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Aims: This study aims to (1) define the prevalence of spinopelvic abnormalities amongst patients with hip osteoarthritis (OA) and controls (asymptomatic volunteers); and (2) identify factors that reliably predict the presence of lumbar spine stiffness.

Patients and Methods: This is a prospective, cross-sectional, case-cohort study of patients with end-stage primary hip OA, who underwent primary THA between January 2019 and December 2021. Patients were compared with a cohort of asymptomatic volunteers, matched for age-, sex- and BMI, serving as a control group with a 2:1 ratio. Spinopelvic pathologies were defined as having a lumbar spine flatback deformity (PI-LL≥10°), a standing sagittal pelvic tilt of ≥19° and lumbar spine stiffness (lumbar flexion <20° between both postures).

Results: The prevalence of spinopelvic pathologies was similar between patients and controls (flatback deformity: 16% vs. 10%, p=0.209; standing pelvic tilt >19°: 17% vs. 24%, p=0.218; lumbar spine stiffness: 6% vs. 5%, p=0.827. Age over 65 years and a standing lumbar lordosis angle of less than 45°, were associated with a high sensitivity and specificity for identifying patients with lumbar spine stiffness (age >65 years: 82% and 66%; standing lumbar lordosis angle <45°: 85% and 73%).

Conclusion: The presence of end-stage hip osteoarthritis was not associated with an increased prevalence of abnormal or adverse spinopelvic characteristics compared to matched, asymptomatic volunteers. Age and $LL_{standing}$ are the strongest predictors of lumbar spine flexion

and can guide clinical practice on when to obtain additional radiographs for patients with hip OA prior to arthroplasty to identify at-risk patients.

Key words: Spinopelvic, Hip, Spine, Arthroplasty, Lumbar Spine Stiffness

Level of Evidence: II (Prospective, cohort study)

Introduction

Spinopelvic characteristics, particularly lumbar spine stiffness, defined as lumbar flexion less than 20°, has been identified as an important factor associated with the risk of revision after total hip arthroplasty (THA)[1, 3, 4, 7]. Patients with lumbar spinal arthrodesis and those with degenerate, immobile, lumbar spine have been shown to be at increased risk of dislocation following THA[1, 3, 4, 7]. These associations highlight the importance of studying the hip-spine association in greater detail, especially, with an ageing population and a rising prevalence of hip-spine syndrome.

The femur, pelvis and spine form an important kinetic chain and work together to allow for efficient movement whilst transitioning between various postural changes. Data amongst healthy volunteers and patients has shown great variability in spinopelvic characteristics[13, 14]. Patients with hip osteoarthritis (OA) have increased pelvic motion when transitioning between the standing and seated positions[13, 14], which "normalizes" following hip arthroplasty, as the hip's range of motion is restored[14]. To identify patients at risk of complications post-THA due to lumbar spine stiffness, some advocated for the assessment of change in sacral slope between the standing and seated positions[19]. This parameter measures the sagittal motion of the pelvis and has been adopted as a surrogate measure of lumbar spine motion, due to the direct linkage of the pelvis with the lumbar spine. However, the value of the change in sacral slope has been questioned[12].

The aims of this prospective, case-control, study were to 1) Define the prevalence of spinopelvic abnormalities (lumbar spine stiffness, abnormal pelvic tilt, and spinopelvic imbalance) amongst patients with hip OA; 2) Test if the prevalence is different to matched healthy volunteers; and 3) Identify factors that reliably predict the presence of lumbar spine stiffness, which can be used as useful screening tool for patients pre-THA.

Patients and Methods

Study design

This is a prospective, case-control study of patients with end-stage hip OA, who underwent primary THA between January 2019 and December 2021 in two tertiary academic centres. The patients were compared with a cohort of asymptomatic volunteers, matched for age-, sex- and BMI, serving as a control group with a 2:1 ratio.

Study power

Study power was determined as per lumbar flexion. Lumbar spine flexion in patients with hip OA has been reported to be 40°±14°, whilst lumbar flexion has been reported to be 46°±15° for asymptomatic volunteers[12, 20]. Therefore, a priori sample size calculation was performed in G-power (G*Power Version 3.1.9.2, University of Duesseldorf, Germany) aiming to detect a minimum difference in 6°for the change in lumbar lordosis angle when moving from the standing to deep-seated position between both cohorts[13]. Assuming a 2:1 matching ratio for patients and controls, a minimum of 137 patients and 69 controls was needed to achieve sufficient power (1-β=0.95, α=0.05). The study was approved by the institutional review board of the YYY (YYY) and the XXX (XXX) and conducted as per the Helsinki Declaration of 2008. All participants signed an informed consent.

Study population

Study group – Hip Osteoarthritis patients

During the study period, 357 consecutive patients awaiting total hip arthroplasty for primary or secondary hip OA (Kellgren-Lawrence grade 3-4), were prospectively recruited. Exclusion criteria were age younger than 18 years-old, lack of consent or technical reasons such as poor quality or incomplete radiographs.

Control group – Asymptomatic Volunteers

During the same study period, a control group of 106 volunteers older than 18 years, with BMI ≤40kg/m^2, and absence of hip symptoms (Oxford hip score ≥45; 0-48 worse-best), radiographic signs of hip osteoarthritis (Tönnis ≤1), and history of spinal or any prior lower limb surgery, were recruited.

Matching

A case-control matching was performed for the variables of age (±5 years), sex (identical) and BMI (±3 kg/m^2) for each of the hip OA patients and asymptomatic volunteers using a case-control-matching algorithm, resulting in the final study cohort of 140 patients and 70 matched controls[11] (Fig.1). These factors have been shown to influence spinopelvic characteristics [12, 20]. Demographic details of the study cohort are outlined in Table 1.

Radiographic assessment

Cases and controls underwent the following radiographic assessment which included: supine anteroposterior (AP) radiograph of the pelvis, a lateral radiograph of the symptomatic hip, lateral radiographs of the lumbar spine, pelvis and femur in the standing and "deep-seated" positions. The "deep-seated" position is defined as a sitting position, with the femurs parallel to the floor with the trunk leaning maximally forward[5, 11, 18]. The deep-seated was chosen for detecting lumbar spine stiffness as per definition in the literature[15]. On the lateral spinopelvic radiographs, the following measurements were performed: Lumbar Lordosis angle (LL), Sacral Slope (SS), Pelvic Incidence (PI), Pelvic Tilt (PT), and Pelvic Femoral Angle (PFA) (Fig. 2)[5, 9, 10, 16, 18]. Radiographic measurements were performed by two reviewers, blinded to each other (XX, YY).

105 The spinopelvic movements were calculated as the difference between the standing and "deep-
106 seated" position for all radiographic spinopelvic parameters as follows (LL, SS, PI, PT,
107 PFA)[11]: $\Delta X_{standing/\ deep\text{-}seated} = \Delta X_{\ deep\text{-}seated} - \Delta X_{standing}$.
108 Average-measure correlation coefficients with a two-way random effects model for absolute
109 agreement were calculated, after performing repeated measurements two weeks after the initial
110 radiographic analysis for 10% of randomly selected data sets in a blinded fashion by both
111 reviewers, showing excellent intra- and inter-observer reliabilities (IORs) (range: 0.858 (95%
112 CI; 0.657-0.942) to 0.997 (95% CI; 0.993-0.999).
113
114 *Definitions of spinopelvic pathologies*
115 Spinopelvic pathologies were the following: 1. Flatback deformity on lateral spinopelvic
116 radiographs, defined by a mismatch between the lumbar lordosis angle and pelvic incidence in
117 the standing position (PI-LL≥10°) has been reported to be a strong predictor of instability after
118 THA[6]; 2. Standing sagittal pelvic tilt ≥ 19°, which has been reported to be a strong predictor
119 for hip hypermobility and lumbar spine stiffness[12]; 3.Lumbar spine stiffness, defined as
120 lumbar spine flexion < 20° between standing and deep-seated positions, which has been
121 identified to be a risk factor for dislocation after THA[1, 3, 7, 15].
122
123 ***Statistical Analysis***
124 Non-parametric tests were used after exploratory data analysis. Chi-square tests were used to
125 test for differences between categorical variables. An independent samples t-test or Mann-
126 Whitney-U-test was used to compare demographics and spinopelvic measurements between
127 controls and hip OA patients. Spearman's rho (ρ) correlations were performed in order to
128 investigate the association of demographic factors and spinopelvic pathologies. Factors
129 showing a significant and clinically relevant correlation with the previously defined spinopelvic

pathologies were added in logistic regression analysis. The logistic regression analysis, was conducted in order to identify predictors for lumbar spine stiffness ($\Delta LL_{standing/deep\text{-}seated}<20°$), having inputted parameters that were shown to have an association with the presence of abnormal spinopelvic characteristics, using univariate correlation analysis. A Receiver Operator Curve (ROC) analysis was used to determine the specificity and sensitivity of factors predicting lumbar spine stiffness. Statistical analysis was performed using SPSS v27 (IBM). A value of <0.05 was considered significant.

Results

Prevalence of spinopelvic pathologies amongst patients

The prevalence of spinopelvic pathologies amongst patients is detailed in Table 2. Six percent of patients exhibited spinal stiffness and 17% showed lumbar spine imbalance. There were no meaningful differences between unmatched and matched patients for spinopelvic mobility and the prevalence of pathologies (Table 2).

Differences in prevalence between matched groups

No difference in spinal balance was found between patients (23/140; 16%) and controls (7/70; 10%) (p=0.209). Similarly, no difference in prevalence of standing pelvic tilt ≥19° (24/140; 17% vs. 17/70; 24%) p=0.218) and lumbar spine stiffness (7/140 (6%) vs. 4/70 (5%); p=0.827) was identified between groups. Most patients had no abnormal spinopelvic characteristics at all (n=160/210; 76%); 40 had one abnormal characteristic (19%), eight had two abnormal spinopelvic characteristics (4%) and only two patients (1%) had all three abnormal spinopelvic characteristics (Table 2). There were no differences between cases and controls in number of abnormal spinopelvic characteristics detected (p=0.938) (Figure 3).

Demographic factors being associated with spinopelvic pathologies

Age was associated with spinopelvic balance (ρ=0.315; p<0.001) and lumbar spine stiffness (ρ=0.521; p<0.001), due to loss of lumbar lordosis in both positions ($LL_{standing}$: ρ=0.268; p<0.001; $LL_{deep\ seated}$: ρ=0.263; p<0.001). BMI and gender did not show any clinically-relevant association (Table 3&4). The correlation between age and lumbar spine stiffness and spinopelvic balance was similar between cases and controls (Table 3 and Fig. 4).

Predictors for lumbar spine stiffness

Most patients with stiff spines were older than 65-years-old (9/11) or had $LL_{standing}$ less than 45° (8/11). No patient below the age of 55-years-old showed lumbar spine stiffness (Figure 5). The odd's ratio of having a stiff spine if older than 65-years-old with a $LL_{standing}$ less than 45° was 4.6 (p=0.036). Similarly, the logistic regression analysis demonstrated that the standing lumbar lordosis angle was the only significant predictor of lumbar spine stiffness, whereas age showed borderline lack of significance (Table 4).

The ROC-analysis illustrated that age over 65 years and standing lumbar lordosis angle of less than 45° degrees, was associated with a high sensitivity and specificity for identifying patients with lumbar spine stiffness (Fig 5A&B and Table 5). The relationship between age, standing LL and the presence of a stiff spine is further portrayed in Figure 6.

Discussion

The adverse effects of lumbar spine stiffness on THA outcome have been extensively reported and have raised significant awareness amongst surgeons. However, the pertinent questions of how common adverse spinopelvic characteristics are in a typical arthroplasty clinic and how best to identify lumbar spine stiffness pre-operatively has not been adequately addressed, leading to common questions such as "should all patients be screened for the presence of spinal stiffness?". The presence of end-stage hip osteoarthritis was not associated with an increased prevalence of abnormal or adverse spinopelvic characteristics (lumbar spine stiffness, spinopelvic balance, abnormal pelvic tilt), relative to well-matched, well-functioning, asymptomatic volunteers. This possibly implies that the contribution of the abnormal spinopelvic posture and dynamics due to hip osteoarthritis do not significantly contribute to the degenerative process of the lumbar spine. The identification of spinal stiffness requires dynamic spinopelvic radiographs to accurately assess lumbar motion. However, dynamic radiographs are associated with increased radiation exposure and might be difficult to execute by the hip OA patient due to pain. This raises the question whether it would be possible to obtain the necessary information from a single radiograph. Lumbar spine stiffness exhibited a moderately significant correlation with age, which was also evidence in the ROC analyses; no patient under the age of 55-years-old exhibited any spinal stiffness, regardless of $LL_{standing}$. Similarly, $LL_{standing}$ exhibited a strong association with lumbar spine stiffness, and thus a $LL_{standing}$<45° was identified as an excellent threshold value to use as a screening tool with high sensitivity of 85% and specificity 73%. Based on age and $LL_{standing}$ we were able to identify patients not at risk of adverse spinopelvic characteristics. These patients only require a single standing, lateral spinopelvic X-ray (age <65 years of age, $LL_{standing}$ <45° and no history of spinal pathology) pre-operatively, and don't need seated spinopelvic radiographs. This can help reduce radiation

exposure whilst maintaining the ability to use spinopelvic characteristics during pre-operative THA planning.

The prevalence of abnormal spinopelvic abnormalities amongst arthroplasty patient in recent studies has been reported to vary widely between 4% to 53%[2, 8, 17, 21, 22]. However, many of these studies have included patients with lumbar fusions in their cohorts, and defined stiffness using relaxed-seated assessments, which overpredict the presence of spinopelvic abnormalities[12]. In this study of all patients undergoing THA in two academic units and having detailed radiographic assessments, the prevalence of spinal imbalance, stiffness and increased pelvic tilt were 16%, 5% and 17%, respectively. However, only 4% (6/140%) of patients showed more than two abnormal spinopelvic characteristics. The presence of hip OA was not associated with an increased risk of abnormal spinopelvic characteristics, as evident by the prevalence of these findings in the age-, sex- and BMI- matched control group of well-functioning volunteers. Furthermore, the prevalence of abnormal spinopelvic characteristics were similar between matched an unmatched patients. This likely indicates that the hip and spine degenerate independently and that the influence of hip OA on the pathogenesis of spinal degeneration is small, relative to other factors, described to contribute to increased spinal degeneration. However, with advancing age the incidence of hip-spine syndrome also increases as the incidence of both hip and spine arthritis increase, which fall in line with observations seen in this cohort of advanced age being associated with the presence of abnormal spinopelvic characteristics. These findings are also of significant clinical relevance as they illustrate that the proportion of patients that are at increased risk due their individual spinopelvic characteristics is in fact quite low and likely about 10-15% of most arthroplasty practices. Thus, it is of importance to define how best to utilize resources to appropriately identify these patients at-risk, without over-investigating all patients presenting to clinic.

Several patient- (age and BMI) and static radiographic factors ($LL_{standing}$, PI-LL, $PT_{standing}$, LL_{seated}) were found to be associated with spinal flexion. However, due to significant association and collinearity between these factors, the two factors that were the strongest predictors of spinal flexion/stiffness were age and $LL_{standing}$. ROC analysis of these two factors enabled the description of relevant thresholds (age>65 years old and $LL_{standing}$<45°) that can be used in the clinical setting to predict the presence of spinal stiffness by considering patient age and performing measurement from a single radiograph ($LL_{standing}$<45°). Furthermore, no patient below the age of 55-years of age exhibited spinal stiffness nor spinopelvic imbalance, but five had high $PT_{standing}$. Thus, to minimize radiation and cost, if a surgeon solely wishes to identify patients at-risk, and does not plan as per sagittal characteristics, no sagittal profile radiographs are necessary for patients younger than 55 years-old without spinal pathology. For patients older than 55-years old, we would recommend a single standing spinopelvic view to measure $LL_{standing}$, PI-LL and $PT_{standing}$ to identify at-risk patients. Furthermore, static characteristics change little post-operatively, which makes them more reliable in pre-operative planning of cup orientation than dynamic characteristics, which are subject to change post-THA[6] .

This study has several limitations. Firstly, all assessments were performed using radiographs. Such assessments may thus suffer from variability in the execution of the technician's command by the patients. Secondly, the study was appropriately powered to detect a 6° difference in LL, which has been reported to be a clinically relevant difference. However, if less of a difference is found to be clinically relevant in the future, this study may suffer for Type II bias. However, there were no large differences between unmatched and matched patients for spinopelvic mobility and the prevalence of pathologies. Furthermore, a much larger cohort would be needed to detect small differences in the distribution of spinopelvic pathologies between groups. A

larger cohort would also allow for testing for non-linear association between age and spinal characteristics as it may be plausible that the relationship present amongst the young may not be applicable for patients older than 70 years old. Lastly, prospective, longitudinal assessments would assess the effect of hip OA on lumbar stiffness more accurately. A cross-sectional study may suffer from selection biases that may not be accounted for as part of the study design. To overcome such limitations, we accounted case control matched for demographic factors previously considered to affect spinopelvic dynamics.

In conclusion, the presence of at least one abnormal spinopelvic characteristic can be found in 1-in-6 patients awaiting THA. Spinal stiffness increases with age and the presence of hip OA is not associated with an increased risk of adverse spinopelvic characteristics. Age and $LL_{standing}$ are the strongest predictors of spinal flexion and important thresholds can be defined that can guide clinical practice on when to obtain additional radiographs prior to surgery. Young patients under the age of 55-years-old did not exhibit spinal stiffness. A single, static lateral spinopelvic view would suffice in patients above the age of 65-years-old with a relevant $LL_{standing}$ threshold of 45° as it would provide with all data sufficient for screening for adverse spinopelvic characteristics in patients. These evidence-based recommendations help surgeons stratify radiation exposure and reduce cost whilst incorporating spinopelvic imaging in pre-operative THA planning.

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Figure legends

Figure 1. Flowchart of the cohort included in the study.

Figure 2. Illustration of radiographic measurements for the lumbar lordosis angle (LL), sacral slope (SS), pelvic tilt (PT), pelvic incidence (PI) and the pelvic-femoral-angle (PFA) in the A) standing, B) deep-flexed seated position.

Figure 3. Venn diagrams illustrating the overlap of the abnormal spinopelvic characteristics for controls (A) and patients (B)

Figure 4. Scatterplots illustrating the correlation between age and A) lumbar spine stiffness ($\Delta LL_{standing/deep\text{-}seated}$) and B) mismatch between PI und LL in the standing position for patients (red) and controls (controls)

Figure 5. Receiver operating characteristic (ROC) curve analysis for lumbar spine stiffness and the factors A) standing lumbar lordosis angle and B) age.

Figure 6. Scatterplot illustrating the correlation between age and A) lumbar spine stiffness ($\Delta LL_{standing/deep\text{-}seated}$) and B) mismatch between PI und LL in the standing position.

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