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Original Article

Hip joint space width in an asymptomatic population: Computed tomography analysis according to femoroacetabular impingement morphologies

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ABSTRACT

Background: Although the association between femoroacetabular impingement (FAI) syndrome and hip osteoarthritis (OA) is well established, not all hips exhibiting cam or pincer morphologies (i.e. imaging findings of FAI syndrome) are symptomatic or arthritic. It is difficult to detect which subgroup will wear out, or how does the arthritic process start radiographically. Therefore, we measured in a retrospective study based on computed tomography (CT) analysis, the joint space width (JSW) according to a standard protocol and we investigated its variation according to the presence of a cam and/or pincer morphology. We hypothesized that the radiological presence of a cam and/or pincer hip morphologies, even in asymptomatic subjects, would affect JSW.
Methods: Two hundred pelvic CT scans performed for non-orthopedic etiologies in asymptomatic patients were analyzed using a 3D software. After excluding patients with hip OA or previous hip surgery, 194 pelvic CT scans (388 hips) were retained. We measured for each hip the presence of FAI syndrome imaging findings (cam and pincer morphologies) using the classical parameters of coxometry. In addition, we performed a measurement of articular joint space width according to a standard protocol. We then calculated the mean thickness of 3 defined regions along the femoroacetabular joint: anterior-superior, posterior-inferior, and posterior-superior. Lastly, we compared the JSW across 4 groups: hips with (1) no cam or pincer, (2) pincer, (3) cam, and (4) cam and pincer morphologies using a multivariate analysis. Additionally, a topographic heatmap of JSW was plotted allowing quantitative representation of JSW along the joint.
Results: Increased JSW with peak difference of 0.9 mm (25.7%) was found in hips with cam and pincer morphologies when compared to normal ones ($p = 0.002$) and to hips with pincer or cam morphologies only.
Conclusion: Positive variations in JSW were associated to the presence of cam and pincer morphologies. This significant increase in JSW could be one of the earliest measurable changes preceding later classical alterations.

Introduction

Advances in the understanding of cartilage and labrum lesions of the hip through the concept of "femoroacetabular impingement" (FAI), confirmed the idea of "internal derangement" advanced by Harris[1] in the eighties, and explained how previously considered radiologically normal hips begin to degenerate. Griffin et al. defined FAI syndrome (FAI) syndrome as "a motion-related clinical disorder of the hip with a triad of symptoms, clinical signs and imaging findings. It represents symptomatic premature contact between the proximal femur and the acetabulum."[2]

The majority of studies on this topic are done on patients with

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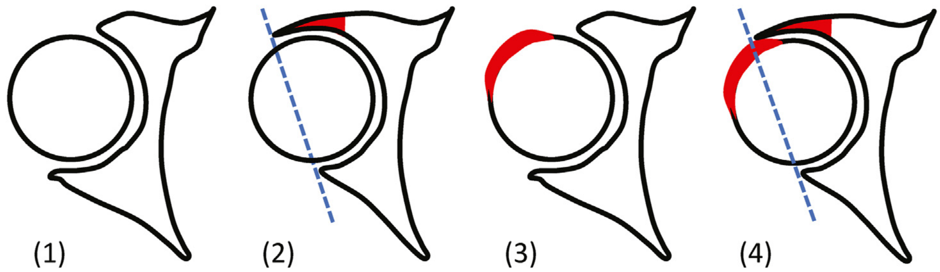

Fig. 1. Illustration of the 4 groups defined according to presence of pincer and/or cam morphologies

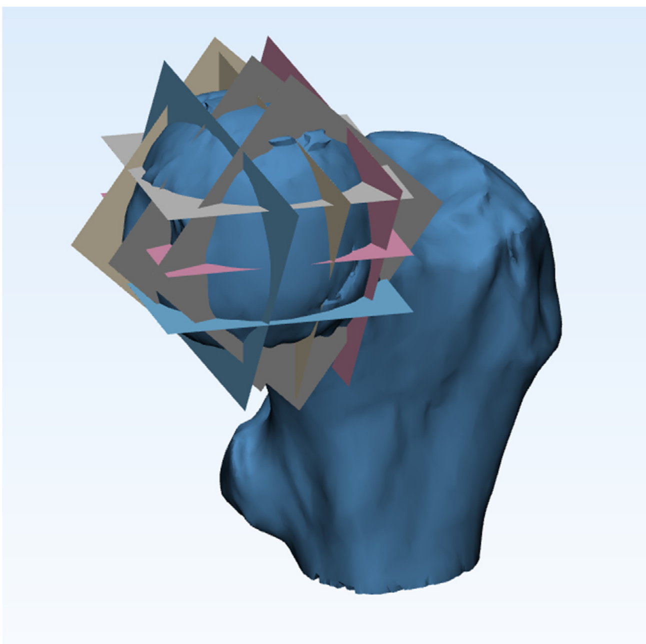

Fig. 2. Nine planes consisting of 3 equidistant axial, coronal, and sagittal planes separating the head at 3 levels each, with the middle planes passing through the center of the femoral head

hip osteoarthritis where a higher frequency of radiographic signs of FAI is noticed.[3–8] Some studies have compared the hip morphology of FAI syndrome patients with healthy control subjects,[9] and others have looked for signs of FAI in healthy but small-scale volunteers.[10]

Most of those studies[8] have searched for the association of FAI syndrome morphologies with classical signs of osteoarthritis (OA) usually starting by a decrease in joint space width (JSW), but no studies have analyzed the presence of cam or pincer morphologies in a general asymptomatic population according to variations in hip morphology. It is not known which individuals with cam or pincer morphologies will develop symptoms and therefore FAI syndrome.

Our aim was to conduct a cross-sectional study establishing normative hip JSW data and investigating its variation according to the computed tomography (CT) scan prevalence of cam and pincer morphologies in an asymptomatic sample of the Lebanese population.

We hypothesized the radiological presence of a cam or pincer hip morphologies might affect JSW even in asymptomatic individuals.

Materials and methods

Joint space width measured at the hip joint is the radiological distance between the subchondral bone of the femoral head and the acetabulum. As epidemiological studies consider this measurement as the most reliable and useful radiographic feature of defining hip OA on plain radiography,[11,12] we decided to adopt JSW (measured on CT scan according to a standard protocol) as our primary assessment variable to define and quantify OA.

Patient selection

We retrospectively studied 200 pelvic CT scans performed for non-orthopedic indications in our radiology department between January and May 2018. A questionnaire was used for each patient assessing for any hip symptoms including: motion or position related pain in the groin, the buttock, the lumbar spine or thigh. Patients were asked to report of any clicking, catching, locking, stiffness, restricted range of motion or giving way if experienced. Upon questionnaire collection, a total of 194 patients were available for our study.

All selected individuals were adults over 20 years of age. There were 100 women and 94 men of mean age 58.80 and 58.85 respectively. The examinations were carried out for various non-orthopedic etiologies with a “General Electric LightSpeed 64″ multidetector CT scanner with slice thickness ranging of 1.25 mm (peak kV = 120 kV and average exposure = 260 mA). 388 hips were available for analysis after applying those criteria. Each exam was subsequently analyzed with the 3D software (Amira, Thermo Fisher Scientific). Each image compilation was imported by the software and opened with 3 orthogonal spatial slices.

This allows the use of the 3D module to reduce the visible image to the region of interest thus excluding the lumbar spine or any artifact. A 3D “isosurface” is subsequently generated which is a volumetric representation of the basin where 2D, 3D distance, or angle measurements can be made.

Groups selection

Hips were divided into 4 groups: hips with (1) no pincer or cam, (2) pincer only, (3) cam only, and (4) pincer and cam morphologies where JSW was compared. The order of the groups is of important clinical significance as having both morphologies (Group 4) predisposes the hip to greater stress in contrast to having only one type of morphology (Group 2 and 3) or none at all (Group 1). (Fig. 1).

Radiographic assessment

Joint space width measurement and region selection

A protocol to define reproducible measurement of JSW and obtaining a global JSW mapping according to common patterns of cartilage breakdown was used. The femoral head was cut with 9 different orthogonal planes consisting of 3 equidistant axial, coronal, and sagittal planes separating the head at 3 equal thickness

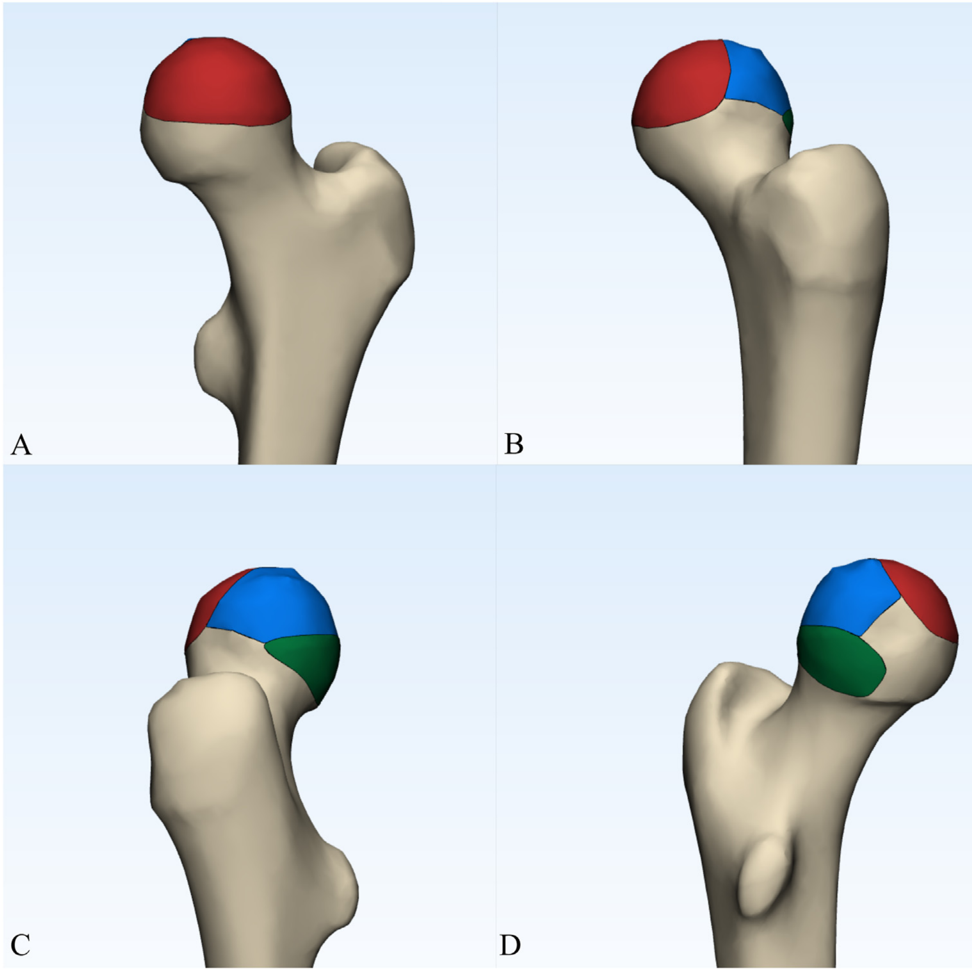

Fig. 3. Color-coded femoral head regions: anterior-superior (red), posterior-superior (blue), and posterior-inferior (green) (A) anterior, (B) lateral, (C) posterolateral, and (D) medial views.

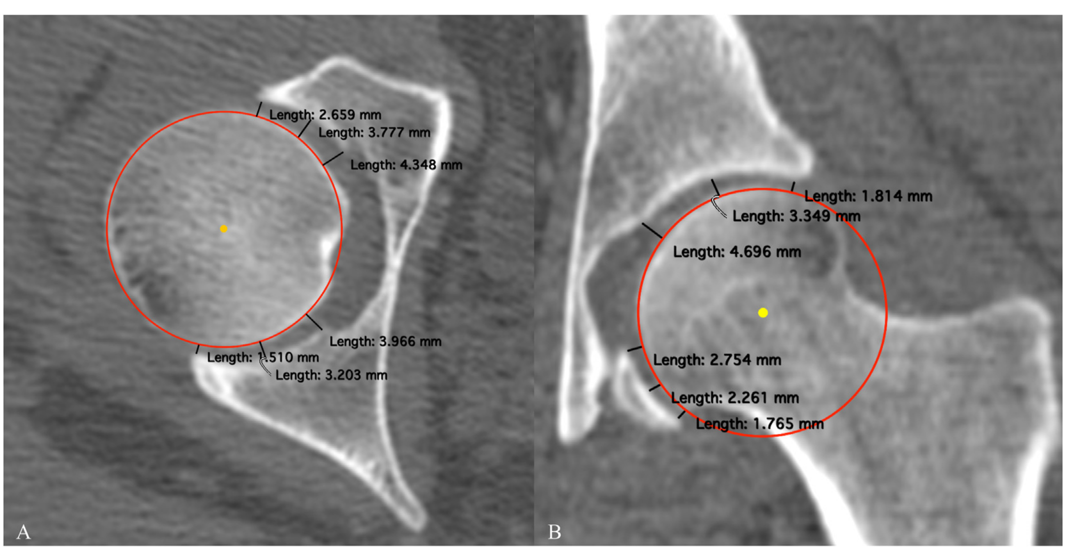

Fig. 4. (A) Axial and (B) coronal measurements

levels each, with the middle planes passing through the center of the femoral head (Fig. 2). JSW measurements were carried for each of the mentioned planes at the level of the joint space.

Usually, abnormal contact between the femoral head and acetabular rim results in supraphysiologic stress that tears the acetabular labrum and delaminates the articular cartilage from the

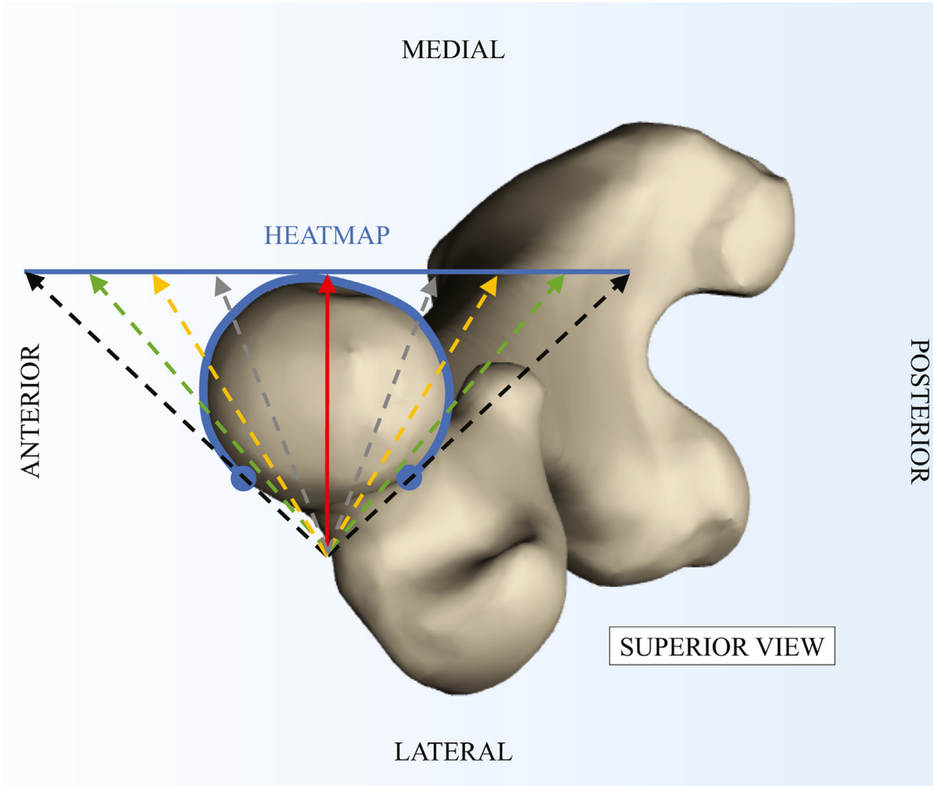

Fig. 5. Superior view of the femur showing the method for stereographic projection

Table 1
Interobserver reproducibility.

Variables	Intraclass Correlation (95% CI)
Joint space width (in anterior-superior region)	0.879 (0.853–0.900)
Roof-edge angle	0.913 (0.895–0.929)
Alpha angle	0.847 (0.813–0.876)
Wiberg's lateral center-edge angle	0.833 (0.776–0.876)

underlying bone in accordance with a specific FAI damage pattern. In cam morphology the anterior location is affected, while in pincer morphology there usually is a more generalized disease.[5] Accordingly, in our study, JSW measurements were grouped into regions based on the prementioned patterns of damage resulting in 3 defined regions: anterior-superior, posterior-superior, and posterior-inferior (Fig. 3). Each region consists of multiple measurement points to quantify the average JSW at the corresponding region. Each JSW measurement was taken along a radial line from the center of the best-fit circle on the femoral head, to the joint space point (Fig. 4).

Given an individual plane, the femoral head is divided into 2 parts separated by the fovea. JSW was then measured at three locations on each side of the fovea: (1) at the lateral margin of the acetabulum, (2) at the border of the fovea, and (3) at the bisectrix of those two lines.

The anterior-superior region was the mean of the anterior and superior measurements on the axial and coronal planes respectively. Similarly, the posterior-inferior and posterior-superior regions were the mean of the corresponding measurements on the aforementioned planes.

Radiologic variables assessing FAI syndrome morphologies

(1) The roof-edge angle (also known as apical acetabular anteversion angle): measured in the axial plane passing at the roof level of each femoral head. It's the angle formed between a line passing through both edges of the acetabulum and the perpendicular to the line joining both ischial spines. A negative angle indicates a pincer morphology.
(2) The alpha angle formed by two straight lines starting from the center of the femoral head. The first passes through the axis of the femoral neck. The second by the point of deviation between the bone and the spherical shape of the femoral head. An alpha angle $>55^{\circ}$ measured in an oblique CT reconstruction of the femoral neck has a high discriminating capacity for the diagnosis of symptomatic cam morpho logy.[13]

Topographic heatmap of the joint space width

We have devised a method for assessing the distribution of JSW in our sample using a topographic heatmap representing the variation of the width measurements along the hip joint space. The

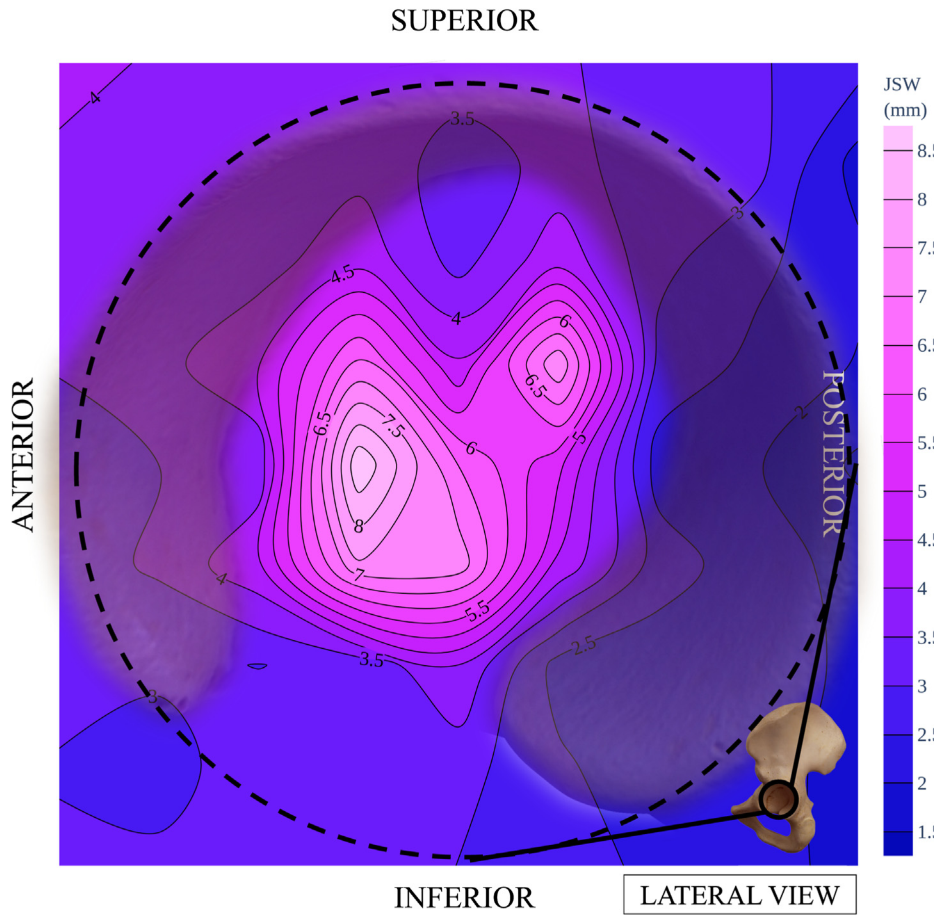

Fig. 6. Heatmap showing JSW of all hips studied in the population. The JSW scale spans from 1 (blue being the thinnest) to 9 mm (pink being the thickest). The hemipelvis at the bottom right serves as guide for orientation with an overlay of the acetabulum over the heatmap. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Patients characteristics.

Number of hips	388
Male	188
Female	200
Age	58.82 ± 18.15 (20–90)
Body mass index (kg/m^2)	24.92 ± 4.29 (17.71–41.93)
Roof-edge angle	12.61 ± 12.98 (−32.8 – 46.5)
Alpha angle	49.40 ± 7.91 (34.13–73.83)
All values are described as mean ± SD (range). Angles are in degrees.	

heatmap was plotted to better visualize the influence of FAI syndrome imaging morphologies. It was created using a stereographic projection of the femoroacetabular joint space hemisphere into a plane, in order to represent the JSW variation in a two-dimensional manner (Fig. 5).

This was achieved by first projecting the recorded JSW points onto a 2D plane. The coordinates (x, y) were then recorded for each data point and this system was used to plot heatmaps according to the studied factors. The resulting map allowed instant visualization of all JSW regions in a single figure.

Interobserver reproducibility

Interobserver reproducibility of measurements (JSW, roof-edge, alpha, and LCE angles) was evaluated by 2 different radiologists in a subset of 25 hips using a two-way, mixed, consistency single-measures intraclass correlation coefficient (ICC). ICC values greater than 0.80 indicate excellent reliability, 0.61–0.80 substantial reliability, 0.41–0.60 moderate reliability, 0.21–0.40 fair reliability and <0.20 poor reliability.[14] The results are shown in Table 1.

Statistical analysis

The Shapiro-Wilk test showed that JSW values followed a normal distribution across the 4 groups. Multivariate analysis of covariance (MANCOVA) was performed to compare the 4 groups: normal (1), pincer (2), cam (3), pincer and cam morphologies (4). MANCOVA is an extension of analysis of covariance (ANCOVA) used when there is more than one dependent variable (3 regions) and where the control for covariates is required (age, sex, and body

Table 3
Joint space width measurements according to gender. Student's t-test performed to compare differences in JSW between male and female subjects. No significant difference was found.

Regions	Male	Female	*P*-value
Anterior-superior	3.52 ± 0.72 (1.94–5.45)	3.32 ± 0.7 (2.13–5.24)	0.238
Posterior-inferior	2.13 ± 0.63 (0.58–4.95)	2.13 ± 0.71 (0.66–5.4)	0.981
Posterior-superior	2.69 ± 0.7 (1.11–4.69)	2.65 ± 0.7 (0.36–4.65)	0.513

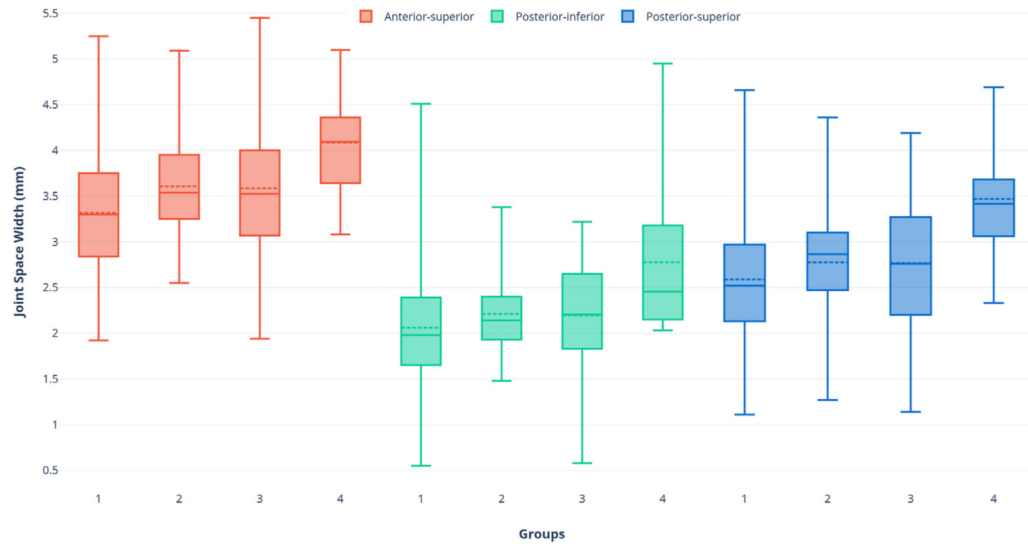

Fig. 7. Boxplot showing the comparison of JSW according to the 4 defined groups: (1) no pincer or cam, (2) pincer only, (3) cam only, and (4) pincer and cam morphologies. Regular and dotted line indicate median and mean respectively. (F (9, 927.404) = 2.895, p = 0.002, Wilks' Λ = 0.935).

Table 4
Patient demographics according of the 4 groups based on having pincer and/or cam morphologies. All values are described as mean ± SD. Angle unit is in degrees.

	(1) Non-pincer, non-cam	(2) Pincer	(3) Cam	(1) Pincer and cam	Total
Number of hips	258	46	70	14	388
Female	151	29	20	0	200
Male	107	17	50	14	188
Age (years)	60.81 ± 18.61 (20–90)	53.87 ± 16.7 (20–78)	57.84 ± 16.78 (25–90)	53.36 ± 8.69 (30–60)	58.82 ± 18.15 (20–90)
Body mass index (kg/m^2)	25.17 ± 4.34 (18.26–41.93)	23.71 ± 3.53 (18.41–33.95)	24.93 ± 4.31 (18.45–38.10)	24.41 ± 4.31 (17.71–37.80)	24.92 ± 4.29 (17.71–41.93)
Roof-edge angle	17.44 ± 8.74 (0.65–43.8)	−10.93 ± 8.33 (−32.8 to −2.19)	14.84 ± 7.74 (3.12–46.5)	−10.25 ± 5.54 (−22.60 to −3.27)	12.61 ± 12.98 (−32.8 – 46.5)
Alpha angle	46.02 ± 4.37 (35.75–54.93)	45.51 ± 4.32 (34.13–52.48)	62.10 ± 4.72 (55.11–73.83)	60.84 ± 3.59 (55.31–68.61)	49.40 ± 7.91 (34.13–73.83)

mass index). The groups were then compared among each other using pairwise comparisons.

The data met all assumptions for data analysis. Analysis was done using SPSS 25.0 software.

Results

We evaluated 94 women and 100 men, with a mean age of 58.8 (minimum = 20, maximum = 89) and 58.85 (minimum = 21, maximum = 90) respectively. Fig. 6 shows the heatmap representing JSW in all studied subjects with an overlay of an acetabulum to show the adopted view and orientation of the projection.

Parameters of the whole cohort

The mean values of the measured parameters are shown in Table 2. Table 3 shows joint space measurements according to gender where no significant difference was found in all regions.

Comparison of JSW according to the presence of cam and/or pincer morphologies

There was a statistically significant difference between the groups on the JSW after controlling for age and BMI: F (9, 927.404) = 2.895, p = 0.002, Wilks' Λ = 0.935 (Table 5).

Table 5
Comparison of JSW among the 4 defined groups according to the presence of cam and/or pincer morphologies. A multivariate analysis (MANCOVA) was performed, with control for age and BMI. All values are described as mean in mm ± SD (range).

Femoroacetabular morphology	Joint space width (JSW)		
	Anterior-superior	**Posterior-inferior**	**Posterior-superior**
(1) Non-pincer, non-cam (n = 258)	3.30 ± 0.72 (2.20–5.25)	2.06 ± 0.7 (0.88–4.51)	2.58 ± 0.69 (2.55–4.66)
(2) Pincer (n = 46)	3.61 ± 0.55 (2.55–5.09)	2.23 ± 0.43 (1.48–3.38)	2.78 ± 0.62 (1.27–4.36)
(3) Cam (n = 70)	3.58 ± 0.7 (1.94–5.45)	2.19 ± 0.59 (0.58–3.23)	2.76 ± 0.66 (0.89–4.19)
(4) Pincer + cam (n = 14)	4.09 ± 0.56 (3.08–5.1)	2.77 ± 0.89 (2.03–4.95)	3.47 ± 0.66 (2.33–4.69)
Total (n = 388)	3.43 ± 0.72 (1.94–5.45)	2.15 ± 0.68 (0.58–4.51)	2.67 ± 0.7 (1.27–4.69)
F (9, 927.404) = 2.895, p = 0.002, Wilks' Λ = 0.935.			

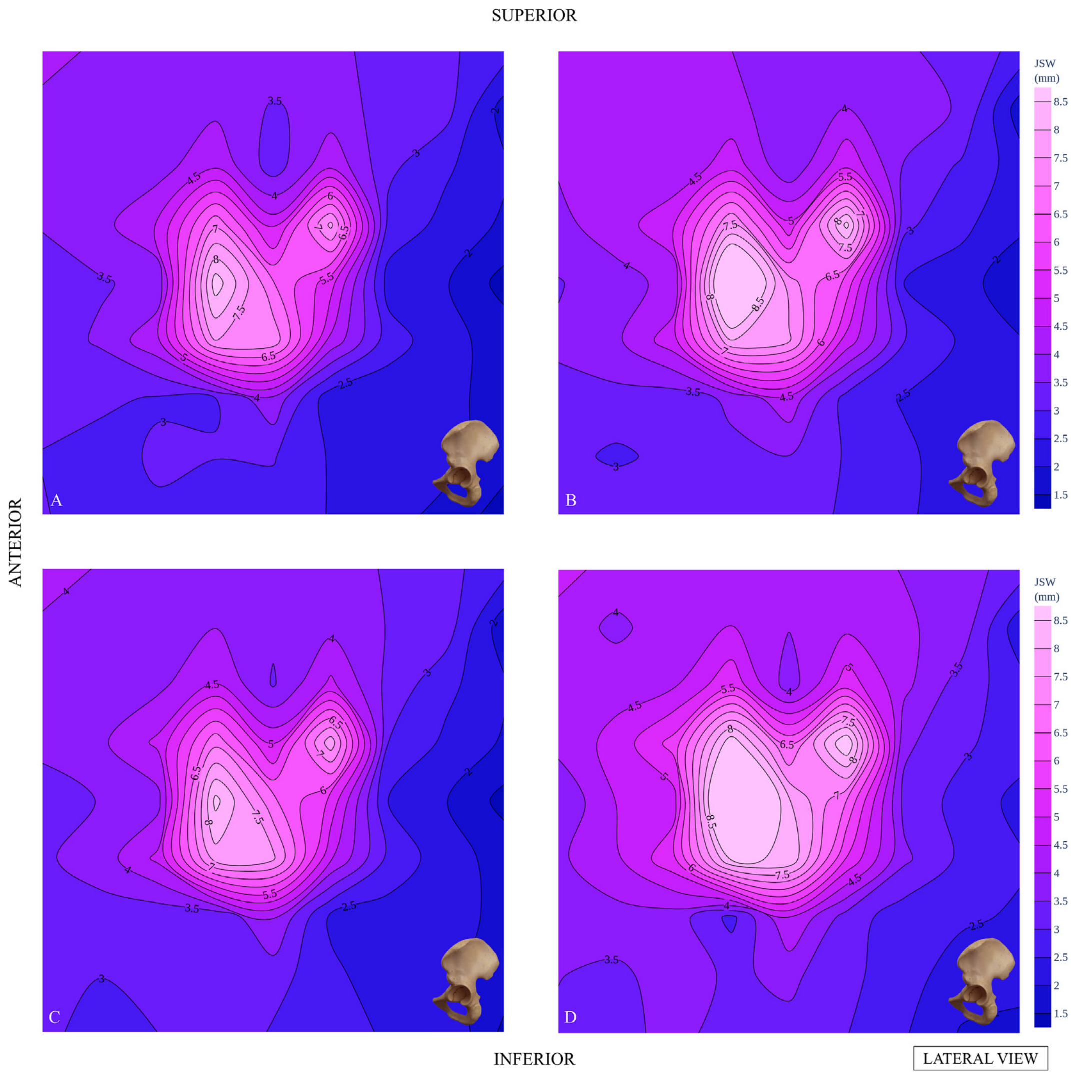

Fig. 8. Heatmap of the projected femoroacetabular joint space width showing gradually increasing JSW starting from hips with (A) non-pincer non-cam, (B) with pincer only, (C) with cam only, (D) to peak JSW in pincer with cam morphology (D). (Hemipelvis indicates orientation).

Furthermore, pairwise comparison among the groups showed significant increase in JSW in hips with pincer and/or cam morphologies compared to normal ones (group 1). In other words, hips with pincer (group 2), cam (group 3), or both morphologies (group 4) were associated with an increased JSW compared to hips having no FAI morphologies, independent from age, sex, and BMI (Fig. 7).

Additionally, there was no statistically significant difference in JSW between hips with pincer only (group 2) and cam only (group 3) compared to each other. However, both groups (2 and 3) were associated with increased JSW compared to hips with absent pincer or cam morphologies (group 1).

Patient demographics are shown in Table 4 and statistical analysis results in Table 5.

Contour heatmap

Fig. 8 shows the heatmap of JSW comparing normal hips, pincer only, cam only, and pincer with cam morphologies (Fig. 8A, B, C, and D respectively). There is a gradual significant increase in JSW reaching the highest values in hips with concomitant presence of cam and pincer morphologies (Fig. 8D).

Discussion

In this study, we have measured the JSW in a series of asymptomatic patients and studied its variation according to the presence of FAI syndrome imaging morphologies: pincer and cam. Values of JSW tended to be higher with the presence of imaging findings of FAI syndrome. We have shown that the presence of pincer and cam morphologies in an asymptomatic hip, seem to reproduce significantly, a pattern of JSW increase independent of age, sex, and BMI. Those findings suggest that the imaging findings in FAI syndrome, although subclinical, might affect the hip joint by an increase in JSW.

Several studies have investigated the hip joint space width. Jacobsen et al. analyzed factors influencing hip JSW measured on pelvic radiographs, particularly in asymptomatic subjects[15] and found that minimum JSW decreased with age in women, was unaltered in men, and found no difference with factors such as: history of smoking, occupational exposure, or body mass index.

Furthermore, in our cohort, when comparing groups according to presence of FAI syndrome morphologies, we have found a peak JSW (4.09 mm) in the anterior-superior region when both pincer and cam morphologies were present. This might be explained by the most common location of the cam morphology, at the antero-lateral femoral head–neck junction,[6] particularly when combined with anterior pincer morphology. In addition to generally being an area of peak pressure,[16] this specific collocation of morphologies cause an increase in shear stress at the level of the anterior-superior acetabulum during deep flexion and rotational maneuvers and has been shown to be the most affected region affected in FAI syndrome.[17] Moreover, these results of increased JSW have been seen in literature where JSW was significantly larger in hips with acetabular insufficiency.[18] One way to relate these findings to our results is by the fact that these two pathologic conditions (FAI and acetabular insufficiency) both involve increased stress on the cartilage. The presence of cam and pincer morphologies induce peak pressure patterns subjecting the cartilage to a mechanical overload. Theoretically, in the early stages, chondrocytes proliferate as a compensatory mechanism, whereas in advanced OA, we see thinning of the cartilage once the chondrocytes are drained. The increase in JSW is an auto-regulatory increase of articular cartilage thickness during growth, as proposed by Lequesne et al.[18]

Thus, thicker growth would be expected in FAI where higher pressure is exerted on the hip cartilage. The extra pressure triggers repair responses including pro-inflammatory pathways and consequently causes the swelling of the cartilage and joint space. This increased swelling, reflected by higher JSW, could be a theoretical explanation of our findings.

Finally, this study defined normative coxometric and JSW data of the Lebanese population and showed that positive variations in JSW are associated to the presence of FAI syndrome imaging findings. Knowing this fact could serve to promote defining population based normative data of JSW where positive variations should be closely monitored.

The strength of this study lies in our use of a CT scan protocol to obtain global femoroacetabular JSW measurements on a series of asymptomatic patients. Whereas plain radiography allows JSW measurement, only at the acetabular roof, in the coronal plane and results also may vary depending on the incidence of the X-ray beam.[19]

Additionally, our CT scans were done in the supine position, where JSW is unaffected by weight-bearing compared to plain pelvic radiographs conventionally taken in standing position which could affect JSW negatively even if studies comparing standing and supine plain radiographs showed no significant difference in JSW.[20]

Limitations

Assessment of the JSW using CT might be considered suboptimal, while other modalities such as MR, provide greater information about the joint and cartilage. Physiological imaging techniques among which delayed gadolinium enhanced MR imaging of cartilage (dGEMRIC), even provide molecular properties of the cartilage. Moreover, no activity level was included in the analysis which is considered an important factor in the manifestation of FAI syndrome symptoms and development.

These methods and additional characteristics can be used in a future longitudinal long-term study assessing JSW in the same patient population with a follow-up to validate and elaborate further on our radiological findings.

Conclusion

Our study of asymptomatic patients individualized a significant association between the presence of radiological signs of FAI syndrome and an increased JSW, reaching a peak thickness when FAI morphologies are concomitantly present. Whereas, similar studies performed on symptomatic patients show that those conditions are associated with joint space narrowing.

These findings suggest that those abnormalities usually leading to hip OA, cause each, in asymptomatic patients, at some point in time a specific pattern of increased JSW that might be a self-regulated increase in cartilage thickness during growth.

Predicting who will become symptomatic in subjects with FAI morphologies was ranked as the top priority in FAI syndrome research and further investigations are critically needed.

Ethical approval and patient consent

The study was reviewed and approved by the Institutional Review Board (IRB) and Research Ethics Committee (REC) in August 2017. Patient's informed consent was obtained by the physician followed by a signature on the questionnaire form.

Conflict of interest statement

The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.asmart.2021.01.001.

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