Surgical implications of the hip-spine relationship in total hip arthroplasty

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Abstract

Total hip arthroplasty (THA) is considered the most successful orthopedic surgical procedure of the last century with excellent survivorship up to 20-years. However, instability remains a major issue representing the most common reason for revision after THA. Hip-spine relationship has gained progressive interest between arthroplasty surgeons and its understanding is crucial in order to identify high-risk patients for postoperative dislocation. Spinal deformity and abnormal spinopelvic mobility have been associated with increased risk for instability, dislocation and revision THA. Preoperative workup begins with standing anteroposterior pelvis x-ray and lateral spinopelvic radiographs in the standing and sitting position. Hip-spine stiffness needs to be addressed before THA in consideration of adapting the preoperative planning to the patient's characteristics. Acetabular component should be implanted with different anteversion and inclination angles according to the pattern of hip-spine motion in order to reduce the risk of impingement and consequent dislocation. Different algorithmic approaches have been proposed in case of concomitant hip-spine disease and in case of altered sagittal balance and pelvic mobility. The aim of this review is to investigate and clarify the hip-spine relationships and evaluate the impact on modern total hip arthroplasty.

Introduction

Total hip arthroplasty (THA) is one of the most successful surgical procedure over the past 50 years. Performed worldwide with excellent results it has recently been proclaimed "the operation of the century".[1] Currently 384 thousand primary THA are performed every year in the United States (US) and the number is projected to grow by 174% in 2030.[2]

Despite the overall success of THA, instability remains a costly and difficult problem with negative implications on quality of life.[3] With a dislocation rate of 1% after primary THAs and up to 25% after revision THAs,[4] instability is considered the most common reason of revision (17-33% of all revisions' indications).[5] Recent data indicate that the prevalence of dislocation is up to 5-10 fold greater in those patients with spinal deformities that lead to spinopelvic stiffness and increased pelvic tilt.[6,7] In order to reduce the risk of dislocation, there has been an increased interest in hip-spine motion abnormalities and their impact on total hip arthroplasty (THA) outcomes.[5,8-11]

The pelvis is an anatomical structure that interface its functions between two joints: the lumbopelvic complex (LPC) and the hip joint. The pelvis moves, rotating around the bicoxofemoral axis leading to anterior tilt when the upper portion of the pelvis moves forward and posterior tilt when moves backward.[10] The hip-spine motion influences the anterior pelvic plane (APP), crucial element in determining acetabular component position in THA, leading to abnormal cup's inclination and anteversion angles with increased risk of postoperative dislocation.[6,10,12-14]

The aim of this study was to give a comprehensive view of the knowledge about the relationship between spine, pelvis, and hip and its surgical implications in THA.

Sagittal Spinopelvic Angles

In order to better understand the hip-spine motion it is mandatory to review the common terms that are used in the literature. The anterior pelvic plane (APP), as defined by Anda *et al*,[13] is the plane formed by the anterior superior iliac spines and the upper border of the pubic symphysis. The angle between the APP and the vertical line, known as the APP angle, indicates the degree of the anterior pelvic plane tilt (APPt): positive or anterior if it leans in front of the vertical line, negative or posterior if it leans backward. Posterior APPt represents pelvic retroversion. The APP angle has a mean value of -6° for males and -4.3° for females.[14,15]

The pelvic incidence (PI), introduced by Duval-Beaupere *et al*,[16,17] is the angle between the line connecting the midpoint of the S1 endplate with the center of the femoral head and the perpendicular line to the midpoint of the S1 endplate. On the lateral view, if the femoral heads do not overlap, the point of reference is the midpoint between the centers of the two femoral heads. PI is an anatomic parameter that determine the position of the femoral heads in relation to the spine, it changes before the bone's maturity and then becomes constant. In addition, it is a biomechanical marker to estimate the potential sagittal pelvic range of motion (ROM).[18,19] Previous studies

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showed that PI is on average 50° (range, 34° to 84°) and corresponds to the sum of the sacral slope (SS) and the pelvic tilt (PT).[20,21] SS and PT are dynamic parameters defined as postural angles, and they change through the different pelvic positions (standing and sitting).[14] The sacral slope (SS) is represented by the angle between the tangent of the S1 endplate and the horizontal line. It measures on average 40° in standing position and decreases to 20° in sitting position (range, 20°-65°).[22] The pelvic tilt (PT) is referred in spine literature as a marker of the position of the sacrum relative to the femoral head, it is on average 12° (range of 5° to 30°) and is represented by the angle between the line connecting the midpoint of the S1 endplate with the center of the femoral head and the vertical line (Figure 1).[17,21]

The Combined Sagittal Index (CSI) is a newly described parameter for sagittal functional hip motion introduced by Heckmann *et al*,[23] it has been introduced in order to evolve the acetabular implantation form a standard coronal plane based safe zone to a new sagittal plane based safe zone. It is obtained from the sum of the acetabular anteinclination (AI) and the pelvic femoral angle (PFA). Abnormal values of CSI are associated with increased risk of impingement and dislocation.[23] The PFA represents the relative sagittal position of the femur and its motion in relation to the pelvis and it averages 180° on standing position and 125° on sitting position.[24] The AI, represents the position of the acetabular component in the sagittal plane, influenced from anteversion and inclination.[25]

Normal Hip-Spine Motion

Pelvic tilt is a key element in order to understand the Hip-Spine Motion. In normal standing position, the pelvis is tilted anteriorly, the lumbar spine is in lordosis, and the legs are extended in order to balance the trunk above the pelvis and position the acetabulum over the femoral head.[26] When transitioning from standing to sitting, the pelvis tilts around 20° posteriorly, the spine becomes less lordotic and acetabular anteversion increases in order to accommodate hip flexion and internal rotation.[27] As the pelvis leans backward and the PT increases by a certain angle, the SS decreases by the same value and the lumbar lordosis (LL) decreases in order to maintain sagittal balance.[10,28] Conversely, in the supine position, the pelvis tilts anteriorly by approximately 5° with a mean pelvic arc of motion from supine to standing position <5°.[26]

Abnormal Hip-Spine Motion

Hip-Spine complex is characterized by a flexible lumbopelvic complex (LPC) that articulates with a flexible hip joint.[19] The coordinated motion of these elements determines the spinopelvic mobility, abnormal motion results in an unbalanced spine and pelvis.[10,25,29]

When one of these elements becomes stiff, the others need to adapt in a compensatory mechanism increasing their mobility. The failure of the compensatory mechanism leads to two different syndromes: the Hip-Spine Syndrome (HSS) when stiffness starts from the hip,[10,30] and the Spine-Hip-Syndrome (SHS) when it starts from the lumbopelvic complex.[10]

Spine stiffness, defined as a limited excursion of sacral slope between standing and sitting positions (SS10°), is frequently observed as a consequence of lumbar degenerative disc disease, lumbar facet spondylosis, ankylosing spondylitis or long segment lumbosacral fusions (3 levels).[10,31,32] In case of spinal stiffness, the acetabular functional anteversion when transitioning from standing to sitting is limited and not accommodating to hip flexion, increasing the risk of anterior impingement and subsequent posterior dislocation.[33,34] Stefl *et al*,[32] described 5 different patterns in relation to the hip-spine motion: the "*neutral stiff"* when the excursion from standing to sitting position is limited, however, the sacral slope crosses the value of 30°. The *"stuck standing"*, when the anterior pelvic tilt is maintained also in the sitting position (sitting SS>30°). The *"stuck sitting"*, when the posterior pelvic tilt is maintained also in the standing position (standing SS<30°). In addition, a *"fused"* pattern has been described for a pathologic stiffness with SS<5° and a *"hypermobile"* pattern for SS>30°. Hypermobility is usually found on younger patients and women; requiring less femoral motion during postural changes, it is usually associated with a lower risk of bony impingement.[32]

Sagittal imbalance can occur with ageing, when the spine becomes progressively more kyphotic due to degenerative disease. The loss of lumbar lordosis and the reduction of sacral slope lead to increased pelvic retroversion in order to maintain sagittal balance.[29] The excessive pelvic retroversion in the standing position is usually balanced by an increased hip extension. When the compensatory mechanism fails and the sagittal balance is lost, the acetabulum is functionally anteverted with increased risk of posterior impingement and anterior dislocation due to anterior undercoverage of the femoral head.[29,32,35] In THA, this condition is frequently associated with increased failure rate due to excessive wear and implant instability.[10,33,36-39]

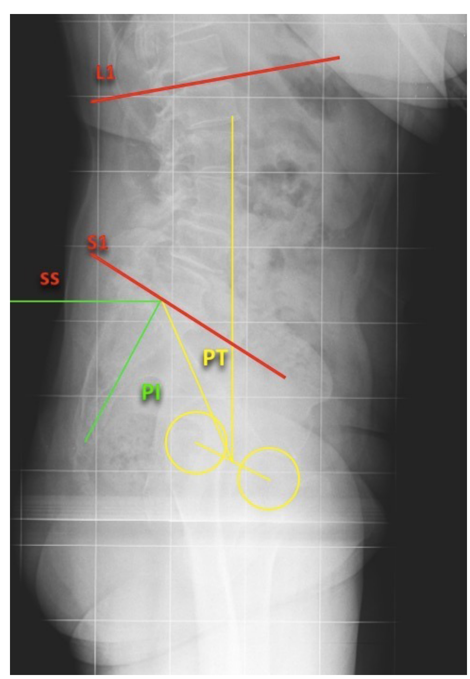

Figure 1. Representation of pelvic parameters. PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; AA, acetabular anteversion.

Phan *et al*,[40] described 4 different patterns based on balance, defined as PT<25° and PI minus lumbar lordosis <10° (PI-LL mismatch), and mobility: mobile and balanced, stiff and balanced, mobile and unbalanced, and stiff and unbalanced. The *"mobile and balanced"* pattern has a fully mobile lumbopelvic complex and capacity to accommodate positional changes of the pelvis. The *"stiff and balanced"* pattern is characterized by a balanced spine in the standing position but with low capacity to compensate with position changes (similar to the "stuck standing" pattern). The *"mobile and unbalanced"* pattern, usually seen in postlaminectomy kyphosis and neuromuscular kyphosis, presents increased pelvic tilt in standing position in order to compensate sagittal imbalance (PT > 25°; PI-LL > 10°). Hip flexion is potentially increased whilst extension is decreased leading to increased risk of posterior impingement and anterior dislocation when extending the hip. Finally, the *"stiff and unbalanced"* pattern is typical in patients with spine ankylosis or long lumbar spine fusion (LSF) reporting an unbalanced spine in the standing and sitting positions and increased pelvis retroversion (PT>25°, PI-LL>10°) with a reduced capacity to accommodate when transitioning from sitting to standing position.

Spine Disorders and Total Hip Arthroplasty

According to Medicare database, 4.5% of patients who undergo THA have had lumbar surgery within five years of the hip surgery.[7] Hip dislocation is one of the potential consequences of lumbar spine disorders. The negative impact of LSF on the outcomes of THA has been widely demonstrated.[7,41] A fused spine stiffens the lumbar segment and the pelvis reducing the posterior pelvic tilt from standing to sitting thereby decreasing the ability of the pelvis to adapt to hip flexion and avoid prosthetic impingement, leading to an increased dislocation rate. In a recent meta-analysis, An *et al*,[42] reported that patients who have had prior lumbar fusion have a higher complication rate following THA with a reported two-fold higher risk of dislocation and a three-fold higher risk of revision THA. In addition, multiple studies reported that the risk of dislocation was significantly increased in patients with long fusion constructs compared to short fusion constructs.[37,43] Patients with THAs and concomitant lumbar spine disease that have not been treated yet have also an increased risk of dislocation and implant revision.[42,44] When patients are affected by hip and spine symptoms the severity of the symptoms and limitations in activities of daily living guides the treatment into which district has the priority.[37,42,43,45-47]

Sultan *et al*,[41] proposed an algorithmic approach in the setting of concomitant lumbar spine disease and advanced hiposteoarthritis (OA) when both require surgical management. The first evaluation is based on the presence of hip flexion contracture; if present, THA should be performed first in order to eliminate these contractures that can contribute to the sagittal imbalance followed by a re-evaluation of the spine balance. If hip flexion contracture is absent, surgical treatment should be performed according to the more symptomatic region then adapting acetabular component anteversion and inclination if THA is performed after spine surgery (Figure 2).

Hip-Spine Motion and Total Hip Arthroplasty

Acetabular anteversion has been considered the most important parameter in determining implant stability.[40,48] Pelvic tilt and acetabular anteversion seems to have a defined relationship: for each degree of increased posterior pelvic tilt, the surgeon can predict a concomitant increase in functional acetabular anteversion of approximately 0.7°-0.8°.[6,13,48-50] In addition, Ranawat *et al*,[51] reported that this relationship can be considered accurate for inclination angles up to 40-45°. Implanted cups remain static within the acetabulum, meanwhile pelvis is a mobile segment that adapts its position during movements in order to maintain sagittal balance and provide hip joint stability by avoiding bony impingement.[52] Acetabular anteversion changes in relation to the pelvic tilt, which challenges the concept of acetabular "safe zone" as defined by Lewinnek *et al*, with 40±10° inclination and 15±10° anteversion (LSZ).[12,14] This has been widely used as reference point for nearly 40 years, but recent studies have demonstrated that cups positioned within this range did not effectively reduce the dislocation rate.[53,54] In order to further understand the pathophysiology of prosthetic dislocation, it has been introduced the concept of functional acetabular orientation related to pelvic and lumbar mobility.[9] The Combined Sagittal Index (CSI) introduced by Heckmann *et al*,[23] has been proposed as a more predictive element for implants' safety than coronal acetabular angles. It is obtained from the sum of cup anteinclination (AI) and PFA and it has been considered an effective tool in predicting the risk of anterior or posterior impingement in patients with abnormal hip-spine motion. The AI is the sagittal acetabular angle introduced by Kanawade *et al*, [25] and it is influenced by acetabular anteversion and inclination and it ranges in standing position between 41° and 63°.[32] Increased standing CSI (>243°) was associated with an increased risk of posterior impingement and anterior dislocation; conversely, decreased sitting CSI (<151°) was associated with increased risk of anterior impinge-

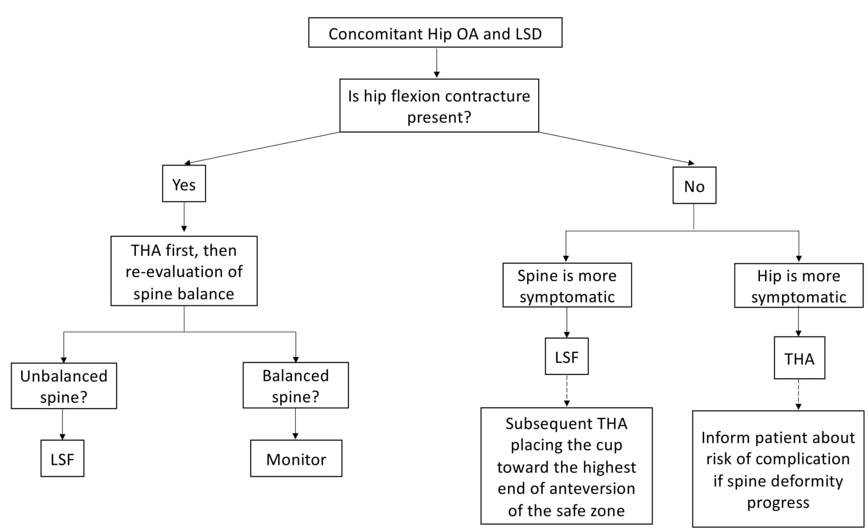

Figure 2. Algorithmic approach in the setting of concomitant lumbar spine disease and advanced hip osteoarthritis according to Sultan et al. (Adapted from Sultan AA, Khlopas A, Piuzzi NS, *et al.* The Impact of Spino-Pelvic Alignment on Total Hip Arthroplasty Outcomes: A Critical Analysis of Current Evidence. J Arthroplasty. 2018).

ment and posterior dislocation. Recently, Tezuka *et al*,[55] proposed a sagittal safe zone to provide an explanation for the dislocations of the cups implanted within the Lewinnek safe zone. The authors defined the PFA, a decreased spinopelvic motion and a low PI as the strongest elements in determining the risk of impingement and dislocation. Femoral mobility is therefore identified as the strongest determinant of impingement, especially when the pelvis is stiff and the hip flexion is increased to allow sitting.[55]

The preoperative work-up in order to identify patients with spinal deformities and stiffness includes anteroposterior (AP) standing radiograph of the pelvis in conjunction with lateral standing and sitting views of the pelvis. Optimal lateral views should include the L1 vertebrae, or at least reach the level of L3 since most of the lumbar motion happens between L3 and L5.[26,56] The APP and PT are the most important elements in preoperative planning in order to adapt cup implantation to spinopelvic imbalance. In addition, lateral views are useful in evaluating spinal deformity such as "flatback deformity" from the evaluation of the PI-LL mismatch (>10°) and stiffness (SS<10°).[56] Once the hip-spine motion has been evaluated, different algorithmic approaches have been proposed in order to address the potential risk of dislocation.

Luthringer *et al*,[56] proposed to adapt the position of the acetabular cup to the functional pelvic plane (FPP), identified on the standing position. In patients with no deformities, the APP is vertical and parallel to the FPP so that traditional cup implantation according to the LSZ was suggested (anteversion 20°-25°). In patients with normal sagittal balance (neutral pelvic tilt) and stiff spine (SS<10°), due to the limited "rollback" of the pelvis when transitioning from standing to sitting, in order to avoid anterior impingement, the cup should be implanted with increased anteversion of approximately 30°. In patient with flatback deformity and mobile spine, the acetabular anteversion should be increased. However, the FPP is retroverted compared to the APP so the acetabular component's position should be referenced to the FPP in order to avoid excessive functional anteversion when standing and increase the risk of anterior dislocation (anteversion 25°-30° from the FPP). In patients with flatback deformity and stiff spine the acetabular anteversion should be increased even more in order to protect from posterior dislocation considering approximately 30° from the FPP. This category of patients has the highest risk of dislocation due to a very narrow safe zone, therefore they are strong candidates for dual-mobility implants (Table 1).

Phan *et al*,[40] proposed different recommendations regarding acetabular implantation for each one of the four setting previously described. In patients with a sagittal balance and mobile spine, acetabular implantation should be performed according to the standard LSZ. In patients with a sagittal balance and stiff spine, the acetabular component should be implanted with increased anteversion (higher end of LSZ, 15°-25°) in order to correct the relative acetabular retroversion in sitting position. In case of unbalanced and mobile spine, the patients can either undergo spine surgery first and then THA. Cup implantation after spine surgery should be performed following the indication given for a balanced and stiff pattern. If THA is performed first, the acetabular component should be implanted with a reduced anteversion in order to reduce the posterior impingement. However, given the fact that hip-spine motion will be affected by the subsequent spine surgery, the patient may need a revision of the cup in the future in order to accommodate to the spinal realignment and avoid impingement and implant instability. In case of unbalanced and stiff spine, THA can either be performed after the spine surgery and the acetabular component placed following the indication of a stiff and balance pattern, or THA can be performed first with a reduced anteversion of the cup as for the unbalanced and mobile pattern (Table 2). Stefl *et al*,[32] similarly proposed different recommendations according to the 5 patterns previously described. Two of them are normal, with one of these being hypermobile; in this case, the acetabular component should be implanted with a reduced anteversion of 15°-20° compared to normal and with inclination between 35° and 40°. In a stiff spinopelvic segment, either in a *"stuck sitting"* or *"stuck standing"* position, given the reduced capacity to increase the functional anteversion when transitioning from

Table 1. Hip-Spine patterns and Acetabular Anteversion Recommendation According to Luthringer *et al.*

Classification	Characteristics	Recommendation
Normal Alignment Mobile Spine	Normal anatomy and normal mobility, APP parallel to FPP	Anteversion 20°-25°
Normal Alignment Stiff Spine	Stiff spine needs more anteversion to protect from posterior dislocation; APP similar to FPP	Anteversion 30° on standing AP pelvis
Flatback Deformity Mobile Spine	FPP different from the APP, posterior pelvic tilt causes more functional anteversion of the cup	Anteversion 25°-30° on standing AP pelvis referred to the FPP
Flatback Deformity Stiff Spine	FPP different from APP, the stiff spine needs more anteversion to protect from posterior dislocation, but the spine deformity will cause more functional anteversion of the cup	Anteversion 30° on the standing AP pelvis referred to the FPP

FPP, Functional pelvic plane; APP, Anterior pelvic plane; AP, antero-posterior. (Adapted from Luthringer TA, Vigdorchik JM. A Preoperative Workup of a "Hip-Spine" Total Hip Arthroplasty Patient: A Simplified Approach to a Complex Problem. Vol. 34, Journal of Arthroplasty. Elsevier Inc.; 2019).

Table 2. Acetabular anteversion recommendation based on spinal mobility and balance according to Phan *et al.*

	Balanced	Unbalanced
Mobile	Acetabular component anteversion 5°-25°	Spinal realignment followed by THA - acetabular anteversion 5°-25° OR Primary THA - kyphotic - decrease component anteversion
Stiff	Acetabular component anteversion 15°-25°	Spinal realignment followed by THA - acetabular anteversion 5°-25° OR Primary THA - kyphotic - decrease component anteversion

THA, Total hip arthroplasty. (Adapted from Phan D, Bederman SS, Schwarzkopf R. The influence of sagittal spinal deformity on anteversion of the acetabular component in total hip arthroplasty. Bone Jt J. 2015)

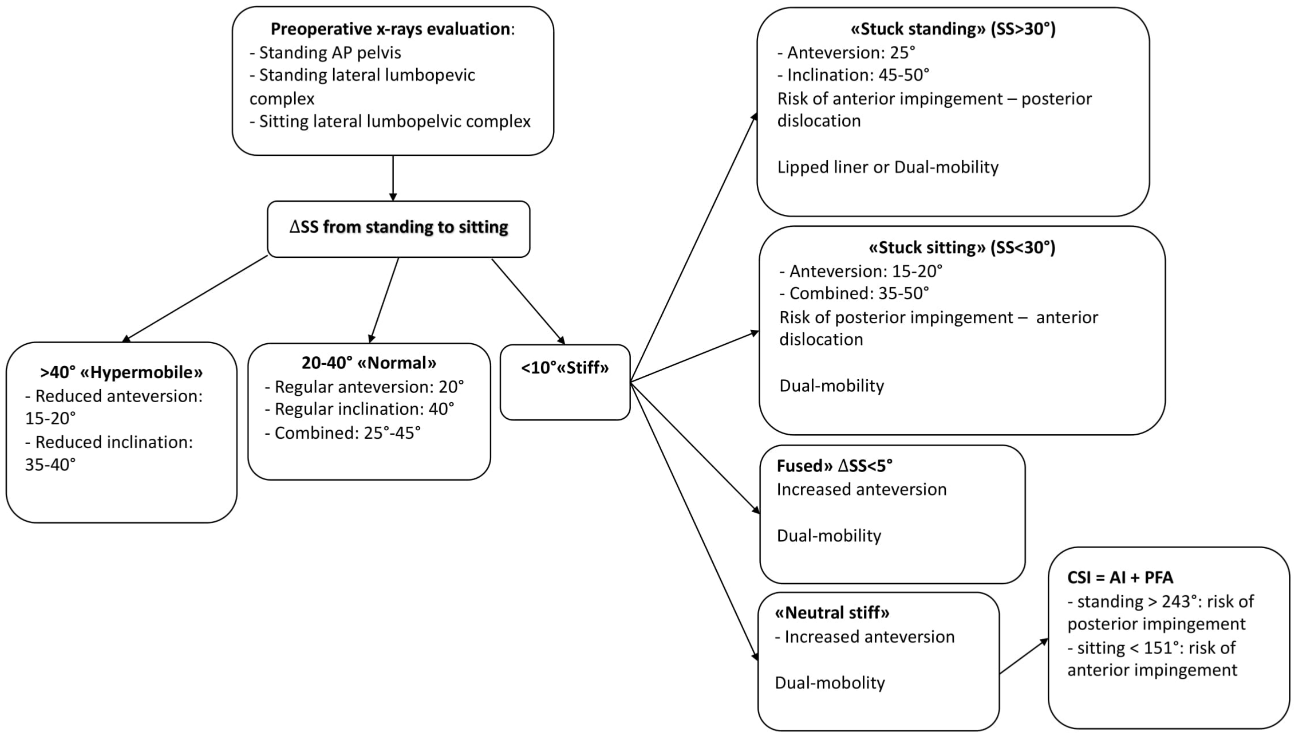

Figure 3. Algorithmic approach for acetabular implantation in different patterns of hip-spine deformities.

standing to sitting the acetabular component should be implanted with increased inclination of 45°-50°, anteversion of 20°-25° and combined anteversion, as described by Ranawat,[57] of 35°-40°. In a kyphotic pattern with normal mobility, the cup should be implanted with inclination and anteversion according to the LSZ, as a for a normal hip. In kyphotic and hypermobile pattern, due to the increased posterior tilt in sitting position, cup's anteversion and inclination should be reduced in order to avoid posterior dislocation (35°-40° and 15°-20° respectively) with a combined anteversion of approximately 25°-35°. In case of a kyphotic and stiff pattern, "stuck sitting" variant (posterior tilt), the acetabular component should be positioned with increased anteversion and inclination in order to avoid anterior impingement in sitting position. However, this expose to a "drop out" dislocation due to a vertical cup when standing. Therefore, these hips should be considered strong candidate for a dual-mobility implant (Figure 3).

Conclusions

Total hip arthroplasty is considered the most successful orthopedic operation of the 20th century, however, instability remains a major issue after THA. In order to reduce the risk of dislocation, a correct understanding of the hip-spine motion and how it affects the acetabular component positioning has become a definite point. The LSZ can be still used as reference for most people, however, patients with high risk of dislocation with hip-spine motion anomalies should be clearly identified through adequate standing and sitting radiographs of the pelvis. Evaluation should include a correct classification of deformity type and definition of the degree of stiffness. Therefore, acetabular cup orientation should be planned according to the hip-spine motion evaluation (different hip-spine patterns) in order to position the cup according to a new sagittal plane safe zone and combined sagittal index. However, the surgeon needs to consider that the postoperative hip-spine motion may change from the preoperative one due to the release of hip flexion contracture or to the physiologic aging of the spine. To date, it has not been determined yet how often these changes induce the cup to fall outside its anteversion and inclination ranges, increasing the risk of dislocation. Finally, in order to have new definite safe zones to be recommended, further studies that assess the stability and survival of acetabular component placed outside the currently recommended ranges are needed.

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