The influence of sagittal spinal deformity on anteversion of the acetabular component in total hip arthroplasty

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The interaction between the lumbosacral spine and the pelvis is dynamically related to positional change, and may be complicated by co-existing pathology. This review summarises the current literature examining the effect of sagittal spinal deformity on pelvic and acetabular orientation during total hip arthroplasty (THA) and provides recommendations to aid in placement of the acetabular component for patients with co-existing spinal pathology or long spinal fusions. Pre-operatively, patients can be divided into four categories based on the flexibility and sagittal balance of the spine. Using this information as a guide, placement of the acetabular component can be optimal based on the type and significance of co-existing spinal deformity.

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Total hip arthroplasty (THA) for arthritis of the hip1,2 and deformity correction for spinal deformity in adults3,4 have been shown to improve pain, function, and quality of life. There has been a growing trend in rates of spinal fusion5-8 and THA9,10 over the last decade. Since the co-existence of degenerative hip and spinal pathology has been well documented,11-13 patients who have undergone surgery to one region may present requesting management for the other. However, the direct anatomical and biomechanical association between arthritis of the hip and spinal deformity in the adult is less well known. Because the sacro-pelvis is the link between the axial and appendicular skeleton, deformity or prior surgery in one area may influence procedures at the other by altering the anatomy and function. Examining this potential influence is crucial to ensure a successful outcome that optimises the benefits provided by treatment to either the hip or spine.

Recent studies investigating the relationship between the spine and the pelvis have refined our understanding of pelvic and spinal orientation. Spino–pelvic radiographic parameters have been used to assess balance in patients with a spinal deformity or spondylolisthesis.14,15 It has been observed that compensatory spine and pelvic dynamics are necessary to maintain optimal balance and a functional range of movement (ROM) in both the native and replaced hip. As such, loss of compensation at the spino–pelvic junction may decrease the efficacy and increase the risk of complications following THA.16

The purpose of this review is to discuss the implications of sagittal imbalance and long spinal fusions on sagittal acetabular orientation during THA. In particular, we provide a guideline for surgeons who undertake THA during pre-operative planning to aid placement of the acetabular component in patients with spinal deformity or a long spinal fusion.

Literature review

Measuring specific parameters at the spino–pelvic junction evaluates spinal balance and pelvic compensation. Pelvic incidence (PI) has been proposed as the main axis of sagittal balance of the spine and ranges between 48° and 53°.17,18 Sacral slope (SS) and pelvic tilt (PT) are two other measurements that can be used to evaluate spinal sagittal balance. SS is the angle between the superior plate of S1 and a horizontal line while PT is the angle between the vertical and the line connecting the midpoint of the sacral plate to the axis of the femoral heads.18 PI is equivalent to the sum of SS and PT (Fig. 1).18 Knowing that PI is fixed in skeletally mature patients and specific to each individual, changes (or lack thereof) in SS and PT are an indication of compensatory adjustments by the lumbar spine and pelvis in relation to the body to maintain balance. With changes in pelvic parameters at the spino–pelvic junction, the rotational movement of the pelvis as a whole can be defined. For instance, with decreased PT, there is anterior flexion (pelvic anteversion) with the cranial pelvis tilting forward, while with increased PT,
there is posterior extension (pelvic retroversion) with the cranial pelvis tilting backwards.\textsuperscript{16}

It has been shown that the overall lumbar lordosis (LL), as a Cobb angle from L1 to S1, should be within 10° of PI.\textsuperscript{15} A significant mismatch between PI and LL may be an indication of deformity. The patient may have evidence of sagittal imbalance with a stooped posture, or alternatively, if able to stand upright, is likely to be using a compensatory mechanism such as increasing pelvic extension (pelvic retroversion) identifiable by an increased PT. Schwab et al\textsuperscript{15} found that the optimal spinal sagittal balance should have a PT of < 22° and a PI–LL mismatch of < 11°. These pelvic parameters are commonly used in pre-operative planning for the correction of deformity and are easily obtained from standard upright lateral lumbar spinal radiographs.

Acetabular anteversion (AA) is a set of specific parameters used by arthroplasty surgeons to describe the orientation of the acetabulum. Operative AA, defined as the angle subtended by the longitudinal axis of the patient and the acetabular axis as projected on the sagittal plane, is the measurement based upon flags or jigs commonly used during surgery.\textsuperscript{19} In contrast, radiographic AA is the angle between the acetabular axis and the coronal plane of the pelvis, and is measured using radio-opaque markers.\textsuperscript{19} Finally, anatomical AA is the angle between the acetabular axis and the transverse axis when projected on the transverse plane.\textsuperscript{19} Radiographic and anatomical AA are measured post-operatively (unless intra-operative imaging is used). Operative AA can be adjusted before final fixation of the acetabular component. Owing to the plane of measurement, and unlike operative AA, radiographic AA is significantly affected by coronal spinal deformity. Therefore, operative AA was considered a suitable measurement for evaluating sagittal imbalance.

The acetabulum (and AA) is a fixed part of the pelvis, but will change in relation to the position of the body.\textsuperscript{18,20} With the advent of computer navigation systems for THA, the longitudinal axis of the patient has been represented by the Lewinnek plane, or anterior pelvic plane, measured as the line connecting the anterior superior iliac spines and the pubic tubercle.\textsuperscript{21} This plane may be an inconsistent marker with variation between subjects and with positional changes, which may interfere with appropriate placement of the acetabular component.\textsuperscript{22,23} Constant sagittal spine parameters, such as PT, have been proposed as a reference for pelvic orientation to limit variability with acetabular orientation.\textsuperscript{24} Specifically, PT has not been shown to change significantly after THA and adjustment of placement of the acetabular component based on pre-operative imaging has been recommended to improve functional component position.\textsuperscript{25}

The suggested degree of AA for placement of the acetabular component has varied based on surgeon and approach.\textsuperscript{25-29} Currently, many surgeons attempt to place acetabular components in a ‘safe zone’ of 5° to 25° of anteversion\textsuperscript{21,30} to minimise the likelihood of impingement and provide the greatest ROM. Surgeons who use combined acetabular and femoral anteversion will attempt to place acetabular components in a mean ‘safe zone’ of 25° (standard deviation (SD) 10°) of anteversion, with a goal of combined anteversion at 35° (SD 10°).\textsuperscript{31-33} Studies on ROM using radiographic, cadaveric, and synthetic anatomical models have confirmed that a maximal sagittal arc with flexion and extension of the hip can be maintained with placement of the acetabular in the safe zone.\textsuperscript{34,35} ROM after THA varies depending on the size of the acetabular component, the diameter of the head, and soft-tissue integrity, but is generally accepted as flexion of 110° and
extension of 30°. This arc will change based on acetabular orientation, with increased AA allowing more flexion and less extension before impingement. Functional movement is highly sensitive to positioning of the acetabular component, with limits to activities of daily living (ADL) occurring during changes of anteversion of as little as 10° to 15°.

In patients with a balanced and mobile spine, there is a predictable change in the sagittal alignment of the pelvis during change from a standing to seated position. This alteration will proceed in spite of any baseline pelvic variance, such as an extremely vertical or horizontal sacrum. When standing, the cranial pelvis will tilt forward (pelvic antversion), increasing the SS and decreasing the PT. As the patient goes to a seated position, the cranial pelvis will tilt backwards (pelvic retroversion), which places the sacrum more vertically and can decrease the SS by 15° or 25°. Because of the mathematical relationship, the PT will conversely increase by the same amount.

Patients who have undergone THA and have a balanced spine will show a similar adjustment in acetabular alignment in positional change. Radcliffe et al showed that unilateral THA does not cause significant change in spinal alignment and the natural dynamic change of the spino–pelvic junction will be maintained. Lazennec et al recorded a mean increase in AA of 15.6° in patients who have undergone THA going from a standing to a sitting position and concluded that lumbosacral mobility was critical for this natural change, especially to limit post-operative impingement. Kanawde et al noted a mean increase in the verticality of the acetabular component, which they termed “ante-inclination”, of 25° going from standing to sitting in patients who have undergone THA with normal spinal mobility and recommended adjusting placement of the components to avoid edge loading and instability, especially in patients with a hyper-mobile pelvis. Further studies attempted to quantify the amount of change. Using a silicone jig fitted with acetabular components to allow modification in anteversion, Wan et al determined that for every 1° change in PT, there would be a 0.8° change in AA. Similarly, Lembec et al used an inclinometer and determined that for every 1° increase in pelvic retroversion, there would be a 0.7° increase in AA.

There have been several studies examining the change in acetabular orientation with co-existing spinal deformity. Tang et al noted that anatomical positioning of the acetabular component in a pelvis with sagittal malalignment would result in instability if malalignment was greater than 20° and recommended placement of the acetabular component in a compensated position in order to correct for the sagittal imbalance. Legaye similarly noted that compensatory adjustments during positioning were required to match sagittal plane imbalance. Zheng et al noted a high rate of dislocation for patients with severe ankylosing spondylitis who first underwent THA and then had a corrective spinal osteotomy. It was recommended that lumbar lordosis should be restored before THA to prevent dislocation from altered acetabular orientation. Although the study was limited by the small number of patients, it comprises the only current clinical review examining the effect of the sequence with which operations were performed on patients with both spinal and hip degeneration.

As seen from the literature, a dynamic interplay between the position of the patient and spinal malalignment, which will ultimately influence acetabular component positioning during THA, has been described. Placement of the acetabular component with the desired AA in patients with co-existing spinal pathology or after spinal fusion may limit flexion and extension of the hip, yielding a decrease in functional ROM during ADL such as going from a standing to seated position or vice versa. Ultimately, there will be an increased risk of impingement and a higher rate of dislocation post-operatively.

**Treatment recommendations**

Patients can be categorised based on spinal flexibility and deformity, both of which will affect natural spino–pelvic reciprocal changes. A history of spinal surgery, clinical postural imbalance, or significant arthritic or operative changes at the lumbosacral junction on pre-operative imaging would support further evaluation. Radiographic assessment using standing and sitting (90° trunk–thigh angle) lateral views provides visualisation of the potential movement arc of the hip. Based on these radiographs, the natural orientation of the pelvis and the spatial change influenced by positioning can be determined. Lateral radiographs will also allow measurement of lumbar lordosis which, when compared with PI, will help determine the presence and severity of any spinal imbalance such as PI–LL mismatch. Our recommendations are based on patients with significant spinal ankylosis or spinal fusion extending to the sacrum that will minimise the amount of adaptive pelvic rotation.

Patients assessed for THA can be categorised with flexible or rigid spino–pelvic junctions and with appropriate sagittal spinal balance (PT < 25°; PI–LL < 10°) or persistent imbalance (PT > 25°; PI–LL > 10°). With these two designations, we can conceptualise recommendations for treatment as demonstrated in Table I.

**Flexible and balanced (F/B).** These patients have no prior spinal conditions and have a fully mobile spino–pelvic junction. They will mostly have a neutral spinal sagittal balance and full compensation of the spine to accommodate positional changes of the pelvis. Exact AA in these patients will be dictated by surgeon preference, but should be in the acetabular safe zone of 5° to 25° of anteversion to enable a functional ROM and decrease the likelihood of impingement. A representation of pelvic parameters with positional change for the F/B category is shown in Figure 2.

**Rigid and balanced (R/B).** This represents a large subset of patients with significant degenerative changes or prior long lumbosacral fusion, with a resultant spine that is balanced in the standing position, but without significant ability to...
compensate with positional change. Because of the rigidity, AA will not naturally increase during sitting as with the F/B spine, potentially causing a loss of functional range of flexion of the hip. A representation of pelvic parameters with positional change for the R/B category is shown in Figure 3. Patients in this category will have AA comparable with the standing flexible patient in relation to the ground because the acetabular component is normally placed in a position of extension or very mild flexion of the hip in the operating room, replicating a standing position. However, when seated, there is relative decrease in AA compared with the flexible patient because of the lack of relative pelvic extension. Each degree of loss of extension will result in an approximate loss of 0.8° of AA, decrease potential flexion and increase potential extension of the hip. The loss of flexion may lead to anterior impingement and posterior dislocation when sitting.

Placement of the acetabular component for these patients should be more anteverted to help correct the relative acetabular retroversion when seated. However, because these patients have a normal arc in the standing position, a too-great increase in AA may limit the ROM when standing. The placement of the acetabular component should be towards the higher end of the traditional safe zone, with AA of 15° to 25°, to provide an optimal balance in providing the best ROM in both the standing and seated position.

Flexible and unbalanced (F/U). Examples of patients with flexible but unbalanced spines may include those with post-laminectomy kyphosis and with neuromuscular kyphosis (e.g. camptocormia) as seen in patients with Parkinson’s disease or dystonic disorders. With abnormal pelvic parameters (PT > 25°; PI–LL > 10°), there will be increased pelvic extension (retroversion) with an increased AA during standing to compensate for sagittal imbalance. This will yield a potential increase in flexion and decrease in extension of the hip corresponding to the degree of kyphosis and will possibly lead to posterior impingement and anterior dislocation when extending the hip. Depending on the spinal flexibility and deformity, there is variable compensation with positional change. Assuming full mobility, the pelvis

### Table 1. Treatment recommendations based on spinal flexibility and balance

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<tr>
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<th>Balanced</th>
<th>Unbalanced</th>
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<td>Spinal realignment followed by THA – component anteversion from 15° to 25°</td>
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<tr>
<td>Rigid</td>
<td>Acetabular component anteversion from 15° to 25°</td>
<td>Spinal realignment followed by THA – component anteversion from 15° to 25°</td>
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<td>Primary THA – kyphotic – decrease component anteversion</td>
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THA, total hip arthroplasty

Diagrammatic representation of pelvic tilt (PT) and sagittal acetabular anteversion (AA) in the flexible/balanced spine in the a) standing and b) sitting positions. There is an increase in PT and AA when going to a seated position. Due to the compensatory ability of the flexible spine, there is a low likelihood of hip impingement with hip flexion and extension at both positions.

Diagrammatic representation of pelvic tilt (PT) and sagittal acetabular anteversion (AA) in the rigid/balanced spine in the a) standing and b) sitting positions. In the standing position, with AA similar to that of the flexible/balanced spine, there is low likelihood of hip impingement with hip flexion and extension. There is no compensatory change in PT or AA when going to a seated position because of spinal fusion into the sacrum; with the lack of increase in AA, there is increased likelihood of anterior hip impingement with maximal hip flexion (*possible impingement in hip flexion when sitting).
may go into extension, resembling the F/B patient when seated, with the pre-existing AA in kyphotic patients replicating the expected AA seen in flexible patients. Therefore, less change will occur in the seated movement arc, although there can still be significant impingement based on the original imbalance. A representation of pelvic parameters with positional change for the F/U category is shown in Figure 4.

In these patients, there are two possible treatment pathways that can address the concomitant sites of pathology. As recommended by Zheng et al., the first option is to correct the spinal deformity surgically before THA. If the spine is fused in a balanced position, placing the patient into the R/B category, there is a more predictable outcome in terms of the rates of dislocation. For patients unwilling or unable to undergo major spinal surgery, or with overriding pain in the hip, the second possible option is to proceed with THA with placement of the acetabular component in a position more fully replicating that of the balanced patient. For example, in the kyphotic patient, there should be decreased AA to correct the limits of movement, especially when standing. This decreased anteversion should add enough extension arc of the hip to decrease the risk of posterior impingement. However, patients who proceed with THA without a balanced spine, and subsequently undergo spinal surgery, may require revision of the acetabular component to accommodate the pelvic re-orientation following spinal realignment if there is impingement of the hip and instability.

Rigid and unbalanced (R/U). This category represents a large subset of patients with significant ankylosis or with long lumbosacral fusion, with a resultant unbalanced spine in the standing and sitting positions. This abnormal sagittal balance may result in a greater change in functional ROM compared with R/B patients.

Patients with a kyphotic ‘flat-back’ spine (PT > 25°; PI–LL > 10°) will have increased pelvic extension (retroversion) with an increased AA. This will yield a change in the functional ROM when standing, with, potentially, an increase in flexion and decrease in extension of the hip corresponding to the degree of kyphosis, and lead to posterior impingement and anterior dislocation. Because of spinal rigidity, there is no compensatory change in the pelvis with changes in positioning. However, when seated, the pre-existing increased AA in kyphotic patients will tend to replicate the expected AA seen in flexible patients. Therefore, there will be less change in the seated movement arc, although there can still be significant impingement based on the original imbalance. A representation of pelvic parameters with positional change for the R/U category is shown in Figure 5.

For patients with rigid spinal imbalance, placement of the acetabular component should be based on the probability of future spinal surgery, either to balance existing pathology or to correct a malaligned fusion. As with the F/U patients, there are two possible routes for treatment. The first would be to undergo spinal re-alignment surgery, placing the patient into the R/B category. The second would be to proceed with THA, placing the acetabular component in a position which more fully replicates that of the balanced patient. However, as with F/U patients, R/U patients who proceed to THA without a balanced spine, and subsequently undergo spinal surgery, may require revision of the acetabular component to accommodate the pelvic re-orientation following spinal re-alignment if there is impingement of the hip and instability.
Discussion
Understanding the interaction between the lumbosacral spine and the pelvis is important for the outcome following THA. This relationship is complicated in the presence of pre-existing pathology or by changes in position, which should be taken into consideration. Although there have been several previous studies that have attempted to analyse these relationships, none to our knowledge have either taken the presence of long spinal fusion into account, or have provided a treatment algorithm that can be applied to all patients during the pre-operative assessment.

Sagittal imbalance of the lumbar spine, combined with spinal fusion or ankylosis from degenerative changes, influences AA during THA. To determine the type and amount of influence, patients can be screened with standing and sitting lateral lumbar radiographs and divided into four categories. Based on the assessment of flexibility and balance of the spine, the post-operative ROM of the hip in the standing and seated positions can be estimated. For patients who have F/B spine, the acetabular component should be placed in the safe zone of 5° to 25° of sagittal AA. For patients who have R/B spines, it should be placed toward the higher range of the safe zone to compensate for the decreased AA when sitting. Patients who have unbalanced spines should preferentially consider spinal re-alignment, thus converting to a rigid and balanced orientation, or should have the placement of the acetabular component altered to compensate for positional change in order to limit the likelihood of impingement and dislocation.

There are several limitations to this study. First, our recommendations are based on an analysis of historical and current literature and represent a conceptual framework. Future studies, using radiographic and anatomical models are needed to confirm the validity of our guidelines and are currently in process at our institution. In addition, the spinal deformities addressed in this study are based on sagittal spinal alignment, which necessarily influences sagittal pelvic orientation. Although the main prognostic factor for adult spinal deformity is based on the sagittal plane, imbalance of the coronal plane may also influence acetabular orientation. Future studies should examine this relationship.

Using a collaborative approach combining the knowledge of both spinal and arthroplasty surgeons, it is possible to predict the influence of spine imbalance on sagittal acetabular orientation during THA. Importantly, it should be recognised that patients with pathology at the spino–pelvic junction are require special consideration before surgery. A comprehensive discussion between the patient, spinal surgeon, and arthroplasty surgeon should ensue in order to determine the best treatment for the patient.

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D. Phan: Performed literature review, Manuscript creation, Illustration creation.
S. S. Bederman: Designed study, Manuscript revision, Illustration revision.
R. Schwarzkopf: Designed study, Manuscript revision, Illustration revision.
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