

Abstract

Osteoarthritis (OA) presupposes the interaction of systemic and/or local factors. In hip joint OA, congenital or developmental malformation is believed to constitute an individual risk factor for premature degeneration. Hip dysplasia (HD) is such a malformation. The radiological and epidemiological studies had several aims:

- To critically evaluate the radiological source material of the Copenhagen Heart Study: The Osteoarthritis Substudy, consisting of 4,151 standardized, weight bearing pelvic radiographs recorded 1991–1994.
- To qualify or disqualify the radiological source material for further studies.
- To develop a comprehensible and reproducible radiographic discriminator of hip OA with as close an association to self reported hip pain as possible.
- To identify prevalences of hip OA and HD in a Caucasian, urban background population and investigate the influence of sex, age, physical and occupational parameters on these prevalences.
- To evaluate the influence of HD on hip OA development relative to other potential risk factors.
- To evaluate degeneration in dysplastic hips over time.
- To evaluate the three dimensional anatomy of HD and the distribution of degenerative features in severely dysplastic hips, and
- To evaluate risk factors for total hip replacement surgery.

In the course of the studies we found that assessments of classic indices of HD were significantly

influenced by pelvic orientation during x-ray recording and identified exclusion limits of rotation and inclination/reclination of pelvic radiographs to stay inside a measurement error of $\pm 3^\circ$. We found that minimum joint space width (JSW) ≤ 2.0 mm constituted a radiologic hip OA discriminator of superior reproducibility and clinical relevance compared to composite, radiological OA classifications. We documented a progressive postmenopausal decline in female minimum JSW, while male minimum JSW remained relatively unaltered throughout life. We found no evidence that smoking, occupational exposure to repeated, heavy lifting or overweight significantly influenced minimum JSW.

Prevalences of hip OA was approximately 5.5% in subjects ≥ 60 years of age, and HD prevalence was 4–10%, depending on the radiographic criteria applied. Age and HD were significant risk factors for hip OA development in women, and HD was found to be a significant risk factor for hip OA in men. However, only obesity was found to determine an event of hip replacement surgery.

In a longitudinal study of 81 subjects with mild or moderate hip dysplasia followed for a decade we did not document a tendency for radiological degeneration compared to 136 control subjects.

In a computerized tomographic study of severely dysplastic hips we found a close relationship between insufficient anterior, acetabular containment and proximal femoral anteversion. The primary area of degeneration in dysplastic hips was in the antero-lateral quadrant of the joint.

List of Papers

The thesis is based on the following articles, which will be referred to in the text by their Roman numerals (I–X).

- I Jacobsen S, Sonne-Holm S, Lund B, Søballe K, Kjær T, Røvsing H, Monrad H. Pelvic orientation and assessment of hip dysplasia in adults. *Acta Orthop Scand* 2004; 75: 721-29.
- II Jacobsen S, Sonne-Holm S, Søballe K, Gebuhr P, Lund B. The distribution and inter-relationships of radiologic features of osteoarthritis of the hip. *Osteoarthritis Cartilage* 2004; 12: 704-10.
- III Jacobsen S, Sonne-Holm S, Søballe K, Gebuhr P, Lund B. The relationship of hip joint space to self reported hip pain. *Osteoarthritis Cartilage* 2004; 12: 692-97.
- IV Jacobsen S, Sonne-Holm S, Søballe K, Gebuhr P, Lund B. Factors influencing hip joint space in asymptomatic subjects. *Osteoarthritis Cartilage* 2004; 12: 698-03.
- V Jacobsen S, Sonne-Holm S, Søballe K, Gebuhr P, Lund B. Radiographic case definitions and prevalence of osteoarthritis of the hip. *Acta Orthop Scand* 2004; 75: 713-20.
- VI Jacobsen S, Rømer L, Søballe K. Degeneration in dysplastic hips. A computer tomography study. *Skel Rad* 2005; 34: 778-84.
- VII Jacobsen S, Sonne-Holm S, Søballe K, Gebuhr P, Lund B. Joint space width in hip dysplasia. A case-control study of eighty-one adult subjects with hip dysplasia followed for a decade. *J Bone Joint Surg (Br)* 2005; 87-B:471-77.
- VIII Jacobsen S, Sonne-Holm S, Søballe K, Gebuhr P, Lund B. Hip dysplasia and osteoarthritis of the hip. *Acta Orthop Scand* 2005; 76: 149-58.
- IX Jacobsen S, Sonne-Holm S. Hip dysplasia: a significant risk factor for the development of hip osteoarthritis. A cross-sectional survey. *Rheumatology* 2005; 44: 211-18.
- X Jacobsen S, Sonne-Holm S. Increased body mass index is a predisposition for treatment by total hip replacement. *Int Orthop* 2005; 29: 229-34.

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shared insights into soft tissue lesions associated to hip joint dysplasia, and their role in the pathology of degeneration. From the University Hospital of Aarhus, I am grateful for the support and contributions from Professor Kjeld Søballe and Dr. Lone Rømer. The Research Board of the National University Hospital of Rigshospitalet, the Danish Medical Research Council, the Danish Rheumatism Association, the SAHVA Foundation, and Sygekassernes Helsefond supported the studies.

I dedicate this thesis to my two daughters Ida and Thea.

Summary of Papers

I – Pelvic orientation and assessment of hip dysplasia in adults

In a cadaver study we found that common AP radiographic indices of hip dysplasia (HD) were significantly affected by pelvic orientation during recording. Epidemiological studies of HD based on supine urograms or abdominal radiographs without standardized pelvic orientation and recording techniques run a serious risk of erroneous measurements and faulty conclusions.

II – The distribution and inter-relationships of radiologic features of osteoarthritis of the hip

The inter-relationships of radiologic features of hip joint degeneration were investigated in 4,151 pelvic radiographs of the Copenhagen Osteoarthritis Substudy (COS) cohort. The influence of sex, age, physical and occupational parameters on these features was determined. Only age influenced minimal joint space width (JSW). The presence of subcondral cysts had the highest predictive sensitivity in regard to pathologically reduced JSW.

III – The relationship of hip joint space to self reported hip pain

1) The influence of cadaver pelvic orientation on repeated measurements of hip JSW was investigated. 2) The relationship between JSW and self reported hip pain of the COS cohort was investigated. The assessment of JSW was not significantly influenced by spatial orientation of the pelvis in X-ray recordings. Minimum JSW ≤ 2.0 mm was significantly associated to self-reported hip pain, and seems to be a valid radiographic hip OA discriminator.

IV – Factors influencing hip joint space in asymptomatic subjects

The aims of the study were to investigate the normal course of hip JSW development in asymptomatic subjects of the COS cohort, and the influence of individual parameters on hip JSW. Minimum JSW decreased progressively with age in women, but remained relatively unaltered in men

throughout life. A history of smoking or different exposure to repeated daily lifting did not influence hip JSW significantly, nor did differences in Body Mass Index (BMI).

V – Radiographic case definitions and prevalence of osteoarthritis of the hip

Formation of cysts, osteophytes and subcondral sclerosis were encountered most often in men. Composite OA classifications emphasizing secondary features of sclerosis, osteophytes and cysts runs the risk of inflating male hip OA prevalence, while underestimating hip OA prevalence in women. Applying a JSW cut off values of ≤ 2.0 mm, radiologic hip joint OA prevalence in subjects ≥ 60 years of age ranged from 4.4% to 5.3%.

VI – Degeneration in dysplastic hips

A CT analysis of degeneration and morphology was performed in 193 patients with moderate to severe HD. The formation of cysts and osteophytes were significantly associated with reduced JSW in dysplastic hips. However, the majority of degenerative features were encountered in hips with normal JSW. Paralabral cyst formation and lateral acetabular avulsions were characteristic features of dysplastic hips. Degeneration in dysplastic hips develops antero-laterally.

VII – Joint space width in hip dysplasia

A longitudinal study of 81 adult subjects with hip dysplasia and 138 control subjects followed for a decade. We found no significant differences in JSW reduction between subjects with mild to moderate HD and control subjects at follow-up radiographic examination, nor were there any significant differences in self reported hip pain.

VIII – Hip dysplasia and osteoarthritis of the hip

The study of 4,151 pelvic radiographs of the COS cohort documented that HD is not uncommon in the population, and that radiographic parameters of HD were closely interrelated. Non-adjusted odds

ratios of radiologic OA secondary to HD ranged from 1.0 to 6.2, depending on the radiologic criteria employed.

IX – Hip dysplasia: a significant risk factor for the development of hip osteoarthritis

HD prevalence in the background population ranged from 5.4% to 12.8% depending on the radiographic index applied. Of factors entered into logistic regression analyses only age and HD were significantly associated with hip OA prevalence in women, and only HD in men.

X – Increased body mass index is a predisposition for treatment by total hip replacement

To determine individual risk factors of OA, hip pain and treatment by THR, radiologic and epidemiologic data of 4,151 subjects followed from 1976 to 2003 were investigated. Sequential BMI measurements from 1976 to 1992, age, exposure to daily lifting and hip dysplasia were entered into logistic regression analyses. While radiologic OA was significantly influenced by hip dysplasia and age, the risk of THR being performed was only influenced by BMI assessed in 1976.

Abbreviations

AA	Acetabular Angle.
AASA	Anterior Acetabular Sector angle.
AcAV	Acetabular Anteversion.
ADR	Acetabular Depth Ratio.
AP	Antero Posterior x-ray imaging plane.
BMI	Body Mass Index.
CE	Center Edge angle.
CT	Computer Tomography imaging.
COS	Copenhagen Osteoarthritis Substudy.
FeAV	Femoral Anteversion.
FHEI	Femoral Head Extrusion Index.
FOI	Foramen Obturator Index.
GP	General Practitioner.
GRP	Gross National Product.
HASA	Horizontal Acetabular Sector Angle.
HD	Hip Dysplasia.
JSW	Joint Space Width.
OA	Osteoarthritis.
OR	Odds Ratio
PASA	Posterior Acetabular Sector Angle.
THR	Total Hip Replacement.
3-D	Three dimensional.

The Copenhagen City Heart Study (CCHS): The Osteoarthritis Substudy (COS)

The CCHS is a longitudinal health survey of an adult, Caucasian cohort from the county of Österbro in Copenhagen, Denmark, recruited by a random social security number algorithm. The survey has registered life style factors and medical history of the participants four times since its beginning of 1976 (Schnohr et al. 2001).

The total CCHS III cohort of 1991 consisted of 10.135 subjects. From the cohort 2.949 (1.023M/1.926F) subjects were selected for radiog-

raphy of the pelvis and lumbar spine (economic considerations were prohibitive for complete inclusion of the cohort). Inclusion criteria into the radiography protocol were positive answers in four or more of 50 main questions with up to 5 sub questions in a questionnaire covering musculo-skeletal disorders. In addition, 1.202 subjects (533M/669F), with three or fewer positive answers were selected as sex and age matched controls for radiography. For the purpose of the present studies, extensive independent samples t-tests were performed to make sure that control subjects and primarily selected subjects did not differ significantly in regard to minimum JSW, other radiological evidence of hip joint degeneration, occupation, smoking habits, body mass index (BMI), height and weight. No significant differences were found, and the two groups were pooled to gain the best possible statistical strength for the ensuing studies.

The cohort consisted of 1,533 men with an average age of 62.5 years (range, 23–93 years), and 2,618 women with an average age of 65.0 years (range, 22–92 years).

Antero-posterior (AP) pelvic and lateral lumbar spine radiographs were obtained. Radiographs were recorded standing. Feet pointed straight forward, and lower extremities were positioned in neutral abduction-adduction along the functional axis. In AP pelvic radiographs the X-ray beam was centred two fingerbreadths over the symphysis in the vertical midline. The X-ray beam in lateral lumbar spine radiographs was centered at the apical midpoint of the iliac crest. Tube to film distance was 120 cm in all cases. Two radiology technicians recorded all radiographs

1. Introduction

Osteoarthritis (OA) accounts for the majority of musculoskeletal disability. OA disables about 10% of individuals older than 60 years, and expenditures related to OA amounts to 1.5–2.0% of Western countries' GNP. The incidence of OA increases with age; and the prevalence and burden of this disorder is progressing rapidly (Buckwalter et al. 2004). Although OA has a characteristic clinical course and distinctive radiology, the aetiology remains elusive. It is uncertain whether OA is a singular entity or the manifestation of different diseases that share a common pathological pathway (Jordan et al. 2000, Birchfield 2001).

OA is pre-conditioned by the interaction of systemic and local factors, unique for each joint system. Certain, significant risk factors have been identified for knee OA, such as repetitive impact loading, prior meniscal injury, ligamentous instability or obesity, while hand OA probably for a large part is determined by heritability, and hip OA can be caused by joint incongruence due to developmental or congenital malformations (Cicuttini and Spector 1995–1996, Cicuttini et al. 1996, Lanyon 2000, Spector 1996). Common for all manifestations of OA is the fact that elderly women are significantly more affected by symptomatic degenerative joint disease compared to men (Oliveira et al 1995, Hochberg 1991, Felson et al. 1995). In Anglo-Saxon literature OA is thus often referred to as *postmenopausal arthritis*. Recent studies have documented increased cartilage-specific collagen type II degradation products (CTX-II) in postmenopausal women Newitt et al. 1996, Mouritzen et al. 2003, Christgau et al. 2004, Hoegh-Andersen et al. 2004).

In the hip joint, biomechanical factors seem to be important in OA development. A number of supposedly idiopathic cases of hip OA can be traced back to disruption of joint congruency caused by unrecognized childhood hip disorders; Calvé-Legg-Perthes disease, slipped capital femoral epiphysis or hip dysplasia (HD). These cases can henceforward be more accurately termed as secondary hip OA (Boles and el Khoury 1997, Bombelli 1997,

Stulberg 1974a, 1975b, Cooperman et al. 1983a, 1993b, Goodman et al. 1997).

Since Wiberg's doctoral thesis on the subject (1939), residual hip dysplasia has been acknowledged as a potentially pre-osteoarthritic condition causing hip OA development in younger individuals. HD is probably the most common hip disorder, although precise incidences or prevalences are unknown. Wynne-Davies' (1970a, 1970b) pioneering work in Edinburgh and Glasgow demonstrated that HD (or *late-diagnosis congenital dysplasia of the hip*) is in all likelihood polygenetically inherited. However, accurate heritability factors have never been estimated and HD-specific genetic polymorphisms or candidate genes has not, to my knowledge, been identified in the human genome. HD must not be confused with congenital dislocation of the hip (CDH), in which there is an intracapsular displacement of the femoral head prior to, or shortly after birth (Wedge and Wasylenko 1978, Weinstein 1987). Prevalences of HD have inter-racial variations, and HD is most often encountered in Asians (Lau et al. 1995–1996, Inoue et al. 2000).

Mathematical, *in vivo* and *in vitro* studies have demonstrated that the reduction in articulating area associated with HD jeopardizes the optimum distribution of load forces across the joint, whereby articular cartilage may be damaged directly Murray and Crim 2001, Maxian et al. 1995, Macirowski et al. 1994, Hadley et al. 1990, Afoke et al. 1987, Bergmann et al. 1993, Brown and Digioia 1984). Furthermore, an incongruent hip joint places abnormal stress on supporting soft tissue structures, and labral and anterior capsular lesions believed to be secondary to HD have been observed consistently in hip arthroscopy and MRI studies (McCarthy et al. 2001a, 2002b, 2002c, Byrd and Jones 2003, Kubo et al. 2000). Once the acetabular labral seal is compromised, and the watershed zone between the bony and the fibrocartilaginous acetabulum is exposed, synovial fluid pressure tends to delaminate cartilage from the subcondral bone in a lateral to medial progression (Ferguson et al. 2002a,

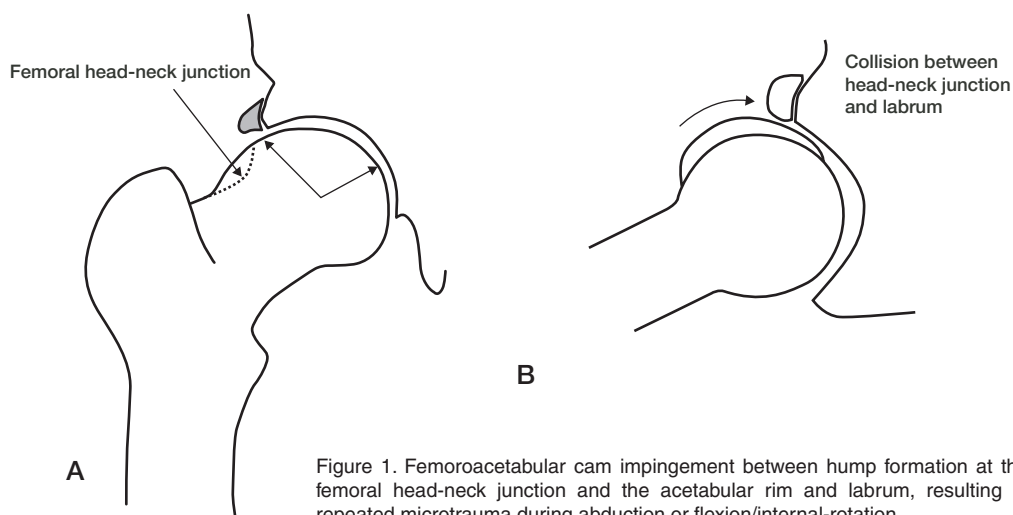


Figure 1. Femoroacetabular cam impingement between hump formation at the femoral head-neck junction and the acetabular rim and labrum, resulting in repeated microtrauma during abduction or flexion/internal-rotation.

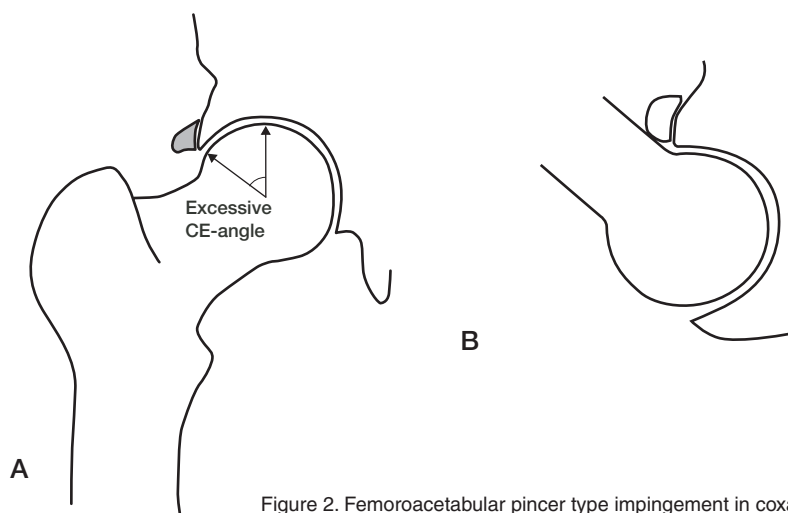


Figure 2. Femoroacetabular pincer type impingement in coxa profunda.

2003b). Subluxation of the hip joint or untreated severe dysplasia will invariably lead to OA, but the rate and extent of secondary OA development in mild to moderate HD is unknown.

The Bern Hip Group by Reinhold Ganz (2003) and Michael Leunig (2004) has focused our attention on femoroacetabular impingement as a principal cause of labral lesions. Femoroacetabular impingement may be due to a) hump or pistol-grip deformity of the femoral head-neck junction resulting in an increase in the radius of the femoral head and an increase in mismatch between the femoral head and acetabular socket during flexion and internal rotation, thereby causing repeated collision between the femoral-head junction and the

acetabular labrum; *Cam Impingement* (Figure 1) (Ito et al. 2001), b) an overtly deepened acetabular socket, *coxa profunda*, or retroverted acetabulum causing impingement between the femoral head neck junction and the supero-anterior portion of the acetabulum; *Pincer Impingement* (Figure 2 and 3) (Reynolds et al. 1999, Mast et al. 2004), or c) shearing or *subluxating impingement* of the femoral head against the labrum in the steep and shallow acetabulum characteristic of the “classical” dysplastic acetabulum (Figure 4) (Leunig et al. 2001). Whatever the malformation, femoroacetabular impingement results in repeated microtrauma to the acetabular rim. The labrum becomes hypertrophied and susceptible to fraying, tearing

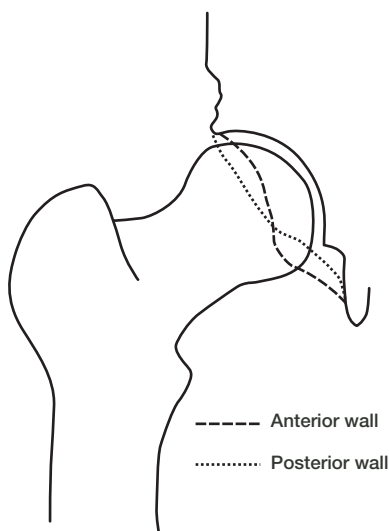


Figure 3. Retroverted acetabulum. The anterior wall being larger than the posterior wall. The cross-over phenomenon is observed in AP hip radiographs.

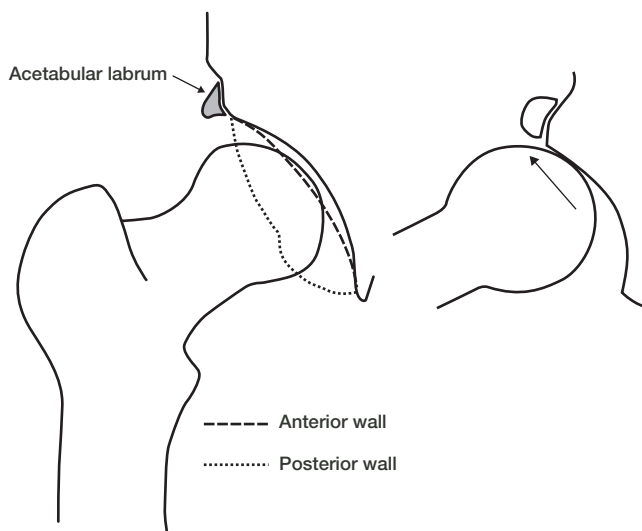


Figure 4. Femoroacetabular shearing or subluxating impingement in the shallow and steep dysplastic acetabulum

and ultimately detachment, and the degenerative process is initiated in earnest (Kubo et al. 2000, Klaue et al. 1991a, 1997b).

Studies in the clinical epidemiology of hip OA and the role of dysplastic malformation has been impaired by the following limitations: a) the use of pelvic radiographs in epidemiological studies recorded for other purposes, i.e. urograms or abdominal radiographs without precise information on pelvic orientation or recording techniques b) the lack of consensus definitions of radiologic OA and HD (Altman et al. 1987, Croft et al. 1990, Lanyon et al. 2003, Spector and Cooper 1993), c) the notorious discrepancy between symptomatic and radiologic OA, d) absent knowledge of the natural history of hip joint morphology relative to sex and age in *asymptomatic* subjects; for instance in regard to

joint space width (JSW), e) absent knowledge of prevalences of developmental hip joint malformation in the general population, f) the lack of long term case controlled studies of HD patients, g) the lack of studies evaluating the importance of hip dysplasia in hip OA development relative to other potential risk factors, f) an incomplete knowledge of the pathological pathway leading from A: hip dysplasia, to B: manifest hip joint degeneration, and g) the lack of case controlled morphometric studies of the complex 3-D dysplastic anatomy in larger cohorts.

These are limitations one has to address in order to arrive at valid conclusions of the relationship between hip dysplasia and premature OA development.

2. The radiology of hip dysplasia

2.1 Radiographs

Standard AP pelvic radiographies constitute the primary source material in epidemiological studies of HD. Several indices and ratios have been developed to characterize 2-D dysplastic morphology. Some of these indices are complex and time consuming to assess and do not seem to hold any advantage over better-known, simpler indices (Tönnis 1984).

The 2-D acetabular anatomy can be assessed geometrically by Sharp's angle (1961), the acetabular angle (AA; obliquity of the weight bearing dome relative to the horizontal axis), or Stulberg and Cooperman's acetabular depth to width ratio (ADR) (1974, 1983). The position of the femoral head to the acetabular cavity is usually assessed by Wiberg's Center-Edge angle (CE) (1939) or Heyman & Herndon's (1950) femoral head extrusion index (FHEI) (Figure 5). There are no rock solid cut-off values designating certain HD. Most authors agree that a center edge (CE) angle of less than 20° is definitively dysplastic, and that a CE angle between 20° and 25° is borderline dysplastic, while a CE angle $> 25^\circ$ is normal. AA $> 15^\circ$, FHEI $\geq 25\%$, Sharp's angle $> 45^\circ$, and ADR ≤ 250 are widely used cut off values, and corresponds approximately to mean values $\div 2$ SD (Fredensborg 1976, VI, VIII, IX). A broken Shenton's line > 5 mm defines subluxation of the hip joint in our studies. The typical dysplastic hip has a shallow and wide acetabular cavity with an excessively oblique articulating dome, deficient anterior and lateral containment of the femoral head, and a hypertrophied rim. The femoral head in HD is usually perfectly rounded, but is migrated laterally; reducing weight-bearing area between dome and head. Dysplastic hip joint anatomy is usually transmitted distally resulting in a rotational deformity of the femoral diaphysis producing excessive anteversion of the femoral neck (Noble et al. 2003, Butler-Manuel et al. 1991, Byrd and Jones 2003, Cardinal and White 1992, Delaunay 1997, Dutoit and Zambelli 1999, Janzen et al. 1998, Kubo et al. 2000, VI).

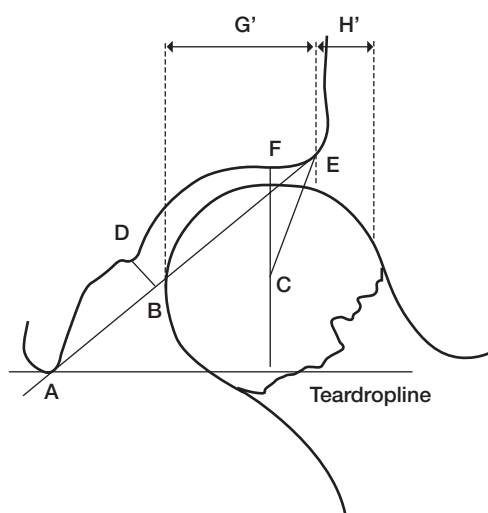


Figure 5. Radiologic indices of hip dysplasia. 1) The CE-angle describes the angle between a perpendicular line to the horizontal teardrop line drawn through the center of the femoral head (C), and a line from C to the lateral edge of the acetabulum. 2) The acetabular depth to width ratio ADR describes the relation of the distance A–E of the distance D–B. 3) The femoral head extrusion index FHEI assesses the percentage of the distance H' (part of the femoral head diameter lateral to Perkin's line) of the distance H' + G'. Sharp's angle (A–E) is the angle of the acetabular lateral aperture relative to the teardrop line.

Most epidemiological studies of residual hip dysplasia and OA in adults are based on urograms or colon radiographs. Usually scarce information is provided regarding rotation or inclination of the pelvis, the distance between tube and film, or centering of the x-ray beam (Ali-Gombe et al. 1996, Croft et al. 1991, Lau et al. 1995, Inoue et al. 2000, Smith et al. 1995). However, assessment of HD is critically influenced by spatial pelvic orientation during recording. Jacobsen et al. observed a significant effect of varying rotation and varying inclination/reclination on the CE- angle, Sharp's angle, and ADR in a radiographic cadaver pelvis study, while 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 is the most vulnerable in regard to varying rotation of the pelvis (*exemplified by the male pelvis in*

Figure 6, I). The authors recommended that only pelvic radiographs with Tönnis' foramen obturator index (FOI) (in which the widest horizontal diameter of the right foramen obturator is divided with the left diameter) within 0.7–1.8 are used in the assessment of acetabular dysplasia in adults to stay inside a measuring error of $\pm 3^\circ$ when measuring the CE-angle. Ball and Kommenda 1968, Tönnis 1976, and Portinaro et al. 1995 have found similar effects of pelvic tilting on measurements of the acetabular index in children. Applying the recommendations to 4,151 standardized, weight-bearing pelvic radiographs of the COS cohort, 188 (4.5%) radiographs had to be omitted from further analyses (I).

Pelvic inclination is difficult to correct at the radiographic examination. However, recordings in all other aspects ought to be standardized to ensure a neutral starting point and reproducible readings. A growing interest in hip dysplasia and re-directional pelvic osteotomies to restore sound biomechanics of the hip are emerging (Ganz 1988, Gillett 2002, MacDonald et al. 1997, Klaue et al. 1988, Søballe 2003, Mechlenburg et al. 2004). First referral and first preoperative planning are often based solely on AP pelvic radiographs. Although most orthopaedic surgeons supplement radiographs with computerized tomography of the pelvis, knowledge of the variations of radiographic parameters of hip dysplasia due to malrotation is indispensable for further decision-making. According to Anda et al. (1990), pelvic inclination in standing and supine pelvic radiographs only varies insignificantly; however, standing radiographs when analyzing HD and OA is to be preferred to obtain the most accurate representations of femoral head translation and JSW. In a study of 4,151 pelvic radiographs of the COS cohort, Jacobsen et al. applied FOI inclusion limits of 0.7–1.8 to radiographs. Furthermore, pelvic inclinations outside 2 SD of the mean were omitted from the study. Median pelvic inclination was measured in lateral lumbar spine radiographs as the angle between the horizontal plane and a line parallel to the cranial articulating surface of the sacrum. Mean pelvic inclination was 38° (0° – 82°), and 1 SD was 9.4° . Inclusion limits of pelvic inclination thus ranged from 19° to 56° (VIII). Due to orientation criteria a total of 314 radiographs (7.6%) were omitted. Male hips were slightly more dysplastic

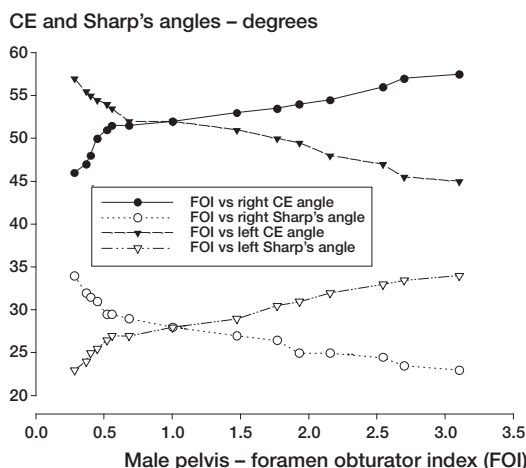


Figure 6. Male pelvic rotation (expressed as FOI), and the influence on repeated measurements of the CE angle and Sharp's angle.

than female hips. However, the sex-related differences in overall hip morphology were negligible for all practical purposes. The CE-angle, ADR, Sharp's angle and FHEI were significantly interrelated. Median values, SD's, interrelationships, and sex related differences are summarized in Table I.

Prevalences of unilateral and bilateral mild to moderate HD prevalences are summarized in Table II (VIII, IX). In Jacobsen et al.'s material there were no cases of hip subluxation or severe HD (\sim CE $< 0^\circ$).

In regard to dysplastic parameters, Jacobsen et al.'s results agree with other authors'. In healthy adults, Stulberg (1975) found average CE angles of 37° (26° – 48°) in men, and 35° (24° – 46°) in women. Murphy et al. (1990) found angles averaging 37° . Cut off values for definite dysplasia vary considerably. Wiberg (1939) found a physiological range of 20° – 40° in normal adults. Tönnis (1976) estimated values of the normal ranging between 26° and 30° at 17 to 20 years of age. The same range was found by Fredensborg (1976) in adults. The parameter is the most widely used, but has some limitations. The CE angle decreases in coxae magna; which increases the head radius, and in subluxation, where the head center migrates laterally and superiorly. The angle increases in coxae plana, where the femoral head center moves cranially, and in OA where the femoral head center migrates cranially due to reduced cartilage height. The CE

Table I. Basic values, interrelationships and sex related differences of Wiberg's CE-angle, Heyman & Herndon's femoral head extrusion index (FHEI), and the acetabular depth ratio (ADR). (M/W: 1.428/2.430)

	CE angle			FHEI (%)					ADR (%)				
	Med.	Range	SD	Med.	Range	SD	r	p	Med.	Range	SD	r	p
Men													
Right hip	35.0°	10°–62°	7.3°	12.0	0–45	8.7	-0.74	0.00	292	164–466	38	0.74	0.00
Left hip	34.0°	8°–60°	7.4°	8.6	0–42	8.6	-0.72	0.00	297	185–451	36	0.69	0.00
Women													
Right hip	35.0°	10°–65°	7.4°	8.0	0–46	7.8	-0.75	0.00	303	136–542	40	0.68	0.00
Left hip	35.0°	6°–67°	7.8°	7.6	0–40	7.6	-0.75	0.00	303	150–476	39	0.70	0.00
Sex related diff.													
		MD	p		MD	p				MD	p		
Right hip	M/W	-0.98°	0.00		2.81%	0.00				-7.01	0.00		
Left hip	M/W	-0.92°	0.00		2.78%	0.00				-5.45	0.00		

p = significance level at < 0.05; r = Pearson's two-tailed correlation coefficient of normally distributed continuous variables; MD = Mean difference; CI = 95% Confidence Interval of mean difference.

Table II. Prevalences of hip dysplasia according to predefined radiographic criteria (n M/F = 1,353/2,215)

Parameter	Right hip (M/W)		Left hip (M/W)		Either hip (M/W)		Bilateral (M/W)	
	No	%	No	%	No	%	No	%
CE angle \leq 20°	48/77	3.6/3.4	42/75	3.1/3.4	73/120	5.5/5.4	17/32	1.5/1.4
ADR \leq 250%	146/187	10.9/8.4	125/168	9.6/7.5	204/281	15.3/12.6	70/74	5.2/3.3
FHEI \geq 25%	50/116	3.7/5.2	35/97	2.6/4.3	71/171	5.3/7.7	14/42	1.0/1.9

angle relates acetabular coverage to the position of the femoral head, but does not indicate the shape or depth of the acetabulum. It does not assess vertical migration of the femoral head: in cases with subluxation and broken Shenton's line, the CE-angle may be the same as in the purely dysplastic joint. The true lateral acetabular margin is difficult to identify in many AP radiographs. The lateral margin may be obscured by the supero-posterior curvature, osteophytes, or the most lateral portion of the acetabular surface may be so oblique that it does not participate in the actual articulation. For further studies, Jacobsen et al. chose to designate the readily identifiable lateral margin of the subcondral sclerotic '*sourcil*' (Fr: Eyebrow) as their lateral point of reference (Katz 1969a, 1979b).

Prevalences of adult HD vary throughout the literature depending on cut off values applied. Croft et al. (1991) found HD prevalences of 3.6% applying CE angles \leq 25°, and 1.0% for CE angles \leq 20° in 1,516 British male urograms. In a survey

of Japanese (n = 651) and French (n = 364) urograms, Inoue et al. (2000) found HD prevalences of 11.6% for Japanese women, and 5.1% for Japanese men. The corresponding prevalences were 5.6% for French women and 1.8% for French men. The cut off CE angle applied was \leq 25°. Smith et al. (1995) found a HD prevalence of 3.8% after studying 203 British female urograms (CE angle \leq 25°), and Lane et al. (2000) found a prevalence of 10.7% in 176 Caucasian women (CE angle \leq 30°). Lau et al. (1990) described HD prevalences of 4.5% in Chinese men (n = 999), and 3.6% (n = 1,315) in British male urograms.

Variations in adult HD prevalences across sexes and races are probably caused by several factors: variations in measurement technique, different radiologic materials and recording techniques, variation in pathological cut off values; the choice of which is seldom explained, and the number of examiners involved in readings of radiographs, and thereby differences in intra- and inter-rater repro-

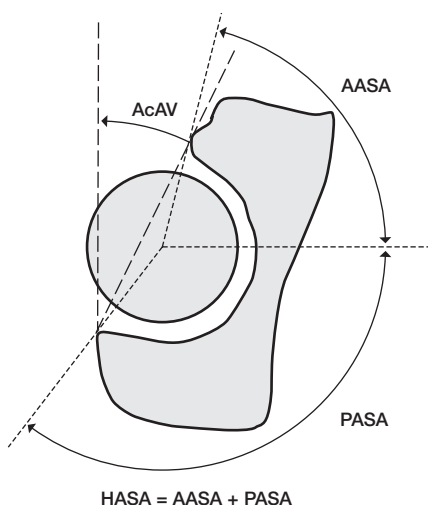


Figure 7. CT morphometrics of the hip joint using the angle between the projected longitudinal axis of the femoral head and neck, and the posterior condylar tangent.

AcAV = acetabular anteversion.

AASA = Anterior acetabular sector angle

PASA = Posterior acetabular sector angle.

HASA = Horizontal acetabular sector angle

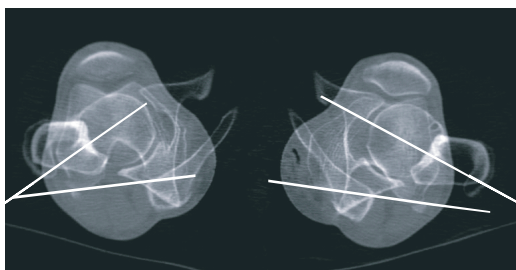


Figure 8. Assessment of the femoral neck anteversion (FeAV): center slice according to Anda.

ducibility. However, most studies arrive at Caucasian HD prevalences of approximately 3.5%, which corresponds to the findings of Jacobsen et al. (VIII, IX). The prevalence of HD is surely somewhat higher in Asian populations.

2.2 Computerized Tomography

The 3-D anatomy of HD is complex. The condition is best understood as a continuum of interrelated acetabular and femoral malformations, and an evaluation based solely on radiographs runs the



Figure 9. Assessment of the neck-shaft angle. The patient is placed in the CT-scanner in a standardized manner with the patellae pointing directly upwards. The longitudinal axis of the femoral head and neck is determined from the middle slice in a 3 cm thickened femoral head center slice. The femoral shaft longitudinal axis is determined from the corresponding knee joint slices.

risk of underestimating the degree of anomaly. The 3-D anatomy of HD has been analysed by transverse pelvic CT scans in small samples. There are few CT morphometric studies of larger samples without prior corrective hip surgery, and very few case-controlled studies (Anda et al. 1986a, 1991b, visser et al. 1982, Nakamura et al. 2000, Noble et al. 2003, Murray and Crim 2001). Consequently, data vary considerably in published studies of the 3-D anatomy of adult hip dysplasia (Kim et al. 1999). Anda et al. (1986a, 1991b) have defined useful indices for accessing acetabular morphology in transverse CT scans (Figure 7). By using CT techniques it is possible to determine femoral neck anteversion by superimposing transcondylar knee images on coronal hip images (Figure 8). Furthermore, it is possible by adding coronal hip slices to estimate shaft-neck angles (Figure 9).

3. The radiology of hip osteoarthritis

3.1 Degenerative features, case definitions and prevalences

The diagnosis of osteoarthritis (OA) is based on a combination of radiologic evidence of joint degeneration; osteophytes, subcondral sclerosis, subcondral cysts and reduced joint space width (JSW), and characteristic subjective symptoms. The incidences and prevalences of OA vary throughout the literature, which is mainly due to the lack of radiographic consensus definitions. Researchers use composite radiographic scores or assessments of individual radiographic features to discriminate between healthy and degenerative joints. However, the widely used classifications of Kellgren & Lawrence (K-L) (1957) or Croft (1990) are not equally suitable at all joints for the assessment of OA; emphasizing the relatively unimportant formations of osteophytes and subcondral sclerosis (Appendix A). Furthermore, reproducibility of readings is problematic (Sun et al. 1997). The nomenclature of the K-L classification is not precise, using terms as “possible”, or “gross” for characterizing reduced joint space. The notion of a chronological sequence of degeneration is implicit: narrowing of joint space precedes the development of osteophytes, which precedes subcondral sclerosis, which precedes the formation of cysts. To my knowledge, this causative string of events has never been evidenced. Recognizing the limitations of composite scores, several authors use minimum joint space width (JSW) as the primary criterion of hip OA, which has superior reproducibility and a more close association with actual clinical status and progression of degeneration (Danielsson et al. 1984, Dougados et al. 1996a, 1997b, Ingvarsson et al. 2000, Altman 1987). However, minimum JSW defining hip OA has ranged from 1.5 to 4.0 mm in studies, and until recently the natural distribution of JSW had not been evaluated in asymptomatic subjects (Goker et al. 2003, Lanyon et al. 2003).

In studies of the standardized pelvic radiographs of 4.151 subjects in COS, Jacobsen et al. arrived at the following conclusions (II, III, V): overall, for-

mations of cysts, osteophytes and increased subcondral sclerosis were more frequently recorded in male hip joints. Average minimum JSW was significantly narrower in women than in men: 3.89 mm (SD=0.8) in male right hips and 3.86 mm (SD=0.9) in male left hips, and 3.7 mm (SD=0.8) in female right and left hips ($p < 0.001$). Average subcondral sclerosis was significantly thicker in male hip joints: 3.0 mm (SD=1.2) in male right hips and 3.2 mm (SD=1.3) in male left hips, and 2.6 mm (SD=1.1) in female right hips and 2.8 mm (SD=1.2) in female left hips ($p < 0.001$). Jacobsen et al. found a significant inverse relationship between age and minimum JSW in both sexes. In both sexes the decrease in minimum JSW was marked after the fourth decade, but progressively more so in women (Figure 10).

In defining a pathological cut off value of minimum JSW, the authors used the male mean values of minimum JSW and subtracted 2 SD, arriving at values between 2.0 mm and 2.1 mm, corresponding to the ones arrived at by Lanyon et al. (2003). In defining a pathological cut off value of maximum subcondral sclerosis, two standard deviations (SD) were added to the mean values of subcondral sclerosis. Mean resultant pathological limit of subcondral sclerosis was calculated to ≥ 5.45 mm for both sexes.

A considerable proportion of cysts, osteophytes and pathologically increased subcondral sclerosis are found in isolation, this is especially the case in male hip joints.

Prevalences of hip OA according to predefined radiographic discriminators are presented in Table III. Using Croft or Kellgren & Lawrence's OA classifications, emphasising the formations of cysts, osteophytes and sclerosis, the prevalences of hip OA was higher in men than in women ($p < 0.001$). Using the cut off JSW value of 2.0 mm regardless of other features of OA, prevalences between the sexes equalised, in accordance with common clinical experience. Using composite radiographic classifications such as K-L (1957) or Croft (1990) (based solely on male urograms) one runs the risk

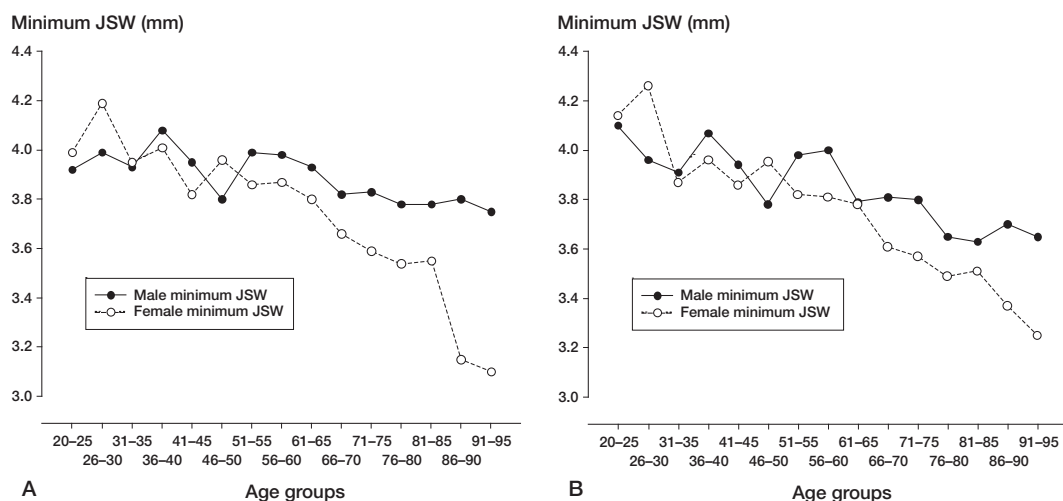


Figure 10. Distribution of right (A) and left (B) hip minimum joint space width (JSW) according to age groups.

Table III. Prevalences of hip OA according to different radiographic discriminators

	< 60 years of age						≥ 60 years of age					
	Men (n=607)			Women (n=841)			Men (n=892)			Women (n=1,452)		
	Right	Left	Bilateral	Right	Left	Bilateral	Right	Left	Bilateral	Right	Left	Bilateral
JSW ≤ 2.0 mm, n	13	4	9	11	3	36	42	17	77	70	29	
percentage	(2.3)	(2.2)	(0.7)	(1.0)	(1.2)	(0.3)	(4.4)	(5.1)	(2.1)	(5.3)	(4.9)	(2.0)
K-L ≥ 2°, n	14	10	7	6	5	2	55	46	25	47	43	15
percentage	(2.3)	(1.7)	(1.2)	(0.7)	(0.6)	(0.2)	(6.7)	(5.6)	(3.1)	(3.3)	(3.0)	(1.0)
Croft ≥ 3°, n	13	9	5	5	5	2	55	51	29	43	42	17
percentage	(2.2)	(1.5)	(0.8)	(0.6)	(0.6)	(0.2)	(6.7)	(6.2)	(3.5)	(3.0)	(2.9)	(1.2)

K-L = Kellgren & Lawrence's composite OA score. JSW = Minimum Joint Space Width.

of over-inflating male hip OA prevalence, whilst underestimating female hip OA prevalence.

Repeatability of readings of minimum JSW was superior to repeated composite scores: intra-class correlation coefficients of minimum JSW were $r = 0.918$ for right hips and $r = 0.875$ for left hips and of maximum subcondral sclerosis $r = 0.73$ for right hips and $r = 0.83$ for left hips. Repeatability of Croft's OA grading was moderate; weighted Kappa coefficients were $\kappa = 0.56$ for the right hips, and $\kappa = 0.46$ for the left hips. If dichotomised into grades 0°-2° denoting absent or slight OA, and grades 3°-5° denoting definite OA, Kappa values increased to $\kappa = 0.65$ for right hips, and $\kappa = 0.65$ for left hips. Repeatability of K-L's OA grading was of the same

order; $\kappa = 0.55$ for right hips, and $\kappa = 0.51$ for left hips. If dichotomised into grades 0°-1° denoting absent or doubtful OA, and grades 2°-4° denoting definite OA, Kappa values increased to $\kappa = 0.82$ for right hips, and $\kappa = 0.85$ for left hips.

3.2 Radiology and clinical status

Radiographic discriminators of OA should ideally reflect clinical status. However, hip pain can be caused by a multitude of different conditions and severe radiographic OA does not always cause pain (Birrell et al. 2005). Jacobsen et al. have examined the relationship between hip JSW and self reported

Table IV. Prevalences of self-reported pain and sex related differences

	Men (n = 1,215)		Women (n = 1,993)		p	Differences OR (95% CI)
	n	(%)	n	(%)		
Gluteal pain	207	(17.0)	526	(26.4)	0.00	1.7 (1.4–2.1)
Hip pain	270	(22.1)	571	(28.7)	0.00	1.3 (1.1–1.6)
Groin pain	162	(13.3)	272	(13.6)	0.44	1.0 (0.8–1.2)
Thigh pain	239	(19.6)	544	(27.3)	0.00	1.5 (1.2–1.7)
Pain in all regions	30	(2.4)	104	(5.2)	0.00	2.1 (1.4–3.2)
Pain in only one region	460	(37.8.)	915	(45.9)	0.00	1.3 (1.1–1.5)

Table V. Relationships between self reported hip pain and minimum hip joint space width \leq 2.0 mm

	Men (n = 1,215)			Women (n = 1,993)		
	n/N	p	OR (95% CI)	n/N	p	OR (95% CI)
Gluteal pain	12/73	0.56	0.9 (0.5–1.8)	29/113	0.51	0.9 (0.6–1.5)
Hip pain	35/73	0.00	3.5 (2.1–5.7)	45/113	0.005	1.7 (1.1–2.5)
Groin pain	18/73	0.003	2.3 (1.3–4.1)	26/113	0.004	2.0 (1.3–3.2)
Thigh pain	23/73	0.008	1.9 (1.1–3.3)	41/113	0.01	1.5 (1.0–2.3)
All regions	4/73	0.09	2.5 (0.8–7.4)	8/113	0.20	1.4 (0.6–3.1)
Only one region	44/73	0.01	1.5 (1.0–2.3)	62/113	0.00	2.7 (1.6–4.4)

n = number of subjects with reported symptom and joint space width \leq 2.0 mm.

N = total number of subjects with joint space width \leq 2.0 mm.

p = significance at the 0.05 level.

OR = Odds Ratio.

CI = Confidence Interval.

pain in or around the hip joint in the COS cohort (III). Participants with rheumatoid arthritis, childhood hip disorders, severe lower back disorder, earlier spine surgery procedures, hip fracture, radicular pain, a history of thromboembolic episodes, and slipped discs were excluded from the study (n = 727). Prevalences of self-reported pain are presented in Table IV. Women reported pain significantly more often than men; irrespective of age, apart from groin pain. Pain in all regions was only reported in 32 of 1,221 men (2.6%), and in 109 of 1,993 women (5.5%). Conversely, the number of cases with pain in only one region was high, 48% for males and 39.4% for females.

The relationship of minimum JSW to self reported hip pain is summarized in Table V. In both males and females significant relationships of reported hip pain, groin pain, thigh pain, and pain in only one region were found if minimum JSW was less than 2.0 mm. We found no statistical sig-

nificant relationship between minimum JSW and gluteal pain.

In the COS segment of participants older than 60 years (n = 3,344), Jacobsen et al. found that the simple discriminator of minimum JSW \leq 2.0 mm had a closer association than the composite scores of K-L or Croft to actual symptoms (V) (Table VI) in accordance with the findings of Lanyon et al. (2003).

3.3 Joint space width in asymptomatic subjects

Recently, Lanyon et al. (2003) and Goker et al. (2003) published influential papers on the relationship between minimum hip joint JSW and age, sex and height in asymptomatic subjects without structural degeneration. The studies were based on supine urograms and abdominal radiographs,

Table VI. Associations between radiographic hip OA discriminators and self-reported pain in subjects ≥ 60 years of age

	Men (n = 892)			Women (n = 1,452)		
	Hip pain n/n	Groin pain n/n	Gluteal pain n/n	Hip pain n/n	Groin pain n/n	Gluteal pain n/n
/JSW ≤ 2.0 mm	218/32	111/16	140/9	445/53	210/26	382/30
p	< 0.001	0.004	0.38	< 0.001	0.01	0.44
OR (95% CI)	3.3 (1.9–5.7)	2.4 (1.3–4.5)	0.8 (0.3–1.7)	3.2 (1.9–5.2)	1.7 (1.1–2.7)	0.9 (0.6–1.4)
/Croft $\geq 3^\circ$	218/35	111/13	140/11	445/39	210/20	382/25
p	< 0.001	0.23	0.30	< 0.001	< 0.001	0.03
OR (95% CI)	2.5 (1.5–4.1)	1.3 (0.7–2.5)	0.7 (0.4–1.5)	1.9 (1.3–2.8)	2.5 (1.5–4.4)	1.6 (0.9–2.7)
/Kellgren $\geq 2^\circ$	218/35	111/13	140/11	445/41	210/20	382/26
p	< 0.0001	0.21	0.32	< 0.0001	0.004	0.06
OR (95% CI)	2.6 (1.6–4.2)	1.3 (0.7–2.5)	0.8 (0.4–1.5)	2.8 (1.8–4.6)	2.2 (1.3–3.8)	1.5 (0.9–2.4)

respectively. In Lanyon's study a progressive decrease in hip JSW was observed after the fourth decade in women, whilst male hip JSW remained relatively unaltered throughout life. In a similar, but extended study, Jacobsen et al. investigated the distribution of minimum hip joint JSW in asymptomatic subjects of the COS cohort, evaluating the relationships between JSW in hips without radiological evidence of degeneration, and age, sex, physical parameters, occupational exposure to repeated, daily lifting, and smoking (IV).

The CCHS III (1991–1994) questionnaire recorded the nature and duration of occupation since leaving school. For each occupation reported, the CCHS III have registered frequency of different levels of lifting during a typical working day. The questions concerning work loads were formulated along the guidelines of The Danish National Board of Industrial Injuries, using the following categories: 1) primarily seated occupation, 2) standing, walking occupation, no repeated lifting, 3) daily repeated lifting equivalent to 50×20 kg, or 20×50 kg, 4) repeated daily lifting equivalent to $50\text{--}100 \times 20$ kg, or $20\text{--}50 \times 50$ kg, 5) repeated daily lifting equivalent to $100\text{--}250 \times 20$ kg, or $50\text{--}100 \times 50$ kg, and 6) repeated daily lifting equivalent to $250\text{--}500 \times 20$ kg, or $100\text{--}250 \times 50$ kg. Likewise, The CCHS III questionnaire recorded the smoking habits of the participants.

The development of hip JSW in different age groups in Jacobsen et al.'s study is presented in Figure 11, and the background data and occupa-

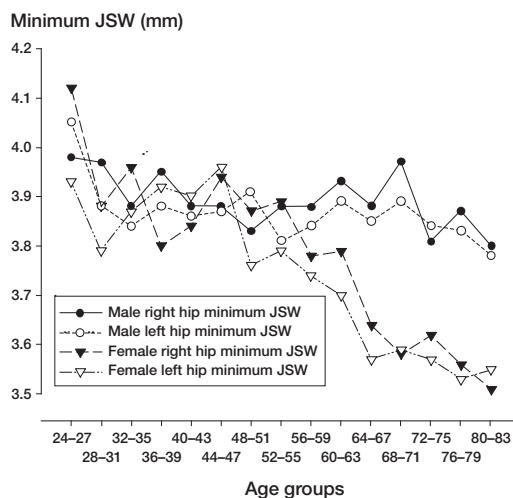


Figure 11. The distribution of male (n = 1,018) and female (n = 1,554) hip JSW in different age groups.

tional exposure to repeat daily lifting is summarized in Table VII.

In asymptomatic subjects, male minimum JSW was significantly larger than female minimum JSW ($p < 0.001$). Minimum JSW was negatively correlated to increasing age in women on both sides ($p < 0.001$). Increasing age did not affect minimum JSW in asymptomatic male subjects ($p = 0.19$ on the right side; and $p = 0.18$ on the left side). In male study subjects 63.8% had a history of cigarette smoking. On average these had smoked 303 packages of cigarettes per year in 35.5 years (29.4 package years). We found no statisti-

Table VII. Background data and occupation of study subjects

	Men (n = 1,018)		Women (n = 1,554)	
	Mean	(SD)	Mean	(SD)
Minimum JSW (mm)	3.75	(0.7)	3.60	(0.7)
Age (years)	60.0	(14.0)	61.5	(13.6)
BMI (kg/m ²)	26.3	(3.7)	25.4	(4.4)
Height (cm)	174.7	(7.2)	162.1	(6.8)
Weight (kg)	80.3	(12.6)	66.6	(12.0)
Occupational exposure to repeated daily lifting				
Seated, monotonous (years)	1.0	(5.2)	3.5	(9.1)
Standing, walking, no repeated lifting (years)	15.3	(17.3)	15.0	(16.2)
Lifting < 50×20 kg, or < 20×50 kg per day (years)	7.4	(13.7)	5.0	(10.8)
Lifting 50–250×20 kg or 20–100×50 kg per day (years)	6.4	(13.2)	0.3	(2.6)
Lifting 200–500×20 kg or 100–200×50 kg per day (years)	1.6	(6.5)	0.03	(0.8)
Lifting > 500×20 kg or > 200×50 kg per day (years)	0.4	(3.9)	0.0	–

cally significant relationship between minimum JSW and package years of cigarette smoking in men ($p = 0.56$ for right hips, and $p = 0.61$ for left hips). In females 928 or 59.7% had a history of cigarette smoking. On average these subjects had smoked 118 packages of cigarettes for 31.6 years (10.5 package years). There were no statistically significant relationships between package years of cigarette smoking and adjusted minimum JSW in women ($p = 0.35$ for right hips and $p = 0.92$ for left hips).

Physical characteristics, occupation, package years of cigarette smoking, and age was entered into multiple logistic regression models to evaluate the influence of individual factors on minimum hip JSW. In men no singular individual factor was found to influence minimum JSW significantly: p ranging from 0.21 to 0.81 for the right hips, and from 0.08 to 0.93 for the left hips. In women only increasing age was found to influence minimum JSW negatively ($p < 0.001$).

The study of Jacobsen et al. found the same age- and sex-related distribution of minimum hip joint JSW in asymptomatic subjects that Lanyon et al. (2003) observed in a study of 1,806 urograms. On average, minimum JSW in women was 0.15 mm narrower compared to men, and a progressive decrease in minimum JSW after the fifth decade of life in women was observed, whereas male JSW remained unaltered. Whether the decrease of cartilage height in women is caused by the onset of menopause or some other factor is unknown. A

positive relationship between female aging and the incidence of hip osteoarthritis has been thoroughly documented (Lane et al. 1999, Oliveira et al. 1995). However, the interaction of reduced estrogen production, vitamin D metabolism or the possible protective effect by estrogen replacement therapy on incident hip OA in women is still controversial (Jordan et al. 2000). In a similar study of minimum hip joint JSW in asymptomatic subjects, Goker et al. (2003) did not observe an age-related decline in female JSW. However, Jacobsen et al.'s study assessed standardized, standing pelvic radiographs of 2,572 subjects, and Lanyon et al. studied 1,806 urograms, while Goker et al.'s conclusions were based on 118 abdominal radiographs. Material size and recording techniques may account for the discrepancies.

Jacobsen et al.'s study found positive relationships of individual height, weight and BMI to minimum JSW. The same relationships were found to other measurements of pelvic morphology, i.e. right and left femoral head radius. It seems that JSW is correlated closely to the overall physical stature of the individual.

In regard to OA and smoking, Felson et al. (1989) convincingly documented a protective effect of smoking on incident knee OA, while the same positive or adverse effect of smoking on incident hip OA is yet to be documented. Smoking did not affect hip joint space positively or adversely in the present study. No negative nor positive correlations of exposure to sedentary or physically strenuous

occupations to adjusted minimum JSW was found in Jacobsen et al.'s study. While the relationship of occupational exposure to manifest hip osteoarthritis has been extensively studied, I have found no prior studies on the relationship of occupation to minimum JSW in asymptomatic subjects (IV).

To summarize: The radiologic hip OA discriminator of minimum JSW ≤ 2.0 mm has superior intra-rater reproducibility compared to composite (global) radiologic OA classifications, and reflects actual clinical status more accurately. Secondary radiologic features of degeneration: osteophytes, subcondral sclerosis and subcondral cysts are most

often encountered in men. However, minimum hip JSW decreases progressively in postmenopausal women. Using minimum JSW as the cardinal radiologic discriminator in epidemiological studies of hip OA, one does not run the risk of inflating male OA prevalence, while underestimating female hip OA prevalence. For men ≥ 60 years unilateral radiologic hip OA prevalence is approximately 4.7%, while hip OA prevalence in women is approximately 5.2%. In a study of asymptomatic subjects, only increasing age in women was found to influence minimum hip JSW significantly.

4. Hip dysplasia and osteoarthritis

4.1 The classics

The propensity of childhood hip disorders for causing premature hip OA has been recognized since early in the last century. Gunnar Wiberg published his influential doctoral thesis on the subject in 1939; '*Studies on dysplastic acetabula and congenital subluxation of the hip joint,*' (Vanförestalten/Serafimer hospitalet), and Erik Severin followed suit in 1941 with '*Contribution to the knowledge of congenital dislocation of the hip joint: late results of closed reduction and arthrographic studies of recent cases,*' (Karolinska Institutet). Other authors, most notably Stulberg (1974a, 1975b), and Cooperman (1983), have since then investigated the topic. Only few longitudinal studies exist including relatively few patients. In Wiberg's longitudinal study of 17 dysplastic hips (CE-angles < 20°) followed for 28 years, OA developed in each case, and Wiberg found a linear relationship between CE-angle and the age of onset of coxarthrosis. However, as pointed out by Cooperman et al. (1983), 7 of 17 hips in Wiberg's study were in fact subluxated with a mean CE angle of 2°. Ten hips were normally seated and had a mean CE-angle of 10°. Average age of onset of OA was 57 years in these latter patients. Radiologic OA criteria in Wiberg's study were a non-standardised mixture of radiographic features of structural degeneration.

Cooperman et al. (1983) performed a similar study of 32 hips in 20 patients followed for 22 years. There were no cases of subluxation. The average CE-angle was 7.4° (range, -5° to 20°). Joint space narrowing expressed as percentages of normal JSW constituted the radiographic OA discriminator. Hip OA developed in an equal number of patients in the sixth and seventh decades as in the fourth and fifth decades of life. Twelve hips had developed OA in the fourth decade. Eleven hips presented themselves without osteoarthritis in the fifth decade, and 9 hips were without OA in the sixth decade.

Hasegawa et al. (1992) followed 86 dysplastic hips for a period of 12.8 years. Thirty-three hips

developed "early" osteoarthritis in an average of 9.2 years, and 66% hips developed "advanced stage" OA from "early" stage OA in 7.8 years. The authors found that CE-angles < 10°, broken Shenton's line > 10 mm, FHEI > 40%, and ADR < 200 were significant predictors for premature hip OA. Radiologic hip OA was assigned according to the following criteria: 1) pre-arthrotic: no sclerotic change in the femoral head or the acetabulum, 2) early OA: sclerotic changes without joint space narrowing, 3) advanced OA: joint space narrowing, and 4) terminal OA: obliteration of the joint space.

Finally, Murphy et al. (1995) followed 286 patients who had had total hip arthroplasty performed for OA secondary to HD in contralateral hips. The follow-up period is *not* stated in the paper. The authors included two groups: Group I; 74 patients developed severe OA, and Group II; 43 patients did not develop significant hip OA. The remaining 125 patients were excluded, because they had not reached 65 years of age. Evidently severe OA had not developed in the group of excluded patients. The mean CE angle in Group I was 7° (range, -22° to 28°), and the average CE angle in Group II was 34° (range, 16°–49°). The parameters of HD were distributed significantly different between the two groups, and the authors concluded a significant relationship between HD and hip OA. The radiographic OA discriminator used was Kellgren-Lawrence's OA score.

These four studies are presented at some length because they illustrate important problems in the epidemiological research of osteoarthritis. Firstly, four different radiologic criteria were used to determine definite OA. We have seen that composite radiographic scores such as Kellgren-Lawrence's score, used by Murphy et al., have significant limitations in hips; due to poor reproducibility, and inaccurate terminology. Using subcondral sclerosis as a cardinal radiographic feature of OA, as in the study of Hasegawa et al., does not seem justified, since subcondral sclerosis can be regarded as a normal ageing phenomenon in otherwise healthy

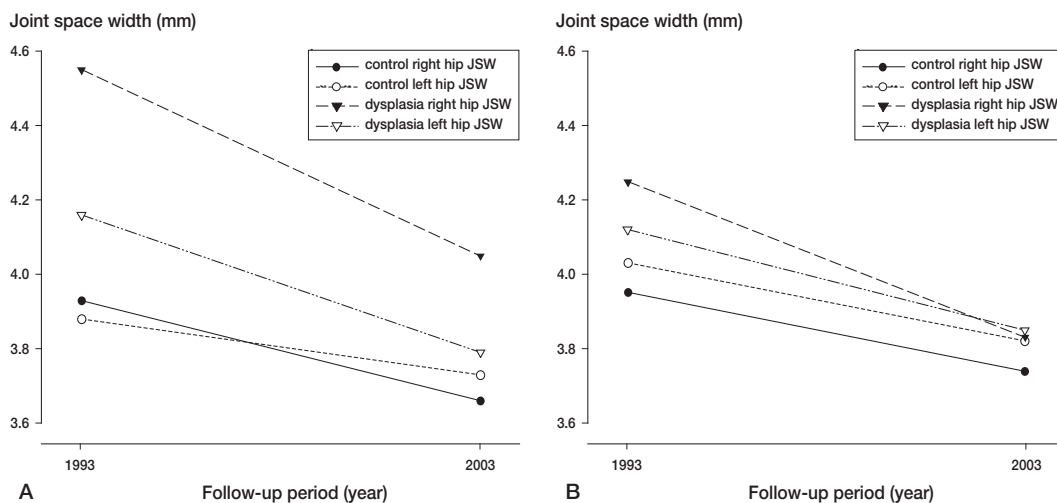


Figure 12. Changes in minimum JSW during follow-up period in women (A) and men (B).

joints (V). To use the percentage of normal JSW to designate the degree of OA, as in the study of Cooperman et al., knowledge of the normal distribution of JSW in asymptomatic subjects is presupposed. This knowledge has just recently been forthcoming (Lanyon 2003, IV).

Secondly, the recording techniques of source radiographs are poorly described in the studies. In a cadaver study, Jacobsen et al. found that pelvic orientation does play a significant role for the measurements of dysplastic hip morphology in AP radiographs (I).

Thirdly, the background incidence of coxarthrosis and the influences of age and sex on this incidence have to be taken into consideration when estimating rates of degeneration in longitudinal cohorts with hip dysplasia. There were no age and sex matched control groups in either of the studies. If HD is considered to be a pre-osteoarthritic condition causing premature coxarthrosis in younger individuals, it is curious that a group of 125 patients in the much referred to study of Murphy et al. was excluded because they had not reached the age of 65 years.

While severe HD and subluxation probably causes premature hip joint degeneration in most cases, the natural course of mild or moderate hip dysplasia has yet to be defined. Furthermore, background HD prevalences are unknown, and no studies on the relationship between HD and OA in rela-

tion to other, potential predispositions of hip OA; overweight, age, gender, smoking, occupational exposure to heavy, repeated daily lifting etcetera exist to my knowledge.

4.2 Changes in minimum hip JSW in dysplastic hips over time

To investigate changes in JSW over time in subjects with mild to moderate HD, Jacobsen et al. performed a longitudinal case controlled study of 81 subjects with HD and 136 control subjects without HD for a decade; assessing radiographic evidence of hip joint degeneration at admission and at follow-up. There were no cases of subluxation in the group with HD. Neither subjects with HD nor control subjects had any radiographic signs of ongoing degenerative disease at admission. There were no significant differences between subjects with HD and control subjects in regard to age, body mass index or occupational exposure to daily repeated lifting at admission. Jacobsen et al. found no significant differences in joint space width reduction at follow-up between subjects with HD and control subjects (VII) (Figure 12).

There is scattered evidence for an association between HD and premature coxarthrosis in the literature. However, as in the study of Cooperman et al. (1983), Jacobsen et al. found no linear relation-

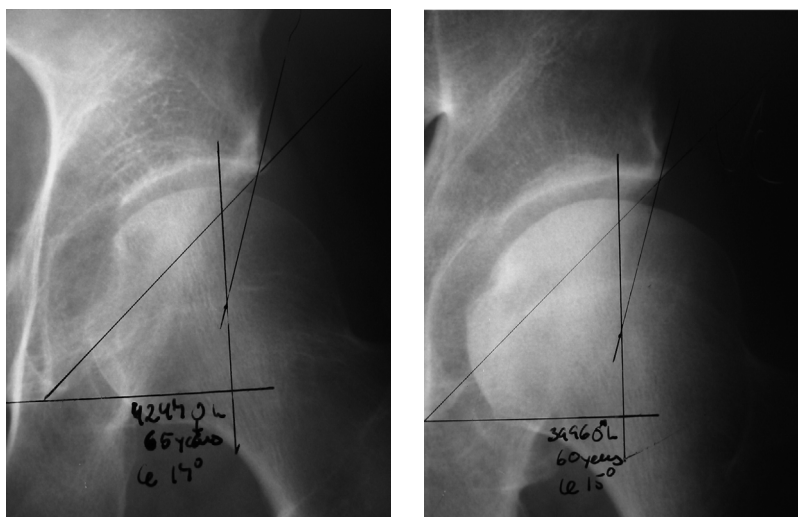


Figure 13. Moderate hip dysplasia in 65 year old subjects with moderate HD, but without radiologic signs of osteoarthritis.

ship between the degree of dysplasia and minimum JSW reduction. There were no cases of subluxation in either the present study or that of Cooperman et al., which may explain the differences between these two studies on one hand, and other longitudinal studies of HD. Eighty subjects with mild or moderate hip dysplasia managed to attain an average age of 60 years, without recognisable degeneration. Only one male subject with hip dysplasia developed coxarthrosis ($JSW \leq 2.0$ mm) at the age of 71 years. There were no differences in hip pain between subjects with HD and control subjects, and none of the subjects with HD had been treated or referred from their GP specifically because of hip pain. It is not permissible to draw far-reaching conclusions on this small sample size, followed for only 10 years. But it does seem possible to live a long and asymptomatic life with mild or moderate HD (Figure 13). It seems that other factors have to interact with the dysplastic malformation to initialize degeneration.

Recent MRI and arthroscopy studies of dysplastic hips suggest that HD-associated soft tissue lesions may play an important role in the degenerative pathway. Using MRI in 60 dysplastic hips, Kubo et al. (2000) found that the acetabular labrum was generally larger in cross-sectional area, compared to 40 normal hip joints. Leunig et al. (1997a, 2001b) evaluated 23 young patients with hip pain by MRI gadolinium-contrast arthrograms. Labral tears were

later confirmed intra-operatively in 18 patients, of whom 15 had hip dysplasia. In Ganz' (1988) paper on the Bernese periacetabular osteotomy for adult hip dysplasia, he found intra-operative evidence of associated labral detachments in 20% of the cases. In a total of 170 hips with either mild or moderate dysplasia, McCarthy (2002) found labral tears in 122 (72%) hips by arthroscopic examination. In another study McCarthy (2001) found labral tears in 241 of 436 younger patients (average age was 37 years) complaining of hip pain. A majority (86%) of tears were located in the anterior quadrant of the acetabulum and always at the articular junction of the labrum. McCarthy identified associated lesions of the acetabular articular cartilage in 273 patients (62.6%), also notably in the anterior quadrant. There were highly significant associations between the presence of labral lesions and degeneration of the articular surface. The authors concluded that labral disruption and degeneration were integrated in the same pathogenesis of joint disease. In a poroelastic finite element model of the hip joint, Ferguson et al. (2000) demonstrated that removal of the labrum meant that solid-on-solid contact stresses between articulating surfaces increased up to 92%. Subsurface strains and stresses of the articular cartilage were higher without the labrum, and the authors found that the labrum provided resistance to lateral motion of the femoral head, enhancing joint stability and congruity.

Table VIII. The relationship between coxarthrosis and hip dysplasia for both sexes according to predefinitions (n = 3,859)

	Right hip			Left hip		
	Croft's score 3–5/	K-L's score 2–4/	JSW ≤ 2.0 mm/	Croft's score 3–5/	K-L's score 2–4/	JSW mm/ ≤ 2.0 mm/
CE >20°	106/3,571	107/3,570	130/3,545	104/3,592	101/3,594	133/3,560
percentage	2.9%	2.9%	3.6%	2.8%	2.8%	3.7%
CE ≤20°	12/125	12/125	0/127	9/119	10/118	9/120
percentage	9.6%	9.6%	7.8%	7.5%	8.4%	7.5%
p	0.001	0.001	0.02	0.01	0.04	0.04
OR (95% CI)	3.4 (1.7–6.0)	3.2 (1.7–5.9)	2.1 (1.1–4.1)	2.6 (1.2–5.2)	3.0 (1.5–5.9)	2.0 (0.9–4.0)
FHEI <25	98/3,577	100/3,575	122/3,551	99/3,624	97/3,625	131/3,590
percentage	2.7%	2.7%	3.4%	2.7%	2.6%	3.6%
FHEI ≥25	19/118	18/119	16/121	13/85	14/84	10/88
percentage	16.1%	15.1%	12.6%	15.2%	16.6%	11.3%
p	0.00	0.00	0.00	0.00	0.00	0.003
OR (95% CI)	5.8 (3.4–9.9)	5.4 (3.1–9.2)	3.8 (2.2–6.6)	5.5 (3.0–10.3)	6.2 (3.4–11.3)	3.1 (1.5–6.1)
ADR >250	92/3,366	95/3,363	117/3,338	99/3,400	96/3,402	129/3,367
percentage	2.7%	2.8%	3.2%	2.9%	2.8%	3.8%
ADR ≤250	26/330	24/332	23/334	14/311	15/310	13/313
percentage	7.8%	7.2%	6.6%	4.5%	4.8%	4.1%
p	0.00	0.00	0.007	0.16	0.08	0.75
OR (95% CI)	2.8 (1.8–4.5)	2.5 (1.6–4.0)	1.9 (1.2–3.1)	1.5 (0.8–2.7)	1.7 (0.9–2.9)	1.0 (0.6–1.9)

CE = Wiberg's Center Edge angle; K-L = Kellgren and Lawrence's osteoarthritis score; Croft = Croft's osteoarthritis score; CI = 95% Confidence Interval of the mean difference; OR = Odds Ratio; JSW = Minimum Joint Space Width; ADR = Acetabular Depth Ratio; FHEI: Femoral Head Extrusion index.

The excessively anteverted femoral head and shallow retaining cavity in HD apply abnormally high stresses on the anterior acetabular labrum and capsule. A hypothesis of labral hypertrophy, tears or detachment as key occurrences in otherwise well functioning dysplastic hip joints catalysing degeneration may be formulated. This would explain why subjects with verified HD do not always develop osteoarthritis in the fifth and sixth decade of life: if labral injuries do not occur in non-subluxated, dysplastic hips, articular cartilage may remain intact throughout life.

4.3 HD and OA; non-adjusted odds ratios

To ascertain the relative risk of having HD and presumably secondary hip OA standardized pelvic radiographs of 1,429 men (age range, 22–93 years) and 2,430 women (age range, 22–92 years) were evaluated. HD was assessed using the CE-angle, FHEI, and ADR according to predefined cut off

values. Radiologic OA was determined using minimum JSW ≤ 2.0 mm, Kellgren-Lawrence's, and Croft's composite OA classifications (VIII). Relationships between HD and hip OA are presented in Table VIII. *Non-adjusted* odds ratios ranged from 1.0 to 6.2. The assumption of HD being prearthrotic was confirmed in the study, odds ratios ranging from 1.0 to 6.2. Mild to moderate HD is not an unusual condition in the population; prevalences ranging from 3.5% to 10.7% according to the index used. Also, a statistical trend for subjects with OA and HD being somewhat younger than subjects with hip OA in normal hips was established in Jacobsen et al.'s study.

4.4 HD and OA; adjusted odds ratios

To my knowledge, HD as a risk factor for developing hip OA, relative to other potential predispositions has not been investigated prior to Jacobsen et al.'s study (IX). COS background data regard-

ing age, sex, package years of smoking, BMI and occupational exposure for repeated daily lifting and radiological evidence of HD were entered into multiple logistic regression analyses. Minimum JSW \leq 2.0 mm was the sole OA discriminator used. The significance level was Bonferroni adjusted to $p < 0.005$ due to the number of variables entered.

Hip OA was significantly influenced by age in women ($p < 0.001$). OR and 95% CI for right-side hips were 1.09 (1.05–1.13). OR and 95% CI for left side hips were 1.08 (1.04–1.12). Hip OA was significantly influenced by Wiberg's CE-angle in women: $p = 0.002$ in right hips and $p = 0.004$ in left hips. OR and 95% CI for right side hips were 1.09 (1.03–1.64) and 1.07 (1.01–1.14) for left-side hips. With regard to men, of the entered potential risk factors only the CE-angle was statistically associated with hip OA: $p < 0.001$ [OR = 1.1 (95% CI 1.0–1.2)] in right hips and $p = 0.001$ [OR = 1.6 (95% CI 1.2–2.1)] in left hips. Age was not associated with hip OA per se after Bonferroni's adjustment: $p = 0.024$ in right hips and $p = 0.01$ in left hips. The authors found neither positive nor adverse effects of occupational exposure to repeated lifting, BMI or smoking on the prevalence of hip OA in either sex.

Recall bias; the ability to accurately recall years and magnitude of smoking, occupation etc., is evident in cross sectional studies. However, the majority of COS subjects have participated in four consecutive surveys from 1976 to 2002, and are well versed in answering the same questions. A limitation of the above study is the lack of information on menarche, menopause, hormonal contraception, postmenopausal hormone replacement therapy or treatment of osteoporosis with gonadal steroids. There is mounting evidence for important relationships between female hormonal status and mono-articular or generalized OA (Christgau et al. 2004, Cooper et al. 1996, Erb et al. 2000, Høgh-Andersen et al. 2004, Oliveira et al. 1996). In a recent study, Birrell et al. (2003) reported a prevalence of acetabular dysplasia of 30% in 195 patients presenting with new episodes of pain at their GP, but with no significant relationship between dysplasia and radiological OA. The authors termed the condition: 'syndrome of symptomatic adult acetabular dysplasia' or SAAD. In the present study, Jacobsen et al. found a significant association between

self-reported hip and groin pain and hip OA in both sexes. Although unilaterality or bilaterality of self-reported hip pain was unfortunately not recorded at the COS baseline examination (1991-94), Jacobsen et al. investigated pain and reduced JSW in various combinations of unilaterality and bilaterality of healthy and degenerated hips. Unlike Birrell et al., Jacobsen et al. did not find consistent associations between HD and pain. It is notoriously difficult to correlate self-reported sensations of pain in or around the hip joint with actual radiological evidence of OA, no matter how advanced the questionnaires might be (Birrell et al. 2005, Christmas et al. 2002). In Jacobsen et al.'s study no fewer than 30% of women and 23.1% of men complained of hip pain, and 14% of women and 13% of men complained of groin pain, while actual radiological hip OA prevalence is 5–7% in this and other epidemiological studies.

An association between overweight and hip OA has not been thought to be as important as in knee OA. However, some studies suggest a significant relationship between overweight and symptomatic hip OA. Vingård (1991) found significantly increased odds ratios for development of end stage hip OA among 239 men, if BMI > mean BMI + 1 SD. Adjusted odds ratios varied between 1.67 (95% CI 0.90–2.97) and 2.49 (95% CI 1.39–4.47). Oliveira et al. (1996) found significant correlations between incident, symptomatic hip OA and overweight in 134 matched case-control pairs of women aged 20–79 years. The authors calculated an odds ratio of 3.4 (95% CI 0.4–25.6) for women having a BMI between 23.91 kg/m² and 27.8 kg/m². Marks and Allegrante (2002) found BMI's in the overweight and obese range in 70% of 586 females and 435 males requiring THR's for end stage hip OA. The authors found that the percentage of overweight or obese subjects with end stage hip OA was higher than the values reported in the adult population generally, but does not state whether the difference was statistically significant. The study design did not permit conclusions whether overweight antedated hip OA. Cooper et al. (1998) reported a definitive positive relationship of increasing BMI to hip OA in a case control study of 611 patients listed for THR compared to an equal number of age and sex matched subjects. The correlation was positive regardless of gender. Odds ratios were

adjusted for individual risk covariates and were 1.9 (95% CI 1.1–3.3) for men with BMI \geq 28 kg/m² and 1.7 (95% CI 1.2–2.4) for women with BMI \geq 28 kg/m². In Jacobsen et al.'s study, no significant influence on hip OA prevalence by increasing BMI was found ($p = 0.56$ for right hips, and $p = 0.83$ for left hips).

Using THR (or TKR) as the natural endpoint of disabling OA in epidemiological studies to extrapolate backwards is risky business. After all, individual orthopaedic surgeons have individual thresholds and indications for listing patients for replacement surgery.

The possible causal relationship between heavy physical workloads over prolonged periods of time and the development of hip OA has been the focus of many studies, but there is an almost uniform absence of women in the studies. In one of the best-executed studies of occupational lifting and hip OA, Coggon et al. (1998) found no association among women. In Lievense et al.'s (2001) review of the influence on work on the development of hip OA, only two retrospective cohort studies and 14 case-control studies fulfilled methodological criteria. Overall, moderate evidence was found for a positive association with odds ratios in the vicinity of 3. It seems that mixed farming for decades do in fact predispose hip OA (Axmacher and Lindberg 1993, Croft et al. 1992).

4.5 HD and total hip replacement

To determine whether or not subjects with mild to moderate HD was more prone to having THR surgery performed, all patients' records of the COS cohort receiving THR's from 1992 to the present day was examined (X). A similar study has not, to my knowledge, been performed earlier. In addition, sequential BMI measurements from 1976 to 1992, age, exposure to daily lifting and hip dysplasia were entered into logistic regression analyses. In the mean 8.3 year follow up period between 1992 and 2004, 66 subjects had had THR performed; 50 cases due to primary OA, equalizing a THR incidence of 146/100.000 persons due to primary OA (20 THR/25 men and 30 THR/26 women). Of 264 hips at admission (1992) with minimum JSW \leq 2.0 mm, THR had been performed in 25 hips (9.4%),

and of 235 hips with Croft grade 3°–5°, THR had been performed in 22 hips (9.3%). BMI was significantly higher in men than in women. However, BMI in women had increased significantly more between 1976 and 1992 than in men. No significant relationships between BMI I (1976), BMI III (1992) or Δ BMI (1976–1992), and minimum JSW in men was found. A significant relationship between Δ BMI and minimum JSW reduction in women was documented. It seems reasonable to conclude that weight loss may delay the age related JSW reduction in women. Significant relationships between BMI I (1976), and BMI III (1992) and self reported hip pain and groin pain were found in both sexes (p ranging from < 0.001 – 0.04), while Δ BMI had no effect on self reported pain in or around the hip joint. BMI I (1976), and BMI III (1992) were significantly higher in subjects of both sexes receiving THR ($p < 0.001$). Even if joint degeneration develops over several years, it seems reasonable to conclude that cohort subjects receiving THR between 1992 and 2003 had comparably higher BMI already in 1976. The continuous variables of age, indices of hip dysplasia, years of varying exposure to repeated daily lifting, BMI I, and Δ BMI were tested against Croft OA grade 3°–5°, minimum JSW \leq 2.0 mm, and \pm THR by multiple regression analyses. While the radiologic OA indices of Croft grade 3°–5° or minimum JSW \leq 2.0 mm were significantly affected by the degree of hip dysplasia in men, and hip dysplasia and age in women, the risk of THR being performed between 1992 and 2003 was only affected by BMI I assessed in 1976 in both sexes.

In this study Jacobsen et al. found that relatively few cohort subjects with definite radiologic hip OA did receive THR during a mean follow up period of 8.3 years (25/264 with minimum JSW \leq 2.0 mm = 9.4%). Those who did had comparatively higher BMI and (therefore?) comparatively more hip pain.

It was concluded that while radiologic evidence of degeneration and treatment by THR are two sides of the same condition, they do not necessarily share the same risk factors, and caution should, as mentioned earlier, be exercised in epidemiological studies in appointing one or the other as the natural end point.

To summarize: Of potential risk factors of radiological hip OA, mild to moderate HD did in fact seem to influence prevalence, albeit not to a dramatic extent. In the longitudinal study, HD did not seem to influence minimum hip JSW adversely. However, degeneration is usually a slow process over decades. There were no cases of subluxation or severe HD in the samples, and follow up period

was only a decade. However, it does seem likely that dynamic factors other than the malformation itself comes into play to initialize degeneration and pain in the mildly to moderately dysplastic hip. In the rather small sample study of THR and HD, HD was not found to be a significant risk factor for total hip replacement surgery; rather overweight and pain seemed to influence THR indications.

5. Degeneration in severely dysplastic hips

In a computer tomography imaging study of 196 consecutively referred younger patients with hip pain believed to be secondary to severe HD; Jacobsen et al. investigated the distribution of degenerative radiological features (VI). There were 51 men and 142 women with mean age of 35.5 years (range, 15–61 years). JSW was measured in the coronal center slice at three locations: 1) at the lateral margin of the subcondral sclerotic line ('the sourcil'), 2) at the apical transection of the weight-bearing surface by a vertical line through the center of the femoral head, and 3) at the medial margin of the weight-bearing surface bordering on the fovea. In the sagittal center slice, JSW was measured at the anterior and the posterior aspect of the facies lunatum and at the apical transection of the weight-bearing surface. Cysts and osteophytes were referred to the lateral, apical or medial third of the weight-bearing surface in the coronal plane, in the acetabulum and the femoral head, and the anterior, apical or posterior third of the weight-bearing surface in the sagittal plane. After applying combined predefined inclusion criteria of CE angles $\leq 20^\circ$, and ADR ≤ 250 , 197 cases of definite HD were found. There were 111 cases of borderline dysplasia, and 78 cases of normal hip morphology. Borderline dysplastic hips were excluded from the study. Unaffected hips constituted controls in the further analyses. In dysplastic hips only the anterior acetabular sector angle (AASA) was significantly and inversely associated to femoral anteversion (FeAV) ($p < 0.001$). The CE angle, the acetabular angle (AA), and ADR were significantly interrelated ($p < 0.001$; correlation coefficients ranging from -0.8 to 0.7). Fifty-one hips were subluxated (24R/27L). There were no cases of complete dislocation.

Mean minimum JSW in the coronal plane was 3.4 mm in dysplastic hips, and 3.2 mm in normal hips. Mean minimum JSW in the sagittal plane was 2.7 mm in dysplastic hips and 2.5 mm in normal hips. There were no significant differences in minimum JSW between dysplastic and normal hips. In dysplastic hips minimum JSW was localized

in the anterior third of the weight-bearing zone in 44% of cases, in the apical third in 18.9% of cases, and in the medial third in 37.1% of cases. In the sagittal plane, minimum JSW was localized in the anterior third of the weight-bearing zone in 44% of cases, in the apical third in 10.5% of cases, and in the posterior third in 45.5% of cases. There were no statistically significant differences in the localisation of minimum JSW between dysplastic and normal hips. The formation and localisation of subcondral cysts and osteophytes in dysplastic and normal hips are presented in Table IX. Subcondral cysts were predominantly localised laterally and anteriorly in dysplastic acetabulae and femoral heads. The formation of subcondral cysts or osteophytes in dysplastic hips was significantly associated with reduced minimum JSW (p ranging from 0.005 to 0.02), however, in the majority of cases cysts and osteophytes were recorded in hips with normal JSW. In 67 cases of hips with acetabular cysts, only 6 cases had minimum JSW ≤ 2.0 mm (8.9%) in the coronal plane. However, in 96 cases with acetabular cysts found in the sagittal plane, 43 cases had minimum JSW ≤ 2.0 mm (44.7%). Paralabral osseous avulsions were recorded in 30 hips. Twenty-three of these were dysplastic ($p = 0.01$).

The formation of subcondral cysts and osteophytes were encountered more frequent in dysplastic hips. There was no difference in minimum JSW between dysplastic and normal hips in either

Table IX. Localisation of cysts and osteophytes in dysplastic hips (n = 198)

	Cysts		Osteophytes	
	Acet.	Fem.	Acet.	Fem.
Coronal plane				
Lateral	52	17	92	18
Apical	8	19	–	–
Medial	7	1	20	65
Sagittal plane				
Anterior	70	6	85	24
Apical	19	19	–	–
Posterior	7	4	24	34

the coronal or the sagittal plane. Predilection area of acetabular and femoral cysts was in the coronal lateral third and sagittal anterior third. This reflects the findings by Yoshida and Konishi (2002) in a similar study of 58 dysplastic hips. Although the formation of subcondral cysts was significantly related to reduced minimum JSW, the majority of cyst and osteophyte formations were encountered in hips with normal cartilage height. This finding may be argumentative in the current debate on the causality between labral injuries and cartilage degeneration. McCarthy et al. (2001) have documented labral detachment or fraying in a majority of cases of hip dysplasia through direct arthroscopic assessment. Most labral injuries are in fact encountered in the anterior and lateral part of the joint in the watershed zone of the labrum's attachment to the bony acetabulum, and not at the free margin. In support of this theory we found that most cysts are in fact paralabral in localisation. We also found that a significant majority of so-called "os acetabuli" are found in dysplastic hips, where they probably represents traumatic injuries to the lateral part of the acetabulum due to femoroacetabular shearing impingement (Klaue et al.



Figure 14. Paralabral osseous avulsion from the acetabular rim.

1991, siebenrock et al. 2003, Leunig et al. 2004, Ito et al. 2004, Ganz et al. 2003). Michaeli (1997) has shown that peak pressures are located in the antero-lateral rim zone under realistic load vectors in dysplastic hips (Figure 14).

6. Conclusions

In the studies presented, the authors have tried to critically evaluate their radiologic source material of 4,151 pelvic radiographs of the CCHS-COS cohort recorded 1991–1994 for further epidemiological purposes regarding the association between childhood hip disorder and adult degenerative hip disease. We recommend standardized, weight bearing pelvic radiographs for epidemiological purposes with known recording technique. We have tried to identify the best possible indices of hip osteoarthritis, instead of using well-known classifications that we have found to be problematic. Applying composite radiological classifications to the hip joint emphasizing secondary degenerative features runs the risk of inflating male hip OA prevalences, while at the same time underestimating female OA prevalences. The singular, and superiorly reproducible radiologic OA discriminator of minimum hip joint space width ≤ 2.0 mm had a close association to self-reported hip pain. Furthermore, one should be cautious in applying total hip replacement surgery as OA endpoint in epidemiological studies. In fact, only a relatively small percentage of subjects with definite radiological hip OA did in fact receive THR in these studies.

We found that mild to moderate hip dysplasia according to commonly accepted pathological cut off values, was not uncommon in the background population, and that HD-associated malformation in fact constituted an individual risk factor

for hip degeneration of some importance. Its significance relative to genetic predisposition and lifelong female hormonal profiles remains to be researched.

We did not find an adverse effect on minimum JSW in subjects with mild or moderate HD followed for a decade. Probably the sample is too small or the follow-up period too short, or the subjects did not experience soft tissue trauma to trigger degeneration. We did not find that patients with mild to moderate HD were more prone to hip replacement surgery being performed than other participants. It seems that factors such as overweight and subjective symptoms may be more important in this respect.

Re-directional pelvic osteotomies (Ganz, Steel, Tönnis) in younger HD patients that aim to restore normal load transfers across the hip joint have become increasingly popular in the last two decades amongst orthopaedic surgeons. A thorough 3-D knowledge of the complex dysplastic malformations is presupposed in pre-operative planning. The importance of HD-associated soft tissue lesions and their role in the degenerative pathway remains to be investigated vis-à-vis pelvic osteotomies. Is it for instance sufficient to restore containment of the femoral head, or is it necessary to evaluate and repair concomitant labral detachment as well arthroscopically, to prevent further degeneration?

7. Future studies

In the near future, the Copenhagen Osteoarthritis Substudy plans to investigate the role of lifelong female hormonal profiles in individual joint and generalized joint degeneration. The significance of HD in hip joint OA relative to menarche, menopause, and number of child-births, hormonal contraception, the occurrence of oophorectomy or hysterectomy, postmenopausal hormone replacement therapy and hormonal osteoporosis treatment will be part of these studies.

Case-controlled longitudinal studies of patients with childhood hip diseases in the CCHS' study population will be carried out as well.

The Copenhagen City Heart Study is in the unique position that it has at its disposal DNA material from all its study subjects. An important long-term objective in further elucidation of childhood hip anomalies would be the identification of candidate genes and polymorphisms in participants with HD, Calvé-Legg-Perthes' disease and slipped capital epiphysis.

The effects of partial or complete acetabular labrum removal on subsequent degeneration are currently being studied in animal models in USA. These studies will no doubt shed important light on the histopathological pathway from soft tissue injury to cartilage destruction in the hip joint.

8. Dansk resumé

Udviklingen af slidgigt forudsætter en interaktion mellem systemiske og lokale, eventuelt biomekaniske faktorer. For hoftedeledet synes medfødte eller udviklingsmæssige ossøse malformationer at spille en væsentlig rolle for især udviklingen af tidlig slidgigt. Hoftedysplasi er en sådan gruppe ossøse malformationer. De præsenterede studier har følgende delmål:

- Kritisk at evaluere studiernes radiologiske kilde-materiale bestående af 4.151 standardiserede, stående bækkenoptagelser for deltagere i III Østerbrounderøgelse (1991 – 1994).
- At kvalificere eller diskvalificere det radiologiske kildemateriale for videre studier.
- At identificere en applicérbar og reproducérbar radiologisk diskriminator for tilstedeværelsen af radiologisk slidgigt i hoftedeledet – så tæt associeret til symptomatisk slidgigt som muligt.
- At identificere prevalensen af hofteslidgigt og hoftedysplasi i Østerbrounderøgelsesernes kohorte og undersøge indflydelsen af køn, alder, fysiske og erhvervmæssige parametre på disse prevalenser.
- At undersøge betydningen af hoftedysplasi på udviklingen af hofteslidgigt relativt til andre, potentielle risikofaktorer.
- At undersøge degeneration i dysplastiske hoftedeled over tid.
- At undersøge hoftedysplasis tredimensionelle anatomi og fordelingen af degenerative radiologiske tegn i svært dysplastiske hoftedeled.
- At undersøge risikofaktorer for at blive opereret med indsættelsen af et kunstigt hoftedeled.

I løbet af studierne fandt vi at opmålingen af klassiske radiografiske indicier af hoftedysplasi blev signifikant påvirket af bækkenets rumlige orientering under røntgenoptagelser. Vi identificerede inklusionsgrænser mht. inklinations/reklination og rotation for bækkenets orientering der

tillod opmålinger indenfor en fejlmargen på $\pm 3^\circ$. Vi fandt at mindste opmålte bruskhøjde ≤ 2.0 mm konstituerede en radiologisk diskriminator af manifest slidgigt, der havde overlegen reproducérbarhed og klinisk relevans sammenlignet med almindeligt anvendte artroseklassifikationer. Vi dokumenterede et progressivt, postmenopausalt fald i bruskhøjde i kvinders hoftedeled, mens mindste opmålte bruskhøjde hos mænd forblev relativt uforandret gennem livet. Vi fandt ikke bevis for at rygning, erhvervmæssig eksposition for repeterede, tunge løft eller overvægt havde signifikant indflydelse på forekomsten af radiologisk slidgigt i hoftedeledet.

Prevalensen af hofteslidgigt var 5.5 % hos individer ≥ 60 år, og prevalensen af hoftedysplasi blev fundet til at være 4 – 10 % afhængig af radiografisk indicium. Tiltagende alder og hoftedysplasi blev fundet at være betydende risikofaktorer for udvikling af hofteslidgigt hos kvinder og hoftedysplasi blev fundet at være en betydende risikofaktor for udvikling af hofteslidgigt hos mænd. Imidlertid fandt vi derudover at kun overvægt var en betydende risikofaktor for at blive opereret med indsættelse af total hoftedealloplastik.

I et longitudinelt studie af 81 individer med mild til moderat hoftedysplasi fulgt et tiår kunne ikke dokumenteres en tendens til degeneration af hoftedeledet hvis man sammenlignede med 136 kontrol individer uden hoftedysplasi.

I et computer tomografi studie af individer med svært dysplastiske hoftedeled fandt vi en tæt sammenhæng mellem utilstrækkeligt lateral og anterior acetabulært dække af ledhovedet og forøget femoral anteversion. Prædilektionsområde for opståen af degeneration i dysplastiske hoftedeled blev fundet at være den antero-laterale kvadrant af hoftedeledet.

9. References

- Afoke NYP, Byers PD, Hutton WC. Contact pressures in the human hip joint. *J Bone Joint Surg* 1987; 69B: 536-41.
- Ali-Gombe A, Croft P R, Silman A J. Osteoarthritis of the hip and acetabular dysplasia in Nigerian men. *J Rheumatol* 1996; 23: 512-15.
- Altman R D, Fries J F, Bloch D A, Carstens J, Cooke T D, Genant H, Gofton P, Groth H, McShane D J, Murphy W A. Radiographic assessment of progression in osteoarthritis. *Arthritis Rheum* 1987; 30: 1214-25.
- Altman R D, Fries J F, Bloch D A, Carstens J, Cooke T D, Genant H, Gofton P, Groth H, McShane D J, Murphy W A. Radiographic assessment of progression in osteoarthritis. *Arthritis Rheum* 1987; 30: 1214-25.
- Anda S, Svenningsen S, Dale L G, Benum P. The acetabular sector angle of the adult hip determined by computed tomography. *Acta Radiol Diagn* 1986; 27: 443-47.
- Anda S, Svenningsen S, Grøntved T, Benum P. Pelvic inclination and spatial orientation of the acetabulum. *Acta Radiol* 1990; 31: 389-94.
- Anda S, Terjesen T, Kvistad K A. Computed tomography measurements of the acetabulum in adult dysplastic hips: which level is appropriate? *Skeletal Radiol* 1991; 20: 267-71.
- Anda S, Terjesen T, Kvistad K A, Svenningsen S. Acetabular angles and femoral anteversion in dysplastic hips in adults: CT investigation. *J Comput Assist Tomogr* 1991; 15: 115-20.
- Axmacher B, Lindberg H. Coxarthrosis in farmers. *Clin Orthop* 1993; 287: 82-6.
- Ball F, Kommenda K. Sources of error in the roentgen evaluation of the hip in infancy. *Ann Radiol* 1968; 11: 298-03.
- Bergmann G, Graichen F, Rohlmann A. Hip joint loading during walking and running, measured in two patients. *J Biomechanics* 1993; 26: 969-90.
- Birchfield P C. Osteoarthritis overview. *Geriatr Nurs* 2001; 22: 124-30.
- Birrell F, Lunt M, Macfarlane G, Silman A. Association between pain in the hip region and radiographic changes of osteoarthritis: results from a population-based study. *Rheumatology* 2005; 44: 337-41.
- Birrell F, Silman A, Croft P, Cooper C, Hosie G, Macfarlane G. Syndrome of symptomatic adult acetabular dysplasia (SAAD syndrome). *Ann Rheum Dis* 2003; 62: 356-58.
- Boles C A, el Khoury G Y. Slipped capital femoral epiphysis. *Radiographics* 1997; 17: 809-23.
- Bombelli R. The biomechanics of the normal and dysplastic hip. *Chir Organi Mov* 1997; 82: 117-27.
- Brown TD, Digioia AMI. A contact-coupled finite element analysis of the natural adult hip. *J Biomechanics* 1984; 17: 437-48.
- Buckwalter J A, Saltzman C, Brown T. The impact of osteoarthritis: implications for research. *Clin Orthop Relat Res* 2004; 427: 6-15.
- Butler-Manuel P A, Guy R L, Reynolds D A. Three-dimensional CT imaging in hip dysplasia. *J Bone Joint Surg Br* 1991; 73B: 686-87.
- Byrd J W, Jones K S. Hip arthroscopy in the presence of dysplasia. *Arthroscopy* 2003; 19: 1055-60.
- Cardinal E, White S J. Imaging pediatric hip disorders and residual dysplasia of adult hips. *Curr Opin Radiol* 1992; 4: 83-9.
- Christgau S, Tanko L B, Cloos P A, Mouritzen U, Christiansen C, Delaisse J M, Hoegh-Andersen P. Suppression of elevated cartilage turnover in postmenopausal women and in ovariectomized rats by estrogen and a selective estrogen-receptor modulator (SERM). *Menopause* 2004; 11: 508-18.
- Christmas C, Crespo C J, Franckowiak S C, Bathon J M, Bartlett S J, Andersen R E. How common is hip pain among older adults? Results from the Third National Health and Nutrition Examination Survey. *J Fam Pract* 2002; 51: 345-48.
- Ciuttini F M, Baker J R, Spector T D. The association of obesity with osteoarthritis of the hand and knee in women: a twin study. *J Rheumatol* 1996; 23: 1221-26.
- Ciuttini F M, Spector T D. The epidemiology of osteoarthritis of the hand. *Rev Rhum Engl* 1995; 62: 3-8.
- Ciuttini F M, Spector T D. Genetics of osteoarthritis. *Ann Rheum Dis* 1996; 55: 665-67.
- Coggon D, Kellingray S, Inskip H, Croft P, Campbell L, Cooper C. Osteoarthritis of the hip and occupational lifting. *Am J Epidemiol* 1998; 147: 523-28.
- Cooper C, Egger P, Coggon D, Hart D J, Masud T, Ciuttini F, Doyle D V, Spector T D. Generalized osteoarthritis in women: pattern of joint involvement and approaches to definition for epidemiological studies. *J Rheumatol* 1996a; (23): 1938-1942.
- Cooper C, Inskip H, Croft P, Campbell L, Smith G, McLaren M, Coggon D. Individual risk factors for hip osteoarthritis: obesity, hip injury, and physical activity. *Am J Epidemiol* 1998; 147: 516-22.
- Cooperman D R, Charles L M, Pathria M, Latimer B, Thompson G H. Post-mortem description of slipped capital femoral epiphysis. *J Bone Joint Surg* 1992; 74B: 595-99.
- Cooperman D R, Wallensten R, Stulberg S D. Acetabular dysplasia in the adult. *Clin Orthop* 1983; 175: 79-85.
- Croft P, Coggon D, Cruddas M, Cooper C. Osteoarthritis of the hip: an occupational disease in farmers. *BMJ* 1992; 304: 1269-72.
- Croft P, Cooper C, Wickham C, Coggon D. Defining osteoarthritis of the hip for epidemiologic studies. *Am J Epidemiol* 1990; 132: 514-22.
- Croft P, Cooper C, Wickham C, Coggon D. Osteoarthritis of the hip and acetabular dysplasia. *Ann Rheum Dis* 1991; 50: 308-10.

- Danielsson L, Lindberg H, Nilsson B. Prevalence of coxarthrosis. *Clin Orthop* 1984; 191: 110-15.
- Delaunay S, Dussault R G, Kaplan P A, Alford B A. Radiographic measurements of dysplastic adult hips. *Skeletal Radiol* 1997; 26: 75-81.
- Dougados M, Gueguen A, Nguyen M, Berdah L, Lequesne M, Mazieres B, Vignon E. Radiographic features predictive of radiographic progression of hip osteoarthritis. *Rev Rhum Engl* 1997; 64: 795-03.
- Dougados M, Gueguen A, Nguyen M, Berdah L, Lequesne M, Mazieres B, Vignon E. Radiological progression of hip osteoarthritis: definition, risk factors and correlations with clinical status. *Ann Rheum Dis* 1996; 55: 356-62.
- Dutoit M, Zambelli P Y. Simplified 3D-evaluation of periacetabular osteotomy. *Acta Orthop Belg* 1999; 65: 288-94.
- Erb A, Brenner H, Gunther K P, Sturmer T. Hormone replacement therapy and patterns of osteoarthritis: baseline data from the Ulm Osteoarthritis Study. *Ann Rheum Dis* 2000; 59: 105-09.
- Felson D T. Osteoarthritis. *Rheum Dis Clin North Am* 1990; 16: 499-12.
- Felson D T, Anderson J J, Naimark A, Hannan M T, Kannel W B, Meenan R F. Does smoking protect against osteoarthritis? *Arthritis Rheum* 1989; 32: 166-72.
- Felson D T, Zhang Y, Hannan M T, Naimark A, Weissman B N, Aliabadi P, Levy D. The incidence and natural history of knee osteoarthritis in the elderly. The Framingham Osteoarthritis Study. *Arthritis Rheum* 1995; 38: 1500-05.
- Ferguson SJ, Bryant JT, Ganz R, Ito K. The influence of the acetabular labrum on hip joint cartilage consolidation: a poroelastic finite element model. *J Biomechanics* 2000; 33: 953-60.
- Ferguson SJ, Bryant JT, Ganz R, Ito K. An in vitro investigation of the acetabular labral seal in hip joint mechanics. *J Biomechanics* 2003; 36: 171-78.
- Fredensborg N. The CE angle of normal hips. *Acta Orthop Scand* 1976; 47: 403-05.
- Ganz R, Klaue K, Vinh T S, Mast J W. A new periacetabular osteotomy for the treatment of hip dysplasias. Technique and preliminary results. *Clin Orthop* 1988; 232: 26-36.
- Ganz R, Parvizi J, Beck M, Leunig M, Notzli H, Siebenrock K A. Femoroacetabular impingement: a cause for osteoarthritis of the hip. *Clin Orthop* 2003; 417: 112-20.
- Gillett C A. Bernese periacetabular osteotomy for hip dysplasia in young adults. *AORN J* 2002; 75: 737-47.
- Goker B, Sancak A, Arac M, Shott S, Block J A. The radiographic joint space width in clinically normal hips: effects of age, gender and physical parameters. *Osteoarthritis Cartilage* 2003; 11: 328-34.
- Goodman D A, Feighan J E, Smith A D, Latimer B, Buly R L, Cooperman D R. Subclinical slipped capital femoral epiphysis. Relationship to osteoarthritis of the hip. *J Bone Joint Surg* 1997; 79A: 1489-97.
- Hadley N A, Brown T D, Weinstein S L. The effects of contact pressure elevations and aseptic necrosis on the long-term outcome of congenital hip dislocation. *J Orthop Res* 1990; 8: 504-13.
- Hasegawa Y, Iwata H, Mizuno M, Genda E, Sato S, Miura T. The natural course of osteoarthritis of the hip due to subluxation or acetabular dysplasia. *Arch Orthop Trauma Surg* 1992; 111: 187-91.
- Heyman CH, Herndon CH. Legg-Perthes disease. A method for the measurement of the roentgenographic result. *J Bone Joint Surg* 1950; 32A: 767-78.
- Hochberg M C. Epidemiology and genetics of osteoarthritis. *Curr Opin Rheumatol* 1991; 3: 662-8.
- Hoegh-Andersen P, Tanko L B, Andersen T L, Lundberg C V, Mo J A, Heegaard A M, Delaisse J M, Christgau S. Ovariectomized rats as a model of postmenopausal osteoarthritis: validation and application. *Arthritis Res Ther* 2004; 6: 169-80.
- Ingvarsson T, Hagglund G, Lindberg H, Lohmander L S. Assessment of primary hip osteoarthritis: comparison of radiographic methods using colon radiographs. *Ann Rheum Dis* 2000; 59: 650-3.
- Inoue K, Wicart P, Kawasaki T, Huang J, Ushiyama T, Hukuda S, Courpied J. Prevalence of hip osteoarthritis and acetabular dysplasia in french and japanese adults. *Rheumatology* 2000; 39: 745-8.
- Ito K, Leunig M, Ganz R. Histopathologic features of the acetabular labrum in femoroacetabular impingement. *Clin Orthop* 2004; 429: 262-71.
- Ito K, Minka M A, Leunig M, Werlen S, Ganz R. Femoroacetabular impingement and the cam-effect. A MRI-based quantitative anatomical study of the femoral head-neck offset. *J Bone Joint Surg* 2001; 83B: 171-6.
- Jacquemier M, Jouve J L, Bollini G, Panuel M, Migliani R. Acetabular anteversion in children. *J Pediatr Orthop* 1992; 12: 373-5.
- Janzen D L, Aippersbach S E, Munk P L, Sallomi D F, Garbus D, Werier J, Duncan C P. Three-dimensional CT measurement of adult acetabular dysplasia: technique, preliminary results in normal subjects, and potential applications. *Skeletal Radiol* 1998; 27: 352-8.
- Jordan JM, Kington RS, Lane NE, Nevitt MC, Zhang Y, Sowers M. Systemic risk factors for osteoarthritis. *Ann Intern Med* 2000; 133: 637-9.
- Katz J F. Identification of the "teardrop" figure and acetabular margins on the roentgenogram. *Clin Orthop* 1969; 62: 232-9.
- Katz J F. Precise identification of radiographic acetabular landmarks. *Clin Orthop* 1979; 141: 166-8.
- Kellgren J, Lawrence JS. Radiological assessment of osteoarthritis. *Ann Rheum Dis* 1957; 16: 494-02.
- Kim SS, Frick SL, Wenger DR. Anteversion of the acetabulum in developmental dysplasia of the hip: analysis with computed tomography. *J Pediatr Orthop* 1999; 19: 438-42.
- Klaue K. Acetabular rim pathology secondary to congenital hip dysplasia in the adult. A radiographic study. *Chir Organi Mov* 1997; 82: 7-8.
- Klaue K, Durmin C W, Ganz R. The acetabular rim syndrome. A clinical presentation of dysplasia of the hip. *J Bone Joint Surg* 1991; 73B: 423-9.
- Klaue K, Wallin A, Ganz R. CT evaluation of coverage and congruency of the hip prior to osteotomy. *Clin Orthop* 1988; 232: 15-25.

- Kubo T, Horii M, Yamaguchi J, Inoue S, Fujioka M, Ueshima K, Hirasawa Y. Acetabular labrum in hip dysplasia evaluated by radial magnetic resonance imaging. *J Rheumatol* 2000; 27: 1955-60.
- Lane N E, Hochberg M C, Pressman A, Scott J C, Nevitt M C. Recreational physical activity and the risk of osteoarthritis of the hip in elderly women. *J Rheumatol* 1999; 26: 849-54.
- Lane N E, Lin P, Christiansen L, Gore L R, Williams E N, Hochberg M C, Nevitt M C. Association of mild acetabular dysplasia with an increased risk of incident hip osteoarthritis in elderly white women: the study of osteoporotic fractures. *Arthritis Rheum* 2000; 43: 400-4.
- Lanyon P, Muir K, Doherty S, Doherty M. Assessment of a genetic contribution to osteoarthritis of the hip: sibling study. *BMJ* 2000; 321: 1179-83.
- Lanyon P, Muir K, Doherty S, Doherty M. Age and sex differences in hip joint space among asymptomatic subjects without structural change: implications for epidemiologic studies. *Arthritis Rheum* 2003; 48: 1041-6.
- Lau E M, Lin F, Lam D, Silman A, Croft P. Hip osteoarthritis and dysplasia in Chinese men. *Ann Rheum Dis* 1995; 54: 965-9.
- Lau E M, Symmons D P, Croft P. The epidemiology of hip osteoarthritis and rheumatoid arthritis in the Orient. *Clin Orthop* 1996; 363: 81-90.
- Leunig M, Podeszwa D, Beck M, Werlen S, Ganz R. Magnetic resonance arthrography of labral disorders in hips with dysplasia and impingement. *Clin Orthop* 2004; 418: 74-80.
- Leunig M, Siebenrock K A, Ganz R. Rationale of periacetabular osteotomy and background work. *Instr Course Lect* 2001; 50: 229-38.
- Leunig M, Werlen S, Ungersbock A, Ito K, Ganz R. Evaluation of the acetabular labrum by MR arthrography. *J Bone Joint Surg* 1997; 79B: 230-4.
- Lievense A, Bierma-Zeinstra S, Verhagen A. Influence of work on the development of osteoarthritis of the hip. *J Rheumatol* 2001; 28: 2520-8.
- MacDonald S J, Hersche O, Rodriguez J, Ganz R. The Bernese periacetabular osteotomy for the treatment of adult hip dysplasia. *Chir Organi Mov* 1997; 82: 143-54.
- Macirowski T, Tepic S, Mann R W. Cartilage stresses in the human hip joint. *J Biomech* 1994; 116: 10-8.
- Marks R, Allegrante J P. Body mass indices in patients with disabling hip osteoarthritis. *Arthritis Res* 2002; 4: 112-6.
- Mast J W, Brunner R L, Zebrack J. Recognizing acetabular version in the radiographic presentation of hip dysplasia. *Clin Orthop* 2004; 418: 48-53.
- Maxian T A, Brown T D, Weinstein S L. Chronic stress tolerance levels for human articular cartilage: two nonuniform contact models applied to long-term follow-up of CDH. *J Biomech* 1995; 28: 159-66.
- McCarthy J C, Lee J A. Acetabular dysplasia: a paradigm of arthroscopic examination of chondral injuries. *Clin Orthop* 2002; 405: 122-28.
- McCarthy J C, Noble P C, Schuck M R, Wright J, Lee J. The Otto E. Aufranc Award: The role of labral lesions to development of early degenerative hip disease. *Clin Orthop* 2001; 393: 25-37.
- McCarthy J C, Noble P C, Schuck M R, Wright J, Lee J. The watershed labral lesion: its relationship to early arthritis of the hip. *J Arthroplasty* 2001; 16: 81-7.
- Mechlenburg I, Nyengaard J R, Romer L, Soballe K. Changes in load-bearing area after Ganz periacetabular osteotomy evaluated by multislice CT scanning and stereology. *Acta Orthop Scand* 2004; 75: 147-53.
- Michaeli D A, Murphy S B, Hipp J A. Comparison of predicted and measured contact pressures in normal and dysplastic hips. *Med Eng Phys* 1997; 19: 180-6.
- Mouritzen U, Christgau S, Lehmann H J, Tanko L B, Christiansen C. Cartilage turnover assessed with a newly developed assay measuring collagen type II degradation products: influence of age, sex, menopause, hormone replacement therapy, and body mass index. *Ann Rheum Dis* 2003; 62: 332-36.
- Murphy S B, Ganz R, Muller M E. The prognosis in untreated dysplasia of the hip. A study of radiographic factors that predict the outcome. *J Bone Joint Surg* 1995; 77A: 985-9.
- Murphy S B, Kijewski P K, Millis M B, Harless A. Acetabular dysplasia in the adolescent and young adult. *Clin Orthop* 1990; 261: 214-23.
- Murray K A, Crim J R. Radiographic imaging for treatment and follow-up of developmental dysplasia of the hip. *Semin Ultrasound CT MR* 2001; 22: 306-40.
- Nakamura S, Yorikawa J, Otsuka K, Takeshita K, Harasawa A, Matsushita T. Evaluation of acetabular dysplasia using a top view of the hip on three-dimensional CT. *J Orthop Sci* 2000; 5: 533-9.
- Nevitt M C, Cummings S R, Lane N E, Hochberg M C, Scott J C, Pressman A. Association of estrogen replacement therapy with the risk of osteoarthritis of the hip in elderly white women. Study of Osteoporotic Fractures Research Group. *Arch Intern Med* 1996; 156: 2073-80.
- Noble P, Kamaric E, Sugano N, Matsubara M, Harada Y, Ohzono K, Paravic V. The three-dimensional shape of the dysplastic femur. *Clin Orthop* 2003; 417: 27-40.
- Oliveria S A, Felson D T, Cirillo P A, Reed J I, Walker A M. Body weight, body mass index, and incident symptomatic osteoarthritis of the hand, hip, and knee. *Epidemiology* 1999; 10: 161-6.
- Oliveria S A, Felson D T, Klein R A, Reed J I, Walker A M. Estrogen replacement therapy and the development of osteoarthritis. *Epidemiology* 1996; 7: 415-9.
- Oliveria S A, Felson D T, Reed J I, Cirillo P A, Walker A M. Incidence of symptomatic hand, hip, and knee osteoarthritis among patients in a health maintenance organization. *Arthritis Rheum* 1995; 38: 1134-41.
- Portinaro N M, Murray D W, Bhullar T P, Benson M K. Errors in measurement of acetabular index. *J Pediatr Orthop* 1995; 15: 780-4.
- Reynolds D, Lucas J, Klauke K. Retroversion of the acetabulum. A cause of hip pain. *J Bone Joint Surg* 1999; 81B: 281-8.
- Schnohr P, Jensen G, Lange P, Scharling H, Appleyard M. The Copenhagen city heart study - Österbundersøgelsen - tables with data from the third examination 1991 - 1994. *Eur Heart Journal* 2001; 3: 1-83.

- Severin E. Congenital dislocation of the hip joint. 1941. Stockholm, P.A. Norstedt & Söner.
- Sharp I. Acetabular dysplasia. *J Bone Joint Surg* 1961; 43B: 268-72.
- Siebenrock K A, Schoeniger R, Ganz R. Anterior femoro-acetabular impingement due to acetabular retroversion. Treatment with periacetabular osteotomy. *J Bone Joint Surg* 2003; 85A: 278-86.
- Smith R W, Egger P, Coggon D, Cawley M I, Cooper C. Osteoarthritis of the hip joint and acetabular dysplasia in women. *Ann Rheum Dis* 1995; 54: 179-81.
- Smith R W, Egger P, Coggon D, Cawley M I, Cooper C. Osteoarthritis of the hip joint and acetabular dysplasia in women. *Ann Rheum Dis* 1995; 54: 179-81.
- Søballe K. Pelvic osteotomy for acetabular dysplasia. *Acta Orthop.Scand* 2003; 74: 117-8.
- Spector T D, Cicuttini F, Baker J, Loughlin J, Hart D. Genetic influences on osteoarthritis in women: a twin study. *BMJ* 1996; 312: 940-3.
- Spector T D, Cooper C. Radiographic assessment of osteoarthritis in population studies: whither Kellgren and Lawrence? *Osteoarthritis.Cartilage* 1993; 1: 203-6.
- Stulberg S D. Acetabular dysplasia and development of osteoarthritis of hip. Harris W H. The hip. Proceedings of the second open scientific meeting of the hip society 1974; 82-93. St.Louis, C.V.Mosby.
- Stulberg S D. Unrecognized childhood hip disease: a major cause of idiopathic osteoarthritis of the hip. Cordell, L D, Harris, W H, Ramsey, P L, and MacEwen, G D. Proceedings of the third open scientific meeting of the hip society 1975; 212-28. St.Louis, C.V.Mosby.
- Sun Y, Günther K P, Brenner H. Reliability of radiographic grading of osteoarthritis of the hip and knee. *Scand J Rheumatology* 1997; 26: 155-65.
- Tönns DE. Congenital dysplasia and dislocation of the hip in children and adults. 1984 Springer-Verlag [Berlin-Heidelberg-New York].
- Tonnis D. Normal values of the hip joint for the evaluation of X-rays in children and adults. *Clin Orthop* 1976; 119: 39-47.
- Vingård E, Hogstedt C, Alfredsson L, Fellenius E, Goldie I, Köster M. Coxarthrosis and physical work load. *Scand.J Work Environ Health* 1991; 17: 104-9.
- Visser J, Jonkers A, Hillen B. Hip joint measurements with computerized tomography. *J Pediatr Orthop* 1982; 2: 143-6.
- Wedge J H, Wasylenko M J. The natural history of congenital dislocation of the hip: a critical review. *Clin Orthop* 1978; 137: 154-162.
- Weinstein S L. Natural history of congenital hip dislocation (CDH) and hip dysplasia. *Clin Orthop* 1987; 225: 62-76.
- Wiberg G. Studies on dysplastic acetabula and congenital subluxation of the hip joint. *Acta Orthop.Scand Suppl* 1939; 58: 1-132. Stockholm, PA Norstedt & Söner.
- Wynne-Davies R. A family study of neonatal and late-diagnosis congenital dislocation of the hip. *J Med Genet* 1970; 7: 315-33.
- Wynne-Davies R. Acetabular dysplasia and familial joint laxity: two etiological factors in congenital dislocation of the hip. A review of 589 patients and their families. *J Bone Joint Surg Br* 1970; 52B: 704-16.
- Yoshida M, Konishi N. Subchondral cysts arise in the anterior acetabulum in dysplastic osteoarthritic hips. *Clin Orthop* 2002; 404: 291-301.

10. Appendix

Widely used composite radiological OA scores

Croft (1990)

0°	No changes of osteoarthritis.
1°	Osteophytosis only.
2°	Joint space narrowing only.
3°	Two of osteophytosis, joint space narrowing, subcondral sclerosis, and cyst formation.
4°	Three of osteophytosis, joint space narrowing, subcondral sclerosis, and cyst formation.
5°	As in grade 4, but with deformity of femoral head.

Kellgren & Lawrence (1956)

0	No degenerative changes.
1	Possible narrowing of joint space width medially and possible osteophytes around femoral head.
2	Definite narrowing of joint space inferiorly, definite osteophytes and slight sclerosis.
3	Marked narrowing of joint space, slight osteophytes, some sclerosis and cyst formation and deformity of femoral head and acetabulum.
4	Gross loss of joint space with sclerosis and cysts, marked deformity of femoral head and acetabulum and large osteophytes.