance between the tip of the stylus and the lateral surface of the greater trochanter represents the change in hip offset. A removable caliper decreases the risk of bending or dislodging the pin. The pin should not be used to retract the wound edge or the abductor muscles because doing so may cause it to bend or dislodge from soft bone. Finally, a separate skin stab incision may be required.

The accuracy of all of the methods that measure from pins anchored in the pelvis to a point on the greater trochanter may be affected by the inherent variability of the leg position when measurements are made. Because bending a pin or dislodging it from osteoporotic bone will compromise measurements, an intraoperative radiograph of the pelvis with
the trial components in place still may be necessary. Variation caused by changes in leg position can be lessened by creating a rigid cradle for the operated leg.39

Performed following reduction of trial implants, the so-called “shuck” test, described by Charnley,42 is affected by many factors that make it unreliable for leg-length measurement.33,43 However, the test can provide some sense of hip stability, and it may influence the surgeon’s decision on the desired final leg length.

The use of a stable pelvic reference, combined with a method for accurately positioning the leg during measurements, provides the surgeon with a practical method for measuring leg length during hip arthroplasty. Such a method helps the surgeon select implants that provide optimal fit and allows him or her to stray from the preoperative plan, confidently using femoral neck and socket modularity to adjust the final leg length.

**Postoperative Assessment and Treatment Options**

Perception of leg-length inequality is common after the surgical procedure.40 Functional but transient inequality was found to occur in 14 of 100 patients in one study. Persistent functional limb-length inequality (FLLI) is far less common and is found most often in patients who are short of stature or who already have some degeneration of the spine.22

**Perceived Inequality of Leg Lengths**

Pain is the most obvious and frequent symptom associated with a perceived postoperative FLLI: low back pain may be associated with an overlengthened leg, impaired abductor function and possibly hip dislocation may occur with shortening.3 Often a patient’s legs were of unequal length before the surgery, and it is important to document this baseline measurement preoperatively. FLLI after THA also may result from a pre-existing degenerative process in the lumbar spine that is producing scoliosis and pelvic obliquity.22

**Postoperative Assessment**

A careful physical examination that includes a neurovascular assessment is important. Determination of FLLI should be delayed until rehabilitation/recovery has plateaued, typically 3 to 6 months after surgery.

Preoperative and postoperative clinical measurement of the legs is important; radiographic measurements may provide further helpful information. Orthoroentgenography, commonly known as a “scano-gram,” may provide a clear measurement of true leg-length inequality.46 In some cases, a computed tomography scanogram may give the most accurate assessment of leg lengths, particularly in patients with a flexion deformity of the knee. In addition, computed tomography delivers only 20% of the radiation needed for orthoroentgenography.46

Perhaps most useful is simple but thorough questioning and observation of the patient. How does the leg feel when standing? How does the leg feel when using the walker? Is there pain in the lower back, iliac crest, groin, or abductors? Is the gait awkward? Do these problems seem attributable, at least in part, to leg-length discrepancy?

**Treatment**

Nonsurgical management of a perceived or true leg-length inequality can take several forms. The most expedient initial treatment is the insertion of a shoe lift for the leg that seems to be shorter; thickness of up to three-eighths of an inch can be inserted without altering the shoe itself. In a study by Edeen et al.,26 24% of patients required a shoe lift after THA. A shoe lift also may alleviate some low back pain. Friberg11 described a series of more than one thousand cases in which simply providing an adequate shoe lift to correct leg-length inequality resulted in permanent and mostly complete alleviation of symptoms.

However, one should be somewhat cautious regarding the early use of a shoe lift because such use may prevent soft-tissue contractures or pelvic obliquity from “relaxing” and perhaps resolving. Therefore, when a lift is used, the surgeon may choose to compensate only for the actual or perceived length discrepancy. Similarly, in most cases, it is desirable to delay the use of a lift for approximately 6 months postoperatively to determine whether the perceived leg-length discrepancy will resolve.

Equally important is the perspective assumed by the physical therapist. A positive attitude toward the outcome of therapy by the therapist may make a difference in the patient’s accommodation of a different sensation. Such a sensation may be felt even when the legs are anatomically the same length after surgery. Most patients experience gradual (over approximately 6 months) improvement with therapy that stretches soft tissue and relieves pelvic obliquity.22 Assurance from the therapist that the leg will work well with adequate stretching and manipulation may affect eventual outcome.

As with any change in the body, the “tincture of time” may be all that is necessary for satisfactory functioning. For example, of the 100 patients reviewed by Ranawat and Rodriguez,22 14 had pelvic obliquity and FLLI 1 month after surgery, but by 6 months postoperatively, all of these symptoms had subsided with the use of physical therapy. Likewise, in a study by Abraham and Di- mon,29 perceived postoperative inequality was most common in patients with preoperative discrepancies in leg length and usually resolved with time.
Surgical options are available when nonsurgical management fails to produce the desired effects. Possible indications for surgical management include severe hip or back pain, hip instability, paresthesias, and foot drop that the surgeon determines may be improved by reducing the leg-length discrepancy. For the small subset of patients who have a leg that is too short, a modular head can be changed to increase leg length; however, the increase in length usually is small. For shortening >2 cm, revision to a femoral component with a longer base neck length (eg, a calcar replacement prosthesis) may be considered. More commonly, patients find the leg length to be too long after THA. Femoral shortening can be accomplished by exchanging a modular head for a shorter one, although this can lead to instability and may only marginally decrease the length. Treatment by shortening may improve motor impairment after lengthening. Pritchett described motor improvement in 7 of 11 patients who had revision shortening of from 0.5 to 3.6 cm. He noted that when painful neurologic symptoms accompany leg lengthening after THA, revision hip surgery may be helpful although patients should be informed that the rate of success is far from uniform. When shortening is done, it may be necessary either to exchange the femoral component for one with an increased offset, use a larger femoral head, or perform a trochanteric osteotomy to achieve stability. A further option is use of a constrained acetabular liner. If the hip is stable and functions well but the leg is still too long, shortening can be accomplished by a distal femoral osteotomy. All surgical options should be undertaken with caution because of the unpredictability of symptom improvement and the risk of creating new problems (eg, hip instability).

Finally, when hip disease exists in the contralateral hip and contralateral arthroplasty is contemplated, it may be reasonable to use a shoe lift and other nonsurgical management until the time of the second operation, when the leg lengths can be approximated.

In the future, it is likely that advances in technology will lead to greater precision and accuracy in the management of leg length. With the advent of navigation/image-guided surgery technologies, correction of limb-length inequality may be dramatically enhanced. Registration of three-dimensional bony anatomy, coupled with real-time tracking during surgery, may allow the surgeon to accurately balance limb length to within 1 or 2 mm of the contralateral side, based on preoperative measurement and planning. Current image-guided systems use computed tomography scans, fluoroscopic imaging, or point matching/surface registration with optical scanners and morphing technology to provide anatomic referencing for the femur and pelvis at the time of surgery. The relative position of these bony structures can then be tracked in real time as implant adjustments (eg, cup position and placement, femoral implant position, offset, femoral head diameter, neck length) are made that affect limb length. Finally, the surgeon can evaluate limb length, range of motion, hip stability, and possible impingement of components or anatomic structures before closure to ensure optimal clinical outcome.

Summary

Careful preoperative measurement and assessment, as well as preoperative and postoperative education of the patient, are important factors in gaining an acceptable result with regard to leg lengths after THA. Equalizing perceived or actual leg length should not be guaranteed. The patient should be given a realistic expectation of what may be likely after surgery; the preoperative and postoperative visits during which this information is conveyed can be quite important to the eventual outcome. Ideally, the surgeon’s communication with the physical therapist should go beyond written orders; a surgeon’s attitude and positive expectations may well be adopted by the therapist and passed on to the patient. Only in rare circumstances in which nonsurgical measures—including education, recovery time, physical therapy, and shoe lifts—fail to bring satisfactory resolution should surgical intervention be considered for leg-length inequality.

Acknowledgment

The authors wish to acknowledge that they and the other members of the Western Consensus Panel of Depuy/Johnson & Johnson were involved in the development of this consensus statement: Peter Buchert, MD, William Bugbee, MD, James Caillouette, MD, Charles Creasman, MD, Robert Gorab, MD, Wayne Hill, Lin Jones, MD, William Lanzer, MD, Richard Rende, MD, and Kirk Kindsfater, MD.

References


