Modern Imaging in Planning a Personalized Hip Replacement and Evaluating the Spino-pelvic Relationship in Prosthetic Instability

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13.1 Introduction

Successful total hip arthroplasty (THA) greatly depends on appropriate implant choice and accurate femoral and acetabular component positioning. Preoperative radiographic templating is crucial, and accurate intraoperative execution of the templated plan is important to maximize implant stability and bearing performance. Traditionally, plain radiographs have been used for preoperative planning, as well as postoperative follow-up and assessment of component position, with historically defined “safe zones”...
for component position. However, as our understanding of optimal implant positioning in the setting of spino-pelvic dynamics has expanded, more advanced methods of radiographic assessment of implant positioning have gained popularity. Given the variations in anatomy and functional kinematics of a patient’s hip joint, the optimal THA component alignment and positioning may differ on a case by case basis, and therefore, advanced methods of assessing optimal patient-specific implant positioning are of prime importance.

13.2 Personalized Total Hip Arthroplasty

Personalized techniques for implanting hip components have been developed with the goal to solve residual complications that occur with conventionally implanted hip prostheses. One of the causes of failure in conventionally implanted hip prostheses is the suboptimal interaction between components (e.g., edge loading and prosthetic impingement). This is primarily related to the systematic and generalized approach for templating and implanting total hip components in the traditional technique (similar implants positioning for all patients), thereby disregarding the unique individual joint anatomy, biomechanics, and spino-pelvic dynamics. Personalized techniques for joint replacement have therefore been developed to address these issues and improve on the outcomes of THA. This represents a paradigm shift in the approach to THA.

Personalized techniques for THA aim to reproduce normal hip anatomy and biomechanics to generate a more physiological prosthetic hip to improve function, patient satisfaction, and implant survivorship. The growing knowledge surrounding the impact of spino-pelvic dynamics on the stability of a THA is an important discussion in the delivery of personalized total hip components. A more detailed description of the evolution of hip arthroplasty from traditional systematic to modern patient-specific kinematic techniques can be found in the Chap. 3 (hip replacement: development and future). This paradigm shift in the technique for implanting hip components from a traditional, systematic approach toward personalized component implantation necessitates developing reliable methods of postoperative radiographic evaluation and assessment of the accuracy and quality of personalized hip component implantation.

13.3 Traditional Radiographic Evaluation

Traditional radiographic evaluation consists of plain films. An array of different projections can be obtained to gain information regarding hip pathology, alignment, osseous anatomy and morphology, as well as bone quality. Following THA, plain films can demonstrate implant alignment, positioning, the presence of a periprosthetic fracture, as well as reactive bony changes such as osteolysis and stress shielding. Radiographs are typically easy to obtain, less expensive compared with advanced imaging, but may be somewhat limited in providing information on important anatomical relationships such as femoral neck anteversion and functional acetabular orientation.

13.3.1 Anteroposterior (AP) View of the Pelvis

This projection is obtained supine or weight bearing, with both legs internally rotated 15° to obtain a profile view of the femoral neck anatomy which is on average 15° antverted. In order to properly assess implant positioning on an AP pelvis, it is important that the image is obtained with the proper technique and with a marker of a known size (typically 25 mm) present as close to the hip joint as possible for calibrating size and accurate magnification. The hip center of rotation is the center of the femoral head articulating within the acetabular cup. Leg lengths can be estimated by drawing a horizontal reference line connecting both teardrops (or ischial tuberosities) and comparing the perpendicular distance from that line to a similar reference point on the
proximal femur, typically the lesser trochanter. On the acetabular side, the static supine or standing cup abduction angle can be measured by using the horizontal reference line connecting both tear drops and measuring the acute angle subtended by an intersecting line connecting the superior and inferior edges of the cup (Fig. 13.1a). The static supine or standing cup anteversion may also be measured on an AP pelvis using one of multiple methods such as the Lewinnek method which is based on a mathematical formula [1] (Fig. 13.1b) or using computer software based on the geometry of the ellipse created by the anterior and posterior lips of the cup. On the femoral side, stem size and fit can be evaluated based on knowledge of the implant and expected fixation pattern. The varus/valgus alignment of the stem can be assessed based on any deviation of the stem from the alignment of the femoral canal, and femoral offset can be measured from the center of rotation of the hip joint to a line traveling down the femoral canal. Furthermore, the static supine or standing femoral version can be estimated based on the AP pelvis radiograph as described by Weber et al. [2]. This technique relies on calculating the femoral version by rotation-based change in the measured neck—shaft angle of the stem, using the following formula: Stem version = arcsin [tan (measured neck shaft angle)/tan (true implant neck shaft angle)]. An alternative technique of measuring femoral version has been described based on a specialized posteroanterior seated hip radiograph called a Budin view [3]. Computed tomography is the gold standard in measuring the anatomic femoral anteversion, which is made relative to the posterior condylar line of the knee.

13.3.2 Cross Table and Frog-Lateral Views

A cross table lateral is obtained in the supine position, with the leg internally rotated 15°, contralateral hip flexed, with the beam centered over the femoral head and aimed 45° in the coronal plane to avoid the contralateral hip. On this projection, the static supine acetabular anteversion can be measured by the angle created between a line over the face of the cup and a line that is perpendicular to the horizontal plane as described by Woo and Morrey. This measurement however is prone to inaccuracy as it can be affected by pelvic tilt, which changes as the contralateral hip is flexed. A more recent employment is the ischio-lateral method of estimating anteversion is based off of the longitudinal axis of the ischial tuberosity and can avoid this issue [4]. The femoral stem fit and anteroposterior angulation is also visualized on this view, but the proximal femur is better visualized on a frog-lateral radiograph, which is obtained by centering the beam.

Fig. 13.1 (a) Acetabular component inclination may be estimated on this supine anteroposterior view of the pelvis based on a horizontal reference line connecting the tear drops. (b) Acetabular component anteversion calculated based on Lewinnek’s method (Version = Arcsin (short axis/long axis)) to be approximately 25°
over the femoral head with the hip flexed and abducted 45°. Although this view is a lateral of the proximal femur, it is not a lateral view of the acetabular cup.

### 13.3.3 Shortcomings of Traditional Radiographic Assessment

There are some important considerations that are not completely evaluated using the traditional radiographic methods. For instance, plain films are two-dimensional, and an AP view of the pelvis only allows for coronal plane templating of the acetabular component. The thickness and width of the anterior and posterior walls are not visualized, and therefore unaccounted for when templating acetabular component size. Although knowing femoral head diameter may reproducibly allow deduction of a reliable cup size template, axial imaging may better visualize acetabular anterior and posterior wall bone stock and therefore more accurate component size templating.

Furthermore, plain radiographic assessment only provides static landmarks of acetabular inclination and anteversion, which assumes a constant position of the acetabulum. Changes in acetabular inclination and anteversion secondary to postural pelvic obliquity, tilt, or rotation in a weight bearing position may be completely missed on AP pelvis views (supine or standing). Static imaging also ignores the dynamic relationships between the acetabular position, the pelvis, and the spine, which change in different postural positions. Patients may have physiologically or pathologically different profiles of spino-pelvic mobility which can impact cup position and therefore their risks of instability, prosthetic impingement, and edge loading if these variables are ignored by using a universally defined “safe zone” target of cup position of 40 ± 10° of inclination and 15 ± 10° of anteversion as defined by Lewinnek [1]. In fact, in a large cohort of 9784 patients, 58% of THA dislocations occurred in patients with components placed in the classically defined “safe zone” [5].

Traditional plain radiography may be inadequate in judging the quality of personalized total hip component implantation. Postoperative radiographs have been shown to lack precision when assessing the quality of the restoration of the hip biomechanical parameters (femoral medial offset and femoral length) and cannot fully inform if the personalized implants have been positioned to reproduce the native hip anatomy and match the individual spino-pelvic dynamics. For instance, plain films do not inform the operator if the cup is oriented parallel to the native transverse acetabular ligament, nor if the adjustment of anteversion to accommodate a stiff lumbar spine has been precisely achieved, or whether the prosthetic neck anteversion has reproduced the native femoral anteversion. These limitations of static, 2-D plain radiographs in the postoperative evaluation of personalized component positioning compel the use of more advanced imaging techniques.

### 13.4 Modern Concepts and Radiographic Evaluation

The dynamic relationship between the pelvis and the lumbar spine affects acetabular cup position and can therefore profoundly impact the stability of THA. Hip pathology frequently coexists with lumbar spine pathology, and lumbar stiffness or fusion has been linked with increased instability following THA [6, 7]. This warrants thorough radiographic assessment and analysis of spino-pelvic parameters and determination of spino-pelvic motion when preoperatively planning the ideal acetabular implant and cup position, to estimate a “safe zone” that is specific to the patient evaluated. Traditionally, the transverse acetabular ligament has been used to guide
patient-specific cup anteversion; however, given
the dynamic nature of the hip joint, the func-
tional anteversion of the acetabulum may differ
based on pelvic tilt [8].

13.4.1 Sitting and Standing
Alignment Radiographs

Although not routinely obtained, sitting and
standing lateral full-length radiographs are often
obtained to determine the changes in spino-pelvic
parameters and become especially important to
obtain in patients with lumbar spinal disease or
fusion or to evaluate acetabular component posi-
tion if presenting with recurrent total hip instabil-
ity [9, 10]. It is known that patients with a stiff or
fused spine, who experience prosthetic disloca-
tion, have a tendency to demonstrate decreased
spine flexion, smaller change in pelvic tilt, and
increased hip flexion from standing to sitting
position [11]. These sitting and standing films
may be obtained on a 36-inch film cassette or if
available, using EOS™ stereoradiographs
(EOS™ Imaging, Paris, France) (Fig. 13.2a–d).
More dynamic imaging including flexed-seated
and single-leg step-up lateral images are gaining
popularity as they may be better at assessing the
functional position of the hip joint and spino-
pelvic dynamics and have been used for an
Optimized Positioning System™ used to
preoperatively plan patient-specific target com-
ponent position [12].

Several spino-pelvic parameters can be mea-
sured and analyzed on the lateral sitting and
standing alignment films (Fig. 13.3):

(a) Pelvic tilt (PT) or pelvic version may be
measured as the angle between the vertical
axis and a line connecting the center of the
S1 vertebral endplate and the center of the
femoral head. Pelvic tilt increases as the pel-
vis retroverts when going from standing to a
sitting position.

(b) Sacral slope (SS) can be measured as the
angle between a horizontal reference line and
a line parallel to the S1 endplate. This param-
eter decreases as the pelvis goes into
retroversion.

(c) Pelvic incidence is the sum of SS and PT and
can be measured as the angle between a line
connecting the femoral head and the center
of the S1 endplate and a line perpendicular to
the S1 endplate. This parameter remains con-
stant through pelvic motion; however, it can
be used as a direct indicator of the ability to
recruit pelvic tilt to compensate for spinal
deformity.

(d) Lumbar lordosis (LL) is the Cobb angle
between two lines parallel to the L1 and the
S1 endplates. This value is typically within
10° of the PI in a normal lumbar spine.

(e) The anterior pelvic plane (APP) can be used
to measure pelvic tilt as well. It is created by
a line connecting both anterior superior iliac
spines and the pubic symphysis, and the
angle created between this plane and the ver-
tical axis represents that anterior pelvic
plane-pelvic tilt (APP-PT) angle.

In a normal and flexible lumbar spine, the pel-
vic tilt increases when going from standing to sit-
ting, which increases acetabular anteversion and
decreases the risk of impingement and posterior
dislocation. Acetabular anteversion increases by
0.7° for each 1° increase in pelvic tilt [13].
However, in the case of a stiff or fused lumbar
spine, the change in pelvic tilt markedly decreases
from standing to sitting. This change is typically
less than 20° [9], although it is not yet entirely
clear what degree of angular difference in these
parameters indicates a stiff spine. When the pel-
vic tilt does not adequately increase, there is con-
sequently less acetabular anteversion when in a
sitting position and, therefore, increased risk of
impingement and posterior dislocation.

Patient-specific acetabular component posi-
tion can be decided based on these standing/
Fig. 13.2 Full leg-length standing anteroposterior (a) and lateral (b) and sitting anteroposterior (c) and lateral (d) films obtained on long cassette
sitting alignment films and changes in spino-pelvic parameters. Increasing cup anteversion may be warranted in patients with a significantly stiff lumbar spine and very limited changes in pelvic tilt from standing to sitting. In higher-risk cases, dual mobility implants may be considered (Fig. 13.4). Without obtaining this radiographic assessment of the patient’s spino-pelvic dynamics, it is difficult to identify who may be at a higher risk of dislocation, and choosing the same target cup position for all may lead to dislocation in those with stiff or fused lumbar spines.

**13.4.2 Stepwise Evaluation of Acetabular Component Position in Total Hip Instability**

When evaluating a patient with prosthetic hip instability for revision surgery or a patient at high-risk of dislocation following primary THA, it is critical to employ a stepwise radiographic assessment of component positioning to determine the optimal patient-specific functional implant position that minimizes the risk of instability.
Initially a supine AP pelvis may be obtained, and the supine cup abduction and anteversion may be deduced as previously described. A standing or weight-bearing AP view of the pelvis can then be obtained for comparison with the supine view. This standing film offers an assessment of the cup abduction and anteversion in the patient’s functional standing weight-bearing position. Pelvic obliquity, rotation, or tilt may affect the functional cup abduction or anteversion positions. For instance, patients with excessive anterior pelvic tilt will functionally have less cup anteversion in a standing position.

Subsequently, sitting and standing lateral full-length radiographs may then be obtained. Lumbar degenerative processes including spinal fusion, spondylosis, spondylolisthesis, or sagittal spinal imbalance or deformity can be assessed through these images. These lumbar pathologies significantly affect spino-pelvic motion and therefore have consequences that impact acetabular component position and therefore risks of instability, prosthetic impingement, and edge loading. The spino-pelvic parameters listed above can be assessed from these sitting to standing films, and based on changes in these parameters, the change in cup anteversion between these two functional positions can be evaluated.

**Fig. 13.4** Lateral sitting (a) and standing (b) plain films demonstrating minimal pelvic tilt change between the two functional positions in a patient with posterior L4-L5 spinal fusion for degenerative lumbar disease. The lack of pelvic tilt change limits cup anteversion in a sitting position, which increases the risk of dislocation.
positions may be deduced as described by Lembeck [13]. In cases with limited changes in pelvic tilt, and therefore limited increase in cup anteversion when going from standing to sitting, it may be important to consider increasing the anteversion of the revision acetabular component to account for this limited pelvic mobility.

13.5 3-D Imaging to Assess Patient-Specific Component Position

13.5.1 Computed Tomography 3-D Imaging

Obtaining a CT scan prior to THA is not routine practice but is often done as part of the protocol of some robotic-assisted computer navigation tools. CT imaging can be used to template component positioning preoperatively and offers the advantage of axial imaging of the acetabular anteversion, anterior and posterior wall thickness, and a better delineation of the proximal femoral anatomy including femoral version. In complex cases of osteolysis and revision THA, CT imaging can better delineate bone loss and becomes even more important for preoperative planning and implant choice. However, CT imaging is still a static imaging modality that does not consider the dynamic changes in acetabular orientation between different functional positions. Furthermore, CT imaging may be used to determine femoral component version, which is useful when evaluating total hip instability.

13.5.2 Statistical Shape Modeling Method of Converting 2-D to 3-D Imaging

Although three-dimensional imaging is useful in preoperative planning and templating for patient-specific component positioning in THA, it is often derived from CT or MRI imaging which carry the inherent disadvantages of being expensive, time-consuming, and may expose the patient to significant ionizing radiation (CT).

A statistical shape model (SSM) reconstruction technique has been used to create a patient-specific 3-D surface model of the pelvis based on a single 2-D AP view of the pelvis [14]. This technique is predicated on landmark-based initialization and iterative matching of apparent image contours extracted from the 2-D radiograph to create a 3-D reconstruction. This method is a feasible technique to create patient-specific 3-D images, which may be used for preoperative planning without obtaining MRI or CT scan. This technique has also been successful in creating 3-D reconstructions of the lumbar vertebral anatomy [15].

13.5.3 The Use of CT Imaging in Assessment of Personalized Component Implantation

Precise assessment of conventionally implanted hip prostheses is possible with CT imaging by measuring component orientation relative to anatomical landmarks. For example, cup orientation and prosthetic neck anteversion are respectively measured relatively to the anterior pelvic plane and posterior condylar line. Similarly, CT imaging is useful in accurate assessment and quality control of personalized THA implantation, particularly if preoperative CT imaging is available for comparison (osteoarthritic vs. prosthetic anatomy). Comparisons of the pre- and postoperative imaging can indicate whether the native proximal femoral and acetabular orientations and the hip center of rotation have been appropriately reproduced and whether the components were implanted with accuracy compared to the preoperative template (Fig. 13.5). 3-D CT imaging of the native hip or the planned hip replacement and the executed THA can be overlaid to provide insight of the precision of the personalized implantation technique. If pre-operative 3-D imaging is unavailable, a direct comparison between the prosthetic and contralateral hip may be of utility. Nevertheless, this method is may be limited, as the symmetry index between the axial anatomical parameters (femoral neck and acetabular anteversion) of both hips in a given individual may be weaker than previously thought. Despite this utility in the postoperative evaluation of a personalized THA, CT imaging is a static modality, obtained in a supine position, and is best interpreted in conjunction with the previ-
ously mentioned dynamic radiographs assessing spino-pelvic dynamics for a given patient.

13.6 Conclusion

Traditional plain radiography in the form of an AP pelvis and frog or cross table lateral of the hip are useful but may not capture spino-pelvic dynamics, which are critical to stability of THA. Based on recent findings, the concept of a defined “safe zone” of component position has evolved to a more dynamic and functional definition. In order to determine this appropriate patient-specific “safe zone,” modern imaging techniques such as sitting and standing alignment plain radiographs are necessary for improved understanding of spino-pelvic dynamics and

Fig. 13.5 This figure illustrates the planning of a total hip replacement on bi-dimensional EOS images (a), with tri-dimensional rendering (b) and relocation of postoperative pelvic radiograph (c) (With the courtesy and permission of E. Maury, MD, University Hospital of Montpellier, France)
more appropriate component positioning to mini-
mize the risk of instability and maximize bearing
performance in THA. Personalized total hip com-
ponent implantation should aim to recreate nor-
mal hip joint anatomy, with a “safe zone” that
matches an individual’s spino-pelvic dynamics.
Three-dimensional imaging systems can be use-
ful in assessing the accuracy and quality of per-
sonalized hip implantation.

13.7 Case Presentation

A 75-year-old man with a history of lumbar
radiculopathy initially underwent a primary right
THA in 2014. He subsequently suffered two sep-
arate incidents of anterior right THA dislocation
4 years later, both in a position of hip extension.
Preoperative evaluation of his total hip instability
was comprised of a supine AP pelvis, cross table lat-
eral of the right hip, as well as sitting and stand-
ing AP and lateral alignment films (Fig. 13.6). Com-
parison of pelvic tilt from standing to sitting
positions demonstrated limited change, signifi-
"ing a stiff lumbar spine. Furthermore, in a stand-
ing position, the cup anteverision was found to be
approximately 35°, while cup abduction was
approximately 50° with respect to the coronal
plane. Given this cup malposition, he was indi-
cated for an acetabular component revision.
Intraoperatively, stem version was found to be
appropriate, and the stem was retained. However,
the cup was revised to a dual mobility acetabular
component, using computer navigation to place
the new component in a position of less ante-
version and inclination. Postoperatively, he recov-
ered well, without further episodes of instability
at 6 months of follow-up.

**Fig. 13.6** Preoperative radiographic evaluation of a right
total hip arthroplasty with anterior instability in the setting
of degenerative lumbar stiffness. (a) Supine AP pelvis. (b)
Supine cross table lateral view demonstrating the acetabu-
lar component anteverision measuring 48° using Woo and
Morrey’s method and 31° using the ischio-lateral method.
This discrepancy can be attributed to this increased
patient’s tilt in a supine position. (c) AP and lateral sitting
and standing alignment films were obtained. (d) Using
software analysis (Intellijoint) of the sitting and standing
alignment films, the anterior pelvic plane-pelvic tilt angle
change from standing to sitting is noted to be limited,
indicating stiffness in lumbar spino-pelvic mobility.
Additionally, the acetabular component inclination and
anteversion in the standing position were noted to be 51
and 35°, respectively.
Fig. 13.6 (continued)
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