Original Research Article

HIP | HIP International

HIP International
1–7

DOI: 10.1177/11207000221145670
journals.sagepub.com/home/hpi
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Unravelling the hip-spine dilemma from the CHECK-cohort: Is sagittal pelvic morphology linked to radiographic signs of femoroacetabular impingement?

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Abstract

Introduction: To date the aetiology of femoroacetabular impingement (FAI) is still not completely understood. There are mechanical theories that suggest symptomatic FAI is linked to sagittal pelvic morphology and spinopelvic-femoral dynamics. The aim of this study is to evaluate the relation of sagittal pelvic morphology and orientation to radiographic signs of FAI. Additionally, we test whether the relation between FAI and spinopelvic parameters differs in osteoarthritic hips.

Methods: From a prospective, observational cohort study, 1002 patients between 45 and 65 years old with a first episode of knee or hip pain were followed for 8 years. All patients who had lateral lumbar radiographs and clinical and radiographic follow-up of the hips were included in the present study. Range of internal rotation of the hip as well as radiographic signs of FAI (alpha and Wiberg angle) and presence of hip osteoarthritis (Kellgren and Lawrence) were systematically measured at baseline. Pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS)) were measured at 8-year follow-up. Associations between PI, PT, SS and FAI parameters were tested using generalised estimating equations.

Results: 421 subjects, 842 hips, were included. No significant relations between PI, PT or SS and alpha or Wiberg angle were found. Comparison of hips with and without radiological sign(s) of FAI showed no differences in PI, PT or SS. There was no relation between range of internal rotation of the hip and spinopelvic parameters.

Conclusion: Sagittal pelvic morphology and orientation are not related to the presence of radiological signs of FAI in this study population.

Keywords

FAI, femoroacetabular impingement, pelvic incidence, pelvic morphology

Date received: 8 December 2021; accepted; 4 November 2022

Introduction

Femoroacetabular impingement (FAI) is a well-known cause of hip pain in young adults and is strongly related to the development of hip osteoarthritis (OA).[1,2] It is believed to originate from pathologic contact between skeletal prominences of the proximal femur and the acetabular rim or labrum, due mostly to flexion, adduction and/or internal rotation. Based on the radiographic signs of FAI, the patho-anatomy can be divided into 3 types: cam, pincer or combined impingement. Cam deformities are characterised by aspherical deformation of the antero-lateral caput-column junction that mostly develops in young men who practice contact sports during adolescence, like rugby, soccer or

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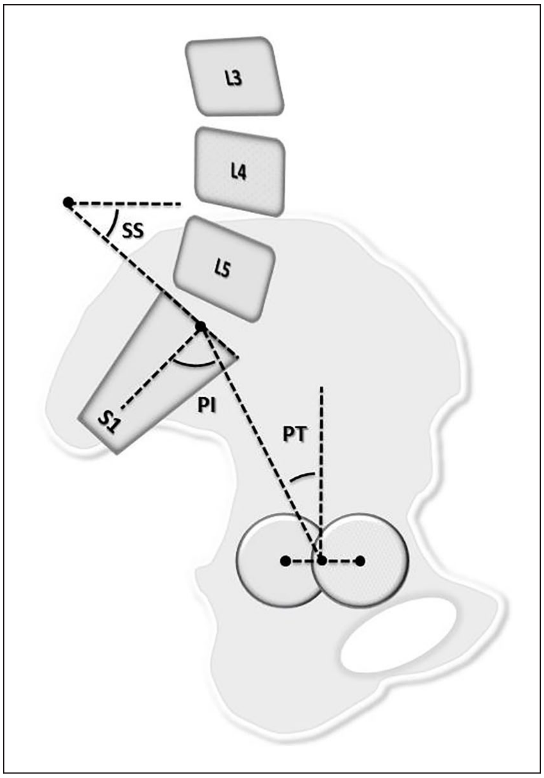

Figure 1. Schematic demonstration of pelvic incidence (PI), pelvic tilt (PT) and sacral slope (SS).

hockey,[3,4] which can result later on in a symptomatic FAI. Pincer-type deformities are characterised by focal or general over-coverage of the femoral head and is frequently symptomatic in woman in their 40s.[5]

Recent evidence demonstrates that the likelihood of cartilage or labral damage in FAI is related to the shape and orientation of the pelvis, and the individual's spinopelvic-femoral dynamics.[6–8] Duval-Beaupère et al.[9] introduced "pelvic incidence" (PI) as a key parameter for sagittal pelvic morphology, and pelvic tilt (PT) and sacral slope (SS) for pelvic orientation (Figure 1). PI varies enormously within the human population (33–85°) and is highly related to one's sagittal pelvic orientation.[10] Pelvic incidence remains stable after adolescence.[10] Via anterior and posterior PT around the hips, the pelvis plays a fundamental role in regulating sagittal spinopelvic femoral alignment and in the onset of the most common lumbar degenerative pathologies.[11,12] Patients with relatively low PI or with lumbar degeneration have limited posterior PT when changing from standing to sitting position and often have flattened lordosis.[13] Anteroposterior pelvic rotations around the hip axis will have important consequences for the biomechanical loading and range of motion of the hips. Low PI and PT limits the anterior 'opening' of the acetabular cavities when changing from standing to sitting, with a higher likelihood of impingement. Recently, this hypothesis has been confirmed in 2 cross-sectional studies that compared the PI of symptomatic FAI patients with an asymptomatic control group.[14,15] They reported that PI is on average 4–6° lower in symptomatic FAI patients compared to asymptomatic controls.[14,15] However, no large-scale prospective cohort study has explored the relation between sagittal pelvic parameters, hip range of motion and the presence of radiological signs of FAI and/or development of hip OA.

The aim of this study was to evaluate the relation between sagittal pelvic morphology and radiographic signs of FAI and range of internal rotation. Additionally, we tested whether the relation between FAI and spinopelvic parameters differs in osteoarthritic hips. The hypothesis of this study is that radiographic signs of FAI are more prevalent in individuals with low PI.

Methods

Study population

For this study, all patients in the CHECK-database with pelvic and lateral lumbar radiographs and complete 8-year follow-up were included. CHECK (Cohort Hip and Cohort Knee) is a multicentre, population based, prospective observational cohort study, initiated by the Dutch Arthritis Foundation. In the database are 1002 patients, between 45 and 65 years old, who presented themselves within 6 months after a first episode of pain of the hip or knee. They were clinically and radiographically followed every year for 10 years.[16] Patients with previous hip or knee surgery, rheumatic diseases, treatment for developmental dysplasia of the hip, osteochondritis dissecans, intra-articular fractures, Perthes' disease, traumatic ligament or meniscus damage, plica syndrome or a Bakers cyst were excluded in the original study. For this study, we also excluded patients in whom pelvic or lateral lumbar radiographs did not include the full pelvis or femoral heads. CHECK was approved by the medical ethics committee and all participants provided informed consent before inclusion in the study.

Radiographic analyses

According to protocol, lateral standing spinal radiographs were obtained at 8-year follow-up. These were used to measure PI and PT and SS.[17] Upright anteroposterior pelvic radiographs collected at baseline were used in this study to assess the presence of a cam deformity (alpha angle >60°) or pincer deformity (Wiberg angle >40°) and presence of hip OA of both hips.[18]

We used a semi-automatic approach to annotate anatomic landmarks to determine the alpha and Wiberg angles from AP pelvic radiographs. First, we used the automatic search algorithm as described in an article by Gielis et al.,[19] which places >100 points on landmarks of

AP pelvis x-rays. Gielis et al.[19] tested the automatically produced data in a prediction model, which proved to be accurate with an area under the curve of 0.86 compared to 0.86 for manual data. Thereafter, an orthopaedic resident with 5 years' experience approved and optimised the annotations around the head-neck junction and acetabulum. These annotations were used in formulae, equal to the definitions described in the methods section. Subsequently, they were entered into the Python 3.6 tool to produce the required angles as described.

The following hip parameters were measured:

- Alpha angle
- Wiberg angle

The alpha angle is the angle between a centred line through the femoral shaft axis and a line from the centre of the femoral head to the point where the femoral head becomes aspheric.[18,20,21] The Wiberg angle is the angle between a perpendicular line between both femoral heads and a line between the centre of the femoral head and the lateral acetabular border.[21] Presence of hip OA was classified according to Kellgren and Lawrence (KL) for previous projects, by 5 observers with an intra-class correlation coefficient (ICC) for inter-observer reliability of >0.9.[22,23]

Clinical parameters

At baseline, all individuals underwent clinical assessment by a trained health professional. The clinical parameters used for this study were the range of internal rotation of the left and right hip at 90° flexion.

Statistical analysis

Data were processed and analysed using Microsoft Excel 2010 and IBM SPSS 23. PI, PT and SS were used as independent variables. The outcome variables were alpha angle, Wiberg angle and internal hip rotation. Sub-analyses were performed based on the presence of hip OA, with subjects divided into 2 groups, and which was defined as KL >1.

The alpha angle showed a strong bimodal distribution and was therefore dichotomised according to the literature (<60°/⩾60°).[18] The Wiberg angle and internal hip rotation were analysed continuously. The association between PI and the alpha angle, Wiberg angle, and internal hip rotation was tested using generalised estimating equations for logistic or linear regression. This method accounts for the correlation between both hips within each patient. Additionally, the effect of SS and PT on the alpha angle, Wiberg angle and internal hip rotation were tested in separate models. All analyses were also corrected for age and sex, to prevent confounding factors. An α of 0.05 was used to test for statistical significance.

Table 1. Prevalence of radiological signs of femoroacetabular impingement and hip osteoarthritis and pelvic parameters in the study population.

		$n = 842$ hips
Hip osteoarthritis	KL < 2	89%
	KL ⩾ 2	11%
Alpha angle		54 ± 23
	<60°	80%
	⩾60°	20%
Wiberg angle		36 ± 7
	<40°	70%
	⩾40°	30%
Hip internal rotation		31 ± 8
Pelvic incidence		58 ± 13
Pelvic tilt		25 ± 11
Sacral slope		34 ± 11
Lumbar lordosis		42 ± 13

KL, Kellgren and Lawrence.
Data are presented as mean ± SD(°), except for hip osteoarthritis.

Results

In CHECK, 1002 subjects were included. After 8 years, clinical data and radiographs of the hip were available for 845 participants (84%); 157 were lost to follow-up. For 421 participants, 842 hips, an appropriate spinal and pelvic radiograph was available for measurement of the PI, PT, SS and FAI parameters and these were included in the present study. For the majority of the excluded subjects, the lateral lumbar spinal radiographs did not include the femoral heads, making PI and PT measurement impossible. 308 (73%) of the included subjects were female. The mean age of the participants was 56 ± 5 years, mean BMI was 27 ± 4. 409 (97%) were Caucasian. Spinopelvic parameters are shown in Table 1.

Pelvic parameters versus alpha and Wiberg

Analyses between pelvic parameters and the radiographic signs of FAI (alpha angle and Wiberg angle) showed no statistically significant correlation (Table 2) (Figures 2 and 3).

Pelvic parameters versus hip internal rotation

Analyses between pelvic parameters and hip internal rotation showed no correlation between pelvic parameters and internal hip rotation (Table 2).

Pelvic parameters in FAI

The pelvic parameters of patients with or without radiological signs of FAI are shown in Tables 3 and 4. No correlation was found between pelvic parameters and radiological signs of FAI.

Table 2. Relation between pelvic parameters and femoro-acetabular impingement and internal hip rotation.

	B	p	95% CI
Alpha angle*			
Pelvic incidence	0.996	0.680	0.975 – 1.017
Pelvic tilt	0.997	0.840	0.972 – 1.023
Sacral slope	0.999	0.930	0.972 – 1.026
Wiberg angle			
Pelvic incidence	−0.023	0.455	−0.085 – 0.038
Pelvic tilt	−0.023	0.579	−0.105 – 0.059
Sacral slope	−0.026	0.459	−0.094 – 0.043
Hip internal rotation			
Pelvic incidence	0.047	0.067	−0.003 – 0.097
Pelvic tilt	0.051	0.088	−0.008 – 0.110
Sacral slope	0.038	0.253	−0.027 – 0.104

B, unstandardised coefficient; CI, confidence interval.
*Odds ratio instead of coefficient due to logistic regression analysis.

Pelvic parameters in relation to hip OA

94 (11%) hips had radiological evidence of hip OA (KL ⩾2). Comparisons of the pelvic parameters between subjects with and without OA and radiological signs of FAI are shown in Table 4; no differences in prevalence in hip OA or FAI were found between groups.

Discussion

The role of sagittal pelvic morphology and orientation on the development of FAI was systematically studied in a cohort of patients between 45 and 65 years old who presented themselves with pain of the hip or knee. Interestingly, in contrast to previous case-control studies on symptomatic FAI patients, we found no correlation between radiological signs of FAI and sagittal pelvic parameters in this cohort. Furthermore, we found no relation between range of internal hip rotation and sagittal pelvic parameters. These results suggest that in our cohort, there is limited aetiological relevance of sagittal pelvic morphology in the development of a symptomatic cam deformity or pincer lesion. The hypothesis of our study is thus rejected; we did not find any relation in our cohort between pelvic morphology and radiographic signs of FAI or internal hip rotation.

The patho-mechanism of symptomatic FAI is multifactorial and has not been completely clarified.[24] Acquired causes as well as genetic predisposition have been implicated in its aetiology.[25] Most of the research on FAI aetio-pathogenesis has been on femoral head-neck deformity, acetabular coverage and mechanical impingement. Acquired factors involved in the development of cam-type deformities are repetitive injury of the physis of the femoral head during adolescence. This is supported by the high incidence of cam-type deformities in adolescents participating in high intensity and frequency sports such as soccer, skiing and ice-hockey.[4,26,27] From a genetic perspective, acetabular over coverage has been associated with certain genotypes. This may also represent the genetic inheritability of certain sagittal spinopelvic alignment.[28]

The pelvis is a key regulator of the sagittal configuration of the spine through anterior and posterior pelvic tilt.[11,29,30] Variation in sagittal pelvic morphology and orientation relative to the femoral heads impacts mechanical loading of both spinopelvic configuration and hip joints. Patients with a low PI, as well as patients with degenerative pelvic disorders, have less ability to retrovert the pelvis when changing from standing to sitting. It can be inferred that in these patients the hip joints are loaded more towards their limit of extension in the standing position. The relative anterior over-coverage of the acetabulum could pose higher joint-reaction forces on the cranial and anterior labrum as well as cause anterior impingement.

In a study of 20 individuals, symptomatic FAI patients used more hip flexion, in a sitting position, due to their lack of compensation in the lumbar spine, compared to controls.[31] More anterior pelvic tilt is required then, which may lead to impingement between the acetabulum and proximal femur. The asymptomatic individuals with radiological signs of FAI, had a higher ability of spine flexion, but similar hip flexion, thus more mechanisms for compensation.[25,31] Femoral retroversion could theoretically contribute to the development of symptomatic FAI as well, since the anterior neck of a retroverted hip easily collides with the acetabulum labrum at slight degrees of internal rotation. Also, functionally, the Wiberg angle will change when the pelvis tilts from a standing to a sitting position.[32]

Studies on sagittal spinopelvic alignment in FAI patients have shown that FAI is more prevalent in individuals with a low PI/SS. This led to the hypothesis that FAI is a result of different mechanical loading on lumbosacral junctions.[7,8,14] In a study by Weinberg et al.,[33] a lower PI was found in patients with symptomatic mixed-type FAI compared to a non FAI control group ($p=0.01$). Patients with only a cam- or pincer- type, had a non-statistically significant different PI compared to the controls. Recently a retrospective cohort study of 40 patients with symptomatic FAI found a significantly lower PI compared to asymptomatic subjects.[14] 2 other recent cohort studies have studied the pelvic morphology parameter PI in FAI: Lerch et al.[34] described a mean PI of 51° in 32 symptomatic FAI patients. Interestingly, Yin et al.[35] also observed a lower PI and PT in patients who experienced pain in the sitting position in comparison to FAI patients without pain in the sitting position (50.1° and 44.2°, $p=0.042$). Their results suggest that sagittal pelvic-femoral kinematics should be explored to understand the influence of pelvic dynamics on the aetiology and symptomology of FAI.

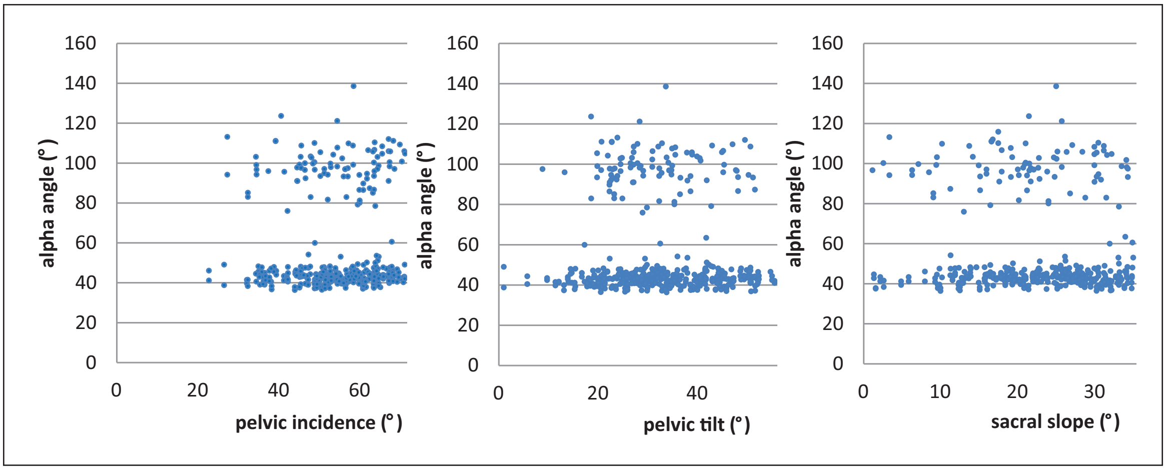

Figure 2. (a) Pelvic incidence versus alpha angle, (b) pelvic tilt versus alpha angle, and (c) sacral slope versus alpha angle.

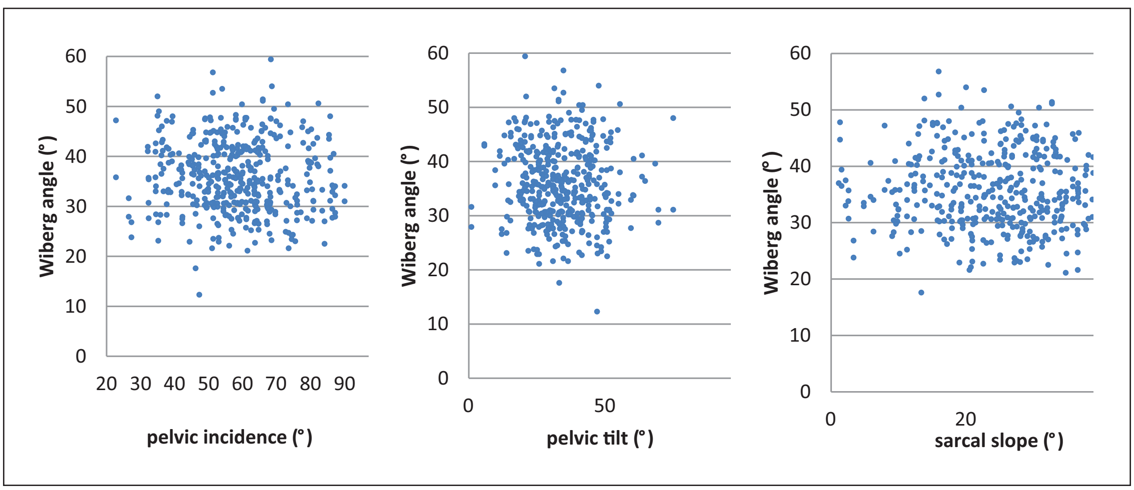

Figure 3. (a) Pelvic incidence versus Wiberg angle, (b) pelvic tilt versus Wiberg angle, and (c) sacral slope versus Wiberg angle.

They stated that a lower PI and insufficient PT during the process of sitting down could be related to the pain experienced by patients with symptomatic cam-type FAI.[35]

Our study confirms the high prevalence of radiographic signs of FAI (cam and pincer) in the population, rather than the theory that these signs are a result of developing, symptomatic FAI. In comparison, a systematic review demonstrated a prevalence of 5–75%, varying across 30 studies.[36] This review was unable to demonstrate a higher prevalence in certain sub-groups, such as athletes or patients with hip pain. This indicates that radiographic signs of FAI often occur in asymptomatic individuals, so possibly other factors (such as certain acetabular/proximal femoral morphology, activities/sports or developmental axial rotational deformity of the lower limb) are required to develop symptomatic FAI.

Variations in spinopelvic dynamics between subjects with radiographic signs of FAI may lead to symptoms of FAI.[25] It can be stated that a cam lesion, combined with a low PI, might result in symptomatic FAI. In summary, the relation between pelvic parameters and FAI is still unclear. The evidence is controversial, as it is not clear at which moment, or for what reason, the radiographic signs of FAI become symptomatic, or the role of pelvic-femoral kinematics in this.

Recently, the possible relation between pelvic morphology and hip OA was explored in the same cohort.[12] There was a trend towards lower PI (and PT) in patients with significant hip OA;[12] a higher prevalence of FAI in subjects with a low PI might explain this phenomenon. Pelvises with low PI, may cause increased force on the anterior labrum of the hip during hip flexion, which causes FAI to develop during adolescence, resulting in early OA of the hip. In our study we did not found any difference between radiographic signs of FAI in subjects with hip OA (KL >1). This results in the rejection of our hypothesis; in

Table 3. Pelvic parameters for patients with or without a radiographic signs of femoroacetabular impingement (FAI), with exclusion of patients with significant hip osteoarthritis (OA) at baseline (Kellgren and Lawrence ⩾2), presented as mean ± SD(°).

	No FAI (*n* = 263)	Cam deformity only (*n* = 84)	Pincer deformity only (*n* = 114)	Mixed (*n* = 21)
Pelvic incidence	59.1 ± 13.7	56.0 ± 13.0	56.3 ± 13.4	61.7 ± 12.4
Pelvic tilt	25.7 ± 11.0	23.4 ± 10.6	23.9 ± 10.6	27.2 ± 9.6
Sacral slope	34.0 ± 11.2	33.3 ± 12.2	32.5 ± 12.3	35.5 ± 13.0

Table 4. Pelvic parameters for patients with or without hip osteoarthritis (OA) at baseline (Kellgren and Lawrence ⩾2) and a radiographic signs of femoroacetabular impingement (FAI), presented as mean ± SD(°).

	Hips without OA		*p*	Hips with OA		*p*
	FAI (*n* = 219)	No FAI (*n* = 263)		FAI (*n* = 57)	No FAI (*n* = 20)	
Pelvic incidence	56.7 ± 13.1	59.1 ± 13.7	0.153	59.3 ± 13.1	55.3 ± 10.0	0.340
Pelvic tilt	24.0 ± 10.5	25.7 ± 11.0	0.264	23.6 ± 11.9	23.4 ± 7.7	0.811
Sacral slope	33.1 ± 12.2	34.0 ± 11.2	0.432	36.0 ± 10.7	33.1 ± 11.6	0.369

this cohort, the early onset of hip OA is not related to the presence of radiographic signs of FAI. The early onset of hip OA in these individuals might be based on another underlying patho-mechanism.

This study has limitations. FADIR/FABER tests of the hip are tests to assess symptomatic FAI with reasonable diagnostic accuracy; however, they were not performed systematically. Internal hip rotation was assessed, which also has a high specificity for FAI of 94%.[37] We explored the relationship between decreased ROM of internal rotation (<20°), a typical finding in patients with FAI and PI (Table 2),[5,37] but there was no significant correlation. Another limitation is that lateral lumbar radiographs were only available at 8-year follow-up. Based on the literature, however, it can be assumed that the PI did not change in individuals during the study, since it remains constant after the adolescent growth spurt, which is the same period cam deformities develop.[3,10] Before inclusion, some patients may have already developed significant hip OA. Because the development of osteophytes might complicate measurements of the alpha angle and Wiberg angle, we chose to exclude patients with significant OA. This might have introduced selection bias.

In future studies, the relation between individual variance in pelvic morphology and the prevalence of (symptomatic) FAI should be explored further. To better understand the development of FAI, dynamic imaging might be required in individuals with different pelvic morphology, to study the 3D orientation between the pelvis and the proximal femoral in movements which might elicit FAI. Clinical findings of large prospective cohorts of patients should be combined with radiographic signs of FAI, in relation to pelvic parameters on radiographs, or more precise, computed tomography or magnetic resonance imaging.

Conclusion

In the present study, no evidence was found of a relation between pelvic parameters (PI, PT and SS) and femoroacetabular impingement of the cam-type FAI nor pincer. Sagittal pelvic morphology and orientation are not directly related to the presence of radiological signs of FAI, which has a high prevalence in the general population. No relation was found between pelvic parameters and internal hip rotation. However, individuals with low pelvic tilt may be more at risk for development of symptoms of FAI.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship and/or publication of this article.

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Supplemental material

Supplemental material for this article is available online.

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