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HIP

Relationship between pelvic incidence and osteoarthritis of the hip

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Objectives

Sagittal alignment of the lumbosacral spine, and specifically pelvic incidence (PI), has been implicated in the development of spine pathology, but generally ignored with regards to diseases of the hip. We aimed to determine if increased PI is correlated with higher rates of hip osteoarthritis (HOA). The effect of PI on the development of knee osteoarthritis (KOA) was used as a negative control.

Methods

We studied 400 well-preserved cadaveric skeletons ranging from 50 to 79 years of age at death. Each specimen's OA of the hip and knee were graded using a previously described method. PI was measured from standardised lateral photographs of reconstructed pelvises. Multiple regression analysis was performed to determine the relationship between age and PI with HOA and KOA.

Results

The mean age was 60.2 years (standard deviation (SD) 8.1), and the mean PI was 46.7° (SD 10.7°). Multiple regression analysis demonstrated a significant correlation between increased PI and HOA (standardised beta = 0.103, p = 0.017). There was no correlation between PI and KOA (standardised beta = 0.003, p = 0.912).

Conclusion

Higher PI in the younger individual may contribute to the development of HOA in later life.

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Keywords: pelvic incidence; hip; osteoarthritis; spine; sagittal balance

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Article focus

- Assess the relationship between increased pelvic incidence and the development of hip osteoarthritis
- Assess the relationship between increased pelvic incidence and the development of osteoarthritis "further downstream" from the pelvis, particularly at the level of the knee joint.
- Develop a theoretical mechanism wherein subjects with increased pelvic incidence may biomechanically compensate and ultimately create a relative acetabular undercoverage.

Key messages

- There was a clear correlation between increased pelvic incidence and the hip osteoarthritis.
- Our analysis did not demonstrate any correlation between pelvic incidence and knee osteoarthritis.
- There was a strong correlation between age and arthritis of both the hip joint and knee joint.

Strengths and limitations

- Strength: We used a large cohort from the largest anatomical collection of its type in order to assess the relationship between two anatomical parameters in a controlled laboratory fashion.
- Strength: Our measurements of pelvic incidence and osteoarthritis grading were shown to be accurate and repeatable.
- Limitations: The study was performed on cadaveric specimens, for whom we had very little clinical data for and whose life-styles may not represent the temporary patient. While a significant relationship between increased pelvic incidence and the presence of hip osteoarthritis was shown, we are unable to define a specific cause and effect of these two parameters.

Introduction

Osteoarthritis of the hip (HOA) is a major cause of pain and disability that results in considerable social and medical costs. While the aetiology of primary HOA is not fully understood, most orthopaedic surgeons believe that factors including genetic and neuromuscular diseases, patient age, gender, obesity, ligamentous stability, occupation, recreational activities, femoral deformity, hip dysplasia, and the native toughness of an individual's cartilage could influence the development of this disease.[1-3] Mechanisms such as posture, alignment and orientation of the hips and the spinal column, and the relationships between these factors, have been implicated in the development of spine pathology, but, with only a few exceptions, ignored with regards to diseases of the hip.[4-6]

Pelvic incidence (PI), a position-independent anatomic parameter that regulates lumbar lordosis and pelvic orientation, has been studied extensively in relation to spine pathology, and numerous studies have shown that increased PI transmits more mechanical forces to the lumbar spine.[7-9] It is defined as the angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the axis of the femoral heads, and can easily be obtained clinically from a lateral radiograph of the lumbosacral spine (Fig. 1).[10] PI has been shown to remain unchanged after the age of ten,[11,12] and it does not vary between genders.[13,14] The impact of the PI angle with regards to stresses placed on the femoroacetabular joint, and the mechanisms of adaptation at the femoroacetabular joint that are governed by this anatomic parameter, are not well understood.

We therefore asked whether an increased PI, and the biomechanical adaptations that result, would be correlated with higher rates of HOA. As a negative control, we assessed whether these adaptations at the pelvis could have effects on the amount of osteoarthritis "further downstream" from the pelvis, at the level of the knee joint (KOA).

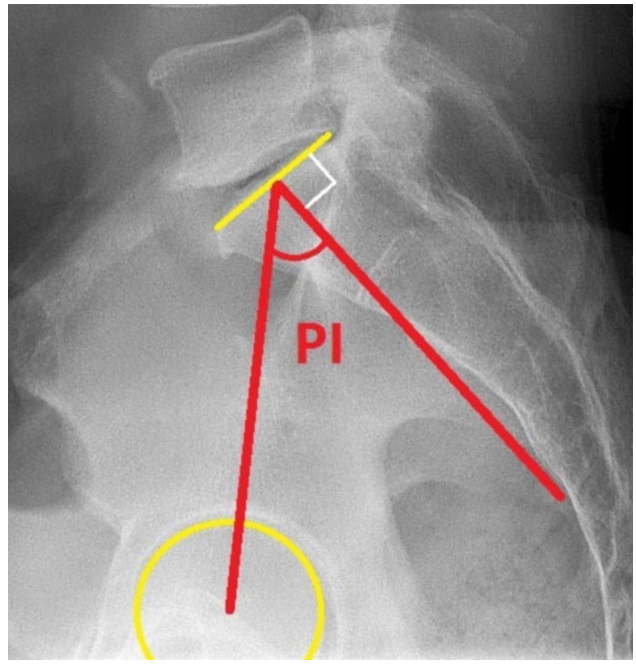

Fig. 1

Radiograph showing an example of radiographic measurement of pelvic incidence obtained clinically from a lateral radiograph of the lumbosacral spine.

Materials and Methods

Specimens. A cohort of 418 specimens were available, for whom pelvic incidence had previously been measured. Of these 418 specimens, we randomly selected 400 which fit our criteria (between ages 50 and 79 years at time of death and no evidence of major osseous abnormalities or damage). The cohort was randomly selected from the Hamann-Todd Osteological Collection at the Cleveland Museum of Natural History (Cleveland, Ohio) for the study. The collection contains approximately 3000 complete, disarticulated human skeletons that have been carefully preserved. The gender, ethnic origin, and age at the time of death are known for nearly every specimen in the collection, including every specimen used in this study. Exclusion criteria included any obvious periarticular trauma, obvious metabolic or rheumatologic disease, evidence of infection affecting the joint surface, incomplete skeletons, or specimens that had degraded or had any evidence of postmortem damage.

Arthritis grading. Arthritis grading was performed by two authors (DSW, RWL) and has previously been reported.[15,16] These two individuals carefully studied a large number of specimens together to establish grading systems for the hip and knee joints. Arthritis of the proximal femur and acetabulum were graded from zero to three and combined to form a composite hip measurement, graded zero to six. The patella and patellofemoral articulation of the femur, medial femoral condyle and medial tibial joint surface, and lateral femoral condyle and lateral tibial joint surface were each graded from zero to three, and these measurements were combined to represent respective patellofemoral, medial knee, and lateral knee compartments. Each compartment was graded zero to six. The mean was calculated for these compartments in order to form a composite knee measurement, graded zero to six (Table I and Fig. 2). A total of 20 specimens were measured independently by each author to establish inter-relator reliability. Intra-relator reliability was assessed by one of the study authors (DSW) with a four-week interval between grading. Each specimen's composite individual hip and knee joint grades were combined with the contralateral side, graded zero to 12, which was used for analysis. Arthritis grading assessors were blinded to specimen PI measurements throughout the data collection process.

Measurement of pelvic incidence. The method for preparing pelvic specimens was similar to that used in previous osteological studies.[17-20] The hemipelvis and sacrum

Table I. Criteria for grading arthritis.

	Grade 0	Grade 1	Grade 2	Grade 3
Acetabulum, proximal femur*, knee compartments	No significant lipping (less than 15% of articular surface)	Mild lipping occupying 15% to 50% of articular surface	Mild lipping occupying greater than 50% of articular surface, or moderate lipping affecting 15% to 49% of articular surface	Moderate lipping affecting ≥ 50% of articular surface, or severe lipping

Lipping was defined as mild when 'edge heaping' was ≤ 2 mm, moderate when edge heaping was 2 mm to 4 mm, and severe when > 4 mm
*Only the most superior 50% of articular surface was considered

of each specimen were assembled using rubber bands and a standardised 12 mm piece of foam that replaced the cartilage of the pubic symphysis. The sacroiliac joints were visually inspected to confirm appropriate configuration of the pelvis.

After reconstructing the pelvis, standardised direct lateral digital photographs were taken of each pelvis specimen with an Easy Square Jr. (EZ Quilting Tools, West Warren, Massachusetts) acrylic 6.5" x 6.5" ruler marking the centre of the sacral endplate (Fig. 3). The PI angle was obtained by measuring the angle formed between a line perpendicular to the midpoint of the sacral endplate and the centre of a best-fit ellipse representing the acetabular rim. For consistency, a single author (MSB) positioned all specimens and took all photographs. ImageJ software (National Institutes of Health, Bethesda, Maryland) was used to obtain angle values. A single author (MSB) measured PI for all specimens, and an additional author (JJG) performed inter-observer reliability measurements for 20 specimens. Both of these authors were unaware of specimen OA scores throughout the data collection process.

Statistical analysis. All statistics were performed using SPSS Statistics Version 22.0 (IBM, Armonk, New York). Inter-relator reliability for arthritis grading was evaluated with the Cohen's Kappa statistic. Comparisons between PI and degenerative arthritis of the hip and knee joints were evaluated with multiple regression analysis with Bonferroni correction. In the multiple regression analysis multicollinearity was assessed as negative based on VIF < 10 and coefficient tolerance > 0.1, normal probability plots of the regression standardised residual were inspected for normality, scatterplots of the standardised residuals were inspected for homoscedasticity, and the lack of any undue influence from outliers was confirmed with a Cook's distance < 1. Intra-observer and inter-observer reliabilities for PI were assessed using the intra-class correlation coefficient (ICC). Continuous data are reported as mean and standard deviation. Significance was set at alpha < 0.05.

Results

The mean age for the 400 skeletons was 60.2 years at time of death (standard deviation (SD) 8.1). There were 359 (90%) male and 41 (10%) female specimens. A total of 305 (76%) of the specimens were Caucasian and 95 (24%) were of African American origin.

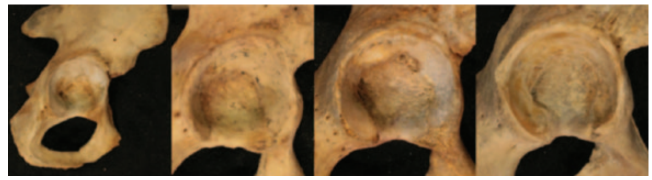

Fig. 2a

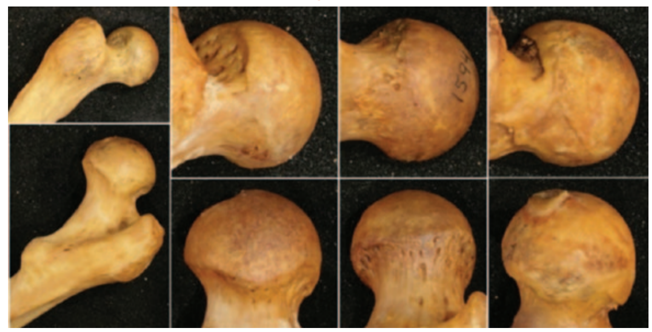

Fig. 2b

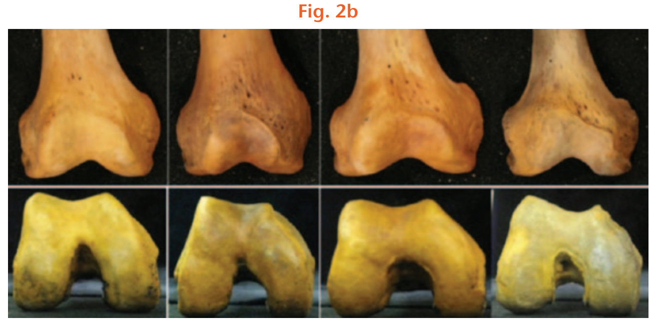

Fig. 2c

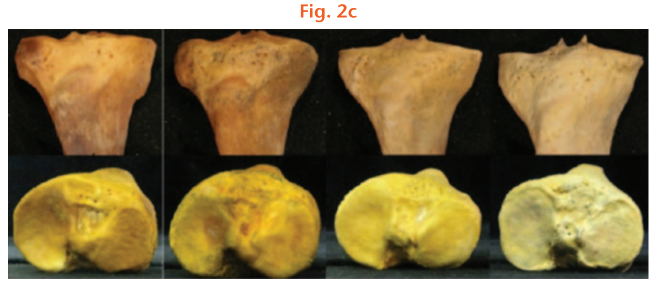

Fig. 2d

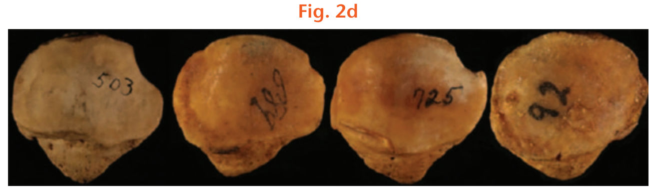

Fig. 2e

Photographs showing examples of a) acetabulum specimens (the increase in osteophytic lipping is clearly demonstrated in these images, while more subtle signs are better appreciated on actual specimens); b) proximal femoral specimens; c) distal femoral specimens; d) proximal tibial specimens and e) patellar specimens - all arthritis grades range from zero to three.

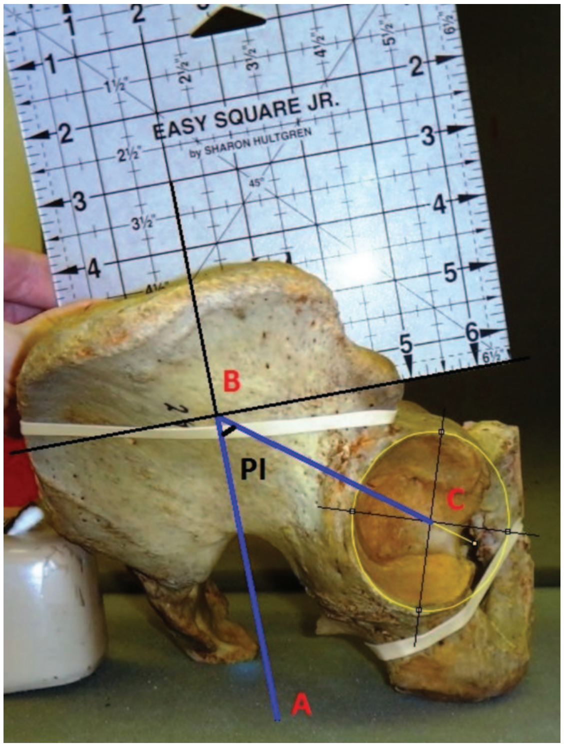

Fig. 3

Photograph showing a specimen of the measurement of pelvic incidence. Point B represents the centre of the sacral endplate. Point C represents the centre of the acetabulum measured from a direct lateral view of the pelvis. Angle ABC represents pelvic incidence.

Table II. Reliability for grading arthritis, assessed with Cohen's Kappa.

	Inter-relator reliability	Intra-relator reliability
Patella	0.88	0.93
Femoral trochlea	0.71	0.75
Medial femoral condyle	0.66	0.66
Lateral femoral condyle	0.85	0.84
Lateral tibial joint surface	0.66	0.88
Medial tibial joint surface	0.60	0.82
Proximal femur	0.60	0.66
Acetabulum	0.65	0.83

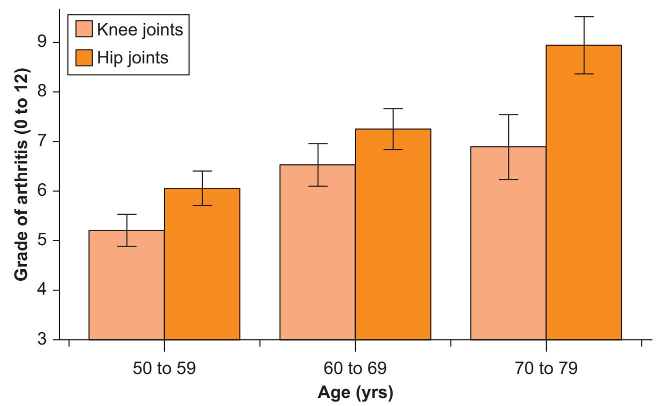

Fig. 4

Graph showing the mean and two standard errors for arthritis grading of the knee and hip at ten-year intervals, confirming a strong linear correlation between age and arthritis.

The mean PI was 46.7° (SD 10.7°; 11.5° to 78.1°). The interobserver ICC and intra-observer ICC were both > 0.99 for measurement of PI. The mean values for grading arthritis for the study sample were 6.9 (SD 2.6; 0 to 12) for HOA and 5.9 (SD 2.5; 0 to 12) for KOA. For specimen grading, a reliability analysis was performed comparing 20 skeletons. All fell within good (0.60 to 0.79) or excellent (0.81 to 0.99) agreement for categorical variables (Table II).[21] Arthritis increased linearly with age at both joints (Fig. 4).

There was a clear correlation between increased PI and HOA (standardised beta (StdB) = 0.103, p = 0.017). Our analysis did not demonstrate any correlation between PI and KOA (p = 0.912). Further analysis showed a clear correlation between PI greater than our sample mean and HOA (StdB = 0.057, p = 0.038). Our analysis did not demonstrate any correlation between PI less than (p = 0.683) or greater than (p = 0.422) our cohort mean and KOA or PI less than our mean and HOA (p = 0.753). There was a strong correlation between age and arthritis of both the hip joint (StdB = 0.530, p < 0.0005), and knee joint (StdB = 0.480, p < 0.0005). Multiple regression analysis results are listed in Tables III and IV.

Discussion

The aetiology of primary HOA is a multifactorial process that has been studied in detail for many years and likely involves a host of factors. Mechanisms such as posture, sagittal alignment and orientation of the hips and the spinal column, and the relationship between these factors have been implicated in the development of spine pathology, but, with only a few exceptions, ignored with regard to HOA and other diseases of the hip.[4-6] To our knowledge, only two published studies have assessed the relationship between PI and the development of HOA. Yoshimoto et al[4] found that in patients with HOA, PI is significantly higher and concluded that patients with higher PIs are at higher risk for developing HOA later in life. However, this study included only patients with known low back pain as a HOA-free control group, and it was later contradicted by data showing no significant difference between the PI values of moderate-to-severe and absent HOA groups in pelvis CT scans.[22] Raphael et al[22] concluded that HOA is not associated with PI angle. We therefore assessed whether an increased PI truly correlated with higher rates of HOA and KOA.

Legaye et al[10] first described pelvic incidence in 1998 as the angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the axis of the femoral heads. It is easily obtained from lateral radiographs of the lumbosacral spine. The PI is considered as a specific morphological parameter for each individual since it does not change with position, e.g. standing or supine.[23] This is attributed to the fact that the

Table III. Results of multiple regression analysis.

	Age		Pelvic incidence	
	Standardised Beta	**Unstandardised Beta (95% CI)**	**Standardised Beta**	**Unstandardised Beta (95% CI)**
HOA	0.530	0.093 (0.078 to 0.108)*	0.103	0.029 (0.007 to 0.050)†
KOA	0.480	0.076 (0.061 to 0.092)*	0.003	0.001 (–0.021 to 0.023)‡

*p < 0.0005
†p = 0.017
‡p = 0.912,
CI, confidence interval; HOA, hip osteoarthritis; KOA, knee osteoarthritis

Table IV. Results of multiple regression analysis: high *versus* low pelvic incidence (PI).

	Age		Pelvic incidence	
	Standardised beta	**Unstandardised beta (95% CI)**	**Standardised beta**	**Unstandardised beta (95% CI)**
HOA, Low PI	0.403	0.117 (0.071 to 0.163)*	–0.032	–0.012 (–0.066 to 0.041)
KOA, Low PI	0.427	0.124 (0.071 to 0.177)*	0.032	0.012 (–0.041 to 0.065)
HOA, High PI	0.441	0.142 (0.100 to 0.187)*	0.136	0.057 (0.003 to 0.111)†
KOA, High PI	0.341	0.052 (0.031 to 0.71)*	0.006	0.002 (–0.051 to 0.056)

Low pelvic incidence (PI), PI < cohort mean of 46.7; High PI, PI > cohort mean of 46.7
*p < 0.0005
†p = 0.038. p > 0.05 for PI *versus* "HOA, Low PI," "KOA, Low PI," KOA, High PI"
CI, confidence interval; HOA, hip osteoarthritis; KOA, knee osteoarthritis

sacrum does not move within the rigid pelvic ring, but rotates around the bicoxofemoral axis as a whole unit.[24,25] PI has been shown to increase until the age of ten and then stabilise throughout the remainder of adulthood,[11,12] and it does not vary between genders.[13,14] The mean PI value obtained in our current study, 46.7° (SD 10.7°), is comparable with large sample-sized studies examining this parameter. Legaye[26] found a PI of 49.6° (SD 10.4°) in a sample of 66 normal subjects, and Mac-Thiong et al[11] found a PI of 49.3° (SD 11.2°) in a sample of 145 subjects that were also normal. With this in mind, our highly controlled laboratory setup allowed for the precise standardised positioning and measuring of pelvises, and such control is often not possible in a clinical setting. The relative scarcity of research studies on PI angle in relation to the hip joint is presumably secondary to the fact that PI is easily measured on a lateral view of the spine, but not conveniently captured in routine pelvis and hip imaging.

In elevated PI, theoretic lumbar lordosis is elevated, and the femoral heads are projected forward with respect to the sacrum.[27,28] In attempts to "spare" the lumbar spine from the mechanical stresses of increased lumbar lordosis, while at the same time maintaining sagittal balance, posterior pelvic tilt can be associated with increasing PI.[4] This posterior tilt of the pelvis results in decreased apparent femoral head coverage[29-31] by creating a more vertical articular surface of the acetabulum.[5] Tsuchie et al[32] report a case of non-traumatic anterior subluxation of bilateral femurs in a patient with severe compensatory posterior pelvic tilt. This anterior uncovering of the anterosuperior aspect of the femoral head by the acetabulum may create a dysplastic hip (Fig. 5) and could potentially be an aetiological factor in the development of HOA.

Acetabular dysplasia, a term that suggests a smaller than normal acetabulum or one that is abnormally vertical, has been strongly linked to the development of HOA over the last 90 years and is the most common cause of secondary HOA.[33] A maloriented, steeper than normal acetabulum creates more shear than normal at the femoral-acetabular interface and acetabular rim complex, and results in elevated joint contact pressures.[34-36] When that load/shear reaches a critical level, articular cartilage will fail, leading to osteoarthritis. This critical level may differ between individuals based on their biology and their lifestyle, but at some level of dysplasia, the altered load bearing surfaces lead to increased and unusual wear, and cause hips to fail. The mechanics of these situations have been well described by Pauwels and colleagues.[37-41] Since Gunnar Wiberg postulated his 1939 thesis, "Studies on Dysplastic Acetabula and Congenital Subluxation of the Hip Joint with Special Reference to the Complication of Osteoarthritis," there has been an very little to contradict the hypothesis that patients with acetabular dysplasia often have labral tearing and cartilage degeneration at an early age, resulting in premature HOA.[42-45]

The role of the pelvic region in sagittal balance is obvious to spine surgeons, who take full account of sacral slope, PI, and pelvic tilt. Interpretation of spino-pelvic parameters is fundamental to the detection and analysis of sagittal imbalance, both compensated and non-compensated. In contrast, the role of the hip joint and of its inter-relations with the lower-limb posture as a whole, remains underestimated and poorly determined. These factors can be neglected by hip surgeons, who focus on the pelvis as bone reference in implantation planning. The AP pelvis view is the benchmark, with lateral views of

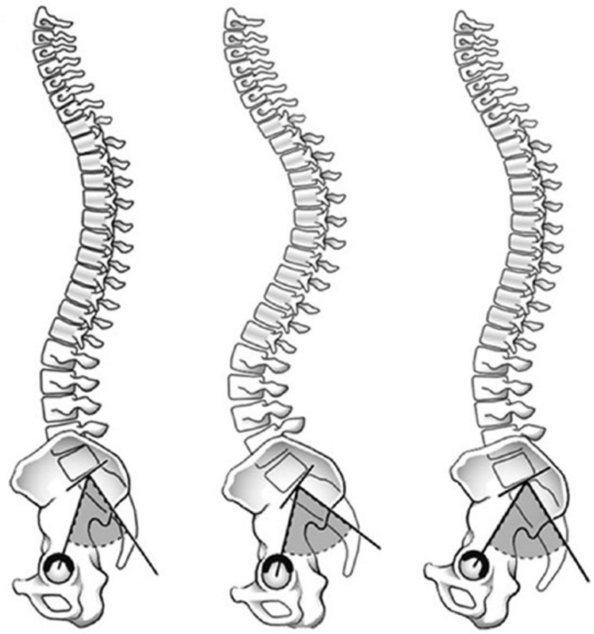

Fig. 5a Fig. 5b Fig. 5c

Images showing a) normal PI with normal lumbar lordosis; b) increased PI with compensatory increase in lumbar lordosis and c) increased PI with compensatory posterior pelvic tilt and undercovering of the hips.

the pelvic region often ignored. The present study draws attention to a more global vision of pelvic and subpelvic regions in the sagittal balance of the trunk.

Our findings have applicability to understanding the mechanical aetiology of HOA and suggest that a higher PI may contribute to this disease process. A greater understanding of the biomechanical adaptations that potentially occur as a result of increased PI also aid in surgical planning and technique for periacetabular osteotomy and reorientation procedures and total hip arthroplasty. In younger patients with excessive PI, bilateral pelvic osteotomies to reduce the PI or rotational acetabular osteotomy to improve the anterior coverage on the affected side might be a worthwhile consideration, with the aim of preventing or delaying the development of secondary OA.[4,46]

There were several limitations to this study. The skeletons that were used for analysis were collected from mostly low-income individuals of the early 20th century, and their lifestyles may not represent a contemporary patient. Although some clinical data on each patient exist, there is insufficient detail to comment on whether each patient had any symptomatology in their hips or knees. Furthermore, this is an anatomic study on dried, preserved osteological specimens, and does not take into account the soft tissue or cartilaginous components of the pelvis and hip and knee joints. Since cartilage surfaces were not maintained in the preservation process of these skeletons, our grading system defined very specific incremental increases in osteophyte formation and other bony findings. This allowed us to demonstrate a strong linear correlation between age and arthritis grading at each site, as supported by the high standardised beta values in Tables II and III. This confirmation of the expected relationship between age and arthritis, in addition to the "good" and "excellent" inter- and intra-observer reliability, strongly supports the validity of our grading system.[22] Additionally, this study had a relatively larger amount of males as well as Caucasians, a similar problem found in previous experiments using the Hamann-Todd Osteological Collection, which is known to be heavily biased with Caucasian male cadavers. The gender ratios in this study are similar to that of the collection as a whole, as was necessary to preserve the integrity of the randomly chosen sample, and as previously noted, PI measurements do not vary between genders. Finally, our study demonstrates a significant relationship between increased PI and the presence of HOA, but we are unable to directly define a specific cause and effect of these two parameters. Within our study limitations, we are confident that our measurements were accurate and repeatable, and that we have identified a true difference in anatomy between the groups we identified.

In summary, this large anatomical study of a random population of normal subjects examines the role of PI, a position-independent anatomical parameter of the pelvis that regulates lumbar lordosis and sagittal alignment, in the development of hip and knee OA. Our findings suggest that higher PI in the younger individual, and the biomechanical adaptations that result, may contribute to the development of HOA in later life. Our results also showed that while high PI may have detrimental effects at the level of the hip joint, low PI is not necessarily protective of the development of HOA. These adaptations that occur at the level of the pelvis were not associated with the development of OA further "downstream" at the level of the knee joint. More investigation will be expected to analyse the role spinopelvic alignment plays in the development of HOA.

Supplementary material

Scatter plots showing PI *vs* arthritis grade are available alongside the online version of this article at www.bjr.boneandjoint.org.uk

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