Journal of Spine

Todd, et al., J Spine 2016, 5:4
DOI: 10.4172/2165-7939.1000326

Research Article | Open Access

Pelvic Retroversion is Associated with Flat Back and Cam Type Femoro-Acetabular Impingement in Young Elite Skiers

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Abstract

Introduction: The spino-pelvic complex in humans helps to maintain an upright posture, by balancing the spinal sagittal alignment with the hip joints and pelvic girdle. The extent of how the hip joint may influence the spino-pelvic alignment is not fully understood. Hip joint cam femoro-acetabular impingement is a common source of hip and groin disability in young athletes and has been linked to abnormal joint morphology from repetitive loading of the proximal femoral head abutting against the acetabulum. The aim of this study was to compare the radiological parameters of spino-pelvic sagittal alignment and spinal types according to Roussouly's classification in relation to hip joint cam femoro-acetabular impingement.

Methods: The sample group (*n*=102), mean age (17.7 ± 1.4) years, consisted of elite skiers (*n*=75) and non-athletes (*n*=27). Hip joints were examined for increased morphological cam deformity, (alpha angle greater than 55°) with Magnetic Resonance Imaging and standing lateral plain radiographs were taken for measurements of the spino-pelvic sagittal alignment.

Results: A significant difference was shown in a mixed population (skiers and non-athletes) for an increased Pelvic Tilt angle (13°, SD 10.2) in the presence of morphological hip joint cam deformity compared with participants without cam deformity (8.5°, SD 7.1, P=0.036). Type II Roussouly spines occurred more frequently in skiers in the presence of increased cam (67%) compared with no cam (33%), however, this was not significant (P=0.19). Secondary findings highlighted significant differences shown for the prevalence of cam in a mixed-population for gender; males 60% (*n*=26) shown to have significantly more cam deformity compared with females 22% (*n*=10, P=0.001). Similar for height, with taller participants being shown to have significantly more cam deformity >177cm (SD 7.6) compared with no cam deformity <170 cm (SD 7.5, P=0.001).

Conclusion: A significant difference was shown with an increased Pelvic Tilt angle for an age-matched mixed-group of elite skiers and non-athletes in the presence of increased morphological hip joint cam type femoro-acetabular impingement. Moreover, Elite skiers were shown to have an increased distribution of spinal Type II classification according to Roussouly in the presence of an increased frequency of cam femoro-acetabular impingement.

Keywords: Hip joint cam FAI; Radiological; Skiers; Spinal curvatures; Spino-pelvic parameters

Abbreviations: CT: Computerized Tomography, FAI: Femoro-acetabular Impingement, LBP: Low Back Pain, LL: Lumbar Lordosis, MRI: Magnetic Resonance Imaging, PI: Pelvic Incidence, PT: Pelvic Tilt, SS: Sacral Slope, SVA: Sagittal Vertical Axis, SD: Standard Deviation, TK: Thoracic Kyphosis

Introduction

The spino-pelvic complex in humans helps to maintain an upright posture, by balancing the interaction of spinal sagittal alignment with the hip joints and pelvic girdle [1-7]. Previous studies have used plain radiographs to evaluate the spino-pelvic sagittal alignment within an asymptomatic and sporting population [1,4,6,8-21]. Moreover, it has been suggested that the evaluation of spino-pelvic alignment is useful for determining the characteristics of the spinal curvatures, pelvic parameters and global spinal orientation [20]. The angle of Pelvic Incidence (PI), Sacral Slope (SS) and Pelvic Tilt (PT) are essential anatomical pelvic parameters (Figure 1) that can be used as a means to classify both the morphology and functionality of the pelvis [2]. Four types of spinal curvatures correlating to the angle of the sacral slope (Figure 2) were defined according to Roussouly et al. [22]. Types I and II generally being more associated with a low PI (pelvic retroversion and reduced lumbar lordosis) as Types III and IV have a high PI (pelvic anteversion and increased lumbar lordosis).

Moreover, it has been shown with radiological methods that Type I and II spinal classifications according to Roussouly et al. [22] appears to be more prevalent within the sporting population [21]. Spinal pathologies have also been shown to correlate with Type I, II, IV spinal types [4], with an increased risk of disc degeneration in Type I, central disc herniation in Type II, a well-balanced spine in Type III and an increased risk of spondylolisthesis in Type IV [23-25]. Moreover, Roussouly et al. [4] suggest that, to maintain such a balanced upright spine, rotation of the pelvis around the femoral head must occur. Therefore, in the presence of hip joint hypomobility, the spino-pelvic alignment may change.

Hip joint cam Femoro-acetabular impingement (FAI) has emerged as one of the most common causes of hip and groin disability in recent

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Received July 27, 2016; **Accepted** August 03, 2016; **Published** August 05, 2016

Citation: Todd C, Thoreson O, Swärd L, Karlsson J, Baranto A, et al. (2016) Pelvic Retroversion is Associated with Flat Back and Cam Type Femoro-Acetabular Impingement in Young Elite Skiers. J Spine 5: 326. doi:10.4172/2165-7939.1000326

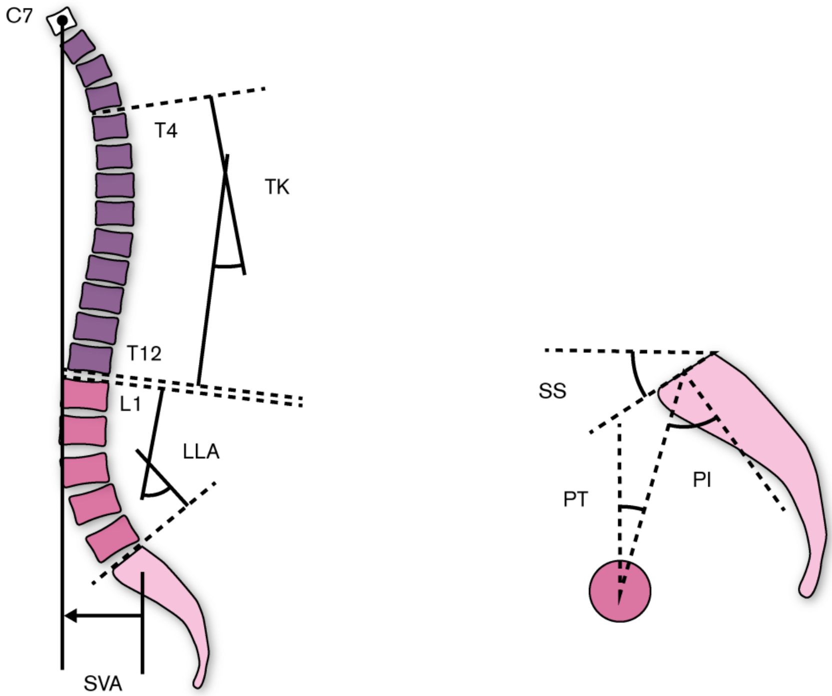

Figure 1: Relationship between spinal curves, pelvic parameters and global balance adapted from Roussouly et al. [22].

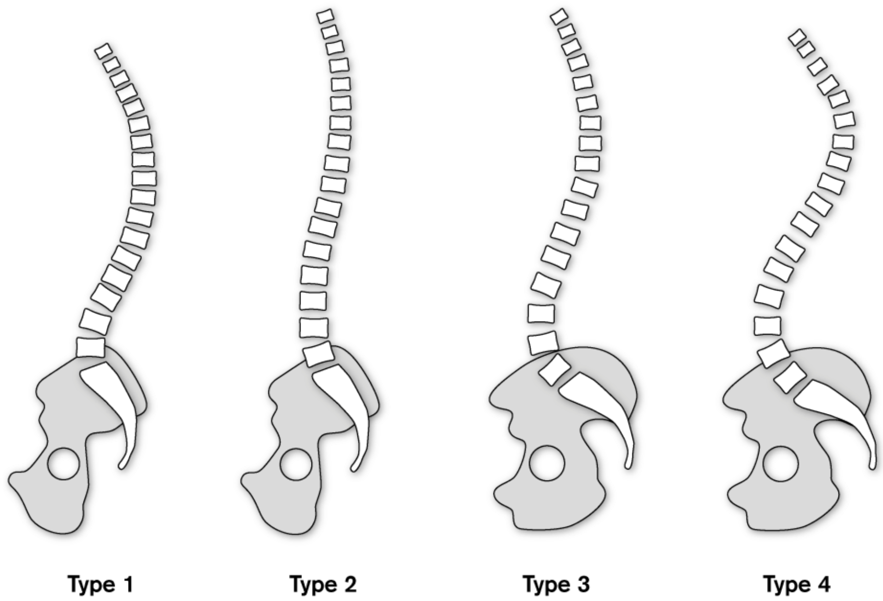

Figure 2: Spinal curvatures adapted from Roussouly et al. [22]. **Type I:** Low sacral slope <35° and a low PI with a long thoracolumbar curve and short lordotic curve resulting in a thoracic/lordosis ratio of 80:20. **Type II:** Low sacral slope <35° and a low PI with a shorter kyphotic curve and a longer lordotic curve resulting in a thoracic/lordosis ratio of 60:40. **Type III:** High sacral slope >35° and <45° and a greater PI. The kyphotic and lordotic curvatures result in an equal thoracolumbar curve with a ratio of 50:50. **Type IV:** High sacral slope >45° and a high PI with a reversed thoracolumbar curve resulting in a long lordotic curve and short kyphotic curve with a ratio of 20:80.

years. FAI is common in young athletes [26], has been shown to result in suboptimal hip function [27], affect spino-pelvic motion [28] and has been linked to abnormal joint morphology from repetitive loading of the proximal femoral head abutting against the acetabulum [29-36]. Diagnosis of FAI is based upon clinical history, physical examination and investigations using plain radiographs, Computerized Tomography (CT) and Magnetic Resonance Imaging (MRI) [27]. Measurement of the alpha angle (Figure 3) is used to determine the prominence of the anterior femoral head-neck junction [27]. The extent of how increased hip joint cam deformities may influence spino-pelvic alignment is not fully understood, e.g. does the hip joint effect the spino-pelvic alignment or vice-versa? Moreover, it may be possible that if, specific spino-pelvic parameters or Roussouly Type spines were found to be more common in the presence of cam FAI, then this may have an impact on treatment options. Therefore, it would appear reasonable to investigate changes to the values of spino-pelvic sagittal alignment in the presence of increased morphological characteristics of hip joint FAI.

The purposes of the present study are to investigate with plain radiography and MRI (1) The spino-pelvic sagittal alignment and the prevalence of Roussouly type spines in the presence of increased MRI morphological characteristics of hip joint cam deformity within the whole study group. (2) The spino-pelvic sagittal alignment and the prevalence of Roussouly type spines in the presence of increased MRI morphological characteristics of hip joint cam deformity in skiers. (3) The spino-pelvic sagittal alignment and the prevalence of Roussouly type spines in the presence of increased MRI morphological characteristics of hip joint cam deformity in non-athletes.

The hypotheses of the present study were that the spino-pelvic sagittal alignment would be different in those individuals with increased morphological characteristics of hip joint cam deformity; moreover, a greater prevalence of Types I and II Roussouly spines is found in those individuals with increased morphological characteristics of hip joint cam deformity. To our knowledge this is the first study of this type to carry out such an investigation.

Materials and Methods

Study subjects

The sample group (*n*=102) consisted of young athletic elite skiers (*n*=75) between 16-20 years of age and a non-athletic population (*n*=27) 16-17 years of age. The inclusion criteria for the skiers group were that they were recruited from the Åre High School Ski Academy, Sweden. Inclusion criteria for the control group was first year High School pupils from a class at a High School in Östersund, Sweden, that have not previously or at present do not participate in any organised sporting or physical activities for more than 2 hours per week.

All participants were invited to participate in this cohort study after a short oral presentation by two of the authors and they also received written information about the project. The radiographic and MRI examinations were taken at the Radiographic Department, Östersund Hospital, Sweden. Participants (skiers and non-athletes) were excluded if they had a history of previous surgery to the lumbar spine, pelvis or hip joint or a history of systemic pathology including inflammatory arthritis or pelvic inflammatory disorders and pregnancy. The demographic characteristics of the full sample are presented in Table 1.

The present study was approved by the Regional Ethical Review Board in Gothenburg, Gothenburg University, Gothenburg, Sweden (ID number: 692-13).

Testing procedure

Plain radiographic examination: For plain radiographic examinations, a standardized protocol was used for all participants [6]. Frontal and a lateral standing plain radiographs recorded from C7 to the femoral head were obtained for each participant (Figure 3). Participants were instructed to stand with the feet together in a natural upright posture, without spinal rotation, with arms hanging by their side for frontal views and arms horizontal resting on supports for sagittal views. The total measurement time was approximately 10 minutes. Automatic Exposure Control (AEC) was completed using a low dose and the edges of the images were enhanced to clearly distinguish vertebral bodies and endplates. Radiographic images were taken from the C7 vertebrae to the femoral head; these were overlapped and automatically stitched for ease of interpretation. Frontal view with posterior-anterior (PA) beam direction, the entire vertebral bodies and half the femoral head were imaged. Lateral view with the beam direction from right to left, the entire vertebral bodies and half the femoral head were imaged. The radiographs were measured for sagittal spinal curvatures by a single blinded experienced radiologist with the angular parameters reported in degrees. A negative value (-) represented a lordotic alignment whilst a positive value (+) represented a kyphotic alignment. Geometrical measurements relating to spinal curvatures were obtained from the following; thoracic kyphosis (TK) (Figure 1) as the angle measured

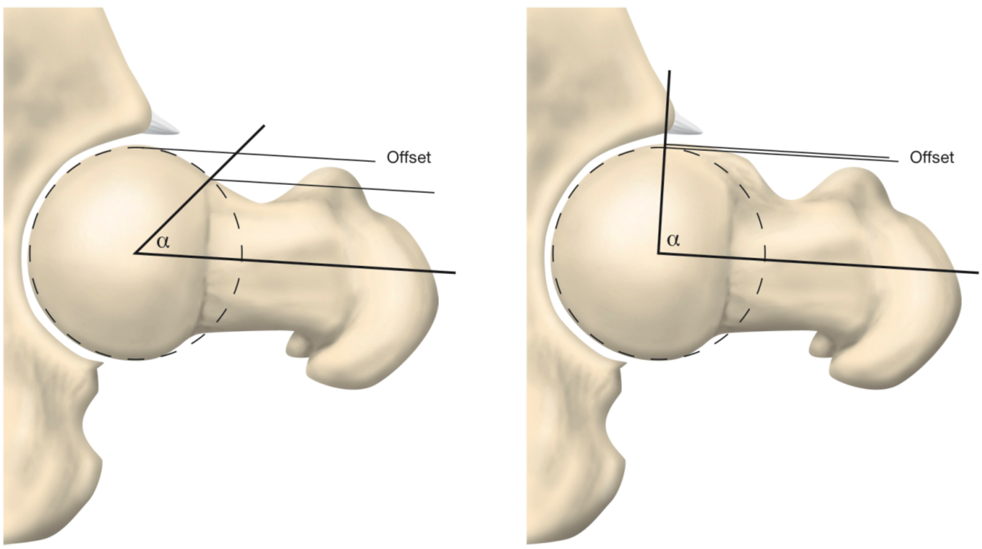

Figure 3: Measurement of the alpha angle to quantify the cam deformity. The *α*-angle was set as greater than 55° and measured in all planes from 9 to 3 o'clock. This is the angle between a line drawn along the axis of the femoral neck and a line drawn from the femoral head center to the point where the head extends beyond the margin of a best-fit circle.

from the upper endplate of T4 to the lower endplate of T12. Lumbar lordosis (LL) (Figure 1) was defined as the angle measured from the upper endplate of L1 to the upper end-plate of S1.

Pelvic parameters

Geometrical measurements relating to the pelvic parameters (Figure 1) were measured and recorded in degrees from the following; Pelvic Incidence (PI) is a morphological parameter and is the angle measured from a perpendicular line to the mid-point of the sacral plate and extended to the centre of the femoral head. Pelvic Tilt (PT) is a positional parameter and is the angle measured from a perpendicular line starting at the centre of the femoral head and extended to the mid-point of the sacral plate. Sacral Slope (SS) is a positional parameter and is the angle measured from the superior endplate of S1 and a horizontal axis [9,22]. A geometrical relationship exists between the morphological (PI) and functional parameters (PT, SS) resulting in the equation PI=PT+SS [22].

Sagittal vertical axis

The sagittal vertical axis (SVA) (Figure 1) was measured and recorded in mm and is defined by using the C7 plumb line that intersects the superior corner of the upper sacral endplate. The sagittal vertical axis assesses if an individual is in neutral, positive or negative alignment by comparing the head position relative to the sacral promontory [37].

Spinal curvatures

Four types of spinal curvatures correlating to the angle of the sacral slope (Figure 2) were defined according to Roussouly et al. [22]. Types I and II generally being more associated with a low PI as Types III and IV have a high PI. Type I: Has a low sacral slope <35° and a low PI. A long thoracolumbar curve and short lordotic curve is noted resulting in a thoracic/lordosis ratio of 80:20. Type II: Has a low sacral slope <35° and a low PI. A shorter kyphotic curve and a longer lordotic curve are noted resulting in a thoracic/lordosis ratio of 60:40. Moreover, in spite of this appearance, the end result is a thoracolumbar flat back. Type III: Has a high sacral slope >35° <45° and a greater PI. The kyphotic and lordotic curvatures result in an equal thoracolumbar curve with a ratio of 50:50. Type IV: Has a high sacral slope >45° and a high PI. A reversed thoracolumbar curvature is shown resulting in a longer lordotic curve and a shorter kyphotic curve resulting in a ratio of 20:80.

Magnetic Resonance Imaging (MRI) examination

MRI scan protocols were performed on both hips for all participants. The MRI machine GE Optima 450 Wide 1.5T was used for all examinations; a coil surface HD 8ch Cardiac Array by GE was used. The total time for examination of two hips was approximately 20 minutes. The protocol was repeated twice in order, first for the right hip and then the left hip. The coil surface was shifted at each hip for maximum signal. Similar to previously performed studies, seven 1 mm thick radial reformats spaced clockwise in 30° intervals around and perpendicular to the femoral neck axis (Figure 4) [38] were measured. These positions are anterior, anterior-superior, superior-anterior, superior, superior-posterior, posterior-superior and posterior and are represented by the clock positions (9, 10, 11, 12, 1, 2, 3). The clock positions are generated from the 3-D data set by using multiplanar reconstruction software [39].

Quantifying the shape of the femoral head (Figure 4) was by measuring the alpha *(α)* angle according to Nötzil et al. [40]. The *α*-angle was measured in all planes from 9 to 3 o'clock. This is the angle between a line drawn along the axis of the femoral neck and a line drawn from the femoral head center to the point where the head extends beyond the margin of a best-fit circle [38]. In the present study, the α-angle was set as greater than 55° for showing increased morphological characteristics of hip joint FAI [39,40].

Statistical Analysis

Data was analysed using IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp. The description of data was expressed in terms of the mean and standard deviation (SD), median and range including frequencies and percentages were appropriate. An independent t-test and Pearson Chi-Square test were performed to compare variables, (skiers and controls and cam and no cam). Fisher's exact test was performed to compare the distribution of spinal curves according to Roussouly et al. [22] between variables. The statistical significance for all tests was set as p<0.05.

Results

Due to drop-out and failure to attend investigations, plain radiographs and MRI data from 89 *(n*=102) participants was available for final analysis. Reasons given were difficulties with timings for radiology and MRI appointments and participant's being worried about claustrophobia. Table 1 summarises the demographic characteristics of the whole population. The mean age of the enrolled population was 17.7 (±1.4) years, (stratified by cam 18.0 SD 1.2 and no cam 17.4 SD 1.2, P=0.021). A significant difference was noted for gender (P=0.001) with males 60% (*n*=26) shown to have cam deformities significantly more often than females 22% (*n*=10). This was similar for height, with taller participants being shown to have significantly more cam deformities >177 cm (SD 7.6) compared with shorter participants <170 cm (SD 7.5, P=0.001).

Figure 4: 20 year old female skier. **A.** Standing radiograph shows thoracolumbar scoliosis convex right. **B.** Standing lateral radiograph highlighting evenly balanced spine (50:50 for thoracic and lumbar curve) Roussouly et al. Type III spine. **C.** MRI shows mild to moderate disc degeneration at L4-5 level.

Table 2 shows the spino-pelvic measurements for all participants stratified by cam and no cam. A significant difference was noted for the measurement of PT (P=0.036) suggesting that greater values of pelvic retroversion 13° (SD 10.2) occur with the cam group compared with the no cam group 8.5° (SD 7.1). Moreover, a difference was noted with the skiers SVA values showing cam group 11.7 mm (SD 40.1) to be numerically greater compared with the no cam group 6mm (SD 43.5), however, this was not statistically significant (P=0.54). No further significant differences were found for the spino-pelvic parameters for comparison of both groups (PI P=0.38, SS P=0.54, TK P=0.52 and LL P=0.60). The mean values for the spino-pelvic measurements for the skiers stratified by cam and no cam are presented in Table 3. The greatest differences were noted with the skiers SVA values showing the cam group 15.2 mm (SD 42.5) to be numerically greater compared with the no cam group 9.9 mm (SD 43.4); however this was not statistically significant (P=0.64). The skiers PT 12.9° (SD 10.8) was shown to be greater in the presence of increased cam deformity compared to those skiers' 9.4° (SD 7.6, P=0.15) without cam deformity. No significant differences were noted for the spino-pelvic parameters for comparison of both groups for (PI, P=0.36, SS, P=0.90, TK, P=0.87 and LL, P=0.53). Table 4 shows the mean values for the spino-pelvic measurements of the control group stratified by cam or no cam. There were no significant differences shown for comparison between groups (PI, P=0.84, PT, P=0.38, SS, P=0.35, SVA, P=0.63, TK, P=0.41 and LL, P=0.15).

The mean values for cam and no cam in spinal categories according to Roussouly et al. [22] for all participants are presented in Table 5. The presence of cam FAI was distributed between all four spinal categories. Types II and IV both appear to be evenly distributed. Less of a presence of cam FAI was shown with Type I Roussouly spines 20% (*n*=2) compared with no cam 80% (*n*=8, P=0.51). Table 6 shows the mean values for cam and no cam in spinal categories according to Roussouly et al. [22] for the skiers. All spinal categories were noted to have cam FAI distributed throughout, with Type II spines according to Roussouly et al. [22] being shown to have the greatest distribution of cam FAI 67% (*n*=2) compared with no cam FAI 33% (*n*=1, P=0.19). The mean values for comparison of cam and no cam in spinal categories according to Roussouly et al. [22] for the control group are presented in Table 7. There were no significant differences found for comparison between groups (P=0.61). The frequencies of cam FAI between groups are presented in Table 8. A significant difference (P=0.009) was found for the frequency of cam FAI for the skiers 49% (*n*=31) compared with the non-athletic group 19% (*n*=5).

Discussion

The most important findings with the present study show that a significant difference was shown with an increased PT (13°) value in the presence of increased cam FAI for a mixed-population compared with the PT (8.5°) of the no cam group. The greatest distribution of cam FAI (67%) was shown to occur in the Type II spinal category according to Roussouly et al. [22] for the skiers compared with no cam FAI (33%). Therefore, the conclusions of the present study show that an increased prevalence of cam FAI may increase the spino-pelvic PT value for an age-matched mixed-population of skiers and non-athletes and that an increased distribution of spinal Type II classification according to Roussouly et al. [22] occurs more frequently in elite skiers in the presence of increased frequency of cam FAI. Moreover, an increased frequency of cam FAI appears to be more common in elite skiers compared with age-matched non-athletes. It is suggested that changes to the spino-pelvic alignment may be related to variables such as hip joint growth related issues and muscular development from heavy loading due to early sports participation.

Measurement of the spino-pelvic parameters in the present study highlighted a significant difference for the values of PT for a mixed-population. Individual's diagnosed with increased morphological hip joint cam showed PT (13°) values to be significantly greater compared to those PT (8.5°) values with no cam. The PT angle describes the orientation of the pelvis, a greater PT angle correlates with a greater degree of pelvic retroversion; therefore, in the present study pelvic retroversion may have occurred in individuals with an increased PT in the presence of morphological hip joint cam deformity. Perhaps such an increase in PT may be seen as compensatory mechanism for individuals to cope with hip joint cam FAI. Moreover, pelvic retroversion as a result of increased PT may have affected spinal sagittal alignment values that may have resulted in a greater prevalence of Type I and II spines according to Roussouly et al. [22]. PT has also been shown to be a functional parameter [22] and therefore; it is possible that an increased PT may have increased pelvic retroversion as means to regulate the spino-pelvic sagittal balance to accommodate increased morphological changes associated with hip joint cam FAI. One reason may be that the spino-pelvic complex may have attempted to rotate around the hip [4] to maintain a balanced spine. This conflicts with other studies that have shown limitations in terms of pelvic mobility [41] to occur in the presence of hip joint cam FAI [28]. However, unlike the present study were spino-pelvic parameters were measured with radiology; those previous studies measured only sagittal range of motion with clinical methods and motion camera analysis.

An important point must be addressed in terms of the geometrical relationship that occurs between the morphological (PI) and the functional parameters (PT, SS) that according to Roussouly et al. [22] results in the equation PI=PT+SS. Accordingly, this would imply that if an increase PT value occurred, then a decrease in the SS value would also be noted. The value for SS (40.8°) in the cam group was reduced compared with the SS (42°) in the no cam group however, this was not statistically different. The reason for this relates to the angle of PI remaining constant after skeletal maturity. Therefore, caution would have to be observed with interpreting these results, as although the present study was able to show a difference in PT between the cam and no cam groups, a major limitation may relate to such small sample numbers and sub-group analysis, therefore any significance may have purely been an error in measurement.

	All subjects (*n*=102)	Cam (*n*=36)	No cam (*n*=53)	*P*-value
Age (years)	17.7 (1.4)	18.0 (1.2)	17.4 (1.2)	0.021
Female sex, n (%)	53 (52)	10 (22)	36 (78)	<0.001[a]
Male sex, n (%)	51 (48)	26 (60)	17 (40)	-
Height (cm)	173 (8.3)	177 (7.6)	170 (7.5)	<0.001
Weight (kg)	69 (12.2)	72 (9.9)	68 (13.7)	0.14
Body mass index (kg/m^2)	22.9 (3.3)	22.7 (2.5)	23.1 (3.8)	0.55
Values are mean and (Standard Deviation: SD).[a] Pearson Chi-Square Test.				

Table 1: Baseline characteristics for all subjects and stratified by cam and no cam.

Parameter	no cam (n=51)	cam (n=36)	*P*-value
Pelvic incidence (°)	50.1 (11.1)	52.2 (12.1)	0.38
Pelvic tilt (°)	8.5 (7.1)	13.0 (10.2)	**0.036**
Sacral slope (°)	42.0 (8.1)	40.8 (10.2)	0.54
Sagittal vertical axis (mm)	6.0 (43.5)	11.7 (40.1)	0.54
Thoracic kyphosis (°)	35.9 (7.3)	34.8 (7.6)	0.52
Lumbar lordosis (°)	-59.5 (10.0)	-58.3 (9.7)	0.60
Values are mean and (Standard Deviation: SD). P-value in bold indicates significant difference between groups.			

Table 2: Spino-pelvic measurements stratified by cam and no cam for all subjects.

Parameter	no cam (n=30)	cam (n=31)	*P*-value
Pelvic incidence (°)	49.8 (11.9)	52.7 (12.4)	0.36
Pelvic tilt (°)	9.4 (7.6)	12.9 (10.8)	0.15
Sacral slope (°)	41.5 (8.2)	41.2 (10.4)	0.90
Sagittal vertical axis (mm)	9.9 (43.4)	15.2 (42.5)	0.64
Thoracic kyphosis (°)	34.5 (7.6)	34.4 (7.4)	0.87
Lumbar lordosis (°)	-57.4 (9.2)	-58.9 (9.6)	0.53
Values are mean and (Standard Deviation: SD).			

Table 3: Spino-pelvic measurements for skiers stratified by cam and no cam (n=61).

Parameter	no cam (n=21)	cam (n=5)	*P*-value
Pelvic incidence (°)	50.4 (9.8)	49.4 (11.1)	0.84
Pelvic tilt (°)	7.4 (6.4)	10.2 (5.7)	0.38
Sacral slope (°)	43.1 (7.8)	39.2 (9.1)	0.35
Sagittal vertical axis (mm)	0.3 (43.5)	-9.6 (13.9)	0.63
Thoracic kyphosis (°)	37.9 (6.6)	35.1 (8.7)	0.41
Lumbar lordosis (°)	-62.4 (10.7)	-54.4 (10.8)	0.15
Values are mean and (Standard Deviation: SD).			

Table 4: Spino-pelvic measurements for controls stratified by cam and no cam (n=26).

	Roussouly type			
	I (n=10)	**II** (n=7)	**III** (n=54)	**IV** (n=16)
Cam	2 (20%)	3 (43%)	25 (46%)	6 (38%)
No cam	8 (80%)	4 (57%)	29 (54%)	10 (62%)
Values are mean and (Standard Deviation: SD). Fisher's Exact Test, *P*=0.51.				

Table 5: Cam and no cam in categories of Roussouly for all subjects (n=87).

	Roussouly type			
	I (n=10)	**II** (n=3)	**III** (n=37)	**IV** (n=11)
Cam	2 (20%)	2 (67%)	21 (57%)	6 (55%)
No cam	8 (80%)	1 (33%)	16 (43%)	5 (45%)
Values are mean and (Standard Deviation: SD). Fisher's Exact Test, *P*=0.19.				

Table 6: Cam and no cam in categories of Roussouly for skiers (n=61).

A greater difference was noted with the spino-pelvic SVA measurement for comparison between cam (11.7 mm) and no cam (6 mm) for all participants, this was also similar for cam (15.2 mm) and no cam (9.9 mm) for the skiers group. These values were not statistically significantly different but may still have a clinical relevance as it highlights that those individuals with cam FAI may stand in a more forward flexion posture compared to those individuals with no cam. Todd et al. [21] previously reported similar SVA values within elite young skiers compared to controls of a similar age and hypothesized that such a change in global spinal positioning may have been related to the skier's postural adaptations from heavy training loads. However, the present study showed that a difference in SVA values also occurred within a mixed-population therefore, it is possible that an increase in SVA value might be related to increased morphological hip joint cam FAI rather than any particular training or sports specific activity.

In the present study, similar values were shown between groups for the spino-pelvic parameters PI, SS, TK, LL. A previous radiological study by Todd et al. [21] reported similar values for the spino-pelvic parameters in skiers and controls without considering the influence of cam FAI. Therefore, this might suggest that an increased prevalence of cam FAI may not actually affect PI, SS, TK and LL parameters. Moreover, perhaps the present study may have been restricted by the limited sample size or young age and therefore, the participants may have not yet developed any significant changes to alter their spino-pelvic parameters.

There were no significant differences in the present study shown in terms of the prevalence of cam FAI for the classification of spinal types according to Roussouly et al. [22]. The presence of cam FAI was shown to occur throughout all four spinal classifications for a mixed-population, which was similar for the skiers, but only for Types II and III with the control group. Moreover, a greater distribution of Type II Roussouly spines were shown to occur more frequently with the skiers in the presence of an increased prevalence of cam (67%) compared with no cam (33%). However, this did not show any level of significance due to such small numbers within this cohort and from further sub-group analysis. One explanation may be that Roussouly's spinal classifications might be a more holistic and sensitive method for analyzing spinal types compared with the measurement of spinal parameters. Roussouly's spinal classification model includes the entire spine rather than specific spinal curvatures. Therefore, it is suggested that further studies should be considered on a larger scale to investigate the distribution of Roussouly Type spines in the presence of hip joint cam FAI. Previous studies have shown Elite skiers to have a greater prevalence of Types I and II spinal curvatures compared with non-athletes of a similar age [21]. However, this must be viewed cautiously as errors in measurement may occur using such a holistic spinal classification model due to an overlap between classifications of Roussouly type spines.

Moreover, it may be possible that the development of spinal types according to Roussouly et al. [22] may be due to a small angle of PI and or growth-related hip joint disturbances [42]. A small PI angle may restrict pelvic retroversion therefore, the spine would have to compensate by reducing the LL and increasing the TK. Similarly, a small PI may also limit hip flexion ROM and therefore, young elite athletes that perform repetitive hip flexion movements may become more susceptible to growth-related disturbances and the development of hip joint morphological cam FAI. However, this would require further investigation in a much larger cohort.

Evaluation of increased hip joint cam FAI in the present study where by the α-angle measurement; this is seen as a quantitative way for evaluating an increase in prominence of the femoral head-neck junction [43]. In the present study, the α-angle was set as greater than 55^o [39,40], however, some studies have shown a huge variability

	Roussouly type			
	I (n=0)	**II** (n=4)	**III** (n=17)	**IV** (n=5)
Cam	0	1 (25%)	4 (24%)	0 (0%)
No cam	0	3 (75%)	13 (76%)	5 (100%)
Values are mean and (Standard Deviation: SD). Fisher's Exact Test, *P=0.61.*				

Table 7: Cam and no cam in categories of Roussouly for controls (n=26).

	Skiers (*n*=63)	Controls (*n*=26)	*P*=value[a]
Cam	31 (49%)	5 (19%)	0.009
No cam	32 (51%)	21 (81%)	-
Values are mean and (Standard Deviation: SD).[a] Chi-Square Test.			

Table 8: Frequencies of cam in groups.

with the α-angle ranging from 32-62° in a mixed-gender population. Moreover, Pollard et al. [44] and Agricola et al. [45] both suggest increasing the α-angle cut off to 78°. It must be pointed out that the α-angle provides only an indication of the size of the cam, and therefore, in the presence of clinical symptoms related to pathology, clinical examination should also be included [46-48]. However, in the present study only the increased morphological characteristics of hip joint cam FAI and not hip joint pathology were evaluated with MRI, and moreover, no clinical evaluations were performed.

The mean value in years for the age of the mixed-population (skiers and controls) (17.7) was shown to be significantly greater for the cam FAI (18) group compared with the no cam FAI (17.4) group. The intentions of the present study were to have age-matched groups; however, this could be viewed as a study limitation as some of the skiers were from High School grade 1-4 as the controls were from the first grade. Moreover, all participants were shown to have a closed spinal physis on plain radiographs and closed growth plate on hip joint MRI; therefore, limiting the possibility of growth-related spurts [49] or a higher prevalence of cam deformity [50] between groups. A significant difference was shown regarding the prevalence of hip joint cam FAI within the mixed-population group (skiers and controls), with males (60%) showing an increased frequency compared to females (22%), which appears similar to previous studies [26,29,49,51-53]. Likewise, a significant difference was also shown for the height variable of a mixed population (skiers and controls). In the present study, taller individuals were shown to have a significant increased prevalence of cam FAI (177cm) compared with the no cam FAI (170cm) group.

There are other limitations to the present study. These include a limited sample size of the cohort and the statistical analysis of the subgroups. In spite of a greater PT value being shown with the cam group, such small sample numbers would question any such significance. Moreover, it is possible that such small sample numbers may have impacted the statistical analysis and therefore, the significance shown may have purely been an error in measurement. Selection of a larger sample group may have also affected the drop-out rate and perhaps may have shown a greater difference in the values for spino-pelvic parameters and spinal types according to Roussouly et al. [22]. Further limitations include accuracy and interpretation of the radiological measurements. A blinded radiologist measured the spinal curvatures, which were calculated from measurements taken from the end-plates of the vertebral bodies [3,53-57], whilst the pelvic angles were calculated from measurements taken from the pelvic paramenters [22]. It has been suggested that spinal posture may be affected by lower limb alignment [1,58-61], therefore, in the present study; errors may have occurred if participants were not standing evenly in a similar position, fatigued from prolonged standing [62] or postural variances due to lower limb asymmetries [63]. The inclusion criteria selected only a healthy population however; this may have limited the ability to distinguish greater differences in the spino-pelvic parameters or spinal types according to Roussouly et al. [22] in the presence of increased morphological hip joint cam FAI.

The present study showed that an increased PT angle occurs in a mixed-population of Elite athletes and non-athletes in the presence of hip joint cam FAI. Type II spinal classifications according to Roussouly et al. [22] were also shown to occur more frequently with the skiers in the presence of an increased prevalence of cam FAI. Moreover, secondary findings highlighted that age, gender and height variables were all shown to occur more commonly in a mixed-population, with hip joint cam FAI. Therefore, the present study supports the hypothesis that changes may occur to the spino-pelvic alignment of a mixed-population of Elite skiers and non-athletes in the presence of increased morphological hip joint cam FAI and that Type II spinal classifications according to Roussouly et al. [22] occurs more frequently in Elite skiers, in the presence of increased morphological hip joint cam FAI.

The clinical relevance of this study highlights that increased levels of pelvic retroversion, lumbar kyphosis and other lumbar pathologies may be found in individuals who are also shown to have increased hip joint morphological cam deformities. It is suggested that other studies involving larger samples of athletes and non-athletes and also adult athletes should be considered to quantify further the relationship between PT and the prevalence of Types I and II Roussouly spines (low Pelvic Incidence) in the presence of increased morphological hip joint cam FAI and pincer lesions.

Conclusion

The conclusions of the present study is that a significant increase in the spino-pelvic sagittal alignment values for Pelvic Tilt angle occurs in an age-matched mixed-population in the presence of hip joint cam FAI and that Elite young skiers are shown to have an altered spino-pelvic sagittal alignment resulting in a retroverted pelvis and low lumbar lordosis (flat back) especially in the presence of increased morphological hip joint cam FAI.

Acknowledgement

The authors acknowledge the financial support of The Medical Society of Gothenburg, Sweden, Governmental grants under the ALF agreement, Handlanden Hjalmar Svenssons Research Foundation and Doktor Felix Neuberghs Foundation, Carl Benett AB, Swedish National Centre for Research in Sports. The authors would also like to thanks Dr Flemming Pedersen and Dr Zaid Obady at Dep. of Radiology Östersunds Hospital, Sweden for their help with the radiological examination and Christer Johansson, OrigoVerus AB, Gothenburg, Sweden for statistical assistance.

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