Pelvic orientation and assessment of hip dysplasia in adults

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Background The study was performed to qualify the source material of 4 151 pelvic radiographs for the research into the relationship between unrecognised childhood hip disorders and the development of hip osteoarthrosis, and to investigate the effect of varying degrees of pelvic tilt and rotation on the measurements of radiographic indices of hip dysplasia.

Material and methods We investigated the effect of varying pelvic orientation on radiographic measurements of acetabular dysplasia using a cadaver model. Results from the cadaver study were used to validate the radiographic assessments of acetabular dysplasia in the longitudinal survey cohort of the Copenhagen City Heart Study (CCHS; Osteoarthrosis Sub-study).

1) Cadaver pelvises and proximal femurs from a male and a female donor were mounted anatomically in holding devices allowing independent inclination/reclination and rotation. An AP pelvic radiograph was recorded at each 3° increment. The most widely used radiographic parameters of hip dysplasia were assessed. 2) Critical limits of acceptable rotation and inclination/reclination of pelvises were determined on 4 151 standing, standardised pelvic radiographs of the CCHS cohort.

Results Wiberg's CE angle, Sharp's angle, the x-coordinate of Goodman's Cartesian coordinate system, and the acetabular depth ratio were significantly affected by varying rotation and inclination/reclination of the cadaver pelvises. Femoral head extrusion index was not significantly affected within the applied rotation and inclination/reclination of the cadaver study. Application of the corresponding critical limits of Tönnis' foramen obturator index of 0.7–1.8 meant that 188 of 4 151 (4.5%) of the CCHS-III pelvic radiographs had to be omitted from further studies.

Interpretation To ensure a neutral starting point and reproducible readings, especially in epidemiological and clinical studies, and when performing preoperative planning and follow-up of patients undergoing redirectional pelvic osteotomies, it is important that all aspects of the radiographic examination are controlled and reproducible. Furthermore, we found that studies of acetabular dysplasia based on supine urograms or colon radiographs without information about pelvic orientation, centering of the X-ray beam and tube to film distance, run a serious risk of erroneous measurements. ■

Since Wiberg's doctoral thesis from 1939 on the relationship of hip dysplasia and subluxation to premature osteoarthrosis (OA), several studies have attributed from half to three fourths of so-called idiopathic coxarthrosis to residual joint incongruency in dysplastic hips (Wiberg 1939, Murray 1965, Stulberg and Harris 1974, Croft et al. 1991, Lau et al. 1995, Smith et al. 1995, Ali-Gombe et al. 1996, Inoue et al. 2000, Lane et al. 2000). Several indices and ratios have been developed to characterize dysplastic hip morphology in anteroposterior (AP) radiographs. However, there is no agreement on radiographic cut-off values of dysplasia leading to hip OA. Most studies of residual hip dysplasia and coxarthrosis in adults have been based on urograms or colon radiographs. Usually there is little

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or no information regarding rotation or inclination of the pelvis, the distance between tube and film, or centering of the X-ray beam.

To investigate the relationship between hip dysplasia and the development of OA, we classified 4 151 pelvis radiographs of adults of the osteoarthrosis sub-study cohort in the third Copenhagen City Heart Study (CCHS-III), according to widely used radiographic parameters. These measurements were correlated to measurements obtained from consecutive radiographs of cadaver pelvises mounted in holding devices that permitted gradual shift in rotation and inclination/reclination. We evaluated how pelvic rotation and inclination/reclination influenced radiographic parameters of dysplasia. A better understanding of this relationship might improve proper determination of hip pathology in epidemiological studies, provide knowledge for critical evaluation of future studies, and improve preoperative planning of redirecting pelvic osteotomies.

Materials and methods

Copenhagen City Heart Study (CCHS-III)

The CCHS is a longitudinal health survey of adult citizens of the county of Österbro in Copenhagen. The survey has registered their medical history, level of sports participation, occupational exposure, smoking, alcohol consumption, cardiopulmonary disease and musculosceletal disease since the beginning of 1976 (Schnohr et al. 2001).

From 1992 to 1994, 4 151 anteroposterior pelvis and lateral lumbar spine radiographs were obtained from the participants of CCHS-III. There were 1 533 male participants with an average age of 62 (23–93) years, and 2 618 female participants with an average age of 65 (22–92) years. Radiographs were obtained in the standing position. The feet were pointed straight forward, and the lower extremities were positioned in neutral abduction-adduction along the functional axis of the lower extremity. In AP pelvis radiographs the X-ray beam was centered two finger-breadths over the symphysis pubis in the vertical midline. The X-ray beam in lateral lumbar spine radiographs was centered at the apical midpoint of the iliac crista. Tube to film distance was 120 cm in all cases. Two radiographers obtained all the radiographs and aimed at neutral pelvic rotation during recording.

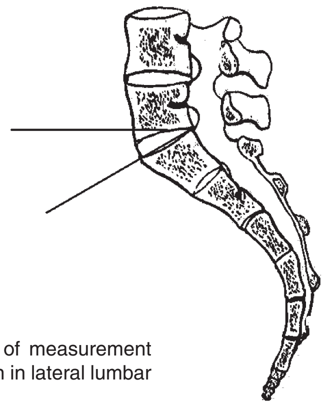


Figure 1. Method of measurement of pelvic inclination in lateral lumbar spine radiographs.

Parameters of CCHS radiographs

We measured pelvic inclination on lateral lumbar spine radiographs as the angle between the horizontal plane and a line parallel to the cranial articulating surface of the sacrum. All lumbar spine measurements were recorded by two investigators (HR and HM) (Figure 1).

We assessed hip morphology on AP pelvis radiographs by 1) Wiberg's center-edge (CE) angle (Wiberg 1939), 2) Sharp's angle (Sharp 1961), 3) the femoral head extrusion index of Heyman and Herndon (FHEI; Heyman and Herndon 1950), 4) Goodman's coordinate system (Goodman 1990), and 5) the acetabular depth ratio of Murray and Stulberg (ADR; Murray 1965, Stulberg et al. 1975) (Figure 2). The lateral margin of the sourcil was used to denote the lateral acetabular rim in relevant measurements. Pelvic rotation was assessed using Tönnis' foramen obturator index (FOI), where maximum horizontal width of the right obturator foramen was divided by left obturator foramen width (Tönnis 1976). All pelvic measurements were recorded by one investigator (SJ).

Cadaver pelvises

Pelvises and proximal femurs were obtained form one male donor aged 65 and one female donor aged 68, without known skeletal pathology or hip OA. All soft tissues were removed, except ligaments. The pelvises were mounted solidly and anatomically in specially constructed holding devices which permitted independent rotation and inclina-

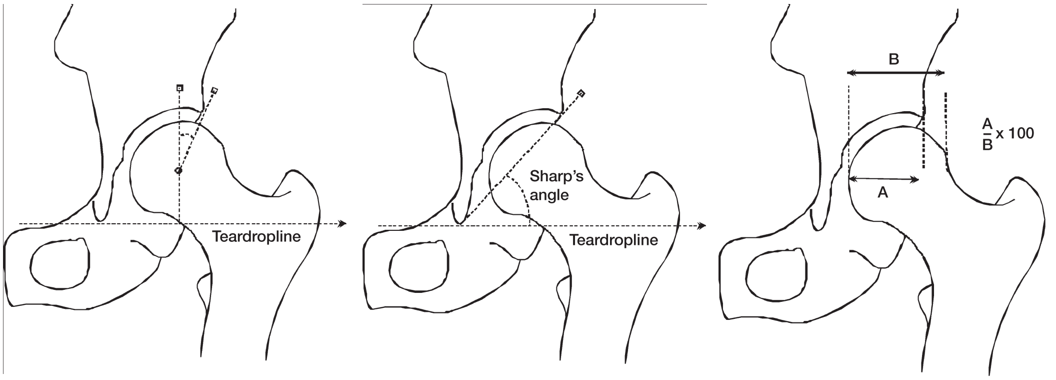
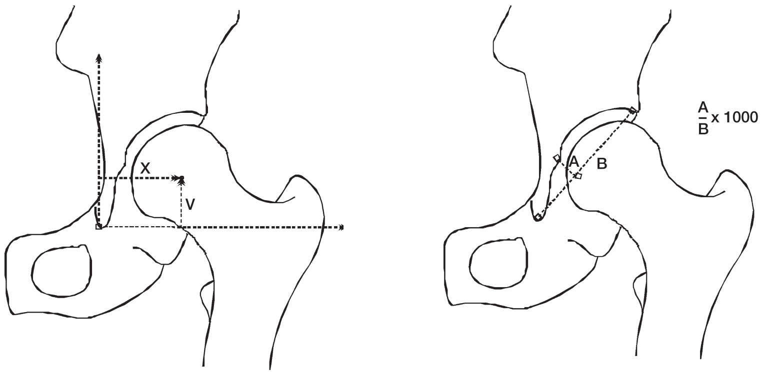


Figure 2. The CE angle of Wiberg. Sharp's angle. The femoral head extrusion index (FHEI)



Goodman's Cartesian coordinate system. The acetabular depth ratio (ADR).

tion (Figure 3). The transverse plane was defined by trial radiographs with horizontal alignment of the teardrop line. Neutral rotation was defined by an FOI of 1.0 in trial radiographs. A pelvic forward inclination of 38° was chosen as the starting point, defined by the median values of female and male pelvic inclinations of the CCHS-III material. The pelvises were rotated in 3° increments to the right and to the left, in an arc totalling 42°. The pelvises were tilted 12° forward (inclination) and 12° backward (reclination) from the starting point. Consecutive radiographs were obtained in starting positions and at each 3° increment. Tube to film distance was 120 cm and the X-ray beam was centered two finger-breadths above the symphyseal junction and perpendicular to the film. Distances and angles in each radiograph were assessed by the same methods as in the CCHS-III radiographs.

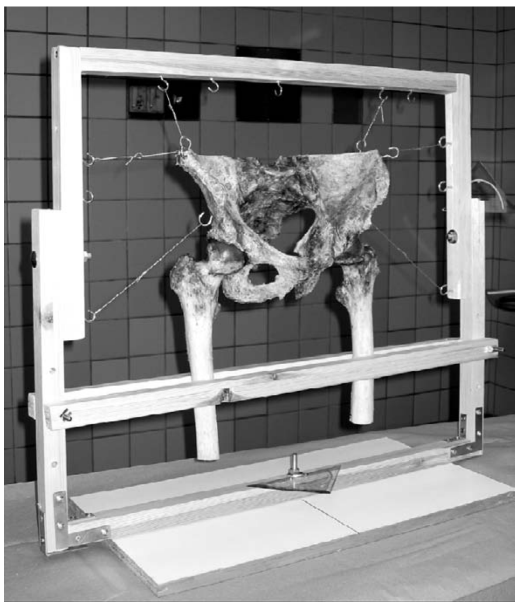


Figure 3. Male pelvis and femurs mounted in the holding device.

Statistics

We used linear regression analysis to assess the

Table 1. Measurements of acetabular dysplasia: the CCHS III cohort (n = 4,151)

Parameters	Right hip Median	SD [a]	Range	Left hip Median	SD [a]	Range
Men (n = 1,533)						
Pelvic inclination (°)	38.0	9.3	0.0–82.0	–	–	–
Acetabular width (mm)	75.0	4.6	60.0–92.0	75.0	4.7	62.0–93.0
Acetabular height (mm)	22.0	3.0	12.0–34.0	23.0	2.9	13.0–35.0
Acetabular depth ratio (ADR)	300	36.8	167–452	293	41.9	163–467
CE angle (°)	35.0	7.3	10.0–62.0	34.0	7.6	5.5–60.0
Sharp's angle (°)	37.0	3.5	26.0–54.0	37.0	3.6	23.0–50.0
X–coordinate (mm)	40.0	4.1	26.0–55.0	40.0	3.9	27–58
Y–coordinate (mm)	15.0	3.6	1.0–38.0	15.0	3.8	4.0–30.0
FHEI [b]	12.5	8.8	0.0–45.0	11.7	8.6	0.0–42.4
FOI [c]	1.0	0.2	0.4–2.3	–	–	–
Women (n = 2,618)						
Pelvic inclination (°)	38.0	9.5	0.0–89.0	–	–	–
Acetabular width (mm)	67.0	4.3	52.0–85.0	69.0	4.3	55.0–85.0
Acetabular height (mm)	20.0	2.8	8.0–38.0	20.0	2.8	10.0–30.0
Acetabular depth ratio (ADR)	306	40.9	107–543	300	39.4	151–476
CE angle (°)	35.0	7.5	7.0–65.0	35.0	7.9	0.0–67.0
Sharp's angle (°)	39.0	3.7	25.0–52.0	38.0	4.0	24.5–56.0
X–coordinate (mm)	33.0	3.6	19.0–57.0	35.0	3.5	22.0–50.0
Y–coordinate (mm)	15.0	3.2	4.0–30.0	15.0	3.5	4.0–33.0
FHEI [b]	8.0	7.9	0.0–46.3	7.4	7.7	0.0–45.0
FOI [c]	1.0	0.1	0.5–2.0	–	–	–

[a] Standard deviation from mean
[b] FHEI = Femoral head extrusion index (Heyman ans Herndon)
[c] FOI = Foramen obturator index (Tönnis)

effect of varying pelvic orientation on parameters of dysplasia in cadaver pelvises. A significance level of $p < 0.05$ was chosen. Statistical analysis was performed using the SPSS 11.5 statistical software (SPSS, Chicago, IL).

Results

Radiographic parameters of the CCHS III cohort

Table 1 summarizes measurements from the CCHS III cohort.

Radiographic parameters of the cadaver study

Median values, ranges, and results of the linear regression analyses (p and r^2) of the effects of varying pelvic orientation on parameters of dysplasia in the cadaver pelvises are presented in Tables 2 and 3. The linear relationships between varying rotation and FOI for the male and female cadaver pelvises are presented in Figure 4. The relationships observed between FOI and parameters of dysplasia are presented graphically in Figure 5 (male pelvis) and Figure 6 (female pelvis). Since FOI is the measurable parameter in daily clinical practise when evaluating pelvic radiographs, and a clear linear relationship has been established between rotation and FOI, the FOI has been used as the clinically relevant intermediary parameter in estimating effect of rotation on parameters of acetabular dysplasia.

Rotation of cadaver pelvises

Rotation of the cadaver pelvises through a total arc of 42° had significant effect on measured CE angles ($p < 0.001$), on Sharp's angles ($p < 0.001$), the acetabular depth ratio index ($p < 0.001$) and on Goodman's x-coordinate in both the male and the female cadaver pelvises. FHEI and Goodman's y-coordinate were not significantly affected. FOI ranged between 0.2 and 3.1 when the male cadaver pelvis was rotated through an arc of 42°, and it ranged between 0.4 and 3.1 in the female cadaver pelvis.

Table 2. The effect of right and left rotation on parameters of acetabular dysplasia in cadaver pelvises. The total arc of rotation was 42°

Parameters	Right hip Median	Range	(p/r^2 [a])	ΔFOI	Left hip Median	Range	(p/r^2)	ΔFOI
Male pelvis								
Acetabular width (mm)	60.0	58.0–62.0	(0.00/0.97)	–	60.0	56.0–63.0	(0.00/0.98)	–
Acetabular height (mm)	21.0	20.0–22.0	(0.79/0.00)	–	24.0	22.5–26.0	(0.34/0.06)	–
ADR (‰) [b]	3445	325–379	(0.14/0.15)	0.4–2.6	402	368–429	(0.01/0.38)	0.4–2.5
CE angle (°)	52.0	46.0–57.5	(0.00/0.97)	0.7–1.9	52.0	45.0–57.0	(0.00/0.98)	0.5–1.7
Sharp's angle (°)	28.0	23.0–34.0	(0.00/0.98)	0.4–1.8	28.0	23.0–34.0	(0.00/0.99)	0.5–1.7
X–coordinate (mm)	30.5	27.0–33.5	(0.00/0.94)	0.4–2.1	30.0	27.0–34.0	(0.00/0.95)	0.4–2.5
Y–coordinate (mm)	12.0	11.0–13.0	(0.50/0.03)	–	12.5	11.0–15.0	(0.14/0.15)	–
FHEI (%) [c]	10.0	5.8–10.4	(0.39/0.05)	–	6.0	5.0–7.0	(0.73/0.00)	–
FOI [d]	1.0	0.2–3.1	(0.00/0.93)	–	–	–	–	–
Female pelvis								
Acetabular width (mm)	58.0	54.0–62.0	(0.00/0.97)	–	57.0	50.0–63.0	(0.00/0.94)	
Acetabular height (mm)	16.0	15.0–17.0	(0.26/0.02)	–	15.0	14.5–16.0	(0.77/0.03)	–
ADR (‰) [b]	281	246–296	(0.00/0.38)	0.4–2.1	268	230–300	(0.00/0.80)	0.4–2.1
CE angle (°)	43.0	39.0–48.0	(0.00/0.96)	0.8–2.1	44.0	39.0–47.5	(0.00/0.95)	0.5–1.8
Sharp's angle (°)	31.0	28.0–34.5	(0.00/0.94)	0.4–2.4	30.0	28.0–34.0	(0.00/0.91)	0.4–1.8
X–coordinate (mm)	30.0	27.0–36.0	(0.00/0.71)	0.4–2.3	32.0	28.0–35.5	(0.00/0.74)	0.8–2.1
Y–coordinate (mm)	10.0	8.0–11.0	(0.94/0.00)	–	11.0	9.0–13.0	(0.39/0.05)	–
FHEI (%) [c]	10.8	9.4–13.6	(0.15/0.08)	–	–	–	–	–
FOI [d]	1.0	0.4–3.1	(0.00/0.85)	–	–	–	–	–

[a] p/r^2 = p is significance of linear regression analysis, with significance level set at < 0.05. r^2 is r–square value of analysis, [b] ADR = Acetabular depth ratio (acetabular height/acetabular width × 1000), [c] FHEI = Femoral head extrusion index (Heyman and Herndon), [d] FOI = Foramen obturator index (Tönnis), [e] ΔFOI = Variation in FOI affecting the parameter 2°, 2 mm or 10 ‰ on each side of the neutral starting point.

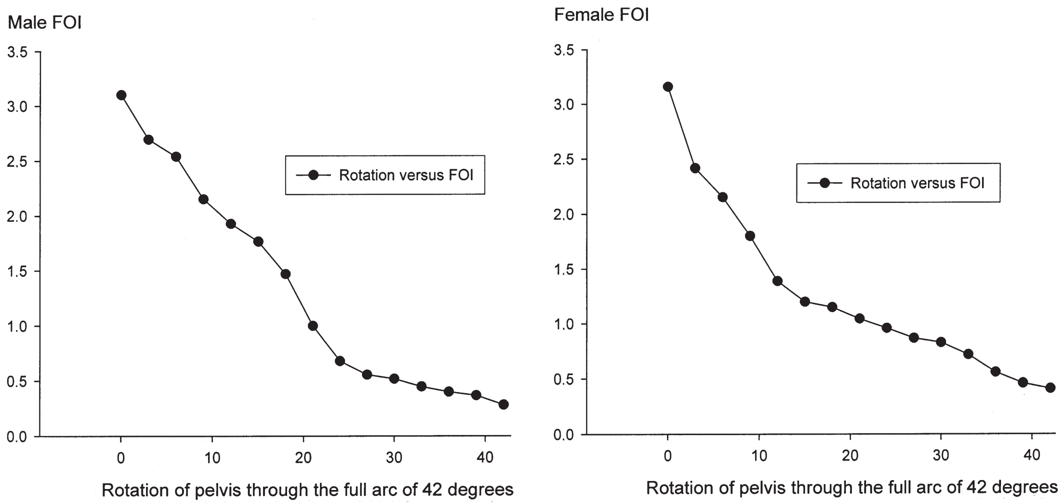


Figure 4. Association between pelvic rotation and foramen obturator index (FOI).

Inclination and reclination of the cadaver pelvises

Inclination/reclination of the cadaver pelvises through an arc of 24° also had significant effects on measured CE angles, and Sharp's angles. FHEI was not significantly affected by inclination/reclination in the male pelvic measurements (P_{right} = 0.83; P_{left} = 0.37). In the female pelvic mea-

Table 3. The effect of inclination and reclination on parameters of acetabular dysplasia in cadaver pelvises. Inclination: 40° to 28°, and reclination 40° to 52°

Parameters	Right hip Median	Right hip Range	(p/r^2) [a]	Left hip Median	Left hip Range	(p/r^2)
Male pelvis						
Acetabular width (mm)	60.0	59.0–62.0	(0.08/0.38)	60.0	57.0–61.0	(0.78/0.01)
Acetabular height (mm)	22.0	21.0–22.0	(0.64/0.00)	22.0	22.0–24.0	(0.20/0.29)
ADR (‰) [b]	367	339–373	(0.22/0.12)	377.0	367–400	(0.27/0.23)
CE angle (°)	51.0	48.0–54.0	(0.00/0.91)	53.0	52.0–57.0	(0.05/0.56)
Sharp's angle (°)	30.5	29.0–32.0	(0.05/0.56)	29.0	28.0–35.0	(0.51/0.08)
X–coordinate (mm)	32.0	30.0–33.0	(0.65/0.00)	30.0	30.0–31.0	(0.93/0.00)
Y–coordinate (mm)	12.0	12.0–13.0	(0.09/0.46)	12.0	10.0–15.0	(0.41/0.13)
FHEI (%) [c]	5.7	4.6–6.0	(0.83/0.00)	6.0	6.0–7.2	(0.37/0.16)
FOH [d]	36.0	31.0–50.0	(0.00/0.77)	40.0	33.0–55.0	(0.00/0.81)
Female pelvis						
Acetabular width (mm)	62.0	58.0–63.0	(0.00/0.68)	60.0	56.0–62.0	(0.04/0.46)
Acetabular height (mm)	16.0	15.0–16.0	(0.71/0.02)	16.0	15.0–17.0	(0.22/0.20)
ADR (‰) [b]	258	246–276	(0.12/0.30)	267	250–293	(0.03/0.43)
CE angle (°)	40.0	32.0–45.0	(0.00/0.93)	41.0	37.0–42.0	(0.00/0.68)
Sharp's angle (°)	31.0	30.5–33.0	(0.00/0.73)	30.0	28.0–32.0	(0.00/0.81)
X–coordinate (mm)	35.0	34.0–38.0	(0.49/0.06)	35.0	30.0–36.0	(0.66/0.02)
Y–coordinate (mm)	10.0	9.0–11.5	(0.94/0.00)	10.0	9.0–12.0	(0.06/0.40)
FHEI (%) [c]	14.5	14.0–15.2	(0.01/0.57)	11.3	10.8–11.9	(0.12/0.13)
FOH [d]	25.0	15.0–40.0	(0.00/0.98)	28.0	13.0–40.0	(0.00/0.00)

[a] p/r^2 = p is significance of linear regression analysis, with significance level set at < 0.05, r^2 is r–square value of analysis
[b] ADR = Acetabular depth ratio (acetabular height/acetabular width X 1000)
[c] FHEI = Femoral head extrusion index (Heyman and Herndon)
[d] FOH = Foramen obturator height.

surements, FHEI was significantly affected by inclination/reclination on the right side, but not on the left (P_{right} = 0.01; P_{left} = 0.12). ADR was not significantly affected by inclination/reclination in the male pelvic measurements (P_{right} = 0.22; P_{left} = 0.27). In the female pelvic measurements, ADR was affected on the left side, but not on the right (P_{righ}t = 0.12; P_{left} = 0.03). Goodman's x/y-coordinates were not significantly affected by varying inclination/reclination in either sex.

ΔFOI for relevant parameters is presented in Table 2. ΔFOI describes variation in FOI to affect the parameter in question, 2° for the CE-angle or Sharp's angle, or 2 mm of the X or Y coordinate of Goodman by rotation on each side of the starting point. ΔFOI is slightly narrower for CE angles than for Sharp's angles and Goodman's X-coordinates. To keep variation in measurements of CE angles due to pelvic rotation within ± 2°, ΔFOI should be kept within 0.7–1.8 in recorded radiographs. To keep variation of Sharp's angle within ± 2°, ΔFOI should be kept within 0.5–1.8. To keep variation of ADR within ± 10 ‰, ΔFOI should be kept within 0.4–2.1. Goodman's Cartesian coordinate system is particularly robust regarding variations of pelvic rotation and inclination, and ΔFOI is approximately 0.5–2.2 for the x-coordinate. The y-coordinate was not significantly affected by pelvic rotation or inclination/reclination. Applying the narrowest sets of limits of ΔFOI = 0.7–1.8 in rotation to the pelvic radiographs of CCHS-III (total range of FOI in rotation: 0.43–2.31), 188 of 4.151 (4.5%) of the radiographs had to be omitted from further analysis.

Discussion

Wiberg (1939) established a relationship between acetabular dysplasia and hip subluxation to development of secondary coxarthrosis. After measuring healthy hip joints, he constructed the CE angle, and established the normal distribution of the parameter. By comparing these measurements in

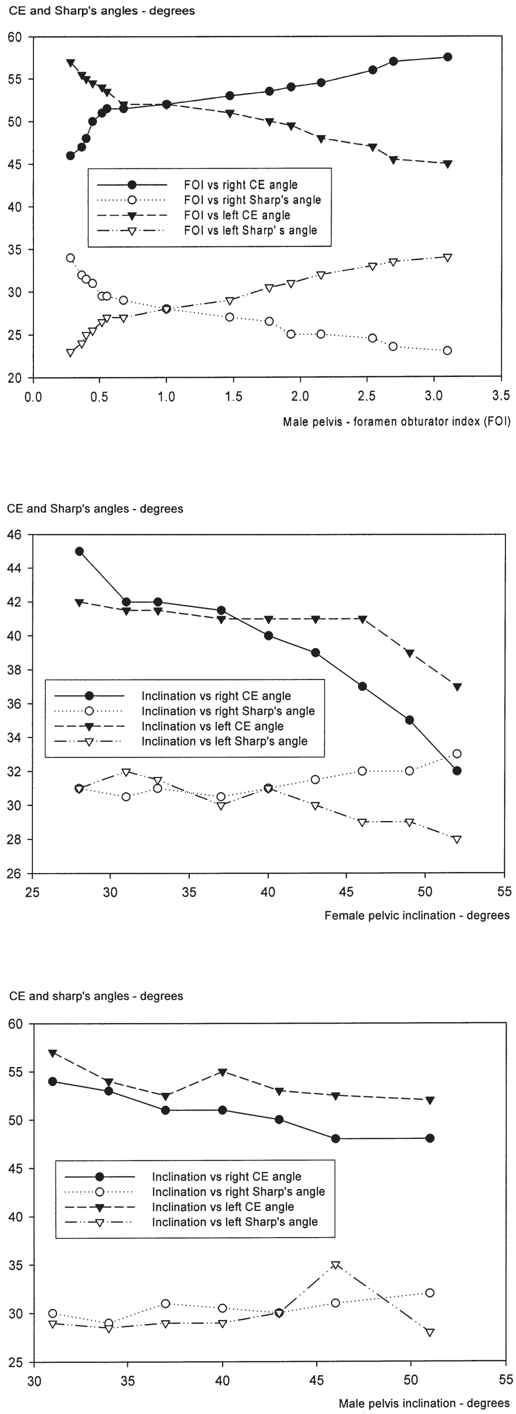


Figure 5. Male pelvis rotation (FOI) versus CE and Sharp's angles (top) and versus acetabular widths and X-coordinates (middle), and pelvic inclination versus CE and Sharp's angles (bottom).

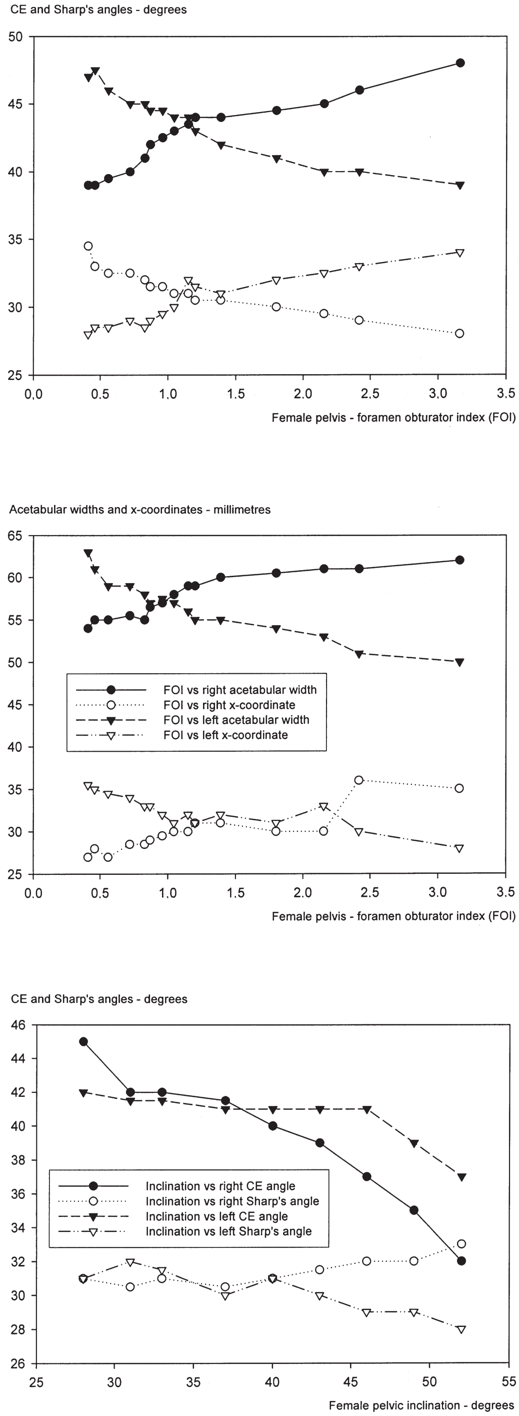


Figure 5. Female pelvis rotation (FOI) versus CE and Sharp's angles (top) and versus acetabular widths and X-coordinates (middle), and pelvic inclination versus CE and Sharp's angles (bottom).

36 adult cases of subluxation or dysplasia, Wiberg established the CE angle of 20° as the radiographic borderline between a normal and a dysplastic hip. Wiberg noted the effect of varying pelvic inclination on CE angle measurements, and observed a decrease of the CE angle of 2°–4° when the pelvis was tilted about 15° posteriorly in two consecutive radiographs. He also noted an effect on the CE angle in pelvic rotation, but did not do precise assessments.

Most authors agree that untreated severe dysplasia or subluxation of the hip invariably leads to OA. The underlying biomechanical concept hypothesizes that concentration of compressive stress in the reduced weight-bearing area of the dysplastic hip leads to accelerated degeneration of the articular cartilage. This hypothesis has been substantiated in mathematical, in vivo and in vitro studies (Afoke et al. 1987, Hadley et al. 1990, Bergmann et al. 1993, Maxian et al. 1995, Michaeli et al. 1997). However, neither the prevalence of unrecognized hip dysplasia in the population at large, nor the natural history of untreated mild to moderate dysplasia is known.

Most cross-sectional studies of the relationship between hip dysplasia and premature, secondary coxarthrosis are based on urograms or colon radiographs. Usually the studies are deficient regarding information on selection of patients and technique of X-ray recording (Croft et al. 1991, Lau et al. 1995, Smith et al. 1995, Ali-Gombe et al. 1996, Yoshimura et al. 1998, Inoue et al. 2000). Cut-off values of radiographic parameters are chosen somewhat arbitrarily in cross-sectional studies, the CE angle designating significant dysplasia ranging from 20° to 30°.

We found a highly significant effect of rotation and inclination on the CE angle, Sharp's angle, the acetabular depth ratio and, to a lesser extent, on Goodman's Cartesian coordinate system. FHEI was not significantly affected by rotation within a total arc of 42°. The CE angle is the most commonly used parameter of hip dysplasia, and it is the most vulnerable to varying rotation of the pelvis. We recommend that only pelvic radiographs with a foramen obturator index within 0.7–1.8 be used for assessment of acetabular dysplasia in adults. Other authors have found similar effects of pelvic tilting on the measurement on the acetabular index in children before skeletal maturity (Tönnis 1962, Ball and Kommenda 1968, Portinaro et al. 1995). Applying our limits to the CCHS-III cohort radiographs, 188 of 4 151 (4.5%) radiographs had to be omitted from analysis.

Pelvic inclination is naturally integrated into the patient's general posture and is difficult to correct at the radiographic examination. However, we have found that such examinations should be standardized in all other possible respects to ensure a neutral starting point and reproducible readings; especially in epidemiological and clinical studies, and when performing preoperative planning and follow-up of patients. Actualized by the now popular use of redirecting pelvic osteotomies to prevent secondary coxarthrosis in young patients (e.g. Ganz' osteotomy), there is a growing interest in hip dysplasia and procedures for correction (Ganz et al. 1988, Azuma and Taneda 1989, Murphy et al. 1999, Siebenrock et al. 2001, Sanchez-Sotelo et al. 2002, Tomlinson and Cook 2002). First referral and first preoperative planning is often founded solely on AP pelvis radiographs. Although some orthopedic surgeons usually wish to supplement radiographs with computerized tomography of the pelvis, knowledge of the variations of radiographic parameters in hip dysplasia due to malrotation is indispensable for decision-making regarding indication and surgical procedure. According to Anda (Anda et al. 1990), pelvic inclination in standing and supine pelvis radiographs shows insignificant variation; however, we prefer standing radiographs in analyzing hip dysplasia and coxarthrosis to obtain the most accurate representation of femoral head translation and joint space widths.

We have provided a useful quantitative basis for future cross-sectional and longitudinal radiographic and epidemiological studies on the relationship between childhood hip disorders and development of coxarthrosis.

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