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Current Evidence for Spinopelvic Characteristics Influencing Total Hip Arthroplasty Dislocation Risk

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Abstract

Background: Decreased pelvic mobility and pelvic retroversion may result from spinal degeneration and lead to changes in the orientation of the acetabular implant after total hip arthroplasty (THA). While multiple patient and surgery-related factors contribute to THA dislocations, there is increasing evidence that sagittal spinopelvic dynamics are relevant for THA stability. The aim of this systematic review was to assess the relationship between previously described sagittal spinopelvic characteristics and implant dislocations after primary THA.

Methods: A comprehensive literature search in the PubMed and Embase databases was conducted for studies reporting on spinopelvic morphology, alignment, pathology, or surgery and THA dislocations. Risk of bias was assessed using the MINORS criteria. Because of high heterogeneity in study methodology, a synthesis of best evidence was performed. Odds ratios (ORs), relative risks (RRs), and effect sizes (g) were calculated.

Results: Fifteen studies (1,007,900 THAs) with quality scores of 15 to 23 out of 24 were included. Nine different spinopelvic alignment parameters (8 studies, g = 0.14 to 2.02), spinal pathology (2 studies, OR = 1.9 to 29.2), and previous spinal fusion surgery (8 studies, OR = 1.59 to 23.7, RR = 3.0) were found to be related to THA dislocation. Conflicting results were found for another sagittal pelvic morphology parameter, pelvic incidence.

Conclusions: Several sagittal spinopelvic patient characteristics were found to be related to THA dislocation, and the associated risks were greater than for other patient and surgery-related factors. Future research is needed to determine which of those characteristics and parameters should be taken into account in patients undergoing primary THA.

Level of Evidence: Prognostic Level III. See Instructions for Authors for a complete description of levels of evidence.

Despite the introduction of a "safe zone" for acetabular component orientation in total hip arthroplasty (THA) in 1978 by Lewinnek et al.[1], THA dislocation is still one of the commonest reasons for revision surgery[2]. A THA dislocation can be a traumatic experience causing fear of recurrence and decreasing health-related quality of life[3]. In addition to an implant position that is not within the safe zone, several patient and surgery-related risk factors, such as American Society of Anesthesiologists (ASA) classification, surgical approach, and soft-tissue tensioning, have been identified[4-8]. It has been reported that up to 58% of THA dislocations involve an acetabular component placed within the safe zone[1,9,10], and such dislocations often also do not involve any other identifiable patient-related risk factors.

Decreased sagittal pelvic mobility and pelvic retroversion have been suggested as

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSREV/A854).

important factors for THA instability[11-13]. Both could be consequences of spinal degeneration and lead to changes in orientation of the acetabular implant in patients after THA[5]. The orientation of the pelvis in relation to the spine and femur changes during postural changes of the body as part of the complex motion of the spine-pelvis-hip unit[5,14]. The sagittal spinal configuration is regulated by anterior and posterior tilting of the pelvis relative to the hip axis to keep the center of mass of the trunk directly above the pelvis for efficient bipedal locomotion. These pelvic dynamics, however, vary widely among individuals, can be affected by spinal pathology, and may change substantially after spinal surgery[15-19]. For example, lumbar degenerative disease straightens the lumbar lordosis, which leads to compensatory posterior pelvic tilting with opening of the acetabula anteriorly. Therefore, the actual orientation of the acetabular component (also referred to as the functional orientation) after THA changes with body position and can be altered by sagittal spinopelvic pathology and/or spinal surgery[5,9,11].

Recently, a growing number of studies have reported on the relevance of sagittal spinopelvic morphology, alignment, dynamics, pathology, and surgery to the risk of sustaining a THA dislocation. The aim of this systematic literature review was to assess the association between any sagittal spinopelvic characteristic and THA dislocation.

Materials and Methods

Search Strategy and Study Selection

A comprehensive systematic search was conducted in the PubMed and Embase databases on December 29, 2021, in accordance with the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) statement[20]. Search terms were constructed by combining MeSH (Medical Subject Headings) terms and keywords related to pelvic morphology or orientation and THA (e.g., pelvi*; incidence; sagittal; total hip arthroplasty*; total hip replac*; total hip prosthes*; lumbar degenera*; spinal deformity). The queries are presented in Table I.

Titles and abstracts were screened on the basis of study design, population characteristics, and outcomes according to inclusion and exclusion criteria. Articles were eligible for inclusion if they presented any information on sagittal spinopelvic alignment (e.g., spinopelvic parameters involving morphology, alignment, and/or dynamics; presence of spinal pathology; and/or previous spinal surgery) as well as (in)stability after THA. Systematic reviews, meta-analyses, and studies written in a language other than English were excluded. The screening process was conducted by 2 authors independently. All studies that were not eliminated during the title and abstract screening process were screened by reviewing the full text. All conflicts were resolved by discussion. The reference lists of all included studies were searched for other potentially relevant studies.

Quality Assessment and Synthesis of Best Evidence

Based on the MINORS (Methodological Index for NOn-Randomized Studies) criteria[21], the included studies were assessed for quality and bias. Each item is scored as 0 if not reported, 1 if reported but inadequate, or 2 if reported and adequate; the maximum total quality score (QS) is 16 for non-comparative studies and 24 for comparative studies.

Data Extraction

Study design, sample size, age, ASA scores, length of follow-up, surgical approach, available data on any sagittal spinopelvic characteristic, and THA stability were extracted from the articles. Some of the included studies were cohort studies that provided details on dislocation rates in cohorts with particular sagittal characteristics, but others were case-control studies that compared sagittal plane parameters between dislocators and non-dislocators. These variations led us to conduct a systematic qualitative synthesis instead of a quantitative analysis. The odds ratio (OR) or relative risk (RR) was calculated for the cohort and case-control studies that reported on the proportion of subjects with dislocations in different groups. For the other studies describing parameters in dislocators and non-dislocators, effect sizes (Hedges g) were calculated based on the reported data, if the required data were available (Table II). For the best-evidence synthesis, the results are presented in order of decreasing study quality within 4 categories: sagittal pelvic morphology, spinopelvic alignment, spinal pathology, and previous spinal fusion surgery.

Source of Funding

No external funding was received for this study

TABLE I Searches Conducted on December 29, 2021

Database	Search Query	Results
Embase	((pelvi*:ab,ti AND incidence:ab,ti) OR (pelvi*:ab,ti AND sagittal:ab,ti) OR 'lumbar degenera*':ab,ti OR 'lumbar disc disease':ab,ti OR 'degenerative disc disease':ab,ti OR 'spinal deformity':ab,ti OR 'scoliosis':ab,ti) AND ('total hip arthroplast*':ab,ti OR 'total hip replac*':ab,ti OR 'total hip prothes*':ab,ti OR 'total hip prosthes*':ab,ti)	487
PubMed	(((pelvi* [tiab] AND incidence [tiab])) OR (pelvi* [tiab] AND sagittal [tiab])) OR Lumbar degenera* [tiab] OR lumbar disc disease [tiab] OR degenerative disc disease [tiab] OR spinal deformity [tiab] OR scoliosis [tiab] AND (total hip arthroplast* [tiab] OR total hip replac* [tiab] OR total hip prothes* [tiab] OR total hip prosthes* [tiab])	401

TABLE II Summary of the Included Retrospective Studies*

Study	Design	Comparison	Follow-up	Surgical Approach	Total No.	No. of Dislocators	No. of Non-Dislocators	Included Sagittal Parameters or Characteristics	Statistical Results
Andah et al., 2021[28]	Cohort	THA + LSF dislocators vs. THA + LSF non-dislocators	≥1 yr	Direct anterior: 20 Lateral: 38 Posterior: 51	109	8	101	Pelvic incidence, sacral slope, lumbar lordosis, pelvic incidence-lumbar lordosis mismatch	Insufficient data
Bédard et al., 2016[30]	Cohort	THA with spinopelvic fusion vs. THA without spinopelvic fusion	1.5-10 yr	Unknown	58,758	1,709	57,049	THA with spinopelvic fusion vs. THA without spinopelvic fusion	RR = 3.0 (95% CI = 1.2-7.6, p = 0.02)†
Dagneaux et al., 2019[24]	Case-control	Stable conventional THA vs. unstable conventional THA vs. stable DM THA	≥0.5 yr	Posterior	115	33 (conventional THAs)	82 (41 conventional THAs and 41 DM THAs)	Pelvic tilt	g = 0.48 (p = 0.03)†
								Sacral slope	g = 0.38 (p = 0.29)
								Lumbar lordosis	g = 0.17 (p = 0.47)
								Pelvic incidence-lumbar lordosis mismatch	g = 0.67 (p = 0.005)†
								Pelvic incidence	g = 0.59 (p = 0.01)†
								Anterior pelvic plane tilt	g = 0.72 (p = 0.002)†
								Sacrospinal angle <127°	g = 0.35 (p = 0.02)†
								C7-sagittal vertical axis	g = 0.58 (p = 0.02)†
DelSole et al., 2017[23]	Cohort	THA dislocators vs. THA non-dislocators	Unknown	Posterior: 11 dislocators	107	10	97	Pelvic tilt	g = 0.66 (p = 0.05)†
								Lumbar lordosis	g = 0.07 (p = 0.83)
								Pelvic incidence-lumbar lordosis mismatch	g = 0.82 (p = 0.015)†
								Sacral slope	g = 0.25 (p = 0.45)
								Pelvic incidence	g = 0.52 (p = 0.12)
								T1-pelvic angle	g = 0.71 (p = 0.03)†
								C7-sagittal vertical axis	g = 0.14 (p = 0.58)
								T9-spinopelvic inclination	g = 1.1 (p = 0.43)
Furuhashi et al., 2021[29]	Case-control	THA + LSF dislocators vs. THA + LSF non-dislocators	≤1.5 yr	Anterolateral: 12 Posterolateral: 14 Direct lateral: 1	27	6	21	Lumbar lordosis	g = 0.196 (p = 0.58)
								Sacral slope	g = 0.575 (p = 0.31)
								Pelvic tilt	g = 2.015 (p = 0.02)†
								Pelvic incidence	g = 0.602 (p = 0.18)
								C7-sagittal vertical axis	g = 0.679 (p = 0.43)
Ochiai et al., 2021[33]	Case-control	THA and spinopelvic fusion vs. THA without spinopelvic fusion	1-17 yr	Direct anterior: 80 Anterolateral: 59 Posterolateral: 62	201	5	196	THA with spinopelvic fusion vs. THA without spinopelvic fusion	OR = 23.67 (95% CI = 1.29-434.8, p = 0.033)†
Parilla et al., 2019[27]	Cohort	LSF prior to THA vs. THA prior to LSF	≤2 yr	Posterior	135	11	124	THA + LSF extended to the sacrum vs. THA without spinal fusion surgery	RR = 3.0‡
								THA + spinal fusion revision surgery vs. THA without spinal fusion surgery	RR = 2.7‡
								Pelvic tilt, lumbar lordosis, pelvic incidence-lumbar lordosis mismatch, sacral slope, pelvic incidence	Insufficient data

continued

TABLE II *(continued)*

Study	Design	Comparison	Follow-up	Surgical Approach	Total No.	No. of Dislocators	No. of Non-Dislocators	Included Sagittal Parameters or Characteristics	Statistical Results
Penrose et al., 2018[22]	Case-control	THA + primary LSF vs. THA + revision LSF vs. THA	<1 yr	Unknown	882,434	27,213	855,221	THA + LSF	OR = 1.87 (95% CI = 1.75-1.99, $p < 0.001$)†
								THA + revision LSF	OR = 3.44 (95% CI = 2.90-4.08, $p < 0.001$)†
								THA + history of LSF with increasing no. of fused levels	OR = 1.62 (95% CI= 1.55-1.70, $p < 0.001$)†
Perfetti et al., 2017[32]	Case-control	LSF prior to THA vs. THA + lumbar degenerative disc disease without LSF	≤1 yr	Unknown	1,868	32	1,836	LSF and subsequent THA vs. THA without LSF	OR = 7.19 (95% CI = 2.51-20.58, $p < 0.001$)†
Snijders et al., 2021[25]	Case-control	Stable THAs vs. posteriorly dislocated THAs	Stable THAs: 3-4 yr Unstable THAs: 0-18 yr	Unknown	248	15	233	Change in pelvic tilt	g = 1.03 ($p < 0.001$)†
								Sacral slope	g = 0.66 (p = 0.004)†
								Change in sacral slope	g = 0.996 (p = 0.000)†
								Pelvic incidence	g = 0.63 (p = 0.010)†
York et al., 2018[26]	Case-control	THA with prior LSF vs. THA without spinal fusion	<3 yr	Posterior	509	28	481	THA with prior LSF vs. THA without prior LSF	OR = 9.88 (95% CI = 4.01-24.34, $p < 0.0001$)†
								Pelvic tilt, sacral slope, pelvic incidence	Insufficient data
Esposito et al., 2018[19]	Case-control	Dislocators vs. non-dislocators Normal lumbar spine vs. lumbar multilevel degenerative disc disease (DDD)	≥1 yr	Posterior	158	12 (11 with DDD and dislocation, 1 with a normal spine and dislocation)	146 (106 with a normal spine and no dislocation, 40 with DDD and no dislocation)	THA + multilevel DDD vs. THA without multilevel DDD	OR = 29.15 (95% CI = 3.6-233, p = 0.002)†
								Change in sacral slope	g = 0.82 ($p < 0.001$)†
								Change in lumbar lordosis	g= 0.71 ($p < 0.001$)†
								Hip flexion	g = 0.60 (p = 0.001)†
								Pelvic incidence	Insufficient data
Fessy et al., 2017[7]	Case-control	Stable THA vs. unstable THA	≤6 yr	Posterior: 395 Anterolateral: 78 Lateral: 41 Anterior: 52	566	128	438	THA + history of spinal disease vs. THA without history of spinal disease	OR = 1.89 (95% CI = 1.0-3.6, $p < 0.05$)†
Salib et al., 2019[18]	Cohort	Spinal fusion prior to THA vs. THA only	2-17 yr	Posterolateral: 117 THAs Anterolateral: 147 THAs Direct anterior: 27 THAs	278 patients	9 patients	269 patients	THA + LSF (≥1 fused vertebral levels + fusion involving sacrum) vs. THA without history of spinal fusion	OR = 3.5 (95% CI = 0.81-14.8, p = 0.09)
								Pelvic tilt, sacral slope, pelvic incidence	Insufficient data
Malkani et al., 2018[31]	Cohort	Spinal fusion prior to THA vs. THA only	0-10 yr	Unknown	62,387	3,042	59,345	Primary THA with LSF in the 5 years before vs. primary THA without LSF in the 5 years before	OR = 1.59 (95% CI = 1.33-1.90, $p < 0.001$)†

*THA = primary total hip arthroplasty, LSF = lumbar spinal fusion, RR = relative risk, CI = confidence interval, g = effect size, DM = dual mobility, OR = odds ratio. †Results reported as significant in the original article. ‡Insufficient data to calculate 95% CI and significance level.

Results

Search and Study Selection

The PRISMA flow diagram is shown in Figure 1. Five hundred and fifty-five unique records were found by the database searches, and 516 were excluded by applying the inclusion and exclusion criteria to the titles and abstracts. In addition, 4 conference abstracts were excluded because no full text was available despite correspondence with the authors. Two studies were excluded because no full text was available. Four additional studies were found during the study process (retrieved from reference lists or found by a coauthor), of which 1 was excluded because no full text was available despite correspondence with the authors. The full text of 36 studies was assessed for eligibility; 21 did not compare data for unstable and stable THAs or had no data about sagittal spinopelvic characteristics and THA. Eventually, 15 studies could be included for quality assessment and quantitative assessment.

Quality Assessment

The QS of the included studies ranged from 15 to 23 (Table III). Of the 15 studies, all were comparative, including no prospective studies, 6 retrospective cohort studies, and 9 retrospective case-control studies. All included studies stated a clear aim for the research and applied appropriate end points.

Study Characteristics

The studies included 1,007,900 THAs, of which 32,262 (3.2%) were unstable. The sample size per study ranged from 27 to 882,434 (Table II). One study did not present data about the average age of the study population[22]. One study did not present data about the follow-up period[23]. Eleven studies were conducted in North America; 2, in Europe; and 2, in Asia.

Sagittal Pelvic Morphology

Nine studies (QS: 15 to 23) studied pelvic incidence (PI, the angle between a line tangent to the superior end plate of S1 and a line from the midpoint between the femoral heads to the center of the superior end plate of S1; PI = pelvic tilt [PT] + sacral slope)[18,19,23-29]. Conflicting results and effect sizes were

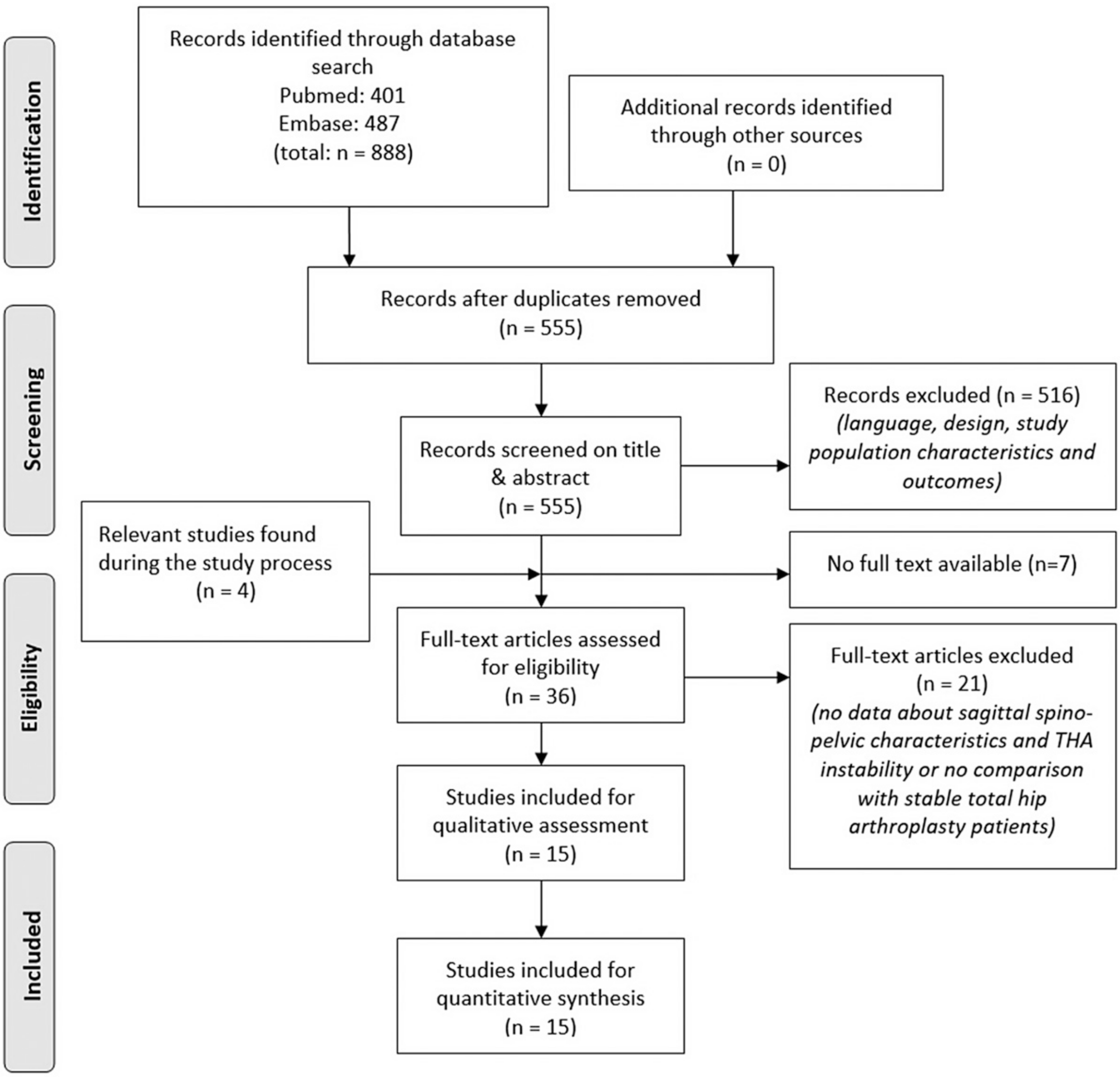

Fig. 1
PRISMA flowchart.

TABLE III Quality Score Based on MINORS[21] Criteria

Item	Andah et al.[28]	Bédard et al.[30]	Dagneaux et al.[24]	DelSole et al.[23]	Esposito et al.[19]	Fessy et al.[7]	Furuhashi et al.[29]	Malkani et al.[31]	Ochiai et al.[33]	Parilla et al.[27]	Penrose et al.[22]	Perfetti et al.[32]	Salib et al.[18]	Snijders et al.[25]	York et al.[26]
1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	1	2	1	2	2	2	1	2	1	2	2	1
3	1	0	2	2	2	2	1	2	1	2	2	2	1	1	2
4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	2	0	2	2	1	2	2	1	2	1	0	0	1	2	1
6	2	2	1	0	2	2	1	2	2	1	2	1	2	2	1
7	1	2	2	1	2	2	2	0	0	0	2	1	1	2	1
8	1	0	0	0	2	0	1	0	0	0	0	0	1	0	0
9	2	1	2	0	2	2	2	2	2	0	2	2	2	2	2
10	1	1	2	2	2	2	1	2	2	2	2	2	2	2	2
11	2	1	2	2	2	1	1	2	2	2	1	1	2	2	1
12	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2
Total	20/24	15/24	21/24	16/24	23/24	20/24	18/24	19/24	19/24	15/24	19/24	16/24	20/24	21/24	17/24

found, with both high PI (g = 0.52 to 0.60) and low PI (g = 0.63) identified as risk factors[23-25,29]. Dagneaux et al. described a higher PI in patients with unstable THAs (n = 33, 58°) compared with stable conventional THAs (n = 41, 51°) (p = 0.01, g = 0.59)[24]. Two studies also found a higher PI in patients with unstable THAs compared with

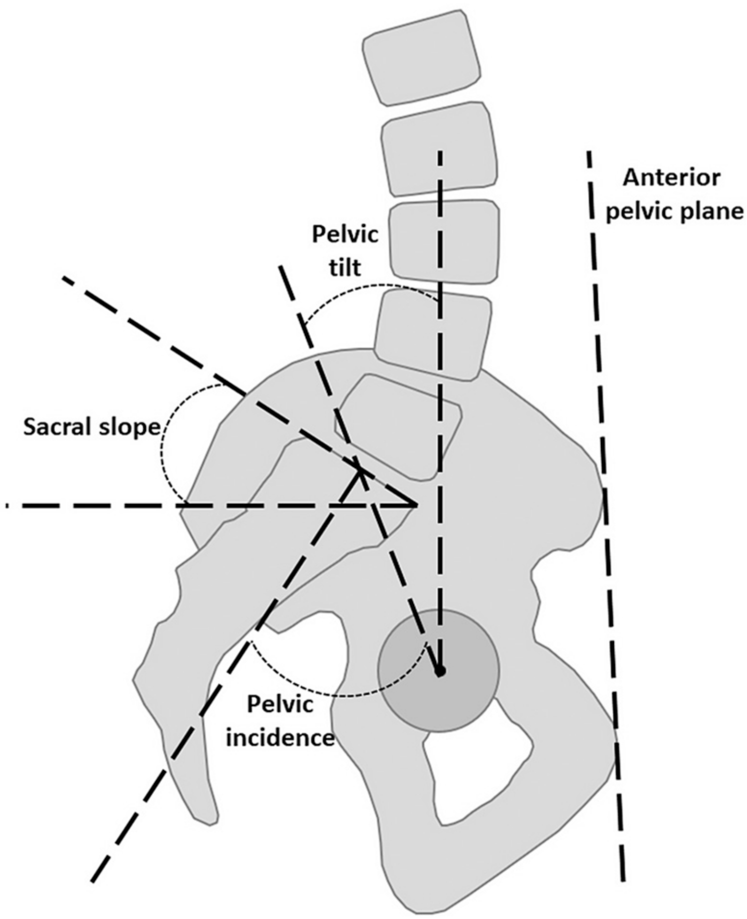

Fig. 2

Sagittal lumbopelvic alignment parameters. Sacral slope (SS) = the angle between a line tangent to the superior end plate of S1 and a horizontal line. Pelvic tilt (PT) = the angle between a line from the midpoint between the femoral heads to the center of the superior end plate of S1 and a vertical line. Pelvic incidence (PI) = the angle between a line tangent to the superior end plate of S1 and a line from the midpoint between the femoral heads to the center of the superior end plate of S1 (PI = PT + SS).

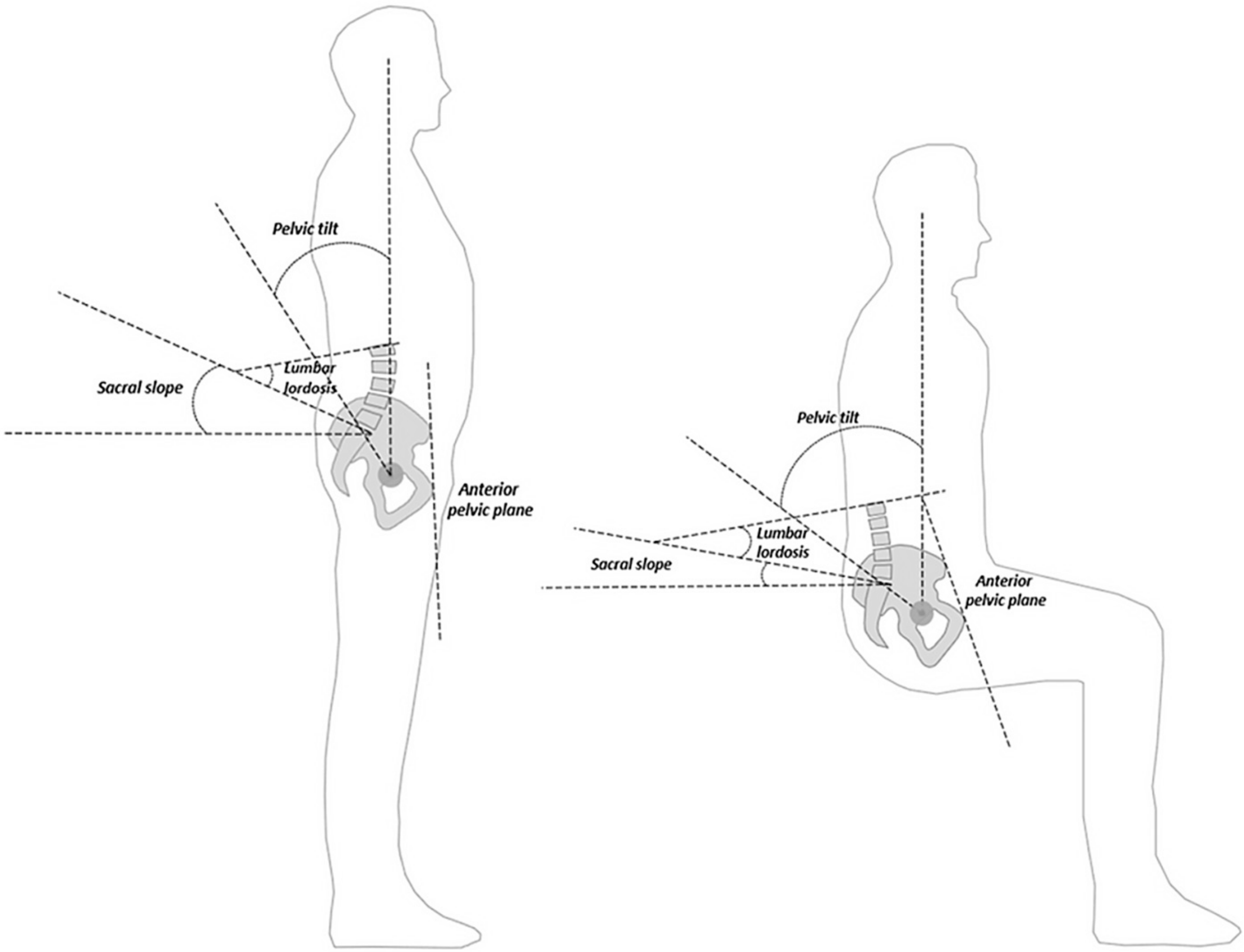

Fig. 3
Pelvic dynamics, showing the differences between standing and sitting in pelvic tilt, lumbar lordosis, sacral slope, and the anterior pelvic plane.

stable THAs, although the differences were not significant (65° versus 52°, $p = 0.12$, $g = 0.52$; and 56° versus 49°, $p = 0.18$, $g = 0.60$)[23,29]. On the contrary, Snijders et al. reported a lower PI in patients with unstable THAs (n = 15, 48°) compared with stable THAs (n = 233, 55°) ($p \leq 0.01$, $g = 0.63$)[25]. Five studies did not report significant differences in THA patients who had degenerative disc disease (DDD) or had undergone lumbar spinal fusion (LSF), or reported insufficient data to calculate effect sizes[18,19,26-28].

Spinopelvic Alignment

Nine studies (QS: 15-23) investigated spinopelvic alignment parameters and THA dislocation[18,19,23-29]. Several spinopelvic parameters were found to be related to THA dislocation (Table II). The effect size range was 0.14 to 2.02[19,23-25,29].

Pelvic tilt (PT): Effect sizes were 0.48, 0.66, and 2.02 based on 3 studies (QS: 16-21)[23,24,29]. One study reported a higher posterior PT in unstable THAs (n = 33) compared with stable THAs (n = 41, 18° versus 13°) ($p = 0.03$, $g = 0.48$)[24]. Another study also reported higher posterior PT in unstable THAs compared with stable THAs, in a population with concomitant adult spinal deformity (defined according to the International Spine Study Group [ISSG] criteria, which include age of ≥18 years and the presence of at least 1 of the following: Cobb angle of >20°, sagittal vertical axis of ≥5 cm, PT of >25°, or thoracic kyphosis of >60°) (n = 97, 29° versus 22°) ($p = 0.05$, $g = 0.66$)[23]. Furthermore, a higher PT was reported in patients with unstable THAs and LSF (n = 6) compared with stable THAs and LSF (n = 21, 31° versus 20°) ($p = 0.02$, $g = 2.015$)[29]. In contrast, 2 other studies did not report significant differences, and reported insufficient data to calculate effect sizes[26,27].

Change in PT (between standing and sitting): 1 study (QS: 21) reported that patients with posterior THA dislocations show less pelvic retroversion, when changing from standing to sitting, compared with stable THAs (+11° versus +21°) ($p < 0.001$, $g = 1.03$)[25].

Sacral slope (SS, the angle between a line tangent to the superior end plate of

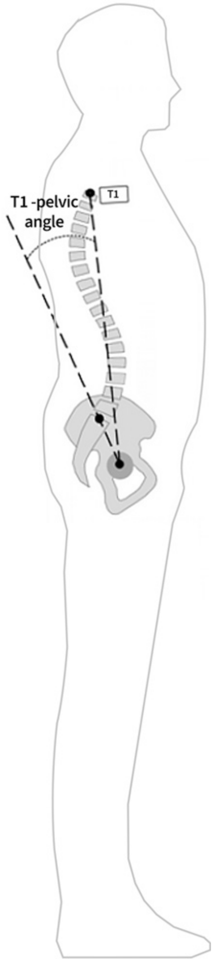

Fig. 4

Global balance as measured by the T1-pelvic angle, T1PA (between a line from the centroid of T1 to the midpoint between the femoral heads and another line from the midpoint between the femoral heads to the center of the superior end plate of S1).

S1 and a horizontal line) (Figs. 2 and 3): 8 studies (QS: 15 to 21) investigated SS and THA dislocation (g = 0.25 to 0.66)[18,23-29]. Snijders et al reported a significantly lower SS in patients with a dislocated THA (33° versus 39°, p = 0.004, g = 0.66)[25]. In contrast, 7 other studies did not report significant differences (g = 0.25, 0.38, and 0.58; the remaining 4 did not report sufficient data to calculate the effect size)[18,23,24,26-29].

Change in SS (between standing and sitting): 2 studies (QS: 21 and 23) reported on the change in SS (g = 0.82 and 0.996)[19,25]. Snijders et al. found a significantly smaller decrease in SS in the unstable THA group (n = 15, −12°) compared with the stable THA group (n = 233, −21°) (p = 0.000, g = 0.996)[25]. The other similarly reported a smaller decrease in SS in patients with DDD and unstable THAs (n = 11, 9°) compared with patients with normal spines and stable THAs (n = 106, 17°) ($p < 0.001$, g = 0.82)[19].

L1-S1 lumbar lordosis (LL, the angle between the lines tangent to the superior end plates of L1 and S1): 5 studies (QS: 15 to 21) reported nonsignificant results regarding LL and THA dislocation (g = 0.07 to 0.196)[23,24,27-29]. Two studies did not report sufficient data to calculate the effect size[27,28].

Change in LL (between standing and sitting): A smaller change in LL was reported for 11 patients with DDD and unstable THAs compared with 106 patients with normal spines and stable THAs (−14° versus −23°) ($p < 0.001$, g = 0.71) in 1 study (QS: 23)[19].

PI-LL mismatch: 4 studies (QS: 15-21) reported on the PI-LL mismatch and THA dislocation[23,24,27,28]. Effect sizes of 0.67 to 0.82 could be calculated based on 2 studies reporting higher PI-LL mismatch in patients with unstable THAs[23,24]. Two other studies did not report sufficient data to calculate the effect size[27,28].

T1-pelvic angle (between a line from the centroid of T1 to the midpoint between the femoral heads and another line from the midpoint between the femoral heads to the center of the superior end plate of S1) (Fig. 4). A higher T1-pelvic angle was found in patients with unstable THAs (n = 10, 29°) compared with stable THAs (n = 97, 22°) (p = 0.034, g = 0.71) in 1 study (QS: 16)[23].

Sacrospinal angle (SSA, the angle between a line from the center of C7 to the center of the superior end plate of S1 and a line tangent to the superior end plate of S1): A higher proportion of patients with unstable THAs had an SSA of <127° (n = 33, 70%) compared with stable THAs (n = 41, 43%) (p = 0.02, g = 0.35)[24].

Anterior pelvic plane tilt (APPT) (Figs. 2 and 3): A smaller APPT was found in patients with unstable THAs (n = 33, 2°) compared with stable THAs (n = 41, 7°) (p = 0.002, g = 0.72) in 1 study (QS: 21)[24].

C7-sagittal vertical axis (C7-SVA, the horizontal offset between a plumb-line dropped from the center of the C7 vertebral body and the posterosuperior corner of the superior end plate of S1): 3 studies (QS: 16 to 21) reported on the C7-SVA and THA dislocation (g = 0.14 to 0.68)[23,24,29]. One reported a greater C7-SVA offset in patients with unstable THAs (n = 33) compared with stable THAs (n = 41, 68 versus 36 mm) (p = 0.02)[24]. In contrast, the other 2 studies did not report significant differences[23,29].

T9-spinopelvic inclination (T9-SPI, the angle between a line from the midpoint between the femoral heads to the center of the T9 vertebral body and the vertical): 1 study (QS: 16) reported on T9-SPI and found no difference between unstable and stable THAs (−10° versus 0°) (p = 0.43, g = 1.1)[23].

Radiographic hip flexion (from standing to sitting): 1 study (QS: 23) reported greater hip flexion in patients with DDD and nunstable THAs (n = 11, 72°) compared with patients with normal spines and stable THAs (n = 106, 65°) (p = 0.001, g = 0.60)[19].

Spinal Pathology

Two studies (QS: 20-23) investigated spinal pathology and THA dislocation[7,19]. The OR was 1.9 (95% confidence interval [CI]: 1.0 to 3.6; $p < 0.05$) for a history of spinal disease (scoliosis, lumbar stenosis, spinal fusion, discectomy, or history of spinal trauma) and 29.2 (95% CI: 3.6 to 233; p = 0.002) for multilevel DDD[7,19].

Previous Spinal Fusion Surgery

Eight studies (QS: 15-20) investigated the role of previous spinal fusion surgery in THA dislocation[18,22,26,27,30-33]. Based on the calculated ORs of 1.59 to 23.7 in 5 studies[22,26,30-33] and the RR of 3.0[30] in another, previous spinal fusion was found to be a risk factor for THA dislocation. The OR for prior revision spinal fusion surgery was 3.44 (95% CI: 2.90 to 4.08; $p < 0.001$)[22]. One study did not report a significant association between spinal fusion surgery and THA dislocation (OR: 3.5, 95% CI: 0.81 to 14.8, p = 0.09)[18]. Another study did not report sufficient data to calculate the significance level[27].

Discussion

Many sagittal parameters or characteristics describing pelvic morphology, spinopelvic alignment, spinopelvic dynamics, spinal pathology, and previous spinal surgery have been implicated as risk factors for THA dislocation in the literature. The aim of this systematic literature review was to assess the correlation between any sagittal spinopelvic characteristics and THA dislocation. A total of 15 studies presented data on this topic. Because the qualitative synthesis showed that all studies were of moderate to high quality, we can ultimately conclude that there is a comprehensive relationship between sagittal spine-pelvis-hip dynamics and the risk of primary THA dislocation.

The complex spine-pelvis-hip dynamics find their origin in the adaptation of the pelvis to upright locomotion and development of lordosis in the lumbar spine during human evolution[34]. The combination of an energy-efficient upright body position and the ability to simultaneously extend both the hips and the knees is unique for the human species and allows the body's center of gravity to be positioned directly above the pelvis[34]. In this, the pelvis acts as a double hinge between the spine and the hips. Anterior and posterior pelvic tilting allows the spinal configuration to be regulated, which is essential to maintain the center of mass of the head and trunk directly above the legs. For example, during the change from standing to sitting, the pelvis normally tilts posteriorly to decrease the lordosis and allow for femoroacetabular flexion[35]. Sagittal pelvic rotation around the femoral heads, better known as posterior PT or retroversion, directly affects the acetabular orientation. Posterior PT would increase the functional sagittal acetabular tilt and transverse version, whereas anterior PT would decrease these[35]. In patients with a THA in situ, the acetabular component is fixed in the acetabular cavity and it will automatically follow the sagittal pelvic orientation changes.

In 1992, PI was introduced as a parameter for assessing differences in sagittal pelvic morphology between individuals[36]. It describes the orientation of the superior end plate of S1 relative to the functional pelvic ring (the angle between a line tangent to the superior end plate of S1 and a line from the midpoint between the femoral heads to the center of the superior end plate of S1). PT and SS describe the pelvic orientation relative to the vertical and horizontal, respectively. In the contemporary human population, there are large variations in sagittal pelvic morphology[34] and the corresponding pelvic dynamics. Schlösser et al.[34] showed that PI varies between 14° and 77° within the human population. Furthermore, it is well known from the spine literature that on average, pelves with low PI have less ability for posterior pelvic tilting when changing body position or for compensation for degenerative lumbar pathology. Therefore, it can be expected that within the population undergoing primary THA, there will also be wide variation in the pelvic orientation in the static, upright position as well as variation in the functional changes in pelvic orientation when changing body positions.

The data in this review showed that pelvic retroversion and global sagittal imbalance as well as decreased pelvic dynamics significantly increased the risk of THA dislocation. However, conflicting results were found for sagittal pelvic morphology (PI). The relation of spinopelvic alignment parameters to THA dislocation was described in 9 studies[18,19,23-29]. The parameters that may directly or indirectly indicate that pelvic retroversion is a risk factor for THA dislocation were high posterior PT (g = 0.48 to 2.02), low SS (g = 0.25 to 0.66), large PI-LL mismatch (g = 0.67 to 0.82), and small APPT (g = 0.72). The parameter that described global sagittal imbalance as a risk factor was a high T1-pelvic angle (g = 0.71). Decreased pelvic dynamics were demonstrated by smaller changes in SS (g = 0.82 to 0.996), PT (g = 1.03), and LL (g = 0.71) when changing from standing to sitting and by high radiographic hip flexion (g = 0.60).

Severe lumbar degeneration is mostly associated with a stiffer spine, loss of intervertebral disc height, and therefore loss of lordosis. In order to compensate for the loss of lordosis, the pelvis tilts posteriorly. This is, however, at the cost of less functional PT and a compensatory increase in hip range of motion[19,24]. Previously, an inverse relationship between spinopelvic range of motion and hip range of motion has been shown: for every 1° loss of spinopelvic range of motion, there was an increase of 0.9° in femoral range of motion[11]. Several studies included in this review showed that spinal pathology and previous spinal fusion surgery were risk factors for THA dislocation[7,19,22-26,30-33]. ORs of 1.9 to 29.2 were found for spinal pathology, and ORs of 1.59 to 23.7 and RRs of 2.7 to 3.0 were found for previous spinal fusion surgery. Previous literature indicated that the risk of THA dislocation increases if 3 or more lumbar spine levels have been fused[37]. The wide range in the ratios in this study can be explained by the heterogeneity in severity and type of spinal pathology (stenosis, history of spinal trauma, severe adult spinal deformities, ankylosing spondylitis, etc.), type of surgery (LSF with or without fusion of the lumbosacral junction and/or sacroiliac joints), range of indications, and number of levels fused among the studies. Compared with the ORs (1.27 to 1.64) calculated for other patient-related risk factors for THA dislocation analyzed in previous literature (age of >75 years, ASA score of 3 or 4, small femoral head component)[38], the ORs (1.59 to 29.2) calculated in this review are relatively high.

There are a few limitations to this study. First, the current literature reported on a wide variety of sagittal parameters. Second, positioning during image acquisition may vary among the included studies, and the positioning of the hands, extremities, and line of sight could affect the spinopelvic configuration, especially for functional radiographs. Third, not all 15 studies reported sufficient data to objectively quantify the correlation with THA dislocations in terms of an effect size or OR, 95% CI, or significance level. Fourth, the measurement error and clinically important differences for many spinopelvic parameters have not yet been defined.

Nevertheless, based on the results of this study, it can be suggested that acetabular cup placement within the recommended Lewinnek safe zone[1], without taking account of pelvic orientation and dynamics, is no longer sufficient. The variations in pelvic morphology and pelvic motion among individuals demand a more patient-specific approach[39]. The reliability of assessment of spinopelvic-femoral dynamics based only on medical history and physical examination has not previously been investigated, to our knowledge. For now, sagittal spinopelvic parameters should be measured preoperatively on standing and sitting lateral pelvic radiographs to provide information about the pelvic orientation and pelvic motion and the active compensatory mechanisms to maintain a balanced spine. With this work-up, one could differentiate within the spectrum between so-called "hip users" and "spine users."[35,39] Early recognition of patients at the ends of this spectrum will lead to more realistic patient expectations regarding the risk of THA dislocation. Furthermore, it could help to improve the preoperative work-up in terms of optimal implant selection (dual-mobility articulation, high-offset stem, or large femoral head)[40] and patient-specific implant orientation.

Previously, Snijders et al. showed that unstable THAs reveal a compromised 3-dimensional functional safe zone with diminished pelvic dynamics compared with stable THAs, which emphasizes the importance of determining functional cup orientation by biplanar imaging[25]. The "functional safe zone" has not yet been well defined. While this study confirmed several sagittal pelvic plane characteristics as risk factors for THA dislocation, future studies are needed to demonstrate that dislocation rates can be reduced by implementing the concept of a patient-specific functional safe zone in which the 3-dimensional orientation of the acetabular component is adapted for functional PT[5,41].

Conclusions

This systematic review found support for a relationship between spinopelvic sagittal characteristics and THA dislocation. This may explain why THA dislocation frequently occurs with an acetabular component placed within the so-called safe zone. Preoperative evaluation of sagittal spinopelvic alignment and pelvic dynamics using lateral pelvic radiographs in standing and sitting body positions should be considered before surgery, especially in patients with a history of spinal pathology or surgery. Future studies are needed to demonstrate that dislocation rates can be reduced by implementing the concept of patient-specific functional safe zones for acetabular cup placement.

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