Assessment of adult hip dysplasia and the outcome of surgical treatment

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ABSTRACT
Hip dysplasia and hip joint deformities in general are recognized as possible precursors of osteoarthritic development. Early and correct identification of hip dysplasia is important in order to offer timely joint preserving treatment. In the contemporary literature, several controversies exist, and some of these were the focus of this doctoral thesis. Categorized into subjects, the major findings and their possible importance are listed below.

Diagnostic assessment of hip dysplasia
A multi-observer study quantified the variability of different methods for diagnostic assessment of hip dysplasia and osteoarthritis and resulted in general recommendations regarding diagnostic assessment of hip dysplasia. Pelvic tilt was shown to differ significantly between the supine and weight-bearing positions in patients with dysplastic hip joints. This is a finding that adds controversy to the application of neutral pelvic positioning during assessment of hip deformities because pelvic tilt affects the appearance of acetabular version. Weight-bearing assessment of acetabular version showed the presence of retroversion in 33% of dysplastic hips. The establishment of retroversion as a rather frequent entity in dysplastic hips is contradictory to the historical finding that hip dysplasia is characterized by insufficient anterior and lateral coverage. In general, the findings have important implications for orthopedic surgeons and radiologists dealing with diagnostic assessment of painful hips in young adults, and for surgeons planning and performing joint-preserving peri-acetabular osteotomies.

Assessment of acetabular labral tears in hip dysplasia
The roles of ultrasound and clinical tests in acetabular labral tear diagnostics were established. After overcoming an initial learning curve, ultrasound investigation was highly reliable in diagnosing labral tears, whereas only a positive impingement or FABER test was reliable in identifying a labral tear. It seems that non-invasive and rapid ultrasound examination performed by an experienced examiner can potentially alter the traditional diagnostic algorithm in which magnetic resonance arthrography remains the gold standard.

Peri-acetabular osteotomy for surgical treatment of hip dysplasia in adults
Encouraging hip joint survival and clinical outcome were reported at medium-term follow-up after peri-acetabular osteotomy. The small number of studies reporting the outcome beyond a 5-year follow-up is in contrast to the wide application of the peri-acetabular osteotomy. The performed analysis of predictors of
conversion to total hip replacement following periacetabular osteotomy documented the importance of different biomechanical and degenerative factors. Knowledge about factors predicting early conversion to total hip replacement has the potential to refine patient selection and to improve treatment by periacetabular osteotomy. Cartilage thickness was documented to be preserved up to 2½ years after periacetabular osteotomy. All but 1 hip joint had acetabular labral tears, thus indicating that the presence of labral tears does not accelerate cartilage degeneration after periacetabular osteotomy.

1. INTRODUCTION
In 1939, Wiberg outlined a new paradigm for hip dysplasia research (1). He called attention to hip dysplasia as a possible precursor of premature osteoarthritic development. Among the most important contributors to this paradigm in the half century that followed were Stulberg and Harris, Cooperman et al., Hasegawa et al., and Murphy et al., who all investigated the suggestions of Wiberg on the association between hip dysplasia and osteoarthritides (2-6).

The understanding that structural hip deformity may cause osteoarthritis was also the focus of other important research of the 1960s. Murray, followed by Solomon and Harris, suggested that structural hip deformities of the proximal femur (i.e. pistol grip deformities) were associated with osteoarthritic development (7-12). The understanding that proximal femoral and acetabular deformities give rise to disturbed biomechanics and early degeneration has been addressed by Ganz and colleagues by introducing the concept of femoroacetabular impingement (FAI) (13-14).

Contemporary research into hip dysplasia was founded by the introduction of the periacetabular osteotomy (PAO) for the treatment of symptomatic hip dysplasia in adults by Ganz and colleagues in 1988 (15). The systematic understanding of the role of the acetabular labrum and of the pathological biomechanics characterizing the dysplastic hip joint was initiated by a description of the “acetabular rim syndrome” by Klaue et al. a few years later (35). Research efforts have been progressive, but more than 20 years later controversies and unanswered questions still exist.

The aims of the studies presented in this doctoral thesis were inspired by these controversies, unanswered questions, and questions not yet asked in the contemporary research on hip dysplasia. Diagnostic assessment and treatment of structural hip deformity make a thorough radiographic understanding an important tool. In this thesis focus has been on the contemporary controversies of reliability of radiographic assessment, optimal positioning of the patient for pelvic radiography and assessment, and acetabular retroversion in hip dysplasia and the issues related to the dependence of these factors on pelvic positioning (I-III). In accordance with the present intense interest in labral pathologies, it seems that the procedure can successfully preserve selected dysplastic hip joints (73). However, few data about the medium- and long-term efficacy of PAO have been forthcoming, and knowledge about predictors of outcome following this major surgical procedure remains sparse. These subjects and the role of acetabular labral tears for the outcome of treatment of hip dysplasia have been investigated in this doctoral thesis (VI-VII).

Figure 2.1. A section of an anteroposterior pelvic radiograph showing the right hip. Hip dysplasia is present, and the center-edge angle of Wiberg is ≤20°.

2. A SHORT OVERVIEW OF HIP DYSPLASIA

2.1 Pathoanatomy and pathological biomechanics
Hip dysplasia is characterized by a steep and shallow acetabulum and insufficient acetabular coverage of the femoral head (Figure 2.1). Because of the decreased area of acetabular and femoral head contact, load forces on the joint increase. Acetabular structural change is often transmitted distally during development, and excessive femoral neck anteversion and varying degrees of coxa valga can result (30-34,38-40). To further complicate the 3-dimensional pathoanatomy of hip dysplasia, it has been documented that varying degrees of acetabular retroversion coexist in as many as 40% of the hips (41-42).

For decades it has been speculated that hip joint deformity could cause osteoarthritis (2-12). During the past decade, knowledge of the pathologically altered biomechanics caused by hip deformities and which lead to osteoarthritides of the hip joint has grown exponentially. The biomechanical concept of FAI has been introduced, and it is now commonly accepted that repeated collisions between the acetabular rim and the femoral head or femoral head-neck junction with time cause tearing of the labrum and subsequent joint deterioration (13,14,17-28). Hip dysplasia is one of the hip deformities found to be associated with FAI and osteoarthritic development. General joint instability and a shearing kind of impingement may cause repeated, chronic overload of the acetabular rim, with possible tearing of the labrum and subsequent destruction of adjacent cartilage. In classical cases, the lack of coverage has an anterolateral location, and this is the most frequent location of labral tears in dysplastic hips (35-37).

2.2 Epidemiology and risk of osteoarthitis
The femoral neck and the acetabular rim at the site of overcoverage in the acetabular retroversion, can also cause collisions between the femoral head into the acetabulum. Focal overcoverage, as seen in the acetabular rim. The mechanism is named “pincer” type FAI, in which direct damage to the labrum occurs in the anterior part of the joint. Secondary contrecoup-like chondral damage in the posterior-inferior part of the acetabulum can be seen due to leverage of the head into the acetabulum. Focal overcoverage, as seen in the acetabular retroversion, can also cause collisions between the femoral neck and the acetabular rim at the site of overcoverage extending beyond the anterolateral femoral head-neck junction is characteristic of the deformity underlying "cam" type FAI. It is named a pistol grip deformity because of its appearance on anteroposterior (AP) radiographs. The head-neck offset is reduced, and the relative prominence of the head-neck junction is jammed into the acetabulum. Distinct from the damage pattern in pincer FAI is that cam FAI initially produces a progressive chondral delamination starting at the junction between the labrum and cartilage (13,14,17-28,43,44).

Only few population-based prevalence estimates of hip joint deformities exist: An overall prevalence of pistol grip deformity of 8% has been reported in an investigation of 2655 human skeletons (48). Population-based prevalence estimates by Gosvig et al. show that pistol grip deformity is predominantly a male condition (19.6% of males vs. 5.2% of females) with a male to female ratio of approximately 4:1 (52). A deep acetabular socket was found to be a common hip joint deformity in both sexes, with prevalences of 15.2% in males and 19.4% in females (52).

The evidence that these hip joint deformities can cause osteoarthritis development through FAI mechanisms is primarily derived from clinical observations in small, highly selected cohorts (13,14,18-28,53-58,64-66). However, in the population-based setting a deep acetabular socket (risk ratio: 2.4), and pistol grip deformity (risk ratio: 2.2) has been identified as significant risk factors for the development of osteoarthritis (52).

### 3. Diagnostic Assessment of Hip Dysplasia

#### 3.1. Errors in the diagnostic assessment of hip dysplasia

Patients with symptomatic hip dysplasia may benefit from joint preserving surgery (67). Therefore, identification of these young adult patients is an important task. Delay of diagnosis may result in progression of joint degeneration into an advanced stage necessitating hip replacement surgery. Assessment of hip dysplasia includes the patient history, clinical examination, and radiographic evaluation. The AP pelvic radiograph is the traditional cornerstone of initial conventional radiographic assessment of any hip deformity (I-III). For clinical use it should be supplemented with a cross-table or frog-leg lateral view of each hip. On the AP pelvic radiograph, the most commonly used radiographic indices for assessment of hip dysplasia are the CE angle of Wiberg and the acetabular index angle of Tönnis (1,68). However, several radiographic indices can be used to describe the degree of hip dysplasia (2,4,69-71). It is widely accepted that a CE angle <25° is diagnostic of hip dysplasia in symptomatic patients in a clinical setting. A CE angle of >20°<25° is often referred to as borderline dysplasia. The cut-off value of ≤20°corresponds approximately to the lower limit of 2 standard deviations from the mean value in the population (52). Thus, this cut-off is used in the epidemiological setting of population-based surveys (47,52,59). It is also commonly accepted that an AI angle >10° is pathological. Initial assessment of osteoarthritis is important because hips with advanced stages of osteoarthritis are not candidates for joint-preserving surgery (72-74, VI). In the literature pertaining to the treatment of hip dysplasia, osteoarthritis has classically been assessed by means of the Tönnis classification (0-3) or less frequently by measuring the minimum joint space width (JSW) (72-74, VI). Computed tomography (CT) scans represent a high diagnostic standard in the assessment of hip dysplasia and aid the surgeon during preoperative planning.
Table 3.1. Agreement between assessed parameters on conventional radiographs and on CT-scan.

<table>
<thead>
<tr>
<th>Observer</th>
<th>Parameters</th>
<th>Assessment of parameters vs. CT scan</th>
<th>Observed agreement</th>
<th>Weighted kappa value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1</td>
<td>Presence of hip dysplasia (by vision)?</td>
<td>82%</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Presence of hip dysplasia (by drawing)?</td>
<td>86%</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Presence of joint space width ≤ 2mm?</td>
<td>92%</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grading osteoarthritis 0-3?</td>
<td>40%</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grading osteoarthritis 0-1 vs. 2-3?</td>
<td>72%</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>No. 2</td>
<td>Presence of hip dysplasia (by vision)?</td>
<td>90%</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Presence of hip dysplasia (by drawing)?</td>
<td>78%</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Presence of joint space width ≤ 2mm?</td>
<td>86%</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grading osteoarthritis 0-3?</td>
<td>36%</td>
<td>-0.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grading osteoarthritis 0-1 vs. 2-3?</td>
<td>82%</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td>No. 3</td>
<td>Presence of hip dysplasia (by vision)?</td>
<td>80%</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Presence of hip dysplasia (by drawing)?</td>
<td>84%</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Presence of joint space width ≤ 2mm?</td>
<td>92%</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grading osteoarthritis 0-3?</td>
<td>56%</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grading osteoarthritis 0-1 vs. 2-3?</td>
<td>86%</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>No. 4</td>
<td>Presence of hip dysplasia (by vision)?</td>
<td>82%</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Presence of hip dysplasia (by drawing)?</td>
<td>88%</td>
<td>0.76</td>
<td></td>
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<tr>
<td></td>
<td>Presence of joint space width ≤ 2mm?</td>
<td>88%</td>
<td>0.35</td>
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<td></td>
<td>Grading osteoarthritis 0-3?</td>
<td>60%</td>
<td>0.33</td>
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<tr>
<td></td>
<td>Grading osteoarthritis 0-1 vs. 2-3?</td>
<td>84%</td>
<td>0.34</td>
<td></td>
</tr>
</tbody>
</table>

When assessing conventional AP pelvic radiographs for the presence of hip dysplasia and osteoarthritis, it is important to realize that assessment of the commonly used parameters has inherent intra- and inter-observer variability (75-79, I). This has implications for the intra- and interobserver interpretation of the diagnosis of hip dysplasia and the degree of hip dysplasia and osteoarthritis. Because of these variations, opinions on the indication for joint-preserving surgery may vary.

Troelsen et al. (I) conducted a blinded, 4-observer study with each observer performing 2 assessments by vision and 2 assessments by angle construction in 50 hip joints. All assessments were compared to those made on CT scan. The intra- and interobserver variability of angle assessment was less when angles were constructed compared with assessment by vision. Intraobserver variability was confined within approximately ± 10° for assessment by vision and within approximately ± 5° to ± 7° for assessment by angle construction. Inter-observer assessments showed slightly higher variability, and a similar difference between assessments by vision and by angle construction. The observers’ ability to diagnose hip dysplasia were in general improved when angles were constructed compared with assessment by vision. Assessment of osteoarthritis in general showed poor agreement with findings on CT scan, with assessment of a JSW <2mm and a dichotomized grading of the Tönnis classification in grades 0-1 and 2-3 showing the best agreement with findings on CT scan (3.1). Previous studies have reported measures of intraobserver variability of the CE and AI angle of approximately ± 5° (75,79, II), which is comparable to the findings by Troelsen et al. (I). Other studies that investigated the intra- and interobserver variability for angle measures used in assessment of hip dysplasia reported the results as intraclass coefficients, which does not convey information on the actual magnitude of the variability (77,78). A Bland-Altman approach should be the means of presenting these data (105,106). The study by Troelsen et al. (I) is the first to report the variability of angle assessment by vision, and to compare the findings on conventional radiographs to that on CT scans. Troelsen et al. (I) confirmed that assessment of hip dysplasia and osteoarthritis is very reliable on CT scans, and previous studies have found similar satisfactory levels of intraobserver variability (33,34).

Some general methodological problems are involved in the assessment of angles in pelvic radiographs: Identification of anatomical landmarks may be difficult, and methods may vary between observers. This will add variability to measurements, and this is probably the reason why the inherent variability of ± 5° cannot be diminished significantly. Standardized protocols for the radiographic assessment may assist multiple observers with different experiences in achieving acceptable variability (76, I). In studies investigating the ability of observers to diagnose pathomorphologies on conventional radiographs, this inherent, increased focus on their presence may lead to more positive findings than are actually present. As an example Closby, et al. reported that 64% of radiographic and clinical normal hips were diagnosed as having a pathomorphological finding in a multiobserver study (76). Finally, the radiographic diagnostic assessment of hip pathomorphologies should always be evaluated in a clinical context with knowledge of the patient’s medical history and the findings on clinical examination. This likely has the potential to improve the ability to correctly diagnose hip deformities, but it has not been done in radiographic reliability studies (76, I).

In conclusion, any observer, regardless of his or her level of experience, should refrain from assessment of radiographic angles using only vision. This will result in an unacceptably high variability of angle measures and a poorer ability to correctly diagnose the presence of hip dysplasia (I). One should be aware of the inherent variability of approximately ± 5° for angle measures used in the diagnostic assessment of hip dysplasia (75,79, I, II), and as a consequence consider reevaluation by CT scan in symptomatic patients in whom a CE angle of 20° to 30° has been measured on conventional pelvic radiographs (I). Angle measurements of hip dysplasia performed on a CT scan by a senior consultant radiologist represent a high radiographic standard with diminished variability between measurements to approximately ± 3° and excellent agreement between assessments of the presence of hip dysplasia (I). Measurement of the JSW or a dichotomized assessment of the Tönnis grade should be preferred for the most reliable assessment of osteoarthritis (I).

3.2. Weightbearing or supine assessment of hip dysplasia?

Not only intra- and interobserver variability of radiographic assessment can affect the interpretation of radiographs. The position of the pelvis during recording has also been hypothesized to affect the interpretation of AP radiographic indices (II). Previous studies have shown that AP radiographic indices of hip dysplasia are not affected beyond inherent measuring errors unless the pelvis is excessively rotated or tilted (79-81). Siebenrock et al. reported an easily understood relationship between the degree of pelvic tilt and the appearance of acetabular deformities (82). Accordingly, well-defined limits for neutral pelvic positioning have been published and are now applied in studies pertaining to AP radiographic assessment of the
A section of an anteroposterior pelvic radiograph showing both hip joints. The line with arrowheads marks the distance from the symphysis to the sacrococcygeal joint.

acetabular version (82-86). Clearly, the application of neutral pelvic positioning is only meaningful if pelvic tilt is not affected significantly by differing patient positioning within the physiological range of motion (i.e., repositioning from supine to weightbearing position). However, in the literature, there has been controversy regarding the effect of change of position from supine to weightbearing on pelvic tilt (87-93). Traditionally, AP pelvic radiographs have been recorded with patients in the supine position.

Troelsen et al. assessed AP radiographic indices of hip dysplasia, pelvic tilt, and acetabular version in 31 sets of supine and weightbearing pelvic radiographs (II). Small mean reductions in the CE angle (1.3° – 1.6°) and small mean increases in the AI angle (1.6° – 2.3°) were observed when repositioning from the supine to the weightbearing position. However, the changes in angle measures were contained within the inherent intraobserver variability (III). Fuchs-Winkelmann et al. (94) assessed 61 sets of supine and weightbearing radiographs, and reported a marginally bigger, significant reduction in the CE angle (3.6°) when repositioning than did Troelsen et al. Intra- and interobserver variability measures were, however, expressed by Pearson’s correlation coefficients, leaving no possibility to assess the actual magnitude of the variability. Fuchs-Winkelmann et al. observed a significant mean reduction in JSW of 0.49 mm after repositioning (94). Troelsen et al. observed a significant reduction in male left hips of 0.67 mm on repositioning (87-93, II). Comparison of studies is not possible because a wide variety of methods are used and study populations show both intra- and interstudy heterogeneity (Table 3.2). It seems, however, that study populations with normal subjects or hip dysplasia are associated with the report of significant changes of pelvic tilt during repositioning (88,89,91,93, II). At least in patients with hip dysplasia, the often generalized instability and coverage deficiency could contribute to increased pelvic mobilization during repositioning.

It is clear that results are diverging, but despite controversy, there are studies to support the hypothesis that pelvises are significantly extended when repositioned from supine to weightbearing (88,89,91,93, II). In the light of this, the application of standardized, so-called neutral pelvic positioning (i.e., assuming no difference in pelvic tilt between supine and weightbearing positions) is controversial (82). This is further amplified by Troelsen et al. who reported that only 32% of patients in the weightbearing position were confined within the limits of normal pelvic positioning suggested by Siebenrock et al. (82, II). Also the position of the patient was found to affect the appearance of acetabular version because 11 patients showed signs of retroversion in the supine position versus 4 patients in the weightbearing position (II). This is explained by the extension of the pelvis in connection with repositioning.

A moderately strong correlation between the distance from the symphysis to the sacrococcygeal joint (used by Troelsen et al. (III)) and the degree of pelvic tilt has been reported (97) (Figure 3.1). Overall, the studies agree that an extension of the pelvis takes place on repositioning (87-93, II). Comparison of studies is not possible because a wide variety of methods are used and study populations show both intra- and interstudy heterogeneity (Table 3.2). This is explained by the extension of the pelvis in connection with repositioning.

In summary, pelvic radiographs for assessment of hip deformities are usually recorded with the patient supine, and neutral pelvic positioning has been advocated (82). However, based on the present literature, a significant pelvic extension may take place after repositioning from the supine to the weightbearing position (88,89,91,93, II). Further, pain originating from prearthritic structural deformities is often attenuated or only present during function. It is thought that weightbearing radiographs secure the best coherence between symptoms, functional ap-

<table>
<thead>
<tr>
<th>Study</th>
<th>No. of patients (females/males)</th>
<th>Description of patients</th>
<th>Method of assessment</th>
<th>Results (diff. supine to weightbearing)</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anda et al. 1990 (II)</td>
<td>42 (27/15)</td>
<td>Healthy young adults</td>
<td>Pelvic inclinometer</td>
<td>Females: Extension: 2.1° Males: Extension: 0.4°</td>
<td>No significant change</td>
</tr>
<tr>
<td>Kruiswijk et al. 1993 (88)</td>
<td>54 (27/27)</td>
<td>Normal subjects 15-19 years</td>
<td>Lateral x-rays correlated with AP x-rays</td>
<td>Females: Extension: 5° Males: Extension: 5°</td>
<td>Significant change (p&lt;0.001)</td>
</tr>
<tr>
<td>Ekdahl et al. 2001 (90)</td>
<td>71 (9/62)</td>
<td>Healthy subjects 24-41 years</td>
<td>Females and males: Extension app. 0°-6°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Norbash et al. 2003 (94)</td>
<td>105 (75/30)</td>
<td>Degenerative OA: Bi: 20-23 years</td>
<td>Image-tracting between CT and AP x-ray</td>
<td>Females and males: Extension: 2°</td>
<td>No significant change</td>
</tr>
<tr>
<td>Lendack et al. 2005 (91)</td>
<td>30 (13/17)</td>
<td>Healthy subjects 20-40 years</td>
<td>Pelvic inclinometer</td>
<td>Females and males: Extension: 2°</td>
<td>Significant change (p&lt;0.001)</td>
</tr>
<tr>
<td>Mayr et al. 2005 (92)</td>
<td>120 (60/60)</td>
<td>Adults and children 21-91 years</td>
<td>Pelvic and/or hip digitized measurements</td>
<td>Young and healthy: Females and males: Extension: 1.0°</td>
<td>No significant change</td>
</tr>
<tr>
<td>Babisch et al. 2006 (93)</td>
<td>50 (9/41)</td>
<td>Hip dysplasia: 17 Osteoarthritis: 12</td>
<td>Standing lateral x-ray and supine CT scan</td>
<td>Females and males: Extension: 5°</td>
<td>Significant change (p&lt;0.002)</td>
</tr>
<tr>
<td>Troelsen et al. 2008 (II)</td>
<td>31 (24/7)</td>
<td>Bilateral (18) or unilateral (13) 18-50 years</td>
<td>Supine and standing AP x-rays</td>
<td>Females: Extension: 1.3° Males: Extension: 1.0°</td>
<td>Significant change (p&lt;0.002) and p&lt;0.002</td>
</tr>
</tbody>
</table>

a: Values are calculated from the original data. 

b: Values of the mean differences in distance from the symphysis to the sacrococcygeal joint are converted according to Tanmay et al. (97).
pearance, and hip deformities. Finally, AP radiographic indices of hip dysplasia, femoral head translation, and the JSW show only minor differences between the supine and weightbearing positions (94, II). Troelsen et al. recommend weightbearing AP pelvic radiographs for assessment of hip deformities (II).

### 3.3. Acetabular retroversion in hip dysplasia

Acetabular retroversion has been recognized as a possible precursor of osteoarthritic development and as a source of hip pain (43, 44, 86, 98). The entity has been found to be associated with the presence of labral tears, and it is incorporated into the biomechanical concept of FAI as a focal overcoverage causing pincer impingement (14, 56, 57). The first assessment of acetabular retroversion is made on an AP pelvic radiograph by identification of a crossing of the anterior and posterior acetabular rims. Reynolds et al. described this so-called “crossover” sign approximately a decade ago (98) (Figure 3.2). Jamali et al. found the crossover sign to be highly valid in assessment of acetabular retroversion on AP pelvic radiographs (99). Siebenrock et al. reported that acetabular retroversion gets more pronounced with increasing pelvic flexion (inclination or forward rotation) (82).

Historically, hip dysplasia has been described as a condition associated with lateral and anterior acetabular deficiency and acetabular anteversion (30, 31, 33, 34, 37, 100). It is therefore somewhat surprising that during the last 5 to 10 years, especially the last 2 years, acetabular retroversion has been reported to coexist with hip dysplasia in a considerable minority of dysplastic hip joints (41, 42, 83-86, 101, 102, III). The reported prevalences of acetabular retroversion in dysplastic hips ranges from 15% to 42% (Table 3.3). The crossing of acetabular rims is most frequently seen in the cranial third of the dysplastic acetabulum (86, 101, III). The degree of hip dysplasia, quantified by the CE angle, does not seem to differ between retroverted acetabuli and normally oriented acetabuli (42, 84, 86, III).

As already outlined (see section 3.2), it is controversial whether hip deformities should be assessed in AP pelvic radiographs with the pelvis neutrally positioned or in the weightbearing position. The appearance of acetabular version and its extent depend on the degree of pelvic tilt, and thus the prevalence estimates of acetabular retroversion will depend on the radiographic method applied (82, II, III). Most studies reporting the prevalence of acetabular retroversion in dysplastic hips include only radiographs if they meet certain standardized criteria with respect to pelvic tilt (Table 3.3). In light of the believed difference in pelvic tilt after repositioning and the coherence between deformities and functional appearance in the weight-bearing position, Troelsen et al. assessed the prevalence of retroversion in weightbearing AP pelvic radiographs (III). Troelsen et al. found acetabular retroversion in 33% of dysplastic hips, which is higher than the estimates of approximately 15% to 20% reported in the majority of studies (83-86, 101, III). This difference is explained by the exclusion of pelvises with excessive flexion (inclination or forward rotation). That is, those pelvises are excluded that by nature are excessively flexed and therefore are prone to have a more pronounced appearance of retroversion. In general, studies report a satisfying or good intra- and inter-observer variability in the assessment of the crossover sign (93, 103, 104, III). Assessment of the acetabular rims and the crossover sign demands good quality radiographs. As an alternative, the ischial spine sign has been introduced as a valid indicator of acetabular retroversion (103).

The clinical importance of acetabular retroversion in hip dysplasia and its implications for performance of a redirective PAO are not yet fully understood. Recently, hip dysplasia with acetabular retroversion was found to be associated with an earlier onset of pain (86). Also, recent studies have stressed the importance of recognizing acetabular retroversion during preoperative planning and performance of redirective PAO (84, 85, 102). Failure to do so will result in continued or even aggravated retroversion with a decreased range of motion and a postoperative FAI with continued joint deterioration. Acetabular retroversion has been re-

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**Table 3.3. Studies reporting the prevalence of acetabular retroversion in dysplastic hips.**

<table>
<thead>
<tr>
<th>Study</th>
<th>No. of hips (paring)</th>
<th>Dysplastic hips included</th>
<th>Radiographs included</th>
<th>Prevalence of retroversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>U and Ganz (2013)</td>
<td>252 (189) (64/51)</td>
<td>CE angle = 20°</td>
<td>Crossover to synphysis distance was &gt;2 cm</td>
<td>17%</td>
</tr>
<tr>
<td>Most et al. (2004)</td>
<td>215 (225) (20)</td>
<td>CE angle = 62°</td>
<td>Crossover to synphysis distance was &lt;2 cm</td>
<td>57%</td>
</tr>
<tr>
<td>Hess et al. (2009)</td>
<td>74 (54) (26/39)</td>
<td>CE angle = 30°</td>
<td>Sarcocoopied joint to synphysis distance 15-40 mm in males; 40-55 mm in females</td>
<td>28%</td>
</tr>
<tr>
<td>Fail et al. (2009)</td>
<td>100 (80/60)</td>
<td>Operated hips w/ CE angle &gt;20° to 34°</td>
<td>NR</td>
<td>28%</td>
</tr>
<tr>
<td>Narese et al. (2009)</td>
<td>105 (115) (23/77)</td>
<td>CE angle = 30°</td>
<td>Crossover to synphysis distance 6-2 cm</td>
<td>15%</td>
</tr>
<tr>
<td>Kr et al. (2010)</td>
<td>205 (80) (40/60)</td>
<td>Operated hips with CE angle mean age 9-50 years, all</td>
<td>Sarcocoopied joint to synphysis distance 15-40 mm in males; 40-55 mm in females</td>
<td>18%</td>
</tr>
<tr>
<td>Fuji et al. (2010)</td>
<td>105 (15) (27/48)</td>
<td>CE angle &gt;30°</td>
<td>Sarcocoopied joint to synphysis distance 15-40 mm in males; 40-55 mm in females</td>
<td>18%</td>
</tr>
<tr>
<td>Troelsen et al. (2011)</td>
<td>90 (54) (40/30)</td>
<td>CE angle &lt;25°</td>
<td>Weightbearing radiographs (defined protocol)</td>
<td>28%</td>
</tr>
</tbody>
</table>

* NR = Not reported.
ported to persist in 10% to 62% of dysplastic hips following redi-
rective procedures. (84,85,102).

In summary, the identification of acetabular retroversion in
dysplastic hips potentially has important clinical and surgical
implications that need further investigation. Retroverted
acetabuli are surprisingly frequent in dysplastic hips (15%-42%)
(41,42,83-86,101,102, III). Because the appearance of acetabular
retroversion depends on the pelvic tilt (82, II, III), the position of
the patient during radiographic recording is a potentially impor-
tant factor that needs further exploration.

4. ASSESSMENT OF ACETABULAR LABRAL TEARS IN HIP DYSPLA-
SIA

4.1 The role of the acetabular labrum in hip dysplasia

During the last decade, the understanding of the relationship
between hip joint deformities and osteoarthritic development has
increased significantly. Tearing of the acetabular labrum or the
adjacent cartilage is recognized as the key to joint deterioration in
all cases of biomechanically induced osteoarthrits (14). The de-
scription of acetabular labral tears associated with hip dysplasia is
not new, but the actual biomechanical properties of the acetaba-
larum and its role in initiation of joint degeneration have now
been documented (16,35-37,107-110). The labrum is hypothe-
sized to have a load-sharing role, at least in hip dysplasia, and to
act as a seal optimizing the properties of hip joint lubrication
(108,111). Furthermore, the labrum has a stabilizing function that
protects against critical biomechanical alterations in the hip joint
(112).

The biomechanical changes induced by the osseous deformi-
ties in hip dysplasia, together with the instability of the joint, are
thought to make the acetabular labrum susceptible to overload
and tearing. There is theoretical and clinical evidence that a
“shearing” kind of impingement, with repeated micro trauma to
the labrum, subsequent degeneration, and finally a tear or de-
tachment of the labrum in the chondrolabral transition zone,
underlies the biomechanical concept (16,35-37,113,114).

Acetabular labral tears in hip dysplasia are most frequently found
in the anterior region of the acetabulum, which may be explained
by the demanding biomechanics, with increased joint load and a
weaker mechanical structure of the labrum particularly in this
region (109,110,115,116, IV,V). Another characteristic feature of
the labrum is its often hypertrophic state in dysplastic hips
(35,115).

Tearing of the acetabular labrum is a frequent finding in
symptomatic dysplastic hips. In 170 hips with dysplasia, McCarthy
and Lee found a labral tear on hip arthroscopy in 72% (113).
Studies utilizing magnetic resonance arthrography (MRA) to evalu-
ate the labrum in symptomatic dysplastic hips found labral
tearing in approximately 80% (115, IV). The findings suggest that
joint overload and labral tearing play an important role in the
development symptoms in patients with hip dysplasia. Classical
symptoms of hip dysplasia are sharp groin pain and clicking or
locking of the hip, all of which correspond well with a labral tear
and continuous joint overload.

4.2 The role of MR arthrography, ultrasound, and clinical tests in
acetabular labral tear diagnostics

The identification of an acetabular labral tear as a cause of pain
and a precursor of hip joint degeneration has focused attention
on reliable diagnostic assessment. MRA has been established as the
radiographic gold standard method for the diagnostic assess-
ment of acetabular labral tears (Figure 4.1). Recent studies have
reported a good ability of MRA to diagnose labral tears (117-119).
Toomayan et al. performed MRA in 30 hips and found a sensitivity
of 92% and specificity of 100% when MRA findings were com-
pared with those obtained during hip arthroscopy (117). Chan et
al. reported a sensitivity of 100% and an accuracy of 94% (in 18
hips undergoing subsequent hip arthroscopy) (118). Freedman et
al. reported that 22 (96%) of 23 labral tears diagnosed on hip
arthroscopy had been found on MRA images (119). Ziegert et al.
found a detection rate of labral tears of 97.2% on MRA in 144 hips
with proven tears at arthroscopy (120). Czerny et al. published
the first report of its kind in 1996 (n=22 hip MRAs) and found a
sensitivity of 90% and an accuracy of 91% for MRA compared with
arthroscopic findings (121). In a later study, Czerny et al. showed
that MRA can be used to correctly stage labral tears (122); how-
ever, the staging seems of less prognostic value (119). The in-
traobserver reliability of MRA readings has been reported to be
excellent (119,121, IV, V). In contrast to these encouraging re-
results, Keeney et al. (n=104 hips) and Leunig et al. (n=23 hips)
reported sensitivities and specificities of approximately 40% to
70% for MRA in labral tear detection (123,124). It should be ac-
nowledged that the studies reporting the diagnostic ability of
MRA often suffer methodological problems, such as, a retrospec-
tive design, with lack of a clear prospective protocol for image
readings; bias induced by lack of blinding of radiologists to the
arthroscopic findings; selection-induced bias because all hips may
have been included in the retrospective study due to the finding of
a labral tear on hip arthroscopy; and interobserver variation be-
cause several radiologists or arthroscopic surgeons had as-
sessed the presence of the labral tears.

In the literature MRA, has been established as the radio-
graphic gold standard in labral tear diagnostics. However, the
method is time-consuming and uncomfortable for the patients.
Ultrasound is widely used in musculoskeletal diagnostic radiology,
and it has been hypothesized that it may have the ability to diag-
nose acetabular labral tears reliably (IV, V) (Figure 4.2). Few
studies have investigated the ability of ultrasound examination.
Mitchell et al. reported the results of 8 ultrasound examinations in
hips that had arthroscopic assessment of joint pathology: in 1
of 8 examinations ultrasound diagnosed the pathology present.
Given the methodological flaws of this study, conclusions cannot
be drawn, and the authors make no mention of ultrasound in
their suggested diagnostic approach to hip pain (125). Sofka et al.
reported a subjective improvement in visualization of labral pa-
thology by ultrasound during intra-articular steroid injections in
21 hip joints. Magnetic resonance imaging (MRI) without contrast
was performed in 14 of the 21 hips, and on review, anterior labral
tears were found in 13 hips on both MRI and ultrasound examina-
tion. The authors did not quantify the diagnostic ability of ultra-
sound. The study might represent a show of the potential success
of ultrasound to diagnose labral pathology, but any conclusions
are made invalid by the retrospective design that meant review of
only cases with a positive finding of labral pathology during ultra-
sound examination (126). A prospective comparison of ultrasound
with MRA in labral tear diagnostics was performed by Troelsen et
al. (IV). Examinations were performed in 20 consecutive dysplas-
tic hip joints presenting with pain. The prospective protocol in-
cluded predefined criteria for description of labral tears and
blinding of the MRA radiologist and the ultrasound radiologist to
the findings of the other examiner. The corresponding findings on
ultrasound and MRA are presented in Table 4.1. The resulting
sensitivity was 44% and the specificity was 75%.
Figure 4.1. Coronal view of hip MR arthrography visualizing an acetabular labral tear (arrow). Contrast medium is seen running through the base of the labrum.

Figure 4.2. Ultrasound examination visualizes an acetabular labral tear. There is a hypoechoic cleft running through the base of the labrum (thick arrow), and a cystic formation is visible just superior to the labrum (thin arrows). The crosses mark the limits of the labrum.

<table>
<thead>
<tr>
<th>MRA: Labral tear</th>
<th>Ultrasound: Labral tear</th>
<th>Ultrasound: No labral tear</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

| Sensitivity (true positives) | 7/16 = 44% |
| Specificity (true negatives) | 3/4 = 75% |
| Positive predictive value    | 7/8 = 88%  |
| Negative predictive value    | 3/12 = 25% |

<table>
<thead>
<tr>
<th>MRA: Labral tear</th>
<th>Ultrasound: Labral tear</th>
<th>Ultrasound: No labral tear</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

| Sensitivity (true positives) | 16/17 = 94% |
| Specificity (true negatives) | 0/1 = Not reported |
| Positive predictive value    | 16/17 = 94%  |
| Negative predictive value    | 0/1 = Not reported |

Table 4.3. The diagnostic ability of the impingement test and the FABER test in labral tear diagnostics (V). The resisted straight leg raise test was positive in 1 of 18 cases and thus results were not analyzed further.

<table>
<thead>
<tr>
<th>Impingement test</th>
<th>FABER test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity (true positives)</td>
<td>10/17 = 59%</td>
</tr>
<tr>
<td>Specificity (true negatives)</td>
<td>1/1 = 100%</td>
</tr>
<tr>
<td>Positive predictive value</td>
<td>10/10 = 100%</td>
</tr>
<tr>
<td>Negative predictive value</td>
<td>1/8 = 13%</td>
</tr>
</tbody>
</table>

study by Troelsen et al. (V), the authors examined the ability of ultrasound to detect labral tears, applying a protocol for the performance of examinations similar to the one used in the previous study by Troelsen et al. (IV). The hip joints of 18 patients who previously had had periacetabular osteotomies were examined. The findings on MRA and ultrasound are presented in Table 4.2. Thus, the sensitivity of ultrasound in labral tear diagnostics was 94%. The studies (IV, V) were strengthened by the prospective protocol used for the performance of the examinations, but limited by the relatively small sizes of the study cohorts, and by the fact that the radiographic findings were not verified by hip arthroscopy. However, MRA is well established as the radiographic gold standard in acetabular labral tear diagnostics, with an excellent correlation to arthroscopic findings in recent studies.
The intra- and interobserver variability of ultrasound in labral tear diagnostics remains uninvestigated.

A thorough patient history and a clinical examination should be able to raise suspicion of a labral tear as the cause of hip pain. But how reliable are commonly used clinical tests in the assessment of acetabular labral tears? Evidence in this field is limited. Narvani et al. (51) conducted a study examining 18 hips by an “internal rotation, flexion, axial compression” test and using MRA as diagnostic reference. The sensitivity was 75% and the specificity was 43%. In a study by Martin et al. (127) 6 orthopedic surgeons, specializing in hip pain, performed clinical examinations in 8 patients. The clinical examinations were performed as preferred by each specialist. Based on the clinical examination, the orthopedic surgeons agreed 63% of the time with the finding of a labral tear on the following hip arthroscopy. Troelsen et al. (V) investigated the ability of the impingement test, the FABER test, and the resisted straight leg raise test to diagnose labral tears. The clinical findings in 18 hips were compared to MRA findings of labral tears, and the diagnostic ability of the tests was calculated (Table 4.3). Of the clinical tests, the impingement test showed the best diagnostic ability, with a sensitivity of 59% and a specificity of 100%. Martin and Sekiya investigated the interrater reliability of the impingement test and the FABER test and found a moderate agreement between observers (kappa: 0.58) for the impingement test and a substantial agreement between observers (kappa: 0.63) for the FABER test (128). The few studies investigating the diagnostic ability of clinical tests are in general limited by small study populations (51,127, V). Furthermore, the study by Troelsen et al. (V) is limited by the frequent presence of a labral tear in the selected study population. The diagnostic ability of the impingement test in patients with a normal labrum is thus difficult to assess. The prospective protocol of examinations and blinding of both the clinical, ultrasound, and MRA examiners to each other’s findings is a methodological strength, and one should bear in mind that patients presenting in an outpatient clinic dealing specifically with hip problems are highly selected.

In conclusion, MRA has been established as the diagnostic gold standard in acetabular labral tear diagnostics. The results of studies on the diagnostic ability of MRA have been conflicting. In the most recently published studies, however, MRA has been reported to have excellent diagnostic properties (117-119). Ultrasound is a new and promising tool in labral tear diagnostics. The improvement in the diagnostic ability of ultrasound demonstrated by a comparison of the results of the two studies by Troelsen et al. (IV, V) suggests that a learning curve is associated with the use of ultrasound in labral tear diagnostics. Even in the hands of an experienced ultrasound examiner, as in the studies by Troelsen et al., issues of creating optimal visualization and interpretation of findings represented methodological difficulties that had to be overcome during the first study (IV). Clinical examination to detect labral tears is the “every-day tool” of the orthopedic hip surgeon, and even the most widely used tests (impingement and FABER tests) are not very reliable in labral tear diagnostics (51,127, V). This issue emphasizes the need for reliable radiographic assessment. The knowledge base regarding the role of ultrasound and clinical tests in acetabular labral tear diagnostics is limited, and the role of their use in unselected cohorts remains uninvestigated.

4.3 Suggested strategy for diagnostic assessment of acetabular labral tears

Patients presenting with hip-related pain, especially sharp groin pain, and in some a history of clicking or locking of the hip joint should be suspected to have a tear of the acetabular labrum (Figure 4.3) (129,130). A weightbearing AP pelvic radiograph and a lateral view of the hips are required to diagnose coexisting hip deformities and/or osteoarthritis (129,130, II, III).

To further assess the suspicion of a labral tear in these selected patients, an impingement test and perhaps the FABER test should be carried out, because the use of these tests is supported by the literature (51,127,128, V). Both tests have been reported to have a positive predictive value of 100%, meaning that on reproduction of sharp groin pain, the patient is very likely to have a labral tear (V). Previous studies have reported 25% of impingement tests to be positive in patients with surgically verified labral tears (19,49,50). On the other hand, not all labral tears are diagnosed by the impingement or FABER tests (sensitivities of 59% to 75% and 41%, respectively), and a negative outcome of the tests is unreliable (51, V). In this case, further radiographic assessment is warranted.

If an experienced ultrasound examiner with interest in development of this tool in labral tear diagnostics is available, ultrasound examination can be performed to assess a potential tear of the labrum (IV, V). In the hands of an examiner who has overcome the learning curve regarding the interpretation of the examinations, the method is sensitive (94%) in diagnosing acetabular labral tears (V). A finding of labral tearing on ultrasound makes it very likely that the patient actually has a tear (positive predictive value: 94% (V)). The present literature is inconclusive regarding the reliability of not finding a labral tear and ultrasound therefore should be considered unreliable in this situation. (IV, V).

Further radiographic assessment is then warranted.

MRA is the established gold standard in radiographic assessment of labral tears. The main problem related to clinical tests and ultrasound is the lack of reliability if findings are negative (51, IV,V). Thus, MRA should be performed in patients if groin pain is not produced by the impingement or FABER test and a labral tear cannot be visualized on ultrasound examination, and the patient continues to have specific hip-related pain (V). In the most recent experience with MRA, the diagnostic ability has been reported to be excellent, with sensitivity, specificity, and accuracy measures in the range of 92% to 100% (117-119). However, failure to diagnose a labral tear cannot be ruled out, and on continued suspicion, hip arthroscopy should be performed.

5. PERIACETABULAR OSTEOTOMY FOR SURGICAL TREATMENT OF HIP DYSPLASIA IN ADULTS

5.1 Periacetabular osteotomy: outcome, problems, and perspectives

Since its introduction more than 20 years ago, PAO has been adopted as the preferred contemporary joint preserving surgical treatment for symptomatic hip dysplasia in adults (15,72-
The clinical aims are to relieve hip joint pain, improve function and health related quality of life, and to prevent osteoarthritic development necessitating conversion to THR. The surgical aim is a 3-dimensional reorientation of the acetabulum that will optimize femoral head coverage, decrease hip joint load forces, and relieve the overload of the acetabular labrum and adjacent cartilage and soft tissues (15,72,148-150) (Figure 5.1).

Whereas numerous studies describe the short-term outcome following PAO (132-144), only a few studies report the outcome at medium- and long-term follow-up (i.e. more than a minimum follow-up of 5 years) (72-74,131, VI). This lack of studies reporting the outcome at medium- and long-term follow-up is deeply contrasted by the wide acceptance and worldwide application of this major surgical procedure. In the studies investigating the medium- and long-term outcome following PAO, the main endpoint indicating failure is conversion to THR (72-74,131, VI).

Troelsen et al. reported the medium-term clinical and radiographic outcome in 116 periacetabular osteotomies 5.2 to 9.2 years postoperatively. Seventeen hips were converted to THR, and the Kaplan-Meier hip joint survival rate with conversion to THR as endpoint was 90.5% (95% CI: 83.5-94.6) at 5 years, and 81.6% (95% CI: 69.7-89.3) at 9.2 years [VI]. Other authors reporting the medium- or long-term hip joint survivorship show rates comparable to these numbers (72-74,131) (Table 5.1). Further, as outlined in Table 5.1, the study groups are grossly comparable. Short-term hip joint survival rates (i.e. less than a minimum follow-up of 5 years) are most frequently reported to be >90% (132-147).

The extensive follow-up of PAO patients by Troelsen et al. comprised an interview, a clinical examination, a radiographic examination (weightbearing anterior-posterior pelvic radiograph), and Short Form (SF)-36 (151) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) (152) questionnaires (VI). The results of the follow-up evaluation are presented in Table 5.2. Key features of the interviews and clinical examinations were as follows: Median pain scores on the visual analog scale were 0 at rest and 1 after 15 minutes of normal walking. The groin was the most frequent location of hip-related pain or discomfort. Clicking or locking of the hip joint was seen in 25% of hip joints, and a positive impingement test was found in 18%.

Joint osteoarthritis and possible coexisting intraarticular problems may explain these findings. Steppacher et al. noted the impingement test was positive in 24% of hip joints at 10-year evaluation of patients undergoing PAO surgery (73). Troelsen et al. reported hip range of motion with a median hip flexion of 100° similar to the 10-year follow-up result found by Steppacher et al. (73, VI). Removal of screws was performed in 18% of the operated hips at the time of medium-term follow-up to be diagnose a matter of importance during the initial preoperative patient information session (VI). Troelsen et al. shed new socioeconomic insights on the subject of PAO surgery because only 19% had to change jobs after surgery due to hip problems (VI).

The Harris Hip Score or the Merle d’Aubigné & Postel Score have been the preferred hip-speciﬁc functional scores in previous studies reporting the outcome of PAO surgery (72,73,102,132,133,135-137). It is doubtful whether these scores provide a satisfying assessment in joint preserving PAO surgery in young adults. Troelsen et al. assessed the outcome at medium-term follow-up after PAO surgery using the contemporary SF-36 and WOMAC scores (Table 5.2) (VI). Comparison to the few other studies using the SF-36 and WOMAC scores is compromised by different durations of follow-up and differing strategies of data transformation (72,144,145). Comparison of the SF-36 scores reported at medium-term follow-up by Troelsen et al. with normative data for Danish citizens of a relevant age group showed, not surprisingly, that the physical component score was lower in the hip patients and that the mental component scores were comparable (151, VI). Thus, it seems that mental health is not negatively inﬂuenced by the deterioration in physical health in patients after PAO surgery at medium-term follow-up. In addition, the median total WOMAC score of 84.4 found at medium-term follow-up is satisfactory. Of studies reporting the outcome of PAO surgery at medium- to long-term follow-up, the studies by Kralj et al. (72) (using the WOMAC score) and Steppacher et al. (73) (using the Merle d’Aubigné & Postel Score) report both pre- and postoperative scores, whereas the studies by Matheney et al. (74) (using the WOMAC pain subscale) and Troelsen et al. (VI) are limited by reporting only the postoperative follow-up scores.

Finally, a hip-speciﬁc patient-related outcome measure specially constructed for young patients undergoing joint preserving surgery, such as the PAO, remains to be developed.

Even though widely accepted, the use of conversion to THR as an end point is in some ways problematic. At the time of follow-up, more patients may have developed end-stage hip joint osteoarthritis or functionally compromising pain. Those hip joints may also qualify for a THR in the near future, and thus the true failure rate may be underestimated. There is no commonly accepted deﬁnition of which secondary end points to consider. Matheney et al. considered a score of ≥10 (of 20) on the WOMAC pain subscale at the time of follow-up to be a clinical failure. Consequently, an additional 12% (16 of 135) of the study group joint osteoarthritis or functionally compromising pain. Those hip joints may also qualify for a THR in the near future, and thus the true failure rate may be underestimated. There is no commonly accepted definition of which secondary end points to consider. Matheney et al. considered a score of ≥10 (of 20) on the WOMAC pain subscale at the time of follow-up to be a clinical failure. Consequently, an additional 12% (16 of 135) of the study group
had end-stage osteoarthritis (Tönnis grade 3) or a deterioration of the WOMAC total score of >20 on medium to long-term follow-up after PAO. This group was separated from the groups of patients with an apparently satisfying clinical outcome and patients who had had a THR (72). Steppacher et al. report outcomes in the same cohort as in the study by Siebenrock et al. (131) and found that end-stage osteoarthritis (Tönnis grade 3) had developed in 5 (7%) of 68 hips. Two hips were graded as having a poor result according to the Merle d’Anbigné & Postel Score at last follow-up, but whether the hips also had end-stage osteoarthritis is unclear (73). Troelsen et al. found that end-stage osteoarthritis (Tönnis grade 3) had developed in 6 (6%) of 93 hips (VI). Patients lost to follow-up constitute another problem related to the use of conversion to THR as an end point. How many of these patients have developed end-stage osteoarthritis (Tönnis grade 3) or a deterioration of the WOMAC score of >20 on medium to long-term follow-up after PAO surgery preserves hip joints for up to 2 decades and yields good clinical results in selected patients (72-74,131, VI).

### 5.2 Predictors of outcome following periacetabular osteotomy: results and methodological limitations

Increased knowledge regarding patient selection criteria and further focus on aspects of acetabular reorientation are likely to facilitate future improvements in the outcome of PAO surgery. Using mainly descriptive and comparative statistical approaches, previous studies have suggested that advanced preoperative osteoarthritis (Tönnis grades 2 to 3) is an important predictor of hip joint failure and conversion to THR (72,131,133,154). Few studies have produced actual risk estimates. Steppacher et al. found a statistically significant hazard ratio of 3.39 per Tönnis grade higher (73). Millis et al. reported a statistically significant hazard ratio of 2.19 for hips with a preoperative Tönnis grade of 2 (142). Troelsen et al. found a statistically significant hazard ratio of 5.54 if preoperative Tönnis osteoarthritis grades 2 to 3 were present (VI). In addition to the studies using conventional radiography to diagnose the Tönnis grade of osteoarthritis, Cunningham
et al. found the dGEMRIC (delayed gadolinium-enhanced magnetic resonance imaging of cartilage) index, used as an early measure of osteoarthritis, to be the most important predictor of failure of PAO surgery (143). A cost-effectiveness study supports the above findings in clinical studies because primary THR was shown to be more cost-effective than PAO in Tönnis grade 3 osteoarthritis, and in Tönnis grade 2 osteoarthritis; however, PAO did become more cost-effective if patients survived more than approximately 18 years (155). Very few hips with moderate or advanced osteoarthritis can be expected to last more than approximately 18 years (73).

In the analysis of predictors of conversion to THR following PAO surgery, Troelsen et al. extensively analyzed demographic and radiographic (conventional and computed tomographic (CT)) pre- and postoperative parameters (1,35,68,156,157, II, VI). Using the Cox proportional hazards model and adjusting for the preoperative grade of osteoarthritis, the following 7 statistically significant predictors (1 to 5 assessed on conventional radiographs, 6 to 7 on postoperative CT-scans) were identified: 1) a preoperative CE angle of <0°, 2) a postoperative width of the acetabular sclerotic zone of <2.5 cm, 3) an x coordinate of femoral head translation of ≥2.0 cm (larger values of x means relative lateralization of the femoral head proportional to the acetabulum), 4) a y coordinate of femoral head translation of ≥10.8 cm (larger values of y means relative cranialization of the femoral head proportional to the acetabulum), 5) preoperative presence of an os acetabuli, 6) a coronal CE-angle on the CT scan of <5°, and 7) an acetabular anteversion angle of <10°. The crude and adjusted hazard ratios as well as the level of significance are presented in Table 5.3 for all predictors with a crude (unadjusted) hazard ratio differing statistically significantly from 1.0 (VI). The predictors identified can all be explained in a biomechanical paradigm: Both a low preoperative CE angle and reduced acetabular anteversion represent factors that may cause preoperative overload and preosteoarthritic lesions to the labrum and adjacent cartilage. Further, in cases with such diversions from normal anatomy, it is difficult to achieve proper acetabular reorientation. Preoperative presence of os acetabuli is evidence of advanced damage to the acetabular labrum and rim caused by overload and possible shearing impingement (35,37), and explains why these hips will eventually fail due to already extensive deterioration at the time of surgery. Increasing postoperative x and y coordinates and a narrow postoperative width of the acetabular sclerotic zone are thought to represent hip joints that will continue to overload the acetabulum after acetabular reorientation, resulting in joint deterioration (VI).

Steppacher et al. found in their study increasing age to be a significant risk factor for conversion to THR following PAO (hazard ratio: 1.08) (73). In the study by Troelsen et al., age at surgery ≥45 years was not found to be a significant risk factor after adjustment for the preoperative Tönnis grade of osteoarthritis (VI). This implies that age itself is of less importance compared to the progression and stage of cartilage deterioration. This argument is supported by a retrospective study of 70 patients (87 hips) reviewed 2 to 13 years after PAO (minimum age at surgery 40 years) that showed a significantly increased risk of conversion to THR if Tönnis grade 2 was present preoperatively compared with Tönnis grades 0-1 (142). Somewhat surprising, Matheney et al. (74) in their multivariate logistic regression analysis identified age >35 years to be an independent predictor of failure following PAO surgery. However, in the same analysis, advanced Tönnis grades of preoperative osteoarthritis were not found to be a significant independent predictor.

One of the surgical aims of PAO is to achieve a CE angle of 30° to 40°. In the analysis of predictors of conversion to THR, Troelsen et al. found that a postoperative CE angle outside this interval was a significant risk factor when assessed in relation to the unadjusted (crude) hazard ratio, but after adjusting for the preoperative Tönnis grade of osteoarthritis (adjusted hazard ratio), the predicted risk was adjusted to the 0.05 level (hazard ratio: 4.37) (VI). At least, the finding indicates the importance of proper reorientation. This is supported by Steppacher et al. who report that insufficient acetabular coverage, as measured by the extrusion index, is a significant risk factor (hazard ratio: 1.11) for conversion to THR (73).

In the task to identify the predictors of conversion to THR following PAO surgery, the sound methodological approach is to apply the Cox proportional hazards model. It analyzes the time-dependent association between possible predictors and the time to conversion to THR, thus taking into account the differences in “time at risk” for the operated hips in the study cohort. This method was applied in the studies by Troelsen et al. (VI) and Steppacher et al. (73). Both studies found, like numerous other studies, that an advanced stage of osteoarthritis (Tönnis grades 2-3) is a factor negatively influencing the outcome of PAO (72,131-133,142,154). Therefore Troelsen et al. appropriately adjusted for its presence in their analysis of predictors, whereas Steppacher et al. did not, and the actual effect, independent of concomitant osteoarthritis, of the predictors they identified is not clear (73, VI). Given the sample sizes of 116 hips and 75 hips in the studies by Troelsen et al. and Steppacher et al., respectively, both studies are limited in their analysis of predictors to THR by being underpowered (73, VI). The studies are therefore exploratory in nature, and the findings need to be reproduced in larger studies. On the other hand, the studies are quite sizeable when

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Crude Hazard Ratio (95% CI)</th>
<th>p Value</th>
<th>Adjusted (for preoperative Tönnis grade) Hazard Ratio (95% CI)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DEMOGRAPHIC PARAMETERS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age at surgery</td>
<td>2.91 (1.07-7.90)</td>
<td>0.04</td>
<td>2.35 (0.78-6.81)</td>
<td>0.13</td>
</tr>
<tr>
<td><strong>RADIOGRAPHIC PARAMETERS</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Preoperative center-edge angle &lt;0°</td>
<td>3.52 (1.05-10.48)</td>
<td>0.04</td>
<td>4.71 (1.42-15.76)</td>
<td>0.01</td>
</tr>
<tr>
<td>Preoperative center-edge angle &lt;30° or &gt;40°</td>
<td>5.21 (1.18-22.24)</td>
<td>0.03</td>
<td>4.27 (0.98-18.96)</td>
<td>0.05</td>
</tr>
<tr>
<td>Preoperative First-acetabulum angle Angle &lt;15°</td>
<td>3.81 (1.03-11.75)</td>
<td>0.04</td>
<td>2.30 (1.64-6.29)</td>
<td>0.20</td>
</tr>
<tr>
<td>Preoperative acetabular sclerotic zone Widths &lt;2.5cm</td>
<td>5.50 (1.44-18.10)</td>
<td>0.01</td>
<td>4.17 (1.58-22.07)</td>
<td>0.005</td>
</tr>
<tr>
<td>Postoperative difference X ≥2.5 cm</td>
<td>0.003</td>
<td>0.61 (0.50-13.09)</td>
<td>0.907</td>
<td></td>
</tr>
<tr>
<td>Postoperative difference Y ≥1.25 cm</td>
<td>4.39 (1.55-12.94)</td>
<td>0.005</td>
<td>4.64 (1.65-13.04)</td>
<td>0.004</td>
</tr>
<tr>
<td>Postoperative roundness index X&lt;0.60</td>
<td>5.07 (1.43-17.96)</td>
<td>0.01</td>
<td>3.53 (0.96-12.00)</td>
<td>0.02</td>
</tr>
<tr>
<td>Preoperative-on acetabulum Preservation of os acetabuli</td>
<td>6.80 (1.69-16.36)</td>
<td>0.004</td>
<td>3.40 (1.17-10.09)</td>
<td>0.03</td>
</tr>
<tr>
<td>Preoperative minimal joint space Widths &lt;2.5cm</td>
<td>0.004</td>
<td>3.18 (0.79-12.00)</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Preoperative minimal joint space Widths ≥2.5 cm</td>
<td>0.001</td>
<td>3.45 (0.70-15.00)</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>Preoperative Tönnis grade Grades 2-3</td>
<td>5.54 (1.89-16.24)</td>
<td>0.002</td>
<td>Not adjusted</td>
<td></td>
</tr>
<tr>
<td>Preoperative Tönnis grade Grades 3-4</td>
<td>5.73 (1.56-16.78)</td>
<td>0.001</td>
<td>Not adjusted</td>
<td></td>
</tr>
<tr>
<td><strong>COMPUTED TOMOGRAPHIC PARAMETERS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coronal center-edge angle &lt;5°</td>
<td>5.30 (1.94-13.00)</td>
<td>0.001</td>
<td>4.04 (1.54-12.53)</td>
<td>0.006</td>
</tr>
<tr>
<td>Acetabular anteversion angle Angle &lt;10°</td>
<td>6.79 (1.28-8.09)</td>
<td>0.001</td>
<td>4.29 (1.19-13.60)</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Appraising in the paradigm of clinical studies evaluating PAO surgery, and they will offer guidance for future, larger studies.

In conclusion, PAO surgery should primarily be performed in hip joints with no or only slight signs of osteoarthritis (Tönnis grades 0-1). Performing a PAO in hip joints with advanced osteoarthritis should be restricted to special indications, such as young age of the patient. In addition, when selecting patients for PAO surgery, special focus should be on factors negatively influencing the biomechanical environment both pre- and postoperatively.

5.3 The role of labral tears in the surgical treatment of hip dysplasia.

The role of acetabular labral tears in the management of hip dysplasia remains a discussed and controversial issue in PAO surgery. It is generally accepted that deformities of the hip, including hip dysplasia, can cause FAI with repeated trauma to the acetabular labrum, subsequent labral tearing, and cartilage degeneration (13,14,17-28,35-37,107-110,113,114). Studies have identified the presence of labral tearing in up to 80% of symptomatic hips (115). There was no mention of preoperative acetabular and femoral cartilage thicknesses being an important factor in the development of pain and the risk of joint deterioration in hip dysplasia (115).

The pain of arthroscopy to address labral tears during PAO surgery is inconsistently described in the literature. Positive preoperative impingement test has been suggested by Step-Pacher et al. as a significant predictor of failure following PAO surgery (73). They theorized that the presence of a preoperative labral tear is the reason for the worsened prognosis and further suggested that performing PAO with additional arthroscopy and intraarticular intervention may improve outcome (73). However, drawing conclusions based on outcome of the impingement test is, as previously outlined, doubtful (V). Peters et al. reported the outcome of PAO in 83 hips, with a mean follow-up of 46 months, and in 11 hips with known labral tears, he reported an average Harris Hip score of 90 and no signs of progressive osteoarthritis at the most recent follow-up (102). Further, Matheney et al. were not able to find that the presence of a labral tear predicted failure of the PAO in their multivariate regression analysis (74). The hip joint survival rates reported in studies in which the joint and labrum were left untouched are encouraging (140,141, VI). Arthroscopic treatment of labral tearing without addressing the labral tearing by means of a PAO is controversial. Treatment may cause an adverse outcome (accelerated osteoarthritis), and results beyond short-term follow-up are unknown (158).

Mechlenburg et al. (VII) measured cartilage thickness in the hip joint in 26 patients by using magnetic resonance imaging and application of a stereologic method (159) before and up to 2½ years after PAO surgery. Traction was applied to the leg undergoing magnetic resonance imaging to separate acetabular from femoral cartilage. In addition, 18 patients underwent MRA of the operated hip to diagnose acetabular labral tears. It was found that preoperative acetabular and femoral cartilage thicknesses were similar to measurements 2½ years after surgery. At measurements 1 year postoperatively, the acetabular cartilage was significantly, however marginal, thinner than at 2½ years postoperatively (1.47 mm vs. 1.35 mm). Seventeen of 18 patients undergoing MRA had an acetabular labral tear. Some methodological limitations should be acknowledged (VII). The leg traction approach used during magnetic resonance imaging may have led to an underestimation of mean cartilage thickness due to difficulty in separating cartilages in the thickest central parts of the joint. Due to the randomization of measurements used in this stereologic method, small local areas with thinning over time may go undetected, with only a marginal effect on mean cartilage thickness. This may be important because joint deterioration may initially be characterized by local cartilage damage adjacent to a labral tear. There was no mention of pre- and postoperative functional outcome measures to document the clinical effect of the PAOs performed or of the correlation of outcomes with the findings of cartilage thickness and labral tears. However, the report of pre- and postoperative visual analog scale pain scores documented the major relief of hip pain. Magnetic resonance arthrographies were not performed preoperatively and therefore it cannot be documented whether labral tears were present preoperatively. However, tears of the labrum have been documented in up to 80% of dysplastic hip joints (115, IV).

If one acknowledges that small local areas with cartilage damage may go undetected, it appears that cartilage thickness is preserved up to 2½ years following PAO surgery. None of the hips in the study had an arthrotomy and labral intervention during PAO surgery, and knowing that 17 of 18 arthrographies detected a labral tear, it seems that during short-term follow-up the presence of a labral tear does not accelerate cartilage destruction.

In conclusion, no studies of sufficient methodological value are yet available to definitively clarify whether arthrotomy and labral intervention should be performed or not. According to existing studies, both approaches can be chosen. The redistribution and decrease in load forces together with the resulting relief of overload on the acetabulum thought to be caused by the PAO (15,54,72,148-150) may explain why pain is relieved in the presence of a labral tear and why cartilage destruction is seemingly prevented. Future prospective studies with thorough preoperative magnetic resonance-based diagnostics of labral tearing and comparison of clinical and radiographic outcome are warranted.

6. CONCLUSIONS AND PERSPECTIVES

Awareness of the limitations and controversies of diagnostic assessment of hip joint deformities and osteoarthritis are important because correct diagnosis has great implications for candidates for joint preserving surgery. An extensive quantification of the variability of different methods for the assessment of hip dysplasia and osteoarthritis was carried out (I). The suggestions made regarding assessment of hip dysplasia have implications for all orthopedic surgeons and radiologists dealing with painful hips in young adults. Evidence was given that in patients with hip dysplasia, pelvic tilt may differ between the supine and weight-bearing positions (II). Supported by other studies (88,89,91,93), this finding questions the use of standardized neutral pelvic positioning during assessment of hip joint deformities because the AP radiographic appearance of acetabular version is affected by the degree of pelvic tilt. In an evaluation of acetabular version in dysplastic hip joints in weightbearing AP pelvic radiographs, acetabular retroversion was seen in 33% of hips (III). Awareness of the possible importance of patient positioning and of the frequent finding of acetabular retroversion in dysplastic hip joints is particularly important during assessment of hip dysplasia and the planning and performance of a joint preserving PAO. Larger scale studies recording both lateral and AP pelvic radiographs of both normally structured hips and hips with deformities are needed to shed further light on the importance of patient positioning.
Tearing of the acetabular labrum has been identified as a key feature in the initiation of early osteoarthritic development in hips with structural deformities (13,14,17-28,35-37,107-110,113,114). The role of ultrasound and various clinical tests to diagnose acetabular labral tears was established (IV, V). After overcoming an initial learning curve, ultrasound was showed to be highly reliable in diagnosing labral tears, whereas only a posi-
tive finding with the impingement or FABER tests was reliable in
identifying a labral tear. Very little was previously known about
the ability of these modalities to diagnose labral tears. It seems
that noninvasive and rapid ultrasound examination performed by
the experienced examiner can potentially alter the traditional
diagnostic algorithm in which MRA remains the gold standard.
However, further investigations are needed to explore the full
potential of ultrasound. As experienced by orthopedic surgeons
from around the world, clinical examination remains unreliable in
diagnosing labral tears, even in the hands of hip specialists (127).
Because this situation may never improve, supplementary radi-
ographic examination is needed.

In line with the few other studies (72-74,131) reporting the medium-
and long-term follow-up results after PAO for the treatment of hip dysplasia, encouraging hip joint survival and clinical outcome were reported (VI). The still small number of reports on the outcome beyond 5-year follow-up is contrasted by the wide application of the PAO. Surgeons and patients are await-
ing further consolidation of the so far encouraging joint-
preserving abilities of PAO, and various aspects, especially those
perceived by the patient to be important, are undergoing investi-
gation or remain uninvestigated. The aim should be the perform-
ance of true prospective follow-up studies. The performed analy-
sis of predictors of conversion to THR after PAO documented the
importance of various biomechanical and degenerative factors
(VI). Knowledge about factors predicting early conversion to THR
has the potential to refine patient selection and to improve the
potentials of PAO. The previous documentation of such factors,
beyond the negative influence of preexisting hip joint osteoarthri-
tis, was very limited. Cartilage thickness was documented to be
preserved up to 2½ years after PAO (VII). All but one hip joint had
acetabular labral tears, thus indicating that the presence of labral
tears does not accelerate cartilage degeneration after PAO. How-
ever, the issue of labral intervention during PAO remains highly
controversial. Because final conclusions cannot be drawn from
the present insufficient knowledge base, a prospective, MRI-
based, follow-up study assessing outcome of PAO is being con-
ducted.

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