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

Fabio Mancino,1,2 Giorgio Cacciola,3 Vincenzo Di Matteo,1,2 Andrea Perna,1,2 Luca Priotti,1,2 Alexander Greenberg,4 Malahias MA,4 Peter K. Seulco,4 Giulio Maccario,4 Ivan De Martino4

1Division of Orthopaedics and Traumatology, Department of Aging, Neurological, Orthopaedic and Head-Neck Studies, Fondazione Policlinico Universitario Agostino Gemelli IRCCS, Rome, Italy; 2Università Cattolica del Sacro Cuore, Rome, Italy; 3GIOMI Istituto Ortopedico del Mezzogiorno d’Italia Franco Scalabrino, Ganzirri, Messina, Italy; 4Stavros Niarchos Foundation Complex Joint Reconstruction Center, Hospital for Special Surgery, New York, NY, USA; 5Il Orthopaedic Clinic, IRCCS Istituto Ortopedico Rizzoli, Bologna, Italy

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 pelvic 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 procedures over the past 50 years. Performed worldwide with excellent results it has recently been proclaimed “the operation of the century”. 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. Despite the overall success of THA, instability remains a costly and difficult problem with negative implications on quality of life. With a dislocation rate of 1% after primary THAs and up to 25% after revision THAs, instability is considered the most common reason of revision (17-33% of all revisions’ indications). 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. 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.

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. 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.

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 Andra et al., 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. The pelvic incidence (PI), introduced by Duval-Beaupere et al., 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). Previous studies
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). 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.\(^{21}\) 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.\(^{25}\)

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### 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,\(^{30,36}\) 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).\(^{27,31,32}\) 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.\(^{35}\) described 5 different patterns in relation to the hip-spine motion: the “neural 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.\(^{29,32,33}\) In THA, this condition is frequently associated with increased failure rate due to excessive wear and implant instability.\(^{10,13,36-39}\)

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**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.\(^{28}\) 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°.\(^{26}\)

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**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.4,41 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.,52 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.37,40 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 hip osteoarthritis (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 acetalbal 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.30,40 Pelvic tilt and acetabular anteversion seem 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 In addition, Ranawat et al.,49 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°.52 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).](image-url)
ment and posterior dislocation. Recently, Tezuka et al. 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.

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 views of the pelvis. Optimal lateral views should include the L1 vertebrae, or at least views of the pelvis.

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°). 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. 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 “roll-back” 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. 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).

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

| Classification       | Characteristics                                                                 | Recommendation                              |
|----------------------|--------------------------------------------------------------------------------|---------------------------------------------|
| Normal Alignment     | Normal anatomy and normal mobility, APP parallel to FPP                        | Anteversion 20°-25°                         |
| Mobile Spine         |                                                                                    |                                             |
| Stiff Spine          | Stiff spine needs more anteversion to protect from posterior dislocation; APP similar to FPP | Anteversion 30° on standing AP pelvis       |
| Flatback Deformity   | 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 |
| Mobile Spine         | FPP different from the 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 |
| Flatback Deformity   |                                                                                    |                                             |
| Stiff Spine          |                                                                                    |                                             |

FPP, Functional pelvic plane; APP, Anterior pelvic plane; AP, anteroposterior. (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.

| Classification        | 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, Rederaman SS, Schwarzkopf R. The influence of sagittal spinal deformity on anteversion of the acetabular component in total hip arthroplasty. Bone Jt J. 2015)
standing to sitting the acetabular component should be implanted with increased inclination of 45°-50°, anteverision of 20°-25° and combined anteverision, as described by Ranawat, of 35°-40°. In a kyphotic pattern with normal mobility, the cup should be implanted with inclination and anteverision 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 anteverision and inclination should be reduced in order to avoid posterior dislocation (35°-40° and 15°-20° respectively) with a combined anteverision 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 anteverision 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. Therefore, it has not been determined yet how often these changes induce the cup to fall outside its anteverision 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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**References**

1. Learmonth ID, Young C, Rorabeck C, Bs B. The operation of the century: total hip replacement. Lancet 2007;370:1508-19.
2. Kurtz S, Ong K, Lau E, et al. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Jt Surg - Ser A 2007;89:780-5.
3. Bou Monsef J, Parekh A, Osmani F, Gonzalez M. Failed Total Hip Arthroplasty. JBJS Rev 2018;6:e3.
4. Patel PD, Potts A, Froimson MI. The Dislocating Hip Arthroplasty. Prevention and Treatment. J Arthroplasty 2007;22:86-90.
5. Bozic KJ, Kurtz SM, Lau E, et al. The epidemiology of revision total hip arthroplasty in the united states. J Bone Jt Surg - Ser A 2009;91:128-33.
6. Buckland AJ, Vigdorchik J, Schwab FJ, et al. Acetabular Anteverision Changes Due to Spinal Deformity Correction: Bridging the Gap between Hip and Spine Surgeons. J Bone Jt Surg - Am Vol 2015;97:1913-20.
7. Malkani AL, Garber AT, Ong KL, et al. Total Hip Arthroplasty in Patients With Previous Lumbar Fusion Surgery: Are There More Dislocations and...
Revisions? J Arthroplasty 2018;33:1189-93.
8. Sikes C Van, Lai LP, Schreiber M, et al. Instability After Total Hip Arthroplasty. Treatment with Large Femoral Heads vs Constrained Liners. J Arthroplasty 2008;23:59-63.
9. Ochi H, Homma Y, Baba T, et al. Sagittal spinopelvic alignment predicts hip function after total hip arthroplasty. Gait Posture 2017;52:293-300.
10. Lazennec JY, Brusson A, Rousseau MA. Hip-spine relations and sagittal balance clinical consequences. Eur Spine J 2011;20:686-98.
11. Tamburrelli FC, Meluzio MC, Burrofato A, et al. Minimally invasive surgery procedure in ischimic spondylolisthesis. Eur Spine J 2018;27:237-43.
12. Lewinnek G, Lewis JL, Tarr R, Compere CL. ZJ. Dislocations After Total Hip-Replacement Arthroplasties. J Bone Jt Surg Am 1978;60:217-20.
13. Anda S, Svenningsen S, Grønved T, Benum P. Pelvic inclination and spatial orientation of the acetabulum: A radiographic, computed tomographic and clinical investigation. Acta radiol 1990;31:389-94.
14. Yang G, Li Y, Zhang H. The Influence of Pelvic Tilt on the Anteversion Angle of the Acetabular Prosthesis. Orthop Surg 2019;11:762-9.
15. Lazennec JY, Clark IC, Folinais D, et al. What is the Impact of a Spinal Fusion on Acetabular Implant Orientation in Functional Standing and Sitting Positions? J Arthroplasty 2017;32:3184-90.
16. Duval-Beaupere G SC and CP. A Barycentretic Study of the Sagittal Shape of Spine and Pelvis: The Conditions Required for an Economic Standing Position. Ann Biomed Eng 1992;20:451-62.
17. Legaye J, Duval-Beaupère G, Hecquet J, Marty C. Pelvic incidence: A fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J 1998;7:99-103.
18. Mac-Thion JM, Berthonnaud É, Dimar JR, et al. Sagittal alignment of the spine and pelvis during growth. Spine (Phila Pa 1976) 2004;29:1642-7.
19. Rivière C, Lazic S, Dagneaux L, et al. Spine-pelvis relations in patients with hip osteoarthritis. EORTC Open Rev 2018;3:39-44.
20. Barrey C, Jund J, Nosed aO, Roussouly P. Sagittal balance of the pelvis-spine complex and lumbar degenerative diseases. A comparative study about 85 cases. Eur Spine J 2007;16:1459-67.
21. Van Royen BJ, Toussaint HM, Kingma I, et al. Accuracy of the sagittal vertical axis in a standing lateral radiograph as a measurement of balance in spinal deformities. Eur Spine J 1998;7:408-12.
22. Jacobsen S, Sonne-Holm S, Lund B, et al. Pelvic orientation and assessment of hip dysplasia in adults. Acta Orthop Scand 2004;75:721-9.
23. Heckmann N, McKnight B, Stefl M, et al. Late dislocation following total hip arthroplasty: Spinopelvic imbalance as a causative factor. J Bone Jt Surg - Am Vol 2018;100:1845-53.
24. McKnight BM, Trasolini NA, Dorr LD. Spinopelvic Motion and Impingement in Total Hip Arthroplasty. J Arthroplasty 2019;34:553-6.
25. Kanawade V, Dorr LD, Wan Z. Predictability of acetabular component angular change with postural shift from standing to sitting position. J Bone Jt Surg - Am Vol 2014;96:978-86.
26. Ike H, Dorr LD, Trasolini N, et al. Current concepts review spine-pelvis-pelvic relationship in the functioning of a total hip replacement. J Bone Jt Surg - Am Vol 2018;100:1606-15.
27. Attenello JD, Harpstrite JK. Implications of Spinopelvic Mobility on Total Hip Arthroplasty. Review of Current Literature 2019;78:31-40.
28. Jang JS, Lee SH, Min JH, Maeng DH. Influence of lumbar lordosis restoration on thoracic curve and sagittal position in lumbar degenerative kyphosis patients. Spine (Phila Pa 1976) 2009;34:280-4.
29. Esposito CI, Miller TT, Kim HJ, et al. Does Degenerative Lumbar Spine Disease Influence Femoroacetabular Flexion in Patients Undergoing Total Hip Arthroplasty? Clin Orthop Relat Res 2016;474:1788-97.
30. Offerksi CM, Macnab I. Hip-synovial syndrome. Spine. 1983;8:316-21.
31. Kyo T, Nakahara I, Miki H. Factors predicting change in pelvic posterior tilt after THA. Orthopedics 2013;36:753-9.
32. Stefl M, Lundergan W, Heckmann N, et al. Spinopelvic mobility and acetabular component position for total hip arthroplasty. Bone Jt J 2017;99B:27-35.
33. Lamontagne M, Kennedy MJ, Beaulé PE. The Effect of cam FAI on Hip and Pelvic motion during maximum squat. Clin Orthop Relat Res 2009;467:645-50.
34. Pierrepont JW, Feyen H, Miles BP, et al. Functional orientation of the acetabular component in ceramic-on-ceramic total hip arthroplasty and its relevance to squeaking. Bone Jt J 2016;98B:910-6.
35. Rousseau MA, Lazennec JY, Boyer P, et al. Optimization of Total Hip Arthroplasty Implantation. Is the Anterior Pelvic Plane Concept Valid? J Arthroplasty 2009;24:22-6.
36. Bedard NA, Martin CT, Slaven SE, et al. Abnormally High Dislocation Rates of Total Hip Arthroplasty After Spinal Deformity Surgery. J Arthroplasty 2016;31:2884-5.
37. Sing DC, Barry JJ, Aquilari TU, et al. Prior Lumbar Spinal Arthrodesis Increases Risk of Prosthetic-Related Complication in Total Hip Arthroplasty. J Arthroplasty 2016;31:227-232.e1.
38. Barry JJ, Sing DC, Vail TP, Hansen EN. Early Outcomes of Primary Total Hip Arthroplasty After Prior Lumbar Spinal Fusion. J Arthroplasty 2017;32:470-4.
39. Miki H, Kyo T, Kuroda Y, et al. Risk of edge-loading and prosthesis impingement due to posterior pelvic tilting after total hip arthroplasty. Clin Biomech 2014;29:607-13.
40. 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;97-B:1017-23.
41. Sullivan AA, Khlapas P, Pizzuti NS, et al. The Impact of Spino-Pelvic Alignment on Total Hip Arthroplasty Outcomes: A Critical Analysis of Current Evidence. J Arthroplasty 2018;33:1606-16.
42. An VVG, Phan K, Sivakumar BS, et al. Prior Lumbar Spinal Fusion is Associated With an Increased Risk of Dislocation and Revision in Total Hip Arthroplasty: A Meta-Analysis. J Arthroplasty 2018;33:297-300.
43. Buckland AJ, Puvanesarajah V, Viggard R, et al. Dislocation of a primary total hip arthroplasty is more common in patients with a lumbar spinal fusion. Bone Jt J 2017;99B:585-91.
44. Blizzard DJ, Sheets CZ, Seyler TM, et al. The impact of lumbar spine disease and deformity on total hip arthroplasty outcomes. Orthopedics 2017;40:e520-5.
45. Bala A, Chona D V., Amanallah DE, et al. Timing of Lumbar Spinal Fusion Affects Total Hip Arthroplasty Outcomes. J Am Acad Orthop Surg Glob Res Rev 2019;e00133.
46. Perfetti DC, Schwarzkopf R, Buckland AJ, et al. Prosthetic Dislocation and Revision After Primary Total Hip Arthroplasty in Lumbar Fusion Patients: A Propensity Score Matched-Pair Analysis. J Arthroplasty 2017;32:1635-1640.
47. Barone G, Scaramuzzo L, Zagra A, et al. Adult spinal deformity: effectiveness of interbody lordotic cages to restore disc angle and spinopelvic parameters
through completely mini-invasive trans-psoas and hybrid approach. Eur Spine J 2017;26:457-63.
48. Dorr LD, Malik A, Wang Z, et al. Precision and bias of imageless computer navigation and surgeon estimates for acetabular component position. Clin Orthop Relat Res 2007;92-9.
49. Wan Z, Malik A, Jaramaz B, et al. Imaging and navigation measurement of acetabular component position in THA. Clin Orthop Relat Res 2009;467:32-42.
50. Maratt JD, Esposito CI, McLawhorn AS, et al. Pelvic Tilt in Patients Undergoing Total Hip Arthroplasty: When Does it Matter? J Arthroplasty 2015;30:387-91.
51. Ranawat CS, Ranawat AS, Lipman JD, et al. Effect of Spinal Deformity on Pelvic Orientation from Standing to Sitting Position. J Arthroplasty 2016;31:1222-7.
52. Rivièere C, Lazennec JY, Van Der Straeten C, et al. The influence of spine-hip relations on total hip replacement: A systematic review. Orthop Traumatol Surg Res 2017;103:559-68.
53. Abdel MP, Von Roth P, Jennings MT, et al. What Safe Zone? The Vast Majority of Dislocated THAs Are Within the Lewinnek Safe Zone for Acetabular Component Position. Clin Orthop Relat Res 2016;474:386-91.
54. Danoff JR, Bobman JT, Cunn G, et al. Redefining the Acetabular Component Safe Zone for Posterior Approach Total Hip Arthroplasty. J Arthroplasty 2016;31:506-11.
55. Tezuka T, Heckmann ND, Bodner RJ, Dorr LD. Functional Safe Zone Is Superior to the Lewinnek Safe Zone for Total Hip Arthroplasty: Why the Lewinnek Safe Zone Is Not Always Predictive of Stability. J Arthroplasty 2019;34:3-8.
56. Luthringer TA, Vigdorchik JM. A Preoperative Workup of a “Hip-Spine” Total Hip Arthroplasty Patient: A Simplified Approach to a Complex Problem. J Arthroplasty 2019;34:57-70.
57. Lucas DH, Scott RD. The Ranawat sign - a specific maneuver to assess component positioning in total hip arthroplasty. J Orthop Tech 1994;2:59-61.