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Research Article

Adding false-profile radiographs improves detection of developmental dysplasia of the hip, data from the CHECK cohort

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ABSTRACT

The aim of this study was to determine the additional value of the false-profile (FP) view radiograph in the diagnosis of developmental dysplasia of the hip (DDH), as compared with an anteroposterior (AP) pelvic radiograph only, and evaluate the correlation between the Wiberg-lateral center edge angle (W-LCEA) and Wiberg-anterior center edge angle (W-ACEA). We used baseline data from a nationwide prospective cohort study (Cohort Hip and Cohort Knee). DDH was quantified on AP pelvic and FP hip radiographs using semi-automatic measurements of the W-LCEA and W-ACEA. A threshold of <20° was used to determine DDH for both the W-LCEA and the W-ACEA. The proportion of DDH only present on the FP view determined the FP view additional value. The correlation between the W-LCEA and W-ACEA was determined. In total 720 participants (1391 hips) were included. DDH was present in 74 hips (5.3%), of which 32 were only present on the FP view radiograph (43.2%). The Pearson correlation coefficient between W-LCEA and W-ACEA of all included hips was 0.547 (95% confidence interval: 0.503–0.591) and 0.441 (95% confidence interval: 0.231–0.652) in hips with DDH. A mean difference of 9.4° (SD 8.09) was present between the W-LCEA and the W-ACEA in the hips with DDH. There is a strong additional value of the FP radiograph in the diagnosis of DDH. Over 4 out of 10 (43.2%) individuals' DDH will be missed when only using the AP radiograph. In hips with DDH a moderate correlation between W-LCEA and W-ACEA was calculated indicating that joints with normal acetabular coverage on the AP view can still be undercovered on the FP view.

INTRODUCTION

Developmental dysplasia of the hip (DDH) is a commonly seen developmental disorder of the acetabulum, leading to undercoverage of the femoral head and increase in contact pressure on the joint cartilage [1]. Despite early screening at birth and during infancy, DDH can remain undetected until adulthood, with an estimated prevalence of 0.1% in the United States [2]. DDH has been associated with hip pain and loss of function in young adults, and may lead to an up to six times increased risk of developing hip osteoarthritis (OA) later in life [3–7].

DDH in adulthood is diagnosed based on a combination of symptoms, signs and imaging findings [4, 5]. Symptoms may include hip and groin pain and instability of the hip joint. Clinical findings include pain provoked with the hip instability tests (hyperextension-external rotation (HEER), Abduction-hyperextension-external rotation (AB-HEER) and the PRONE instability test), abductor fatigue with a positive Trendelenburg sign and increased range of motion of the hip [5, 8–11]. In order to make the diagnosis of DDH complete, anteroposterior (AP) pelvic radiographs are usually obtained [12, 13].

The most frequently used parameter to quantify acetabular coverage on an AP pelvic radiograph is the Wiberg-lateral center-edge angle (W-LCEA) [12, 14]. DDH is generally diagnosed with a W-LCEA < 20°, while an W-LCEA between 20° and 25° is considered borderline DDH. A W-LCEA between 25° and 40° is considered normal [1, 12–14]. The exact threshold values are still under debate and some studies also define a W-LCEA between 18° and 25° as borderline DDH [15]. The original description of Wiberg, however, states that hips with an LCEA < 20° were considered pathological, hips with an LCEA > 25° were normal and hips with an LCEA between 20 and 25° were considered uncertain [14, 16].

However, the W-LCEA only quantifies lateral acetabular coverage and might therefore lead to an underestimation of DDH prevalence, potentially resulting in delayed diagnosis [7, 17]. An additional lateral view, the false-profile (FP) view, can be used to determine the anterior acetabular coverage of the femoral head, which can be quantified by the Wiberg-anterior center-edge angle (W-ACEA) [8, 12, 13, 18, 19]. As DDH is a condition

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that can be both present laterally and anteriorly, an additional value of the FP view radiograph is to be expected.

To the best of our knowledge, the additional value of an FP view as opposed to a sole AP view in the diagnosis of DDH is unclear. Several studies mention the possibility of adding the FP view, but the additional value and correlation with the AP view alone has not yet been established [8, 12, 20]. The primary aim of this study was therefore to evaluate the additional value of an FP view in the diagnosis of DDH as compared with an AP view only. The secondary aim was to investigate the correlation between the W-LCEA and W-ACEA as a surrogate of lateral and anterior dysplasia, respectively.

METHODS

Study design and participants

We used data of the Cohort Hip and Cohort Knee (CHECK). CHECK is a Dutch nationwide multicenter prospective cohort study containing 1002 participants, aiming to study the course and risk factors of early hip and knee OA. Participants were eligible for inclusion when they presented with first-onset pain of the hip or knee were aged between 45 and 65 years and had not yet consulted their general practitioner for these symptoms or the first consultation was within 6 months before entry of the cohort [21, 22]. If symptoms could be explained by other pathology (for hip: previous trauma, fracture, subluxation, rheumatoid arthritis, previous hip surgery, bursitis, tendinitis, previously diagnosed congenital dysplasia, osteochondritis dissecans, septic arthritis or Perthes' disease) or co-morbidity that did not allow for physical evaluation and/or follow-up of at least 10 years was present, if malignancy in the past 5 years was established or if participants were unable to understand the Dutch language, they were excluded from the cohort [21, 22]. Participants were included from October 2002 to December 2005. The CHECK study was approved by the medical ethics committees of all participating centers and all participants had signed informed consent forms. For the current study, we used a subset of a previous study [3] that selected participants based on available radiographs of sufficient quality to perform the measurements on baseline and 5-year follow-up, which resulted in 720 participants (1391 hips), see Fig. 1 for details. For the current study, only the baseline radiographs were used.

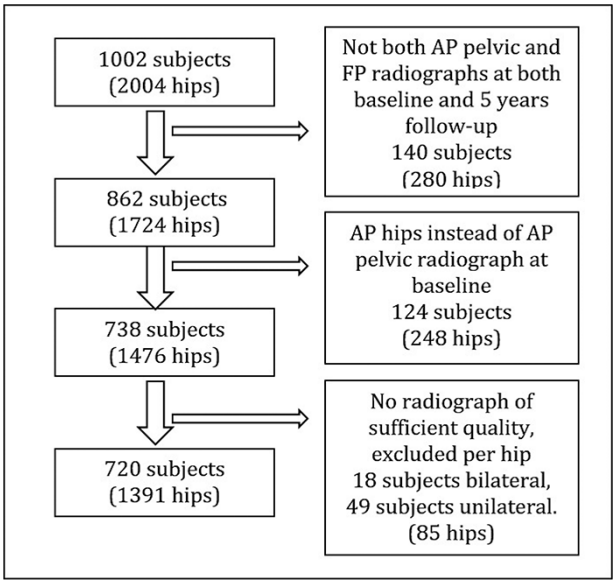

Fig. 1. Flowchart of hips from the start of the cohort to the study population.

Radiographs

At baseline, both an AP pelvic and FP hip view radiograph were obtained. A standardized protocol was used [21, 22] (Supplementary Appendix 1).

In short, the AP pelvic radiograph was made with the participant in weight-bearing position, placing their feet in 15° internal rotation and centered on the proximal edge of the symphysis pubis. The FP view radiograph was also made in weight-bearing position with a 65° angle between the wall bucky and the participants back (Fig. 2) [12, 20, 21].

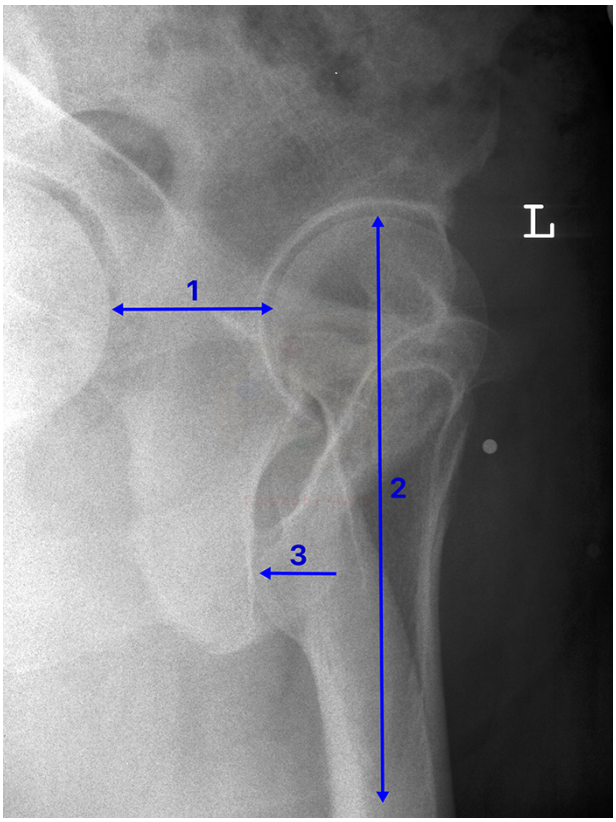

Fig. 2. A false profile (FP) radiograph of the hip. Showing the criteria of a sufficient FP view radiograph: (1) the distance between the two femoral heads should be between two and three thirds of the diameter of the targeted femoral head. (2) The same vertical line could be drawn from the center of the femoral head through the axis of the femoral neck and the femoral shaft. (3) The lesser trochanter minor is visible posteriorly.

Radiographic measurements

The shape of the proximal femur and acetabulum were outlined on both the AP pelvic and FP hip radiographs using statistical shape modeling (SSM) software (ASM tool kit, Manchester University, UK). With this software, a set of landmark points

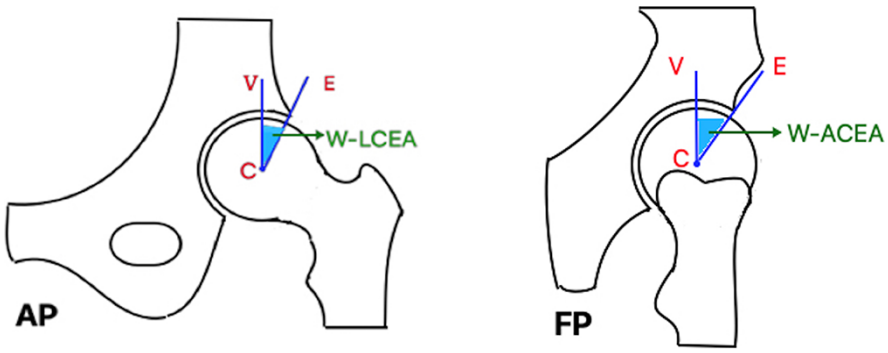

Fig. 3. Schematic drawing of the AP (left) and FP (right) view with respectively the Wiberg lateral centre edge angle (W-LCEA) and Wiberg anterior centre edge angle (W-ACEA). The W-LCEA is the angle between a vertical line(V) from the centre of the femoral head (C) and a second line from C tangential to the lateral margin of the acetabular weight bearing area (E). The W-ACEA is the angle between a vertical line (V) from the center of the femoral head (C) and a line drawn from C anf then tangential to the anterior margin of the acetabular roof (E).

were positioned along the surface of the bone in the image. Each point was placed on the same landmark of the outline. The points were positioned in all radiographs by three researchers. The W-LCEA and W-ACEA were automatically calculated from the point sets of the SSM software using a custom Matlab script (V.7.10). The calculated angle measurement is then visible on the radiograph and was visually checked to confirm that correct measurement has taken place.

On the AP pelvic radiograph, the W-LCEA is defined as the angle between a vertical line drawn upward from the most central point of the femoral head and a line from the central point tangential to the lateral margin of the weight-bearing area of the acetabulum (rather than the lateral rim of the acetabulum) [12, 13]. The central point of the femoral head was found by drawing a best-fitted circle around the femoral head based on the SSM point sets. The vertical line of the W-LCEA was drawn perpendicular to a horizontal line reference line between both obturator rings. A schematic drawing of measurement of the W-LCEA is visible in Fig. 3. DDH on the AP view was defined as a W-LCEA <20° and borderline DDH as a W-LCEA between 20 and 25° [1, 12, 14, 16].

On the FP view, the W-ACEA is the angle between the vertical line starting at the center of the femoral head and a line starting at the center of the femoral head and tangential to the anterior margin of the acetabular roof [8, 12, 20]. A schematic drawing of measurement of the W-ACEA is visible in Fig. 3. DDH on the FP view was defined as a W-ACEA <20° and borderline DDH as an A-LCEA between 20 and 25° [1, 12, 14, 16].

Excellent reliability and reproducibility has been reported previously with inter-observer intraclass correlation coefficients (ICC) 0.97 for the W-LCEA and 0.99 for the W-ACEA, and intraobserver ICCs ranging from 0.91 to 0.96 for the W-LCEA and from 0.97 to 0.99 for the W-ACEA [3].

Statistical analyses

The additional value of the FP view was assessed by examining the number and proportion of hips that were classified as DDH or borderline DDH on the FP hip view but not on the AP pelvic view. By using threshold values, it is anticipated that hips can be differently quantified although still quite similar, e.g. when a W-LCEA of 26° (normal) and a W-ACEA of 24° (borderline dysplasia) is found. In order to determine the linear relationship between the W-LCEA and W-ACEA, the Pearson correlation coefficient (after confirming a Gaussian distribution) was determined in all hips and hips that were classified as DDH, both in all hips with DDH as hips with DDH only visible on the FP view.

RESULTS

Participants

In Table I, we present baseline characteristics of the included participants. The baseline characteristics (age, gender, height and weight) of the 720 included participants did not differ from those of the 282 excluded participants.

Additional value of the FP view

In 74 out of 1391 hips (5.3%), DDH was present. In only 11 of those 74 hips (14.9%), DDH was present on both the AP pelvic and FP hip view. On the AP pelvic view, DDH was present in 42 hips (56.8%). However, on the FP view, another 32 (43.2%) hips with DDH were diagnosed. (Table II). Of the 32 hips with DDH only visible on the FP view, borderline DDH was present in 11 hips on the AP view (W-LCEA 20°–25°), while 21 hips had normal acetabular coverage (W-LCEA > 25°) on the AP view. The difference between the W-LCEA and W-ACEA in the hips with DDH established on the FP view ranged from −3.6° to 34.2°, with a mean difference of 9.4° (SD 8.09).

Borderline DDH was present in 205 out of 1391 hips (14.7%) on either view. Of those 205 hips with borderline DDH, 21 were already classified as DDH on the other radiographic view (AP or FP), resulting in 184 hips (13.2%) with borderline DDH (W-LCEA and/or W-ACEA between 20° and 25° and neither below 20°).

Correlation between the W-LCEA and W-ACEA

The Pearson correlation coefficient between the W-LCEA and W-ACEA of all included hips was 0.547 [95% confidence interval (CI): 0.503–0.591, $P < 0.001$]. The distribution of measurements in all hips is shown in the scatterplot in Fig. 4. The Pearson correlation coefficient between the W-LCEA and W-ACEA in

Table I. Baseline characteristics

	Total n = 720 (1391 hips)	*DDH[a] n = 64 (74 hips)*	*No DDH n = 709 (1317 hips)*
Age in years: mean (±SD)	56.0 (5.2)	57.4 (4.9)	56.0 (5.2)
Women, No (%)	572 (79.4)	52 (81.3)	563 (79.4)
BMI[b], kg/m^2: mean (±SD)	26.1 (4.2)	25.2 (3.1)	26.2 (4.2)
Length in cm: mean (±SD)	169.9 (8.2)	170.0 (8.6)	169.9 (8.2)
Weight in kg: mean (±SD)	75.5 (13.3)	72.9 (11.7)	75.3 (13.9)
Left side, No hips (%)	698 (50.2)	27 (36.5)	671 (50.9)
Both hips, No (%)	671 (93.2)	10 (15.6)	608 (85.8)
W-LCEA mean ° (±SD)	32.9 (6.9)	21.9 (6.8)	31.5 (5.7)
W-ACEA, mean ° (±SD)	35.8 (8.8)	21.3 (8.3)	35.5 (8.3)
K&L[c] grade 0, No hips (%)	1045 (76.3)	55 (74.3)	990 (76.4)
K&L[c] grade 1, No hips (%)	324 (23.7)	19 (25.7)	305 (23.6)

[a]Dysplasia: W-LCEA and/or W-ACEA were measured <20°.
[b]BMI: body mass index.
[c]K&L: Kellgren and Lawrence.

Table II. Distribution of patients with DDH or borderline DDH in groups by means of visibility on either both AP and FP view, only AP or only FP

Measured on	*DDH[a]*	*Borderline DDH[b]*
Both AP and FP view, No hips (%)	11 (14.9%)	30 (14.6%)
Only AP, No hips (%)	31 (41.9%)	104 (50.8%)
Only FP, No hips (%)	32 (43.2%)	71 (34.6%)
Total, No hips (%)	74 (100%)	205 (100%)

Thresholds W-LCEA and/or W-ACEA:
[a]Dysplasia <20°,
[b]Borderline dysplasia 20°–25°.

hips with DDH only ($n = 74$, W-LCEA and/or W-ACEA < 20°) was 0.441 (95% CI: 0.231–0.652, $P < 0.001$).

In the hips with DDH visible on the FP radiograph ($n = 32$), the Pearson correlation coefficient between the W-LCEA and W-ACEA was 0.017 (95% CI: −0.389–0.356, $P = 0.928$). Distribution of measurement of these hips is shown in the scatterplot in Fig. 5.

In the hips where borderline DDH was diagnosed and no DDH was present ($n = 185$, W-LCEA and/or W-ACEA 20–25° + no W-LCEA or W-ACEA <20°) the Pearson correlation was 0.415 (95% CI: 0.548–0.282, $P < 0.001$).

DISCUSSION

This study shows an additional value of the FP view in the radiographic identification of DDH. Over 40% of the dysplastic cases in this cohort were only detected on the FP hip view and not on the AP pelvic view. In the DDH diagnosed hips only visible on the FP view, we found no linear correlation between the W-LCEA and W-ACEA. This means that the lateral coverage of the acetabulum can be normal, while dysplasia can be present anteriorly. Therefore, when only using the W-LCEA, a significant number of hips with DDH will be missed.

Presently, there is no consensual diagnostic imaging workup for the hip suspected of DDH. However, the possibility of adding the FP view in the diagnostic workup for DDH has been mentioned in several studies [8, 12, 20]. Schmitz *et al.* [8] and Beltran *et al.* [12] investigated the ICC of the anterior center-edge angle (ACEA) on the FP view but also pointed out the limitation of the technical adequacy of the images caused by the superimposition of osseous structures. Both studies only focused on the ACEA and did not take the W-ACEA into account and therefore could not compare the ACEA on the FP view with the LCEA on the AP view. However, previous studies using three-dimensional imaging techniques already showed that the acetabulum is a complex acetabular structure with anterior and lateral coverage or both of importance in DDH [23–25].

The W-LCEA (also known as the W-CEA [20]) and W-ACEA are often confused with the LCEA and the ACEA. A small important difference is present however. This difference relates to the point where the lateral or anterior part of the acetabulum is defined. When measuring the LCEA, the point through the most lateral bony rim of the acetabulum is used, whereas the W-LCEA is measured through the lateral part of the weight-bearing area of the acetabulum [14, 20]. Therefore, the LCEA expresses the bony acetabular extension laterally, while the W-LCEA represents the weight-bearing coverage (supero)lateral [20]. In case of the ACEA and the W-ACEA, the same difference can be mentioned. The difference between the W-LCEA and the LCEA ranges from a mean of 2° to 3° up to much larger differences, mainly in dysplastic hips [26–28]. Using the W-LCEA as a diagnostic tool can therefore be seen as a more sensitive tool in the diagnostic workup for DDH.

Borderline dysplasia is not always described as a LCEA between 20° and 25°. In a previous study of McClincy *et al.*, the undetermination surrounding the treatment of hips with an LCEA between 18° and 25° is investigated [15]. The original description of Wiberg, however, states that hips with an LCEA <20° were considered pathological, hips with an LCEA >25° were normal and hips with an LCEA between 20° and 25° were considered uncertain [14]. This created confusion in the literature concerning the spectrum of dysplasia severity resulting in terms as mild dysplasia and borderline dysplasia using thresholds between 18° and 25° [15]. Our study followed the original thresholds as stated by Wiberg.

The additional value of the FP view has been described in the diagnosis of hip OA. In the study by Lequesne *et al.* [18], 72% of the hips without joint space narrowing on the AP view had joint space narrowing on the FP view in the anterosuperior or posteroinferior part of the joint [18]. Agricola *et al.* [3] also found a significant association between both lateral and anterior acetabu-

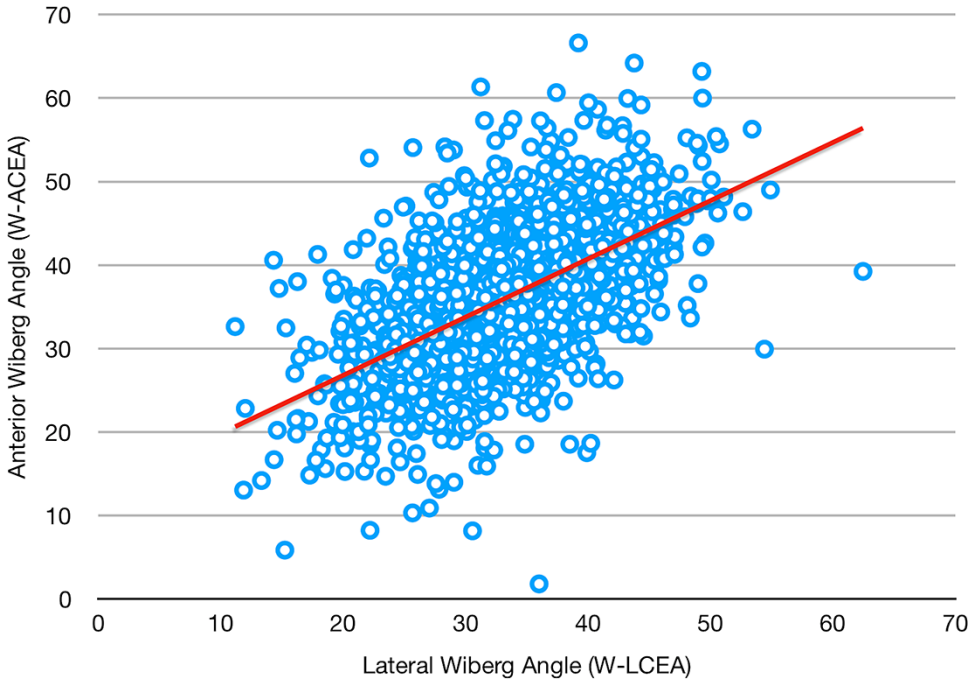

Fig. 4. Scatterplot of all hip measurements, showing the W-LCEA (*x*-axis) and the W-ACEA (*y*-axis) and the distribution of measurements. A Pearson correlation coefficient of 0.547 (95% CI: 0.503–0.591, $P < 0.001$) was found.

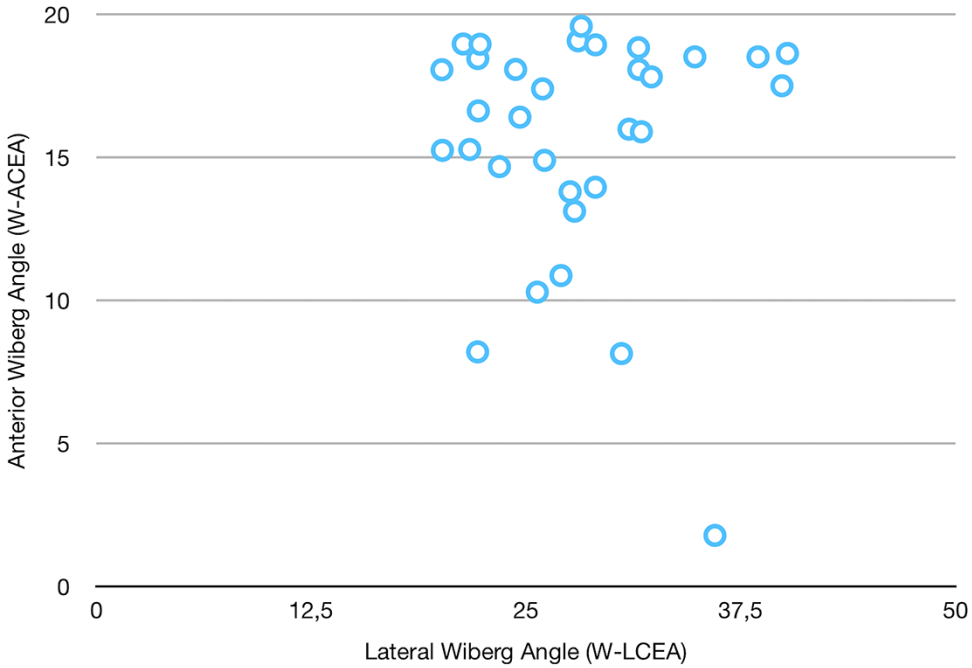

Fig. 5. Scatterplot of hips with DDH only found on the FP view. Showing the W-LCEA (*x*-axis) and the W-ACEA (*y*-axis) and the distribution of measurements. A Pearson correlation coefficient of 0.017 (95% CI: −0.389–0.356, $P = 0.928$) was found.

lar dysplasia and the development of hip OA. The strength of this association increases when dysplasia is present both anteriorly on the FP view and laterally on the AP view in one hip [3]. Therefore, adding the FP view pelvic radiograph, to assess the presence of dysplasia anteriorly, contributes significantly both to the diagnosis of DDH and the prediction of hip OA development.

DDH is a common disorder of the acetabulum, which can remain undetected despite screening in childhood. Delayed diagnosis or misdiagnosis of DDH can result in early onset of hip OA and total hip arthroplasty at a young age [4, 6, 7]. Early detection may allow for non-surgical treatment (such as activity modification, nonsteroidal anti-inflammatory drugs, physical

therapy and intra-articular corticosteroid injections) or surgical treatment and follow-up. Based on the findings of the present study, we recommend using an additional FP view in the first diagnostic workup when DDH is suspected in order to prevent delayed diagnosis.

An extra radiograph besides an AP pelvic view may raise concerns about radiation. The effective dose of a hip or pelvic radiograph is estimated at 0.6 mSv [29]. The background radiation level is about 3 mSv annually [29, 30]. Exposure to an individual dose of 50 mSv or a lifetime dose of 100 mSv has not been associated with health risks [29, 30]. Therefore, the radiation risk of obtaining one extra radiograph is limited.

The main strength of this study is the large sample size. The CHECK study is the first prospective follow-up study that offers a unique population to study hip pain in first presenters [6]. Another strength of this study is the semi-automatic measurements of the W-LCEA and/or W-ACEA. They have been computed automatically from the manually positioned SSM point sets. This has resulted in a high reliability because measurements were not influenced by the subjective assessment of a reader [3].

An important limitation of this study is that FP view radiographs cannot be adjusted for tilting of the pelvis, whereas on an AP view, a horizontal reference line can be drawn between the obturator rings to adjust for differences in positioning. This could potentially influence the W-ACEA measurement. Also, a two-dimensional representation (radiographs) might not always capture the true three-dimensional anatomy of the hip. For example, it has previously been shown that the anterior-wall index and posterior-wall index can differ when measured on radiographs as compared with computed tomography scans [31]. A second limitation is the age of the population studied (45–65 years), which is older than the typical age that first onset of complaints of DDH become apparent and hence the diagnosis of DDH. Although we cannot be absolutely sure that our results are generalizable to younger populations, we expect similar results in younger, skeletally mature patients, first, because DDH remains a condition with the involvement of both the anterior and lateral edge of the acetabulum. Second, there are no indications that acetabular coverage changes in adulthood after skeletal maturation, except for coxa protrusio. Third, in older populations, (early) OA might cause changes in acetabular coverage, e.g. by osteophytes. This is why we only included participants without definite OA.

In conclusion, there is a strong additional value of the FP view radiograph in the diagnosis of DDH. Our results show that over 4 out of 10 individuals with DDH could be missed when only performing an AP pelvic radiograph. The correlation between the W-LCEA and W-ACEA is moderate, meaning that hips with completely normal acetabular coverage on the AP view can still have DDH on the FP view. An AP pelvis and a hip FP view should be included in the diagnostic workup of suspected DDH.

DATA AVAILABILITY

None declared.

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SUPPLEMENTARY DATA

Supplementary data are available at *Journal of Hip Preservation Surgery* online.

CONFLICT OF INTEREST STATEMENT

None declared.

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