Review article

The influence of spine-hip relations on total hip replacement: A systematic review

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A R T I C L E   I N F O

Article history:
Received 10 November 2016
Accepted 28 February 2017

Keywords:
Total hip replacement
Spine-hip relation
Spine-hip syndrome
Pelvic kinematics
Pelvic incidence
Planning

A B S T R A C T

Sagittal pelvic kinematics along with spino-pelvic angular parameters have recently been studied by numerous investigators for their effect on total hip replacement (THR) clinical outcomes, but many issue of spine-hip relations (SHR) are currently unexplored. Therefore, our review aims at clarifying the following questions: is there any evidence of a relationship between articular impingement/dislocation risk in primary THR and (1) certain sagittal pelvic kinematics patterns, (2) pelvic incidence, and (3) types of SHRs? A systematic review of the existing literature utilising PubMed and Google search engines was performed in January 2017. Only clinical or computational studies published in peer-reviewed journals over the last five years in either English or French were reviewed. We identified 769 reports, of which 12 met our eligibility criteria. A review of literature shows that sagittal pelvic kinematics, but not the pelvic incidence, influences the risk of prosthetic impingement/dislocation. We found no study having assessed the relationship between this risk and the types of SHRs. Sagittal pelvic kinematics is highly variable among individuals and certain kinematic patterns substantially influences the risk of prosthetic impingement/dislocation. Recommendations for cup positioning are therefore switching from a systematic to a patient-specific approach, with the standing cup orientation Lewinneck safe zone progressively giving way to a new parameter of interest: the functional orientation of the cup. Based on a recently published classification for SHRs, we propose a new concept of “kinematically aligned THR” for the purposes of THR planning. Further studies are needed to investigate the relevance of such a classification towards the assumptions and hypothesis we have made.

Level of evidence: Level IV, systematic review of level III and IV studies.

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1. Introduction

In total hip replacement (THR), achieving ideal orientation of the cup is crucial in reducing edge loading and articular impingement, which would otherwise lead to accelerated wear [1], squeaking [2], and increased dislocation risk. Proper standing cup positioning, as measured on AP pelvic X-ray, has long been considered a predictive factor for dislocation risk (Lewinneck safe zone) [3] and edge loading (Grammatopoulos safe zone) [4]: however, this is now regarded as highly controversial [5–8]. In fact, many other improvements either technical (less invasive approach, capsular repair) or technological (modern more tolerant implants with notably larger head-neck ratio and jumping distance) [9–12] have significantly, but not entirely, reduced the dislocation rate after THR [5,13–15].

It is likely that most of the atraumatic dislocations that happen with modern implants are the result of atypical pelvic kinematics that lead to aberrant functional acetabular orientation [12,16]. This new parameter, namely functional acetabular orientation, enables us to refine the understanding of the pathophysiology of prosthetic dislocation and is likely to explain why patients with normal standing cup orientation sometime dislocate, while other patients with abnormal ones do not [17]. The fact that functional cup orientation is likely related to pelvic kinematics, which in turn is mostly influenced by lumbar mobility [18], highlights the close relationship between spine and hip biomechanics. This is presently defined in the literature as spine-hip relations (SHRs). Impairment of one body segment (spine or hip) is likely to affect the other, leading to what is known as spine-hip syndrome (SHS) [10] or in consequentially reverse form, hip-spine syndrome (HSS) [19,20].
Parameters such as pelvic incidence (PI), pelvic kinematics and sagittal balance enable a more complete picture of an individual’s SHR. Spino-pelvic angular parameters (Fig. 1) define the shape and behaviour of the spino-pelvic complex [21,22]. The PI is a constant morphologic parameter that grossly enables us to predict the physiologic individual sagittal range of pelvis motion [23]. In contrast, sacral slope (SS), pelvic version (PV) and lumbar lوردosis (LL) are functional parameters, with values dependent on body position. The spino-pelvic parameters can be measured on lateral lumbo-pelvic radiographs and with the EOS™ imaging system (Biospace, Paris, France) [10,24]. By utilising these imaging methods to compare spino-pelvic orientation during different body postures (e.g. standing, sitting, squatting), it is possible to obtain some measure of an individual’s sagittal pelvic kinematic pattern [19]. Sagittal pelvic kinematics and spino-pelvic angular parameters have recently been studied for their relationship with clinical outcomes in THR (dislocation, articular impingement, edge loading, etc.) [25]. Therefore, our review subsequently aims to clarify the following questions: is there any evidence of a relationship between articular impingement/dislocation risk in primary THR and:

- certain sagittal pelvic kinematics patterns;
- pelvic incidence;
- types of SHRs?

2. Search strategy and criteria

A literature search was performed on 16th January 2017 with PubMed and Google Scholar by one author (CR). The search parameters used were: (“total hip replacement” or “THR” or “THA” or “total hip arthroplasty” or “hip replacement”) and (“dislocation” or “hip instability” or “instability” or “edge loading” or “impingement” or “hip impingement” or “articular impingement”) and (“spine-hip relations” or “spine-hip relation” or “pelvic tilt” or “pelvic version” or “pelvic incidence” or “sacral slope” or “pelvic parameters” or “spino-pelvic parameters” or “pelvic retroversion” or “pelvic kinematics” or “spine ageing” or “lumbar ageing” or “spine deformity” or “spine stiffness” or “spine flexibility” or “lumbar flexibility”) for the search on PubMed, and (dislocation or “edge loading”) and (“pelvic tilt” or “pelvic incidence” or “spine-hip relation”) and “edge loading” or dislocation or instability “pelvic tilt” or “pelvic incidence” or “spine deformity” or “spine flexibility” or “spine-hip relation” or “pelvic kinematics” “hip replacement” or “total hip arthroplasty” for the one on Google Scholar. Only articles from peer reviewed journals published over the last five years in either English or French were reviewed. Among the studies that were identified, those eligible were clinical or computational studies that reported the influence of pelvic kinematics or spino-pelvic parameters (pelvic incidence, etc.) on the risks of prosthetic impingement or dislocation (inclusion criteria). References were excluded if they were review articles, case reports, commentary, editorial, insights articles, proceedings or if they focused on revision hip prosthesis (exclusion criteria). The Newcastle Ottawa scale [26] was used to assess the quality of the eligible articles relating to nonrandomized clinical studies.

3. Results

Fig. 2 illustrates the flow chart of our methodology. Twelve studies were eligible for this review and are summarised in Table 1. Table 2 shows the quality assessment of the eligible clinical studies.

3.1. Answer to question 1

There is a high variability among individuals with regards to pelvic kinematics parameters as observed during various tasks (squatting, low-chair rising and picking up objects), which result in a smaller margin of error than anticipated for cup placement in order to avoid impingement (“the safe zone”) [8,17]. Also, standing pelvic retroversion has been shown to progressively aggravate over the years after a THR is performed [36], with more than 20° of tilt shown to increase the risk of superior edge loading [16] and posterior articular impingement [16,35]. Therefore, the risk of THR dislocation for elderly patients with non-instrumented spine disease is very high (7.1%) and also related to the extent of spine stiffening: PI-LL mismatch [31], higher posterior standing PT [31,33], reduced course of posterior pelvic tilt [33]. After lumbar fusion, this risk was reported to be even higher (with the exception of one report [32]) [27–31,37], was proportional to the length of the fusion [30] and whether THR was performed prior to [28,30] or after [27–30,37] the spine procedure.

3.2. Answer to question 2

Delsole et al. [31] and Sariali et al. [34] found no difference in PI between dislocators and non-dislocators (64.6° [10 patients] vs. 52.4° [97 patients] [P=0.121] and 54.1° [12 patients] vs. 56.5° [12 patients] [P=0.4], respectively). However, Delsole et al. [31] assessed 139 THRs in a cohort of 107 patients having spine disease and they did not differentiate between patients with or without lumbar instrumentation in their “dislocated group” (11 THRs in 10 patients). It is important to distinguish between these two groups when assessing the relationship between PI and hip instability:

- since PI influences the outcome and progression of spine disease, a blanket inclusion of all patients with spine disease could inadvertently combine two separate groups of dysmorphic PI ranges, hence confounding any results;
- as the lumbo-pelvic complex (LPC) becomes stiff after fusion and is likely to generate similar sagittal range of motion (ROM) between fused patients, this reduces the clinical influence of the PI and therefore affects the assessment of the relationship between PI and hip instability.

3.3. Answer to question 3

We found no study having assessed the relationship between this risk and the types of SHRs. Therefore, we used a classification summarised in Table 3 and Fig. 3 to assess the relationship between

<table>
<thead>
<tr>
<th>Pelvic parameters</th>
<th>Spine parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI</td>
<td>SS</td>
</tr>
<tr>
<td>LV</td>
<td>TX</td>
</tr>
<tr>
<td>LL</td>
<td>PI</td>
</tr>
</tbody>
</table>
the risk and type of SHRs. In this paper, we’ve refined our classification by adding discriminatory values for sagittal pelvic mobility based on the data from Kanawade et al. [38]. We believe this classification could also have applications in THR, by enabling a more refined surgical plan in order to accommodate the individual functional acetabular orientation and therefore potentially improving clinical outcomes. The determination of an individual’s SHR can be done after measuring pelvic incidence (PI), lumbar lordosis (LL) and sacral slope (SS) variations between standing and sitting positions. Eight different types of SHR have been defined:

- SHRs 1A and 2A represent both a healthy LPC with a pelvis having more than 10° of retroversion while sitting. When the tights move relative to the trunk the motion is shared between the hips and LPC. Therefore, such motion reduces (compared to stiffer LPC), the functional hips’ cone of mobility for activities of daily living (ADLs), and in turn the risk of prosthetic impingement and edge loading. Therefore, a flexible LPC is likely to be a protective factor for hips. However, as sagittal pelvic kinematics is related to the PI (larger for SHR 2A (“spine user”) compared to SHR 1A (“hips user”)), patients with SHR 2A probably have better protection.

- SHRs 1B and 2B define situations where the pelvis displays an abnormally low retroversion (<10°), while sitting, leading to an abnormal functional acetabular orientation (Fig. 4 – type 1), hence increasing the risk of posterior edge loading (2), and probably posterior dislocation as well (when sitting or squatting).

- SHRs 1C/D and 2C/D comprise of situations with degenerated LPCs 1 or 2, respectively. Compared to healthy LPC found in SHR 1A/2A, the degenerated LPC is stiffer with a pelvis in constant excessive pelvic retroversion when standing and with a reduced retroversion when sitting [39]. With time, the patient progressively becomes more and more of a “hip user” (with greater compensatory range of motion in the hips during ADLs), hence becoming increasingly at risk for spine-hip syndrome (SHS) because of excessive anteversion and inclination of the cup while standing (Fig. 4 – type 2). This generates a more anterior edge loading (bearing wear [1]) and anterior dislocation in the standing position [16]. Type C defines a compensated stage where the patient is still sagittally balanced with a stiff LPC [39], while type D defines a patient with sagittal imbalance (decompensated stage) and a very stiff LPC. Because spine degeneration worsens over time, patients with SHR C have to be closely monitored as they can evolve towards a highly deleterious SHR type D [39,40]. As sagittal pelvic kinematics is related to the PI, which is larger in SHR 2A compared to SHR 1A, patients with SHR 2A are likely to lose more pelvic flexibility and thus be more frequently and severely affected by spine-hip syndrome (SHS). The sagittal imbalance of SHR D substantially affects patients’ quality of life and THR outcomes [41–43] and therefore usually requires correction with spine surgery. This will improve the standing functional acetabular [44,45] or cup [46] orientation and switch the patient to a new form of SHR (named “fused spine”), which would otherwise be at a high risk of dislocation [27–30,33].

4. Discussion

The risk of dislocation in modern THR is no longer best correlated with standing cup orientation [6,7]. Instead, it is more relevant to achieve appropriate functional orientation of the cup [17,47]. As functional cup orientation is related to lumbo-pelvic kinematics [48], which in turn is influenced by pelvic incidence [10], we performed a systematic review to clarify the relationship between THR instability and:

- sagittal pelvic kinematics;
- pelvic incidence;
- SHRs.
<table>
<thead>
<tr>
<th>Articles</th>
<th>Material</th>
<th>Spino-pelvic parameters</th>
<th>Follow-up duration</th>
<th>Dislocation rate (number, side)</th>
<th>Other observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barry et al. [27]</td>
<td>Patients with lumbar fusion prior to THR (institution's electronic medical record)</td>
<td>NA</td>
<td>3 months post THR</td>
<td>2.9% (1/35) (0% [0/70] in control group)</td>
<td>Fusion group had much higher rates of complications (31.4% vs. 8.6%) and reoperation (14.3% vs. 2.9%)</td>
</tr>
<tr>
<td>Bedard et al. [28]</td>
<td>Institutional database: 15 patients (18 THRs) with lumbar fusion (4 with fusion first, 11 with THR first)</td>
<td>NA</td>
<td>&gt; 6 m follow-up after either fusion or THR</td>
<td>20% (3/15) for the institutional review 8.3% (4/48) from Humana database (2.9% for the 5,8644 patients without fusion)</td>
<td>The sequence of surgery for dislocated patients was fusion followed by THR (1 patient) and THR followed by fusion (2 patients)</td>
</tr>
<tr>
<td>Perfetti et al. [29]</td>
<td>Patients with degenerative disc disease having lumbar fusion prior to THR</td>
<td>NA</td>
<td>12 months post THR</td>
<td>3% of 1031 fused patients (0.4% of 1084 control patients with degenerative lumbar disc disease not fused)</td>
<td>Fusion patients were 7.19 times more likely to dislocate their THR</td>
</tr>
<tr>
<td>Sing et al. [30]</td>
<td>Patients with lumbar fusion prior to THR</td>
<td>NA</td>
<td>Minimum 24 months post THR</td>
<td>4.26% (488/9695)</td>
<td></td>
</tr>
<tr>
<td>DeSole et al. [31]</td>
<td>Adult patient with sagittal spine deformity (ISSG criteria) and a THR (prospectively collected single-center database)</td>
<td>Dislocators with higher PT and LL-PI mismatch No difference for PI between dislocators and non-dislocators (64.6° vs. 52.4°)</td>
<td>No data</td>
<td>8.0% (1/139) overall 9.4% (5/53) if spinal fusion</td>
<td>Revision rate of 5.8% (8/139) for instability Significant increase in cup inclination from supine to standing – no difference in the rates of “safe zone” placement for cup anteversion or inclination, or both</td>
</tr>
<tr>
<td>Zheng et al. [32]</td>
<td>28 patients with ankylosing spondylitis and bilateral THR (except one patient with unilateral THR)</td>
<td>NA</td>
<td>Mean 3.5 years (2 to 9)</td>
<td>0% (0/28) after fusion 33% (2/6) before fusion</td>
<td>The 6 patients with THR first had their spine fused over the following 6 months</td>
</tr>
<tr>
<td>Nam et al. [33]</td>
<td>Cohort of 7 patients with THR dislocation</td>
<td>Dislocators with higher standing pelvic tilt (23° vs. 13°) and lower change in SS between standing and sitting (12.5° vs. 22.1°)</td>
<td>NA</td>
<td>NA</td>
<td>Dislocators have a decrease in posterior pelvic tilt when moving from the standing to seated position, similar to patients with lumbar fusion</td>
</tr>
<tr>
<td>Sariali et al. [34]</td>
<td>Cohort of 12 patients with early THR dislocation</td>
<td>Dislocators with higher pelvic width but similar PI (54.1° vs. 56.5°)</td>
<td>NA</td>
<td>NA</td>
<td>Tendency towards a higher stem anteversion and decreased femoral offset in the dislocation group</td>
</tr>
<tr>
<td>McCarthy et al. [17]</td>
<td>Computational study</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>The true cup orientation for impingement-avoidance motion is much smaller than previously believed and varies considerably between patients The true cup orientation for impingement-avoidance motion varies considerably between patients. The optimal acetabular component orientation can be determined from a patient’s motion and anatomy Avoiding edge-loading and articular impingement with conventional implant is difficult if there is &gt;20° of posterior PT in the standing position after THR More than 20° of posterior pelvic tilt may cause anterior instability and diminish the optimal range of cup version &gt;20° of posterior PT may cause anterior instability and diminish the optimal range of cup version</td>
</tr>
<tr>
<td>Mellon et al. [8]</td>
<td>Computational study</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Miki et al. [16]</td>
<td>Computational study</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Sato et al. [35]</td>
<td>Jig mounted prosthetic hip model</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Sato et al. [28]</td>
<td>Jig mounted sawbones-THR construct</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

NA: Not assessed; THR: total hip replacement.
This review shows that sagittal pelvic kinematics highly influences the risk of prosthetic impingement/dislocation.

Before interpreting the results of this study, it is important to acknowledge some limitations. Firstly, the relevance of our result regarding the relationship between prosthetic instability and PI is affected by the fact that only 2 studies with a low level of evidence addressed this question. Secondly, the proposed classification for SHR has been established using limited data on pelvic kinematics, which is thought to have far greater complexity and variations within and between individuals. However, we believe this simple classification can serve as a useful baseline, with the aim for further refinements. Finally, in the case of hip dysplasia, our recommendations for cup planning based on the SHR assessment should be adjusted for those with cup dysplasia. In situations where the cup orientation must be adjusted, the goal would be to reach a compromise between prevention of bearing-surface related complications and preservation of sufficient implant-bone contact for safe primary implant stability and secondary osteointegration. However, when no adjustment is needed, the anatomical technique has been shown to provide good clinical outcomes and standing cup alignment [49].

4.1. Question 1

Pelvic kinematics is highly variable between patients without spine disease (flexible LPC) resulting in their optimal cup orientation being different between themselves. This highlights the need for better-individualized preoperative patient-specific planning to prevent impingement (dislocation) and edge loading (wear). In contrast, elderly patients with spine disease (instrumented or not) have a stiffer LPC, likely to have less variability in their pelvic kinematics, but also a source of aberrant functional cup orientation responsible for deleterious (impingement and edge loading) spine-hip syndrome. Therefore, it appears that, whatever the age and the spine condition, a custom (patient-specific) kinematic approach for cup positioning is relevant to further improve clinical outcomes in THR.

### Table 2
Newcastle Ottawa scale for quality assessment of eligible clinical study article [26].

<table>
<thead>
<tr>
<th>Study</th>
<th>Selection</th>
<th>Comparability</th>
<th>Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barry et al. [27]</td>
<td>XXX</td>
<td>X</td>
<td>XX</td>
</tr>
<tr>
<td>Bedard et al. [28]</td>
<td>XXXX</td>
<td>X</td>
<td>XXX</td>
</tr>
<tr>
<td>Perfetti et al. [29]</td>
<td>XXXX</td>
<td>X</td>
<td>XXX</td>
</tr>
<tr>
<td>Sing et al. [30]</td>
<td>XXXX</td>
<td>X</td>
<td>XXX</td>
</tr>
<tr>
<td>DeSole et al. [31]</td>
<td>XXX</td>
<td></td>
<td>XXX</td>
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<tr>
<td>Zheng et al. [32]</td>
<td>XX</td>
<td></td>
<td>XXX</td>
</tr>
<tr>
<td>Nam et al. [33]</td>
<td>XX</td>
<td>X</td>
<td>XXX</td>
</tr>
<tr>
<td>Sariali et al. [34]</td>
<td>XX</td>
<td>X</td>
<td>XXX</td>
</tr>
</tbody>
</table>

4.2. Question 2

As mentioned above, low pelvic flexibility is likely to increase the risk of hip instability. Because a LPC type 1 (“hip user”) is stiffer than LPC type 2 (“spine user”), we can expect to find patients with a lower pelvic incidence (SHR 1A/C/D) at higher risk of instability. However, because degeneration of a LPC type 2 (SHR 2C/D) is likely to generate more severe spine-hip syndrome compared to degeneration of a LPC type 1 and since spine-hip syndrome is a cause of impingement/dislocation secondary to an aberrant functional cup orientation, patients with higher PI can also be at higher risk for complications. Therefore, it is likely that the definition of an individual’s SHR would be of much better value, than only a single measure of an individual’s PI, when it comes to predicting the risk of prosthetic instability.

4.3. Question 3

Pathologic SHRs generate a risk of prosthetic impingement/dislocation and edge loading [10,27–31], known as spine-hip syndrome and are frequent (26% to 40%) in patients scheduled for primary THR [39,47]. Therefore, the ability to characterise an individual’s SHR should be part of the preoperative plan, especially in certain at-risk patient groups.

### Table 3
The Bordeaux classification of spine-hip relations.

<table>
<thead>
<tr>
<th>Spine-hip relation</th>
<th>1A</th>
<th>1B</th>
<th>1C and 1D</th>
<th>2A</th>
<th>2B</th>
<th>2C (compensated stage)</th>
<th>2D (uncompensated stage)</th>
<th>Fused spine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lumbo-pelvic complex (LPC) type and kinematics</td>
<td>LPC type 1 with normal sagittal kinematics</td>
<td>LPC type 1 with abnormal sagittal kinematics type 1</td>
<td>Similar to 2C &amp; 2D but with LPC type 1</td>
<td>LPC type 2 with normal sagittal kinematics</td>
<td>LPC type 2 with abnormal sagittal kinematics type 1</td>
<td>LPC type 2 with abnormal sagittal kinematics type 2 (spine ageing)</td>
<td>PI ≥ 40°</td>
<td>PI-LL mismatch</td>
</tr>
<tr>
<td>Diagnosis</td>
<td>PI &lt; 40° &amp; &gt; 10° decrease of SS between standing and sitting</td>
<td>PI ≥ 40° &amp; &lt; 10° decrease of SS between standing and sitting</td>
<td>Similar to 2C &amp; 2D but PI &lt; 40°</td>
<td>PI ≥ 40° &amp; ≤ 10° decrease of SS between standing and sitting</td>
<td>PI ≥ 40° &amp; &gt; 10° decrease of SS between standing and sitting</td>
<td>PI ≥ 40° &amp; PI-LL mismatch</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Clinically: bilateral reduction of hips extension, patient sagittally balanced</td>
<td>Abnormal C7 plumb line</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Clinically: no hips extension bilaterally and “false fixed flexion deformity”, patient with light to severe sagittal unbalanced</td>
<td></td>
</tr>
</tbody>
</table>

LPC: lumbo-pelvic complex; PI: pelvic incidence; LL: lumbar lordosis; SS: sacral slope.
Fig. 3. Classification of lumbo-pelvic complex (LPC) in type 1 (stiff) or type 2 (mobile). Patients with flat back (spine 1 or 2) are likely to have a stiff LPC (type 1), where the pelvis has a low pelvic incidence (PI) and acetabulum type 1 high anteverted. Patients with LPC type 1 tend to use a large hips’cone of mobility for daily activities of life (hips users). More the spine is curvated (types 3 and 4), more the pelvis has a high PI (types 2 and 3) and acetabulums are likely to be low anteverted (types 2 and 3); this define a sagitally mobile LPC (type 2, spine users).

Based on the risk assumption of prosthetic impingement and edge loading for different SHR types, we established 3 risk-categories (Fig. 5) and developed for each one recommendation for the planning of THR (Figs. 5 and 6). These recommendations differ from already published ones [39,47,50] as our recommendations aim to address every type of SHR (physiologic and pathologic), including cup design, the method for implanting the cup (anatomical technique, see after), and the potential need for further spine surgery or physiotherapy:

• risk 1 defines a “very low” to “low” risk because of the protective effect generated by the very flexible (SHR 2A) to moderately flexible (SHR 1A) LPC. This protective LPC flexibility is likely to make any cup implant design (regarding the tolerance to impingement) suitable for implantation with an anatomical patient-specific version (TAL).
• risk 2 defines a moderate to high risk because of a stiff LPC (SHRs B and C). Modern high tolerant implants (large head and head-neck ratio), which lower the risk of articular impingement and edge loading [9,11,12,16,51,52], and anti-dislocation implants with a mobile liner (dual mobility implants) [53] are likely to be useful in this context. For patients with SHR type B, pelvic physiotherapy aiming at increasing the pelvic posterior tilt (retroversion) [54] and therefore the cup anteversion while sitting could be beneficial in further preventing the risk of posterior edge loading, squeaking [16,55,56], and anterior impingement in sitting position.
• risk 3 defines a very high risk secondary to a very stiff and degenerated instrumented or non-instrumented LPC (SHRs D and fused
Fig. 4. Classification of abnormal functional acetabular orientations. The pelvis normally retroverses when passing from a standing to a sitting position, thus increasing the functional acetabular anteversion while sitting and preventing risks of anterior prosthetic impingement and posterior edge-loading. Abnormal pelvic kinematics type 1 and 2 lead to abnormal functional cup orientation type 1 while sitting and type 2 while standing, respectively, which generate risks of prosthetic impingement and edge loading.

Patients in this risk category would therefore be likely to benefit from anti-dislocation implants with a mobile liner (dual mobility implants) [53]. Regarding SHR D, an adjustment of the cup orientation with less anteverision and inclination would probably reduce this risk [24,35,57,58]. In addition, because the cup loses approximately 1% of bone contact for every degree of adjustment, it is important this adjustment be moderate [57,59]. As patients with SHR 2D are likely to be affected by more severe spine-hip syndrome compared to the one with SHR 1D, their need for spine surgery, dual mobility implant and adjustment of cup orientation is likely to be more frequent. Patients with SHR 1 have a low PI and are therefore not affected (in situations of SHR 1D), by a severe standing pelvic retroversion, which makes anatomical implantation [60] of a high tolerance implant (36/40 mm head diameter) a good option as well [16].

The awareness of the need for personalised cup orientation, in order to avoid prosthetic articular impingement and edge loading is growing [8,17,61–63]. Following on the current concepts in kinematic knee alignment, whereby the implant is aligned to suit an individual’s natural kinematic patterns, we propose naming this method of cup positioning a form of “kinematic alignment in THR” (KA-THR). Our recommendations for cup positioning are patient-specific, respect constitutional acetabular anatomy (for version) as much as possible and take into account individual pelvic kinematics. This concept of KA-THR was originally suggested by Legaye et al. [23,57,64], who suggested that positioning of the cup should be dynamic, functional and based on individual spino-pelvic parameters.

Fig. 6. Illustrations of recommendations for some spine-hip relations (SHR). LDH: large diameter head; SDH: small diameter head.
Existing recommendations for cup positioning based on preoperative assessment of sagittal pelvic kinematics between standing and sitting [24,47,50,65] or supine to standing [66–68] positions have reduced the risk of prosthetic impingement [47] and brought about excellent clinical outcomes [2,47]. The amount of adjustment was either defined arbitrarily [47] or with the use of the Optimised Positioning System™ (OPS, Corin, Cirencester, UK) [2]. Nonetheless, all those recommendations for cup adjustment were made with the aim of maintaining the “Lewinnek safe zone”, whose value itself is becoming increasingly controversial. Those recommendations represent a first step towards the concept of “kinematically aligned THR”, as presented in this paper.

OPS® was recently developed to insert the cup in the optimal orientation to prevent/reduce the risk of dynamic articular surface edge loading (not the risk of prosthetic impingement) in standing, sitting, squatting positions. After assessing an individual’s pelvic sagittal ROM, an optimal position is defined by software and PSI is made to the goal to enable precise intraoperative execution of the plan. Compared to OPS®, our proposal:

- allows a more cost-effective patient-specific approach, which is also easier and faster to implement in practice;
- allows the surgeon to be in full control of the implantation process even during the surgery;
- enables discrimination, for a similar range of sagittal pelvic ROM, between physiologic (1A) or pathologic (2B, 2C) pelvic kinematics, which will allow better selection of patients likely to benefit from spine physiotherapy/surgery;
- enables screening of patients in need for an adjustment of their cup orientation (mainly SHR 2D, maybe SHR 1B/2B if ceramic bearings are used [2]), who would potentially benefit from other technologies such as OPS, CAS, robotics and PSI.

Manual anatomical techniques (TAL) for cup positioning are likely to be precise and reproducible in restoring patient-specific acetabular anteversion. This technique has been shown to be safe and efficient [60,69] and leads to better standing cup orientation [60,70] even in the case of hip dysplasia [49]. The TAL technique seems to be highly relevant for this new concept of KA-THR as it enables, in contrast with the abovementioned tools (OPS, CAS, robotics, PSI), in reproducing individual anatomic and functional acetabular anteversion. This would:

- optimise the implant-bone contact and therefore be beneficial for primary implant stability and secondary osteointegration;
- restore an individual’s acetabular cone of mobility.

Knowing that modern hip implants have a head-neck ratio higher than the native hip, restoring the native cone of mobility would likely prevent prosthetic impingement for most patients. In case of aberrant functional acetabular orientation, the surface bearing related risks (impingement or loss of cup retentiveness leading to dislocation, edge loading leading to excessive wear) can be further reduced by adjusting the cup orientation; the TAL and the relative position of the lateral edge of the cup (roof part) to the most lateral margin of the acetabulum have been shown to be reliable landmarks to adjust cup anteversion and inclination, respectively [60]. Metfah et al. [60] successfully used this “anatomical technique” to position their cups and to make adjustments based on an estimation of individual pelvic kinematics, however as with the OPS approach, they did not deviate away from the Lewinnek safe zone.

To make a good classification of SHRs for the purposes of THR planning, surgeons need to be familiar with and able to distinguish between spine-hip syndrome (SHS) and hip spine syndrome (HSS), as both groups require different strategies for treatment. While the former defines the deleterious impact abnormal LPC kinematics has on hips, the latter defines the impact that pathological hip(s) (capsular contracture and loss of ROM secondary to OA) has on the LPC [20,71,72]. Therefore, with the healthy contralateral hip during physical examination and/or via the « radiographic extension test » [72] enables further diagnosis, allowing for the surgeon to discriminate between the two different syndromes.

### 5. Conclusion

Sagittal pelvic kinematics is highly variable in and among individuals and substantially influences the risk of prosthetic impingement/dislocation. Recommendations for cup positioning are therefore switching from a systematic (Lewinnek safe zone) to a patient-specific approach and the standing cup orientation is progressively giving way to a new parameter of interest namely the functional cup orientation. We propose a classification for SHRs and a new concept of “kinematically aligned THR.” Further studies are needed to investigate:

- the variability of pelvic kinematics parameters between various tasks and their reproducibility;
- the variability of pelvic kinematics patterns in and between individuals;
- pelvic kinematics in frontal and horizontal planes;
- the correlation between PI and prosthetic instability;
- the relevance of our classifications and all the assumptions and hypotheses we have made so far.

### Source of Funding

EA is funded by the Uren Foundation and by the Sackler Trust.

### Disclosure of interest

The authors declare that they have no competing interest. Outside the current study Charles Riviere declares being consultant for Depuy, Catherine Van Der Straeten perceives fee from Smith and Nephew, Sarah Muirhead-Allwood declares being consultant for Depuy and Corin-Tornier and Justin Cobb declares being consultant for Biomet-Zimmer, Morthortho, and to receive fees from Microport, JRI and Royalties from Matortho and Stanmore Implants.

### Acknowledgment

We would like to thank Oliver Boughton and Anthony Leong for their help in this study.

### References


