

What Are the Radiographic Reference Values for Acetabular Under- and Overcoverage?

Moritz Tannast MD, Markus S. Hanke MD,
Guoyan Zheng PhD, Simon D. Steppacher MD,
Klaus A. Siebenrock MD

© The Association of Bone and Joint Surgeons® 2014

Abstract

Background Both acetabular undercoverage (hip dysplasia) and overcoverage (pincer-type femoroacetabular impingement) can result in hip osteoarthritis. In contrast to undercoverage, there is a lack of information on radiographic reference values for excessive acetabular coverage. **Questions/purposes** (1) How do common radiographic hip parameters differ in hips with a deficient or an excessive acetabulum in relation to a control group; and (2) what are the reference values determined from these data for acetabular under- and overcoverage?

Methods We retrospectively compared 11 radiographic parameters describing the radiographic acetabular anatomy among hip dysplasia (26 hips undergoing periacetabular osteotomy), control hips (21 hips, requiring no rim trimming

during surgical hip dislocation), hips with overcoverage (14 hips, requiring rim trimming during surgical hip dislocation), and hips with severe overcoverage (25 hips, defined as having acetabular protrusion). The hips were selected from a patient cohort of a total of 593 hips. Radiographic parameters were assessed with computerized methods on anteroposterior pelvic radiographs and corrected for neutral pelvic orientation with the help of a true lateral radiograph.

Results All parameters except the crossover sign differed among the four study groups. From dysplasia through control and overcoverage, the lateral center-edge angle, acetabular arc, and anteroposterior/craniocaudal coverage increased. In contrast, the medial center-edge angle, extrusion/acetabular index, Sharp angle, and prevalence of the posterior wall sign decreased. The following reference values were found: lateral center-edge angle 23° to 33°, medial center-edge angle 35° to 44°, acetabular arc 61° to 65°, extrusion index 17% to 27%, acetabular index 3° to 13°, Sharp angle 38° to 42°, negative crossover sign, positive posterior wall sign, anterior femoral head coverage 15% to 26%, posterior femoral head coverage 36% to 47%, and craniocaudal coverage 70% to 83%.

Conclusions These acetabular reference values define excessive and deficient coverage. They may be used for radiographic evaluation of symptomatic hips, may offer possible predictors for surgical outcomes, and serve to guide clinical decision-making.

Level of Evidence Level III, diagnostic study.

One of the authors (MT) has received funding from the Swiss National Science Foundation.

All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research*® editors and board members are on file with the publication and can be viewed on request. *Clinical Orthopaedics and Related Research*® neither advocates nor endorses the use of any treatment, drug, or device. Readers are encouraged to always seek additional information, including FDA-approval status, of any drug or device prior to clinical use. Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

M. Tannast (✉), M. S. Hanke, S. D. Steppacher,
K. A. Siebenrock
Department of Orthopaedic Surgery, Inselspital, University of
Bern, Freiburgstrasse, 3010 Bern, Switzerland
e-mail: moritz.tannast@insel.ch

G. Zheng
Institute for Surgical Technology and Biomechanics, University
of Bern, Bern, Switzerland

Introduction

Both acetabular undercoverage (developmental dysplasia of the hip [DDH]) and overcoverage (such as “pincer”-type

Table 1. Demographic data of the four study groups

Parameter	Dysplasia	Control	Overcoverage	Severe overcoverage	p value
Number	26	21	14	25	–
Sex (percent male of all hips)	19	76	36	0	< 0.001
Side (percent right of all hips)	42	62	43	44	0.518
Age (years)	33 ± 9 (16–44)	34 ± 13 (17–58)	34 ± 13 (15–57)	41 ± 15 (15–70)	0.074
Height (cm)	167 ± 8 (152–180)	171 ± 7 (159–182)	167 ± 5 (162–173)	168 ± 9 (157–196)	0.394
Weight (kg)	73 ± 18 (47–73)	69 ± 15 (47–102)	69 ± 14 (53–86)	69 ± 12 (51–93)	0.785
Body mass index (kg/m ²)	26 ± 6 (18–26)	24 ± 5 (19–33)	25 ± 5 (20–33)	25 ± 5 (17–32)	0.420

Continuous data are expressed as mean ± SD and range in parentheses.

femoroacetabular impingement [FAI]) can lead to degenerative hip arthritis. A different pathomechanism for each of these two conditions is supposed. Undercoverage may cause higher joint contact pressures [12] and subsequent degeneration of the articular cartilage resulting from static overload [13, 20]. Acetabular overcoverage may lead to early pathological contact between the overcovering acetabulum and the femoral head-neck junction [11]. This can lead to prearthrotic chondrolabral damage as a result of a more dynamic conflict at the acetabular rim [30].

Although acetabular undercoverage has been quantified before [5, 20, 34], there is a lack of information in the literature on excessive coverage. To our knowledge, an anatomically based quantification of overcoverage has never been explicitly described.

We therefore asked: (1) how do common radiographic hip parameters differ between hips with a deficient or excessive acetabulum in comparison to a control group; and (2) what are the anatomically based reference values for acetabular under- and overcoverage?

Material and Methods

We performed a retrospective comparative study including a total of 86 selected, nonconsecutive nonarthritic hips (Table 1). We compared the radiographic anatomy of the acetabulum among four groups: a “dysplastic,” “control,” “overcoverage,” and “severe overcoverage” group. The allocation to each group (Fig. 1) was based on established radiographic criteria and direct visual inspection of the type of impingement conflict during surgical hip dislocation [9]. The “dysplastic” group consisted of a consecutive series of patients undergoing periacetabular osteotomy (PAO) [10] in 2004 (n = 59 hips). Inclusion criteria was a lateral center-edge (LCE) angle of ≤ 20° [20]. Exclusion criteria were improper/incomplete radiographs (n = 26) and hips with previous surgery (n = 26). The “control” and the “overcoverage” groups were recruited from 481 consecutive

hips undergoing surgical hip dislocation for FAI (Fig. 1) [6]. Exclusion criteria were improper/incomplete radiographs (n = 260), previous hip surgery (n = 37), a history of pediatric hip disorder (n = 58), and hips with mixed cam/pincer-type of FAI (n = 91). The remaining 35 hips either had isolated cam (n = 21 hips, “control” group) or pincer-type FAI (“overcoverage” group). The allocation to these two groups was based on the direct visual intraoperative dynamic assessment. The “control” hips only required a correction of the aspherical femoral head until impingement-free ROM was present during surgical hip dislocation. The “overcoverage” group only required isolated rim trimming without addressing the femoral head-neck junction. The “severe overcoverage” group consisted of hips with acetabular protrusion, which is established as the most severe form of pincer impingement. This group included hips in which the femoral head touches or crosses the ilioischial line on the AP pelvic radiograph [17, 32]. We excluded 26 hips with improper/incorrect radiographs and two hips with previous surgery from an initial cohort of 53 hips leaving 25 hips for the “severe overcoverage” group (Fig. 1). This retrospective comparative study was approved by the local institutional review board.

Two radiographic views acquired with a standardized technique were used for evaluation: an AP and a true lateral pelvic radiograph [32]. The AP radiograph was used to calculate the radiographic parameters; the true lateral radiograph was used to assess the individual pelvic tilt (described later). Both radiographs were taken consecutively without repositioning of the patient (Fig. 2). The film-focus distance was 120 cm for both views. For the AP pelvic radiograph, the center of the x-ray beam was directed to the midpoint of the symphysis and a line connecting the anterosuperior iliac spines. For the true lateral radiograph, the x-ray beam was centered on the tip of the greater trochanter.

We used previously validated and commercially available software (Hip²Norm [31, 33, 38]; University of Bern, Bern, Switzerland) for the evaluation of these radiographs.

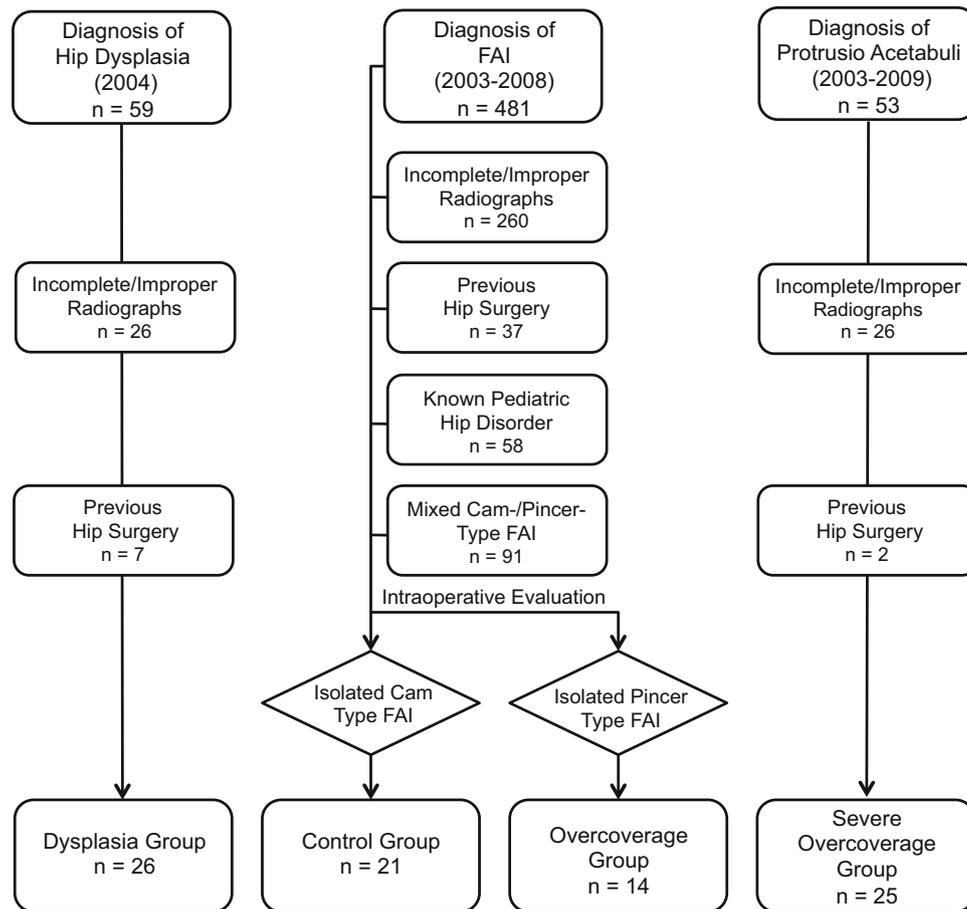


Fig. 1 The figure shows how the four different groups were recruited.

This software allows a reliable and reproducible evaluation of the most commonly used radiographic hip parameters. Repeatability statistics with use of this program have been published elsewhere [31]; briefly, the interobserver reliability and the intraobserver repeatability for the following chosen 11 parameters (Table 2) was good to very good (ie, intraclass correlation coefficient ≥ 0.61): LCE angle, medial center-edge angle, acetabular arc, extrusion index, acetabular index, Sharp angle, crossover sign, posterior wall sign, anterior femoral head coverage, posterior femoral head coverage, and craniocaudal femoral head coverage (Fig. 3). A special feature of Hip²Norm is the ability of correcting the radiographic parameters for tilt and rotation [33]. To exclude the influence of pelvic malpositioning, we calculate all radiographic value relative to a neutral pelvic orientation regarding tilt (around the transverse axis) and rotation (around the longitudinal axis). A neutral pelvic tilt was defined by a pelvic inclination of 60° [6, 19, 37]. This angle is formed by a horizontal line and a line connecting the upper border of the symphysis with the sacral promontory. This angle was measured on the lateral pelvic radiograph. A neutral pelvic rotation was defined

when the center of the sacrococcygeal joint was aligned vertically with the middle of the pubic symphysis [33]. One observer (MT) assessed all radiographs.

Normal distribution was determined with the Kolmogorov-Smirnov test. Differences for demographic and radiographic data among the four study groups were determined with analysis of variance for continuous variables and the chi-square test for categorical variables. Reference values were derived from the intersection points of the normal distribution curves for each continuous variable. Reference values for categorical variables were determined by the highest prevalence in the control group.

Results

All parameters except the crossover sign differed among the four study groups (Table 3). Of the nine evaluated continuous variables, five parameters (LCE angle, acetabular arc, AP/cranial coverage) increased steadily from dysplasia through control and overcoverage to severe overcoverage (Fig. 4). In contrast, four of the continuous

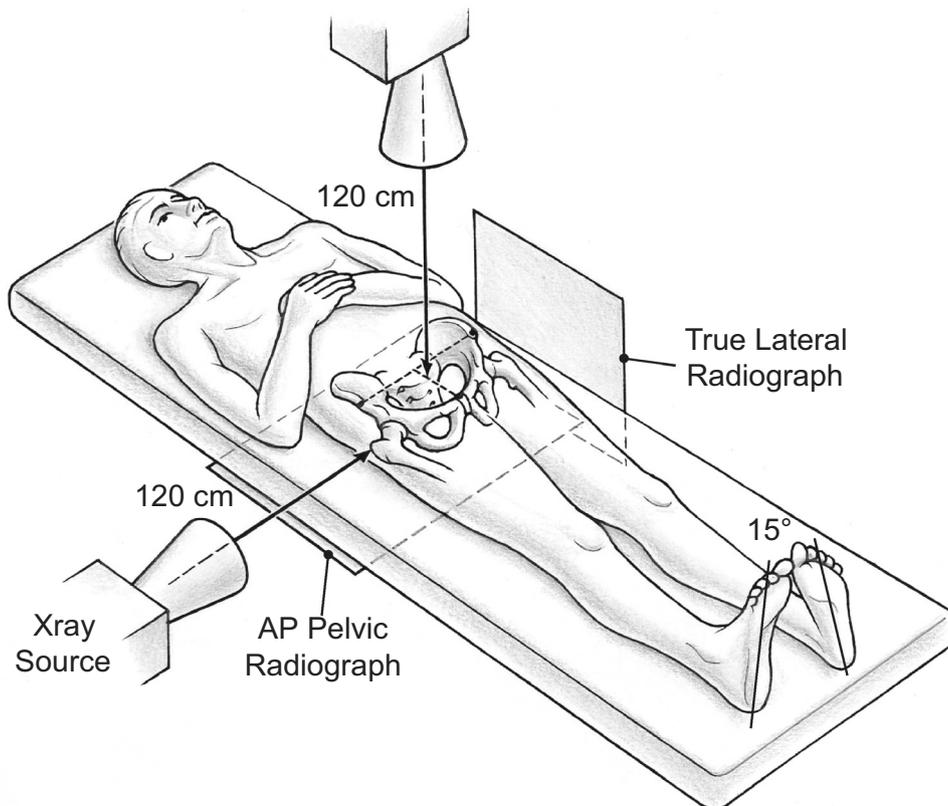


Fig. 2 The figure shows the radiographic setup for the AP and the true lateral pelvic radiographs. Both radiographs are taken consecutively without repositioning of the patient. The film-focus distance is 120 cm for both radiographs. For the AP pelvic radiograph, the center of the x-ray beam is directed to the midpoint of the symphysis and a line connecting the anterosuperior iliac spines. For the true lateral

radiograph, the x-ray beam was centered on the tip of the greater trochanter. Reprinted with kind permission from the American Roentgen Ray Society: Tannast M, Siebenrock KA, Anderson SE. Femoroacetabular impingement: radiographic diagnosis—what the radiologist should know. *AJR Am J Roentgenol.* 2007;188:1540–1552.

Table 2. Definitions of the investigated radiographic hip parameters (see Fig. 2 for schematic illustration)

Parameter	Definition
Lateral center-edge (LCE) angle	Angle formed by a line parallel to the longitudinal pelvic axis and a line connecting the center of the femoral head with the lateral edge of the acetabular sourcil
Medial center-edge (MCE) angle	Angle formed by a line parallel to the longitudinal pelvic axis and a line connecting the center of the femoral head with the medial edge of the acetabular sourcil
Acetabular arc	Angle formed by two lines connecting the center of the femoral head with the medial and the lateral edge of the acetabular sourcil (sum of the LCE and the MCE angle)
Extrusion index	Percentage of uncovered femoral head (A) in comparison to the total horizontal head diameter (A + B)
Acetabular index	Angle formed by a horizontal line and a line through the most medial point of the sclerotic zone of the acetabular roof and the lateral edge of the acetabulum
Sharp angle	Angled formed by a horizontal line and a line through the caudal tip of the teardrop and the lateral edge of the acetabulum
Crossover sign	Positive if the projected anterior wall crosses the posterior wall
Posterior wall sign	Positive if the posterior acetabular rim is projected medial of the center of the hip
Anterior coverage	The percentage of femoral head covered by the anterior acetabular rim in AP direction
Posterior coverage	The percentage of femoral head covered by the posterior acetabular rim in posteroanterior direction
Craniocaudal coverage	The percentage of femoral head covered by the acetabulum in craniocaudal direction

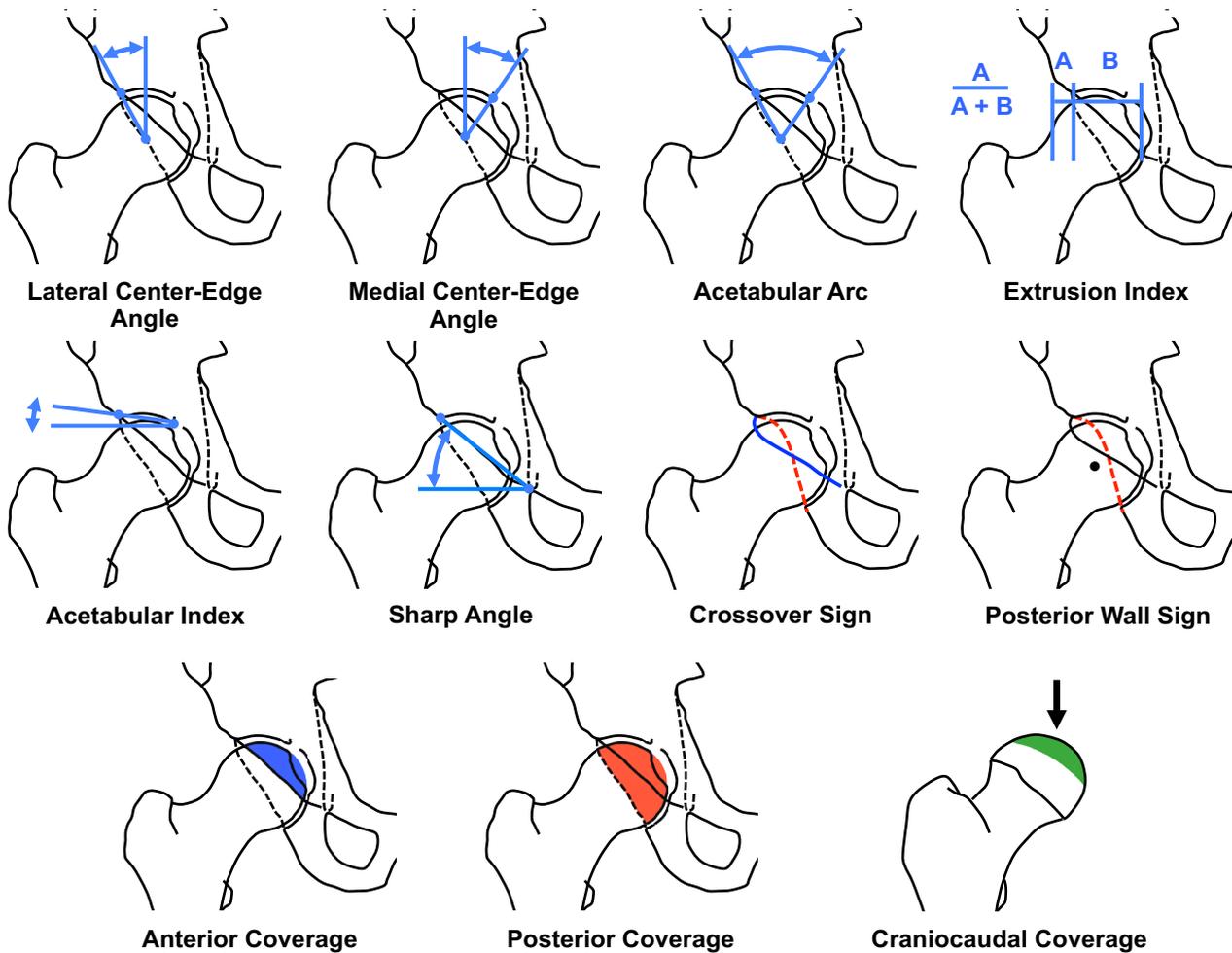


Fig. 3 The definitions of the 11 evaluated radiographic parameters are illustrated using schematic drawings. The craniocaudal view direction is indicated (*black arrow*).

Table 3. Results of the 11 evaluated radiographic parameters for the four study groups

Parameter	Dysplasia	Control	Overcoverage	Severe overcoverage	p value
LCEA (degrees)	16 ± 7 (−1 to 20)	26 ± 5 (20–35)	35 ± 6 (24–46)	49 ± 6 (31–59)	< 0.001
MCEA (degrees)	48 ± 9 (36–63)	41 ± 6 (27–52)	31 ± 5 (24–43)	27 ± 7 (12–40)	< 0.001
Acetabular arc (degrees)	59 ± 7 (46–77)	67 ± 6 (51–77)	66 ± 7 (57–85)	75 ± 9 (60–93)	< 0.001
Extrusion index (degrees)	33 ± 6 (26–54)	23 ± 5 (12–31)	15 ± 5 (5–25)	7 ± 4 (0–18)	< 0.001
Acetabular index (degrees)	13 ± 8 (7–32)	9 ± 4 (4–19)	0 ± 4 (−7 to 7)	−10 ± 6 (−17 to 7)	< 0.001
Sharp angle (degrees)	46 ± 3 (39–52)	40 ± 2 (34–45)	38 ± 4 (32–45)	34 ± 4 (25–44)	< 0.001
Crossover sign (percent positive)	19	10	14	8	0.635
Posterior wall sign (percent positive)	100	71	57	4	< 0.001
Anterior coverage (percent)	12 ± 5 (4–22)	19 ± 6 (7–29)	29 ± 9 (13–42)	42 ± 8 (25–54)	< 0.001
Posterior coverage (percent)	37 ± 8 (15–47)	43 ± 7 (32–59)	49 ± 9 (32–64)	66 ± 7 (55–81)	< 0.001
Craniocaudal coverage (percent)	63 ± 8 (42–76)	78 ± 7 (68–92)	85 ± 7 (72–95)	95 ± 5 (85–100)	< 0.001

Continuous data are expressed as mean ± SD and range in parentheses; LCEA = lateral center-edge angle; MCEA = medial center-edge angle.

parameters (medial center-edge angle, extrusion/acetabular index, Sharp angle) decreased from dysplasia to severe overcoverage.

The intersection of the normal distribution curves results (Fig. 5) in the formulation of characteristic thresholds for each continuous parameter. The following reference values

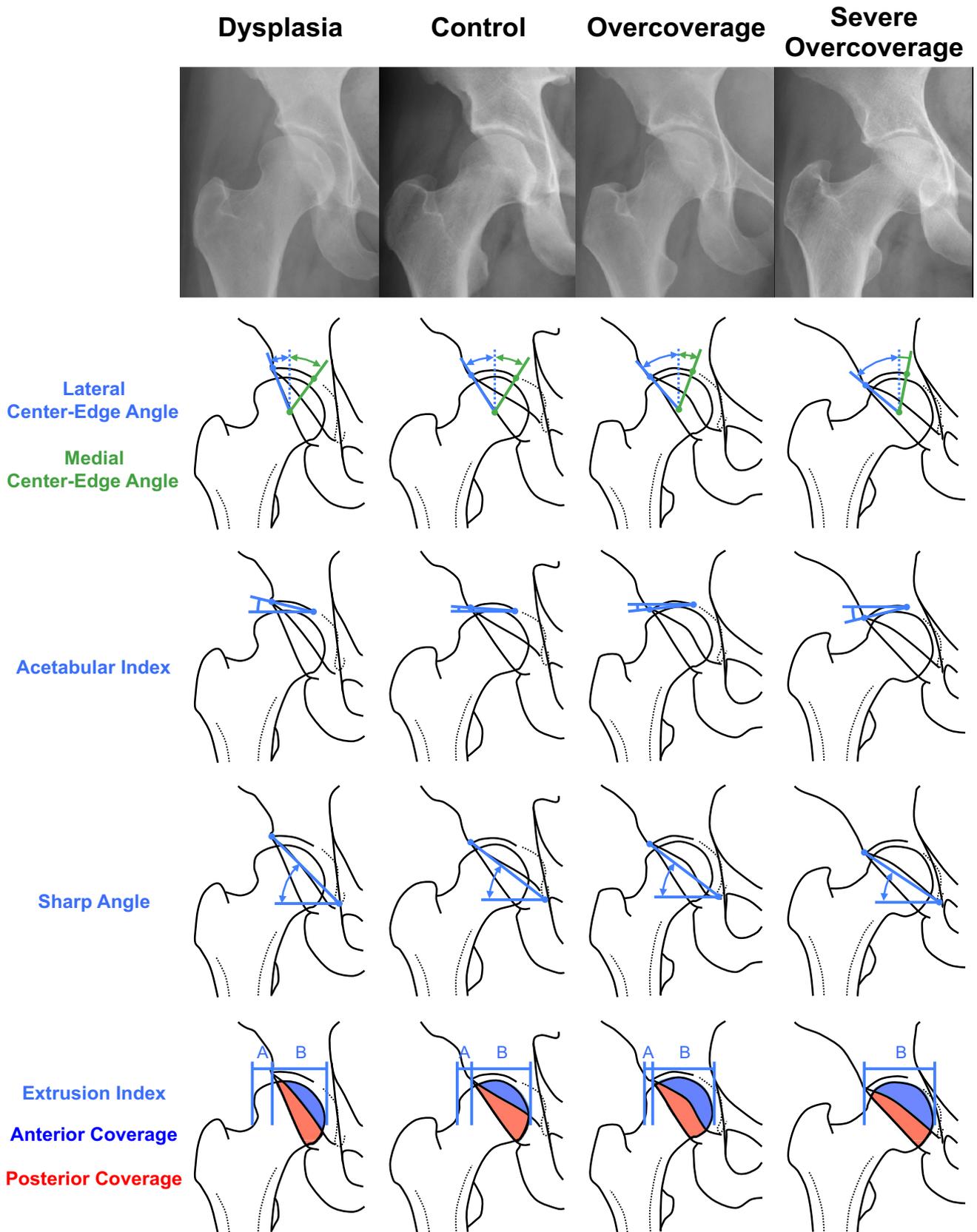


Fig. 4 Schematic illustration showing the differences of the radiographic parameters among the four study groups. From dysplasia through control, overcoverage and severe overcoverage, LCE angle, acetabular arc, and AP coverage increased. In contrast, medial center-edge angle, acetabular/extrusion indices, and the Sharp angle decreased from dysplasia to severe overcoverage.

were found: LCE angle 23° to 33°, medial center-edge angle 35° to 44°, acetabular arc 61° to 65°, extrusion index 17% to 27%, acetabular index 3° to 13°, Sharp angle 38° to 42°, negative crossover sign, positive posterior wall sign, anterior femoral head coverage 15% to 26%, posterior femoral head coverage 36% to 47%, and craniocaudal coverage 70% to 83% (Table 4).

Discussion

Undercoverage and overcoverage are two distinct pathologic forms of acetabular morphology. They can result in two different clinically pathomechanisms: static overload (undercoverage) or dynamic FAI conflict (overcoverage). The overload concept has been widely accepted for decades with a good body of literature on reference values for undercoverage (Table 5). However, because the concept of FAI resulting from excessive acetabular coverage has not gained acceptance until the last 10 years, quantitative data on radiographic reference values are sparse. We therefore raised the following questions: (1) how do the common

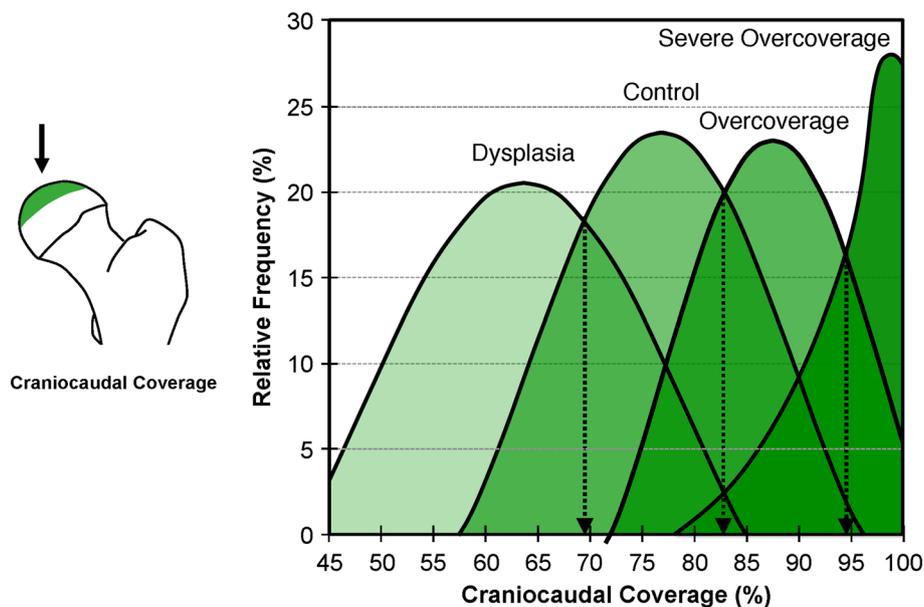


Fig. 5 The distribution curves for craniocaudal coverage of the four study groups are shown as an example for definition of the range of values for each group. The intersection of the distribution curves resulted in the definition thresholds for each parameter (Table 4). Image to the left indicates craniocaudal coverage and craniocaudal view direction (*black arrow*).

Table 4. Novel anatomically based radiographic reference values for the acetabulum on an AP pelvic radiograph

Parameter	Dysplasia	Control	Overcoverage	Severe overcoverage
LCEA (degrees)	< 22	23–33	34–39	> 40
MCEA (degrees)	> 45	35–44	34–29	< 28
Acetabular arc (degrees)	< 60	61–65	66–69	> 69
Extrusion index (percent)	> 27	17–27	12–16	< 11
Acetabular index (degrees)	> 14	3–13	–7 to 2	< –8
Sharp angle (degrees)	> 43	38–42	34–37	< 34
Crossover sign (percent positive)	Positive	Negative	Negative	Negative
Posterior wall sign (percent positive)	Positive	Positive	Positive or negative	Negative
Anterior coverage (percent)	< 14	15–26	27–32	> 33
Posterior coverage (percent)	< 35	36–47	48–55	> 56
Craniocaudal coverage (percent)	< 69	70–83	84–93	> 93

LCEA = lateral center-edge angle; MCEA = medial center-edge angle.

Table 5. Selected publications on normal radiographic values describing the acetabular anatomy

Study	Method	Hips	Hip dysplasia	Normal hips	Pincer/protrusio
Lateral center-edge angle					
Wiberg (1939) [36]	AP pelvic radiograph	200	< 20° Borderline: 20°–25°	> 25°	
Fredensborg (1976) [8]	AP pelvic radiograph	40	Adults: < 20° (borderline 20°–25°) Children: < 15° (borderline 15°–20°)	Adults: > 25° Children: > 20°	
Anda et al. (1986) [2] and (1991) [3]	Scout view of CT	82 and 33	13° ± 5° (3°–19°)	Male: 38° ± 5° (23–42) Female: 35° ± 6° (21–42)	
Murphy et al. (1995) [20]	AP pelvic radiograph	117	7° ± 12° (–22°–28°)	34° ± 9° (16°–49°)	
Kojima et al. (1998) [14]	Computer simulation and AP pelvic radiograph	146	9° ± 9°	Male: 31° ± 6° Female: 29° ± 5°	
Tönnis and Heinecke (1999) [34]	AP pelvic radiograph	NA	< 20°		Deep acetabulum: 39°–44° Protrusio: > 44°
Li and Ganz (2003) [18]	AP pelvic radiograph	232	6° ± 9° (–22°–25°)		
Jacobsen et al. (2005) [13]	AP pelvic radiograph	4151		Male: 35° ± 7° (10°–62°) Female: 35° ± 7° (10°–65°)	
Ecker et al. (2007) [7]	AP pelvic radiograph	25		33° ± 6° (24°–47°)	
Steppacher et al. (2008) [28]	AP pelvic radiograph	100	14° ± 9° (–16°–24°)		44° ± 5° (39°–59°)
Shi et al. (2010) [24]	AP pelvic radiograph	1494		Childhood: 23° (5°–46°) Adolescents: 29° (6°–48°) Adults: 33° (14°–59°)	
Siebenrock et al. (2012) [25]	AP pelvic radiograph	87	10° (–13°–21°)	27° (20°–35°)	42° (24°–56°)
Lepage-Saucier et al. (2014) [16]	AP pelvic radiograph	94		Male: 35° ± 6° (22°–47°) Female: 32° ± 6° (21°–44°)	
Scheidt et al. (2014) [22]	AP pelvic radiograph	164		34° ± 7° (20°–56°)	
Acetabular index					
Murphy et al. (1995) [20]	AP pelvic radiograph	117	25° ± 10° (6°–46°)	6° ± 6° (–5° to 15°)	
Tönnis and Heinecke (1999) [34]	AP pelvic radiograph	NA	> 14°		Deep acetabulum < –5°
Li and Ganz (2003) [18]	AP pelvic radiograph	232	25° ± 10° (0°–50°)		
Ecker et al. (2007) [7]	AP pelvic radiograph	25		9° ± 5° (–4° to 16°)	
Steppacher et al. (2008) [28]	AP pelvic radiograph	100	21° ± 6° (14°–38°)		–1° ± 5° (–13° to 14°)
Lepage-Saucier et al. (2014) [16]	AP pelvic radiograph	94		Male: 6° ± 5° (–3° to 14°) Female: 6° ± 4° (–1° to 16°)	
Scheidt et al. (2014) [22]	AP pelvic radiograph	164		2° ± 5° (–11° to 14°)	

Table 5. continued

Study	Method	Hips	Hip dysplasia	Normal hips	Pincer/protrusio
Extrusion index					
Murphy et al. (1995) [20]	AP pelvic radiograph	117	36% ± 12% (15%–62%)	12% ± 8% (0%–31%)	
Li and Ganz (2003) [18]	AP pelvic radiograph	232	39% ± 12% (11%–65%°)		
Jacobsen et al. (2005) [13]	AP pelvic radiograph	4151		Male: 12% ± 9% (0%–45%) Female: 8% ± 7% (0%–46%)	
Ecker et al. (2007) [7]	AP pelvic radiograph	25		15% ± 6% (2%–33%)	
Steppacher et al. (2008) [28]	AP pelvic radiograph	100	34%° ± 7% (22%–57%)		9% ± 4% (0%–16%)
Scheidt et al. (2014) [22]	AP pelvic radiograph	164		11% ± 6% (6%–27%)	
Sharp angle					
Sharp (1961) [23]	AP pelvic radiograph	200		33°–38°	
Jacobsen et al. (2005) [13]	AP pelvic radiograph	4151		Male: 37° ± 4° (26°–54°) Female: 39° ± 4° (24°–56°)	
Scheidt et al. (2014) [22]	AP pelvic radiograph	164		39° ± 4° (28°–49°)	
Crossover sign					
Reynolds et al. (1999) [21]	AP pelvic radiograph	446	Negative	Negative	
Posterior wall sign					
Reynolds et al. (1999) [21]	AP pelvic radiograph	446	Positive	Negative	
Anterior coverage					
Siebenrock et al. (2012) [25]	AP pelvic radiograph	87	10% (0%–22%)	19% (7%–29%)	36% (13%–54%)
Posterior coverage					
Siebenrock et al. (2012) [25]	AP pelvic radiograph	87	37% (15%–53%)	43% (32%–59%)	59% (32%–79%)
Craniocaudal coverage					
Konishi et al. (1993) [15]	CT	286		Male: 79% ± 5% Female: 77% ± 6%	
Steppacher et al. (2008) [28]	AP pelvic radiograph	100	63% ± 12% (32%–87%)		92% ± 6% (79%–100%)
Dandachli et al. (2013) [5]	CT	75	51% ± 7% (38%–64%)	73% ± 4% (66%–81%)	

NA = not applicable.

Parameter	Dysplasia	Control	Over-coverage	Severe over-coverage
Lateral center edge [°]	< 22	23–33	34–39	> 40
Medial center-edge [°]	> 45	35–44	34–29	< 28
Acetabular arc [°]	< 60	61–65	66–69	> 69
Extrusion index [%]	> 27	17–26	12–16	< 11
Acetabular index [°]	> 14	3–13	(-7)–2	< -8
Sharp angle [°]	> 43	38–42	34–37	< 34
Cranial coverage [%]	< 69	70–83	84–93	> 93
Anterior coverage [%]	< 14	15–26	27–32	> 33
Posterior coverage [%]	< 35	36–47	48–55	> 56



A

Parameter	Dysplasia	Control	Over-coverage	Severe over-coverage
Lateral center edge [°]	< 22	23–33	34–39	> 40
Medial center-edge [°]	> 45	35–44	34–29	< 28
Acetabular arc [°]	< 60	61–65	66–69	> 69
Extrusion index [%]	> 27	17–26	12–16	< 11
Acetabular index [°]	> 14	3–13	(-7)–2	< -8
Sharp angle [°]	> 43	38–42	34–37	< 34
Cranial coverage [%]	< 69	70–83	84–93	> 93
Anterior coverage [%]	< 14	15–26	27–32	> 33
Posterior coverage [%]	< 35	36–47	48–55	> 56



B

Fig. 6A–B This figure shows a potential application of the established reference values in clinical practice. **(A)** The case of a 24-year-old female patient with groin pain is shown. The results of the analysis with Hip²Norm (indicated by *darkened boxes*) show that most of the parameters are indicative for a deficient acetabulum

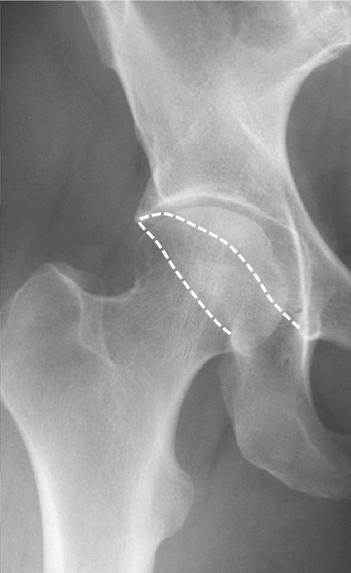
(dysplasia) except the anterior coverage, which is excessive. A dysplastic hip with acetabular retroversion was diagnosed. **(B)** The patient underwent anteverting PAO, which could normalize almost all parameters.

radiographic hip parameters differ in hips with a deficient or excessive acetabulum in comparison to a control group; and (2) what are the reference values determined from these data for acetabular under- and overcoverage?

This study has limitations. First, we were unable to provide radiographic data for the “control” group from asymptomatic patients. This would not have been compliant with institutional review board policies in our country. However, our group of “control” acetabuli consisted of

patients with isolated cam-type FAI who all underwent surgical hip dislocation with offset creation. In all these hips, an impingement-free ROM was ensured by direct intraoperative observation during dynamic examination of the hip. A relevant additional morphology in terms of overcoverage can therefore be excluded. Second, we do not use a population-based approach to determine the reference values, unlike other authors [13, 24]. Third, our determined reference values are only valid in symptomatic patients.

Parameter	Dysplasia	Control	Over-coverage	Severe over-coverage
Lateral center edge [°]	< 22	23–33	34–39	> 40
Medial center-edge [°]	> 45	35–44	34–29	< 28
Acetabular arc [°]	< 60	61–65	66–69	> 69
Extrusion index [%]	> 27	17–26	12–16	< 11
Acetabular index [°]	> 14	3–13	(-7)–2	< -8
Sharp angle [°]	> 43	38–42	34–37	< 34
Cranial coverage [%]	< 69	70–83	84–93	> 93
Anterior coverage [%]	< 14	15–26	27–32	> 33
Posterior coverage [%]	< 35	36–47	48–55	> 56



A

Parameter	Dysplasia	Control	Over-coverage	Severe over-coverage
Lateral center edge [°]	< 22	23–33	34–39	> 40
Medial center-edge [°]	> 45	35–44	34–29	< 28
Acetabular arc [°]	< 60	61–65	66–69	> 69
Extrusion index [%]	> 27	17–26	12–16	< 11
Acetabular index [°]	> 14	3–13	(-7)–2	< -8
Sharp angle [°]	> 43	38–42	34–37	< 34
Cranial coverage [%]	< 69	70–83	84–93	> 93
Anterior coverage [%]	< 14	15–26	27–32	> 33
Posterior coverage [%]	< 35	36–47	48–55	> 56



B

Fig. 7A–B This figure shows a second potential application of the determined reference values for the acetabulum. **(A)** The AP pelvic radiograph of a 32-year-old male patient is shown. The analysis with Hip²Norm reveals excessive values of all parameters (indicated by darkened boxes) except for the anterior coverage, which was normal.

Acetabular overcoverage with a too prominent posterior acetabular rim was diagnosed. **(B)** The patient underwent surgical hip dislocation with trimming of the posterior and superior acetabular rim. The anterior rim was not addressed surgically. This led to normalization of most of the parameters.

They can be used for diagnosis and treatment in these patients but must be used in adjunct with patient history, clinical findings, and the femoral morphology. A potential application of these reference values to the asymptomatic general population and its relevance for the natural history has yet to be proven. Fourth, another potential limitation is the diversity of the selection criteria to create the study groups. We used radiographic criteria for the most severely

affected “dysplasia” and the “severe overcoverage” groups, whereas we depended on intraoperative assessment for the less affected “control” and the “overcoverage” groups. However, the radiographic criteria for dysplasia (LCE angle of less than 20°) are established parameters [20, 35, 36] that have been shown by both finite element analysis [4] and natural history [20] to result in overload and osteoarthritis if untreated. In contrast, a direct

intraoperative dynamic examination offers the best assessment of a potential impingement conflict in a pincer-type hip. We thus feel that the risk of selection bias is minimal.

When comparing our mean values for the four groups with other studies (Table 5), good agreement can be found for many of the parameters, in particular for the dysplasia group. For example, a LCE angle of less than 22° seems to be a reproducible indicator for static overload (Table 5). This is in accordance with the results of various methodologies including population-based approaches [22], finite-element modeling [4], computation of joint-contact pressures [12], and studies on natural history [20]. The upper thresholds for the LCE angle found in our study require further clarification. We believe that the reported upper values from large population-based approaches might include falsely high values. A reason could be the lack of information about the pain status and physical examination [24] or a publication date before the introduction of the FAI concept [8]. The same is true for other parameters (eg, the Sharp angle or the extrusion index).

The established reference values have already been applied in several clinical studies, which support their validity. In a long-term followup study of 147 patients, Albers et al. [1] could show that there is at least a two times higher risk of failure after PAO for DDH if the majority of the radiographic hip parameters for the acetabulum were not in the normal range. Similarly, our determined reference values were found as predictive factors for the 5- and the 10-year followup after surgical hip dislocation for FAI [26, 27]. The reference values described can also be used as an adjunct for choosing the most appropriate surgical option of symptomatic hips. This can be very helpful in borderline cases of mixed DDH and pincer pathomorphologies (Fig. 6) or in the evaluation of acetabular coverage (Fig. 7).

In summary, based on direct intraoperative observation, we developed acetabular reference values for excessive and deficient coverage. These values can be used for radiographic evaluation of symptomatic hips, possible predictors of surgical outcomes, and as an adjunct for clinical decision-making. As shown in a previous study [29], the following parameters can be reliably measured without necessarily compensating for pelvic tilt and rotation on an AP pelvic radiograph (ie, without a true lateral radiograph): LCE angle, Sharp angle, acetabular and extrusion index, and cranio-caudal coverage. Similar to what has been shown for the dysplastic hips [20], future studies need to investigate the natural course of hips with acetabular overcoverage. Despite the establishment of our preliminary guidelines, we emphasize that incidentally found abnormal radiographic values in asymptomatic patients are not an indication for

surgery unless patients at risk would have been identified who will ultimately develop hip osteoarthritis.

References

- Albers CE, Steppacher SD, Ganz R, Tannast M, Siebenrock KA. Impingement adversely affects 10-year survivorship after periacetabular osteotomy for DDH. *Clin Orthop Relat Res*. 2013;471:1602–1614.
- Anda S, Svenningsen S, Dale LG, Benum P. The acetabular sector angle of the adult hip determined by computed tomography. *Acta Radiol Diagn (Stockh)*. 1986;27:443–447.
- Anda S, Terjesen T, Kvistad KA, Svenningsen S. Acetabular angles and femoral anteversion in dysplastic hips in adults: CT investigation. *J Comput Assist Tomogr*. 1991;15:115–120.
- Chegini S, Beck M, Ferguson SJ. The effects of impingement and dysplasia on stress distributions in the hip joint during sitting and walking: a finite element analysis. *J Orthop Res*. 2009;27:195–201.
- Dandachli W, Islam SU, Liu M, Richards R, Hall-Craggs M, Witt J. Three-dimensional CT analysis to determine acetabular retroversion and the implications for the management of femoroacetabular impingement. *J Bone Joint Surg Br*. 2009;91:1031–1036.
- Drenckhahn D, Eckstein F. Lower extremity. In: Benninghoff A, Drenckhahn D, eds. *Anatomy, Volume 1*. 16th ed [in German]. Munich, Germany: Urban & Fischer; 2003:342–350.
- Ecker TM, Tannast M, Puls M, Siebenrock KA, Murphy SB. Pathomorphologic alterations predict presence or absence of hip osteoarthritis. *Clin Orthop Relat Res*. 2007;465:46–52.
- Fredensborg N. The CE angle of normal hips. *Acta Orthop Scand*. 1976;47:403–405.
- Ganz R, Gill TJ, Gautier E, Ganz K, Krugel N, Berlemann U. Surgical dislocation of the adult hip a technique with full access to the femoral head and acetabulum without the risk of avascular necrosis. *J Bone Joint Surg Br*. 2001;83:1119–1124.
- Ganz R, Klaue K, Vinh TS, Mast JW. A new periacetabular osteotomy for the treatment of hip dysplasias. Technique and preliminary results. *Clin Orthop Relat Res*. 1988;232:26–36.
- Ganz R, Parvizi J, Beck M, Leunig M, Notzli H, Siebenrock KA. Femoroacetabular impingement: a cause for osteoarthritis of the hip. *Clin Orthop Relat Res*. 2003;417:112–120.
- Hipp JA, Sugano N, Millis MB, Murphy SB. Planning acetabular redirection osteotomies based on joint contact pressures. *Clin Orthop Relat Res*. 1999;364:134–143.
- Jacobsen S, Sonne-Holm S, Soballe K, Gebuhr P, Lund B. Hip dysplasia and osteoarthritis: a survey of 4151 subjects from the Osteoarthritis Substudy of the Copenhagen City Heart Study. *Acta Orthop*. 2005;76:149–158.
- Kojima A, Nakagawa T, Tohkura A. Simulation of acetabular coverage of femoral head using anteroposterior pelvic radiographs. *Arch Orthop Trauma Surg*. 1998;117:330–336.
- Konishi N, Mieno T. Determination of acetabular coverage of the femoral head with use of a single anteroposterior radiograph. A new computerized technique. *J Bone Joint Surg Am*. 1993;75:1318–1333.
- Lepage-Saucier M, Thiery C, Larbi A, Lecouvet FE, Vande Berg BC, Omoumi P. Femoroacetabular impingement: normal values of the quantitative morphometric parameters in asymptomatic hips. *Eur Radiol*. 2014;24:1707–1714.
- Leunig M, Nho SJ, Turchetto L, Ganz R. Protrusion acetabuli: new insights and experience with joint preservation. *Clin Orthop Relat Res*. 2009;467:2241–2250.

18. Li PL, Ganz R. Morphologic features of congenital acetabular dysplasia: one in six is retroverted. *Clin Orthop Relat Res.* 2003;416:245–253.
19. Lierse W. Pelvis. In: Lanz T, Wachsmuth W, eds. *Practical Anatomy, Volume II/8a* [in German]. Berlin, Germany: Springer; 1984:30–32.
20. Murphy SB, Ganz R, Muller ME. The prognosis in untreated dysplasia of the hip. A study of radiographic factors that predict the outcome. *J Bone Joint Surg Am.* 1995;77:985–989.
21. Reynolds D, Lucas J, Klaue K. Retroversion of the acetabulum. A cause of hip pain. *J Bone Joint Surg Br.* 1999;81:281–288.
22. Scheidt RB, Galia CR, Diesel CV, Rosito R, Macedo CA. Prevalence of radiographic markers of femoroacetabular impingement in asymptomatic adults. *Rev Col Bras Cir.* 2014;41:36–42.
23. Sharp IK. Acetabular dysplasia: the acetabular angle. *J Bone Joint Surg Br.* 1961;43:268–272.
24. Shi YY, Liu TJ, Zhao Q, Zhang LJ, Ji SJ, Wang EB. The normal centre-edge angle of Wiberg in the Chinese population: a population-based cross-sectional study. *J Bone Joint Surg Br.* 2010;92:1144–1147.
25. Siebenrock KA, Kistler L, Schwab JM, Buchler L, Tannast M. The acetabular wall index for assessing anteroposterior femoral head coverage in symptomatic patients. *Clin Orthop Relat Res.* 2012;470:3355–3360.
26. Steppacher SD, Anwander H, Zurmühle CA, Tannast M, Siebenrock KA. Surgical hip dislocation for treatment of femoroacetabular impingement: a concise followup at 10-year. *Clin Orthop Relat Res.* 2014;472:337–348.
27. Steppacher SD, Huemmer C, Schwab JM, Tannast M, Siebenrock KA. Surgical hip dislocation for treatment of femoroacetabular impingement: factors predicting 5-year survivorship. *Clin Orthop Relat Res.* 2013;472:337–348.
28. Steppacher SD, Tannast M, Werlen S, Siebenrock KA. Femoral morphology differs between deficient and excessive acetabular coverage. *Clin Orthop Relat Res.* 2008;466:782–790.
29. Tannast M, Fritsch S, Zheng G, Siebenrock KA, Steppacher SD. Which radiographic hip parameters do not have to be corrected for pelvic rotation and tilt? *Clin Orthop Relat Res.*, 2014 Sep 18 [Epub ahead of print].
30. Tannast M, Goricki D, Beck M, Murphy SB, Siebenrock KA. Hip damage occurs at the zone of femoroacetabular impingement. *Clin Orthop Relat Res.* 2008;466:273–280.
31. Tannast M, Mistry S, Steppacher SD, Reichenbach S, Langlotz F, Siebenrock KA, Zheng G. Radiographic analysis of femoroacetabular impingement with Hip²Norm—reliable and validated. *J Orthop Res.* 2008;26:1199–1205.
32. Tannast M, Siebenrock KA, Anderson SE. Femoroacetabular impingement: radiographic diagnosis—what the radiologist should know. *AJR Am J Roentgenol.* 2007;188:1540–1552.
33. Tannast M, Zheng G, Anderegg C, Burckhardt K, Langlotz F, Ganz R, Siebenrock KA. Tilt and rotation correction of acetabular version on pelvic radiographs. *Clin Orthop Relat Res.* 2005;438:182–190.
34. Tönnis D, Heinecke A. Acetabular and femoral anteversion: relationship with osteoarthritis of the hip. *J Bone Joint Surg Am.* 1999;81:1747–1770.
35. Werner CM, Ramseier LE, Ruckstuhl T, Stromberg J, Copeland CE, Turen CH, Rufibach K, Bouaicha S. Normal values of Wiberg’s lateral center-edge angle and Lequesne’s acetabular index – a coxometric update. *Skeletal Radiol.* 2012;41:1273–1278.
36. Wiberg G. The anatomy and roentgenographic appearance of a normal hip joint. *Acta Chir Scand.* 1939;83:7–38.
37. Williams PL, Warwick R, Dyson M, Bannister LH. The skeleton of the lower limb. In: William PL, ed. *Gray’s Anatomy*. Edinburgh, Scotland: Churchill Livingstone; 1989:422–446.
38. Zheng G, Tannast M, Anderegg C, Siebenrock KA, Langlotz F. Hip2Norm: an object-oriented cross-platform program for 3D analysis of hip joint morphology using 2D pelvic radiographs. *Comput Methods Programs Biomed.* 2007;87:36–45.