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What Factors Predict Failure 4 to 12 Years After Periacetabular Osteotomy?

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Abstract

Background The goal of periacetabular osteotomy (PAO) is to delay or prevent osteoarthritic development in dysplastic hips. However, it is unclear whether the surgical goals are achieved and if so in which patients. This information is essential to select appropriate patients for a durable PAO that achieves its goals.

Questions/purposes We therefore (1) determined hip survival rates; (2) determined how many preserved hips were functionally unsuccessful after PAO; and (3) identified demographic, clinical, and radiographic factors predicting failure after PAO.

Methods We retrospectively reviewed 316 patients (401 hips) who had PAO between December 1998 and May 2007. We evaluated radiographic parameters of dysplasia and osteoarthritis and obtained WOMAC scores. Through inquiry to the National Registry of Patients, we identified conversions to THA. Risk factors for conversion to THA were assessed. Minimum followup was 4 years (mean, 8 years; range, 4–12 years).

Results The overall Kaplan-Meier hip survival rate was 74.8% at 12.4 years. A WOMAC pain score of 10 or more, suggesting clinical failure, was observed in 13% of preserved hips at last followup. Higher age, preoperative Tönnis grade of 2, incongruent hip, postoperative joint space width of 3 mm or less, and postoperative center-edge angle of less than 30° or more than 40° predicted conversion to THA.

Conclusions PAO preserved three of four hips with most functioning well at 4- to 12-year followup. When planning surgery, surgeons should attempt to achieve hip congruence and a center-edge angle of between 30° to 40° to improve the durability of PAO.

Level of Evidence Level II, prognostic study. See Instructions for Authors for a complete description of levels of evidence.

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Introduction

Since the development of the periacetabular osteotomy (PAO) by Ganz et al. [12] more than 25 years ago, the applied surgical techniques have been refined by other surgeons [14, 22, 40, 45]. Many authors prefer a PAO for reorienting the acetabulum in young adults suffering symptomatic hip dysplasia [7, 13, 20, 28, 33, 35, 44, 45]. The reorientation enhances the insufficient acetabular coverage of the femoral head that characterizes hip dysplasia. The ultimate goals are to reduce pain, improve function, and delay or prevent the development of osteoarthritis causing need for THA [13, 28, 34, 35, 44, 45]. Assessed by Kaplan-Meier analysis with conversion to THA as end point, PAO is associated with survival rates of 90% and 84% at 5 and 10 years, respectively [21, 41], and 60.4% at 20 years [35].

Previous studies [20, 21, 24, 27, 35, 41] have identified factors influencing failure and conversion to THA after PAO. Among these patient-related radiographic factors are higher age at surgery [21, 35, 41], severe hip dysplasia [41], osteoarthritic changes (Tönnis grade > 1) [20, 35], presence of an os acetabuli [41], poor hip congruency [21, 24, 27], and small width of the sclerotic zone [41]. Knowing the factors predicting failure has the potential to improve selection of patients who will benefit from PAO and identify patients who might otherwise undergo unnecessarily surgery and should be offered primary THA. Thus, previously reported factors need to be confirmed.

We therefore (1) determined the hip survival rate after PAO (total and divided into subgroups according to surgical approach, degree of osteoarthritis, and achieved center-edge angle postoperatively); (2) determined how many preserved hips were functionally unsuccessful despite not being converted to THA; and (3) identified demographic, clinical, and pre- and postoperative radiographic factors predicting failure after PAO.

Patients and Methods

From our institutional database of PAOs, we identified 354 patients (451 hips) who consecutively underwent PAO in one or both hips from December 1998 to May 2007. Ninety-five of these 354 patients (116 of the PAOs in this study) were reported previously [41]. Throughout the study period, the indications for the PAO were (1) symptomatic dysplasia of the hip indicated by persistent hip pain, (2) center-edge angle of Wiberg of less than 25°, (3) pelvic bone maturity, (4) absence of hip subluxation, (5) internal rotation of greater than 15°, and (6) hip flexion of greater than 110°. The contraindications for PAO were (1) osteoarthritis (this contraindication has gradually changed to exclude any osteoarthritis above Tönnis Grade 1 from PAO surgery), (2) reduced ROM indicating joint degeneration, and (3) lack of hip congruence. We excluded 19 foreigners or emigrants (23 hips) lost to followup, two deceased patients (two hips), and 17 patients who had incomplete radiographic followup or poor radiographic material (25 hips). This left 316 patients (401 hips) in the study group. During May 2011, WOMAC questionnaires were collected from the patients and hips converted to THA identified. Minimum followup was 4 years (mean, 8 years; range, 4–12 years).

All surgeries were performed by one of two surgeons (KS, SO). Until March 2003, PAO surgeries were performed through either the ilioinguinal or the iliofemoral (modified Smith-Petersen) approach (204 procedures) [8, 14, 22, 45]. The osteotomies were performed as described by Ganz et al. [12], leaving the posterior column intact. From April 2003, the PAOs were performed using the minimally invasive transsartorial approach (197 procedures) developed by the senior author (KS) [39, 40]. Since September 1999, a measuring device was used for intraoperative evaluation of the achieved acetabular correction [38].

Patients were mobilized a few hours postoperatively, and a regimen of partial weightbearing using two crutches was prescribed the first 6 to 8 weeks. Physical therapy included instructions during hospitalization and a handout describing a home exercise program. At 6 to 8 weeks, full weightbearing was normally allowed.

WOMAC questionnaires [4] were mailed to all patients with preserved PAO hips and the response rate was 83% (277 of 332 hips). One questionnaire from each operated hip was intended. The WOMAC questionnaire consists of 24 questions in three different categories: (1) pain, (2) stiffness of the hip, and (3) physical function in daily activities. Raw scores of pain (0–20), stiffness (0–8), and physical function (0–68) were summarized into a total score (0–96), with a score of 0 indicating no pain or functional disability. To enhance the comparability with previous studies, each subscale was normalized, taking into account different scale lengths, and a total score on a 0- to 100-scale was calculated, with 100 indicating no pain or functional disability [4]. From our PAO database, we retrieved demographic and clinical data in terms of age, sex, height, and weight (missing for 47 patients), condition underlying hip dysplasia, and previous pelvic and/or femoral surgeries (Table 1). By inquiry to The National Registry of Patients, we identified the conversion of 69 PAOs to THAs in the study group. Complications related to the PAO were not addressed in this study.

One author (CHA), who was not aware of the status of the hip, assessed all conventional radiographs. Where preoperative CT scans were available, the evaluations of these were noted (Table 2). On conventional pre- and postoperative radiographs, the following radiographic parameters were measured: the center-edge angle of Wiberg [46]; acetabular index angle [37]; width of the sclerotic zone; x coordinate [33] and y coordinate [42] of femoral head translation; roundness index of the femoral head [26]; presence of an os acetabuli [19]; minimal joint space width [1], measured as the smallest width between the acetabular sclerotic zone and the femoral head; and femoral offset. We graded the degree of osteoarthritis pre- and postoperatively according to the Tönnis classification

Table 1. Demographic and surgical data for the 316 patients (401 hips)

Parameter	Value
Age of time of operation (years)	
Median (interquartile range)	33.9 (24.4–42.7)
Range	13.2–61.4
Sex (number of hips)	
Female	289 (72.1%)
Male	112 (27.9%)
BMI (kg/m^2)*	
Median (interquartile range)	24.2 (21.5–26.3)
Range	15.1–37.2
Diagnosis (indication for PAO) (number of hips)	
Dysplasia	353 (88%)
Legg-Calvé-Perthes disease	43 (11%)
Miscellaneous	5 (1%)
Previous surgery (number of hips)	
Femoral osteotomy	32 (8%)
Pelvic osteotomy	13 (3%)
Concomitant surgery (number of hips)	
Femoral osteotomy	26 (6%)
Surgical approach (number of hips)	
Ilioinguinal/femoral	204 (51%)
Minimal invasive surgery	197 (49%)

* BMI missing for 47 hips; PAO = periacetabular osteotomy.

(Grades 0–3) [37]. The congruence of the hip was evaluated by identifying the center of the femoral head using the Moses template. The best-fitted circle of the acetabulum was drawn with a compass. We considered the hip congruent if the centers of the femoral head and the acetabulum were concentric (Fig. 1). Lack of congruence was quantified by measuring the distance between the center of the femoral head and the center of the best-fitted acetabular circle. The measure was not performed in hips with Legg-Calvé-Perthes (43 hips) due to the inherent, severe incongruence observed in these hips. The minimal joint space width was measured with a scale loupe. Retroversion of the acetabulum was noted if a crossover sign (crossing of the anterior and posterior acetabular rims) was present on the radiographs [3, 18, 30]. Studies have shown the importance of standardized pelvic radiographs, preferably standing [11, 32, 42], for assessing retroversion. The majority of the radiographs in this study were supine exposures, and therefore we made no definitive conclusions regarding the importance of retroversion before and after PAO. The intra- and interobserver variability of radiographic parameters were assessed in a subset of 25 radiographs by two independent observers (CHA, AT). We computed mean of the difference and 95% limits of agreement according to the Bland-Altman approach [5, 6]. Intra- and interobserver assessments of key measures generally showed similar agreement to those reported in the literature [42] (Table 3).

On preoperative CT scans, the following parameters were assessed by a radiologist [2]: anterior and posterior acetabular sector angles, coronal and sagittal center-edge angles, acetabular version angle, neck-shaft angle, and neck version angle. CT scans were available for 314 of the 401 hips (78%).

Data are presented as means with 95% CIs when normally distributed and as medians with interquartile ranges when not normally distributed. Excluded patients were not a part of the analysis. We calculated crude hazard ratios using Cox regression analyses to identify possible predictors of failure after PAO. The hazard ratios were adjusted for sex, preoperative degree of osteoarthritis, and pre- and postoperative center-edge angles. In the case of a missing value when performing Cox regression analysis, the patient was excluded from the analysis. The proportional-hazard assumption requirements were tested using log-log plots. We calculated hip survivorship, with conversion to THA as an end point, using Kaplan-Meier survival analysis in the entire cohort and dividing operated hips into subgroups according to the surgical approach, Tönnis grade of osteoarthritis, and achieved acetabular reorientation. We used STATA® 11 software package (StataCorp LP, College Station, TX, USA) for all calculations.

Results

Sixty-nine of the 401 hips (17%) were converted to THA at 3.9 to 12.4 years postoperatively. The Cox regression analysis found 13 demographic and radiographic parameters that had a crude hazard ratio different from 1.0 (Table 4). After adjusting crude hazard ratios for potential confounders, including sex, preoperative center-edge angle of less than 0°, postoperative center-edge angle of less than 30° or more than 40°, and preoperative Tönnis grade of 2, we identified five predictors of conversion to THA: (1) age of 40 years or more at time of surgery (hazard ratio, 2.10; 95% CI, 1.29–3.41), (2) postoperative center-edge angle of less than 30° or more than 40° (hazard ratio, 2.00; 95% CI, 1.21–3.33), (3) postoperative minimal joint space width of less than 3 mm (hazard ratio, 2.57; 95% CI, 1.42–4.67), (4) preoperative Tönnis grade of 2 (hazard ratio, 5.37; 95% CI, 2.92–9.88), and (5) postoperative lack of hip congruence (hazard ratio, 2.08; 95% CI, 1.04–4.15) (Table 4). CT scan parameters available for 314 hips identified no risk factors for conversion to THA.

Eighty-four percent of the preserved hips had no pain or a low pain score at 3.9 to 12.4 years after PAO. The median normalized total WOMAC scores was 74.8 (range, 13–100) (Table 5).

Table 2. Radiographic characteristics of the 316 patients (401 hips)

Characteristic	Preoperative value	Postoperative value
Pelvic radiographs		
Center-edge angle (°)		
Median (interquartile range)	11 (6–18)	30 (27–35)
Range	−29 to 29	−5 to 50
Acetabular index angle (°)		
Median (interquartile range)	20 (14–25)	6 (0–10)
Range	3–57	−14 to 47
Horizontal width of the sclerotic zone (mm)		
Mean (95% CI)	31 (31–32)	34 (33–34)
Range	17–50	7–55
x coordinate of femoral head translation (mm)		
Mean (95% CI)	16 (15–17)	15 (15–16)
Range	2–40	0–37
y coordinate of femoral head translation (mm)		
Mean (95% CI)	103 (102–104)	98 (97–99)
Range	72–140	55–136
Roundness index of the femoral head		
Median (interquartile range)	0.51 (0.51–0.51)	0.51 (0.51–0.51)
Range	0.41–0.58	0.43–0.57
Tönnis grade of osteoarthritis (number of hips)		
0	241 (60%)	230 (57%)
1	141 (35%)	154 (39%)
2	19 (5%)	17 (4%)
Presence of an os acetabuli (number of hips)	42 (10%)	49 (12%)
Minimal joint space width (mm)		
Mean (95% CI)	4.6 (4.5–4.7)	4.2 (4.1–4.3)
Range	0.9–9.5	0.6–9.4
Congruence > 0 mm (number of hips)	261 (64%)	281 (69%)
Offset femur (mm)		
Mean (95% CI)	36 (35–37)	
Range	13–68	
CT scans*		
Anterior acetabular sector angle (°)		
Mean (95% CI)	45 (44–46)	
Range	13–73	
Posterior acetabular sector angle (°)		
Mean (95% CI)	86 (85–87)	
Range	2–108	
Acetabular anteversion angle (°)		
Mean (95% CI)	20 (20–21)	
Range	−6 to 38	
Coronal center-edge angle (°)		
Median (interquartile range)	12 (7–20)	
Range	−34 to 40	
Sagittal center-edge angle (°)		
Mean (95% CI)	51 (50–52)	
Range	13–87	

Table 2. continued

Characteristic	Preoperative value	Postoperative value
Neck-shaft angle (°)		
Median (interquartile range)	137 (130–146)	
Range	80–168	
Neck version angle (°)		
Mean (95% CI)	31 (30–33)	
Range	−25 to 77	

* Data available for 314 hips.

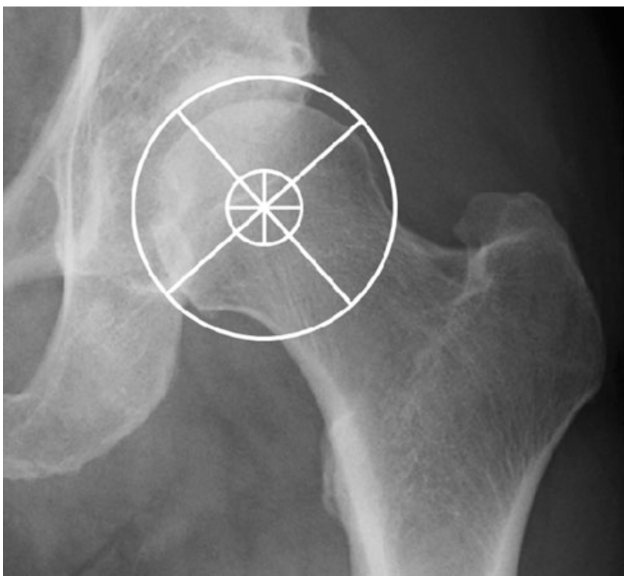

Fig. 1 Lack of hip congruence postoperatively was a factor predicting failure. Congruence was determined by the drawings of two circles. When the center of the best-fitted circle of the acetabulum sclerotic roof is concentric to the center of the femoral head, the joint is considered congruent as shown here. The distance between the two circle centers would thus be 0 mm.

Table 3. Interobserver variability of important radiographic indexes of hip dysplasia and joint degeneration

Radiographic parameter	Difference (mean)	SD	95% prediction interval
Center-edge angle	−0.64	3.5	−7.7 to 6.4
Acetabular index angle	−0.04	3.0	−6.1 to 6.1
Congruence	1.16	1.8	−2.5 to 4.9
Minimal joint space width	0.11	0.4	−0.6 to 0.9

In the entire cohort of 401 hips, we found a hip survival rate of 74.8% (95% CI, 68.1%–80.4%) at 12.4 years using conversion to THA as the end point (Fig. 2). The hip survival rate after 8 years was clearly improved after the implementation of the minimally invasive technique to 91% (95% CI, 84.3%–94.2%) (Fig. 3). Ten-year hip survival rates for Tönnis Grades 0, 1, and 2 were 85.7% (95% CI, 78.0%–90.9%), 68.7% (95% CI, 57.7%–77.3%), and 25.4% (95% CI, 7.5%–48.4%), respectively (Fig. 4). Correction of the acetabulum to a center-edge angle of between 30° and 40° showed a higher 10-year survival rate than correction to a center-edge angle of less than 30° or more than 40° (82.7% [95% CI, 73.3%–89.1%] and 67.0% [95% CI, 57.3%–75.0%], respectively) (Fig. 5).

Discussion

By identifying clinical and pre- and postoperative radiographic factors predicting failure after PAO, we could potentially refine patient selection for PAO and help in the counseling of future patients. We therefore investigated hip survival rates and potential clinical failures in preserved hips after PAO and identified demographic, clinical, and radiographic factors predicting failure after PAO.

Our study has limitations. First, 50 of 451 hips were excluded from followup, leaving 11% of the total cohort unaccounted for, but still 401 hips were represented. We presume those remaining would be representative of the whole since the percentage excluded was relatively small. Second, the WOMAC questionnaire was returned by 83% of the preserved hips, leaving the patient-reported status of 17% unknown. Again, we presume the data obtained would be representative of the entire cohort. Third, WOMAC questionnaires were not distributed preoperatively or routinely postoperatively. Therefore, the onset of the pain was unknown. Fourth, routine pre- and postoperative AP pelvic radiographs were taken with the patient supine for the majority of patients, thus making definite conclusions regarding the importance of retroversion impossible. Finally, even though most indications for PAO were the same during the study period, the increasing attention toward the early need for conversion to THA in osteoarthritic hips has led to a change in indications over the years.

Various studies have reported demographic, clinical, and radiographic factors as predictors of failure (Table 6).

Table 4. Crude and adjusted hazard ratios for predictors of conversion to THA

Parameter	Crude hazard ratio (95% CI)	p value	Adjusted hazard ratio* (95% CI)	p value
Demographic data				
Age at surgery ≥ 40 years	1.97 (1.22–3.18)	0.005	2.10 (1.29–3.41)	0.003
Legg-Calvé-Perthes disease	1.39 (0.71–2.72)	0.337	1.96 (0.93–4.14)	0.077
Previous femoral surgery	2.22 (1.13–4.34)	0.020	1.91 (0.97–3.76)	0.063
Radiographic data				
Postoperative center-edge angle < 30° or > 40°	2.20 (1.34–3.62)	0.002	2.00 (1.21–3.33)	0.007
Postoperative acetabular index angle > 10°	2.31 (1.43–3.74)	0.001	1.57 (0.90–2.75)	0.116
Preoperative presence of an os acetabuli	2.22 (1.21–4.06)	0.010	1.61 (0.84–3.11)	0.155
Postoperative presence of an os acetabuli	2.26 (1.28–4.02)	0.005	1.64 (0.88–3.07)	0.119
Preoperative minimal joint space width < 3 mm	3.54 (1.94–6.49)	< 0.001	1.83 (0.92–3.66)	0.087
Postoperative minimal joint space width < 3 mm	4.29 (2.57–7.17)	< 0.001	2.57 (1.42–4.67)	0.002
Preoperative Tönnis Grade 2	5.66 (3.09–10.38)	< 0.001	5.37 (2.92–9.88)	< 0.001
Preoperative congruence > 0 mm†	2.11 (1.16–3.84)	0.015	1.75 (0.95–3.23)	0.074
Postoperative congruence > 0 mm†	2.54 (1.23–5.02)	0.004	2.08 (1.04–4.15)	0.039
CT data				
Coronal center-edge angle < 5°	2.02 (1.15–3.55)	0.015	1.49 (0.74–3.00)	0.261

* The crude hazard ratio adjusted for sex, preoperative Tönnis Grade 2, and pre- and postoperative center-edge angle; †congruence not measured in hips with Legg-Calvé-Perthes disease (43 hips excluded).

Table 5. Results of WOMAC questionnaires (n = 277)

Domain	WOMAC score (points)		
	Median	Interquartile range	Range
Pain (0–20)*	4.7	1–7	0–19
Stiffness (0–8)*	2.3	0–4	0–8
Physical function (0–68)*	14.9	3–24	0–55
Total (0–96)*	21.9	6–35	0–78
Normalized (0–100)†	74.8	59.8–92.1	13–100

* Raw scores, with 0 indicating best results; †normalized scores, with 100 indicating best result.

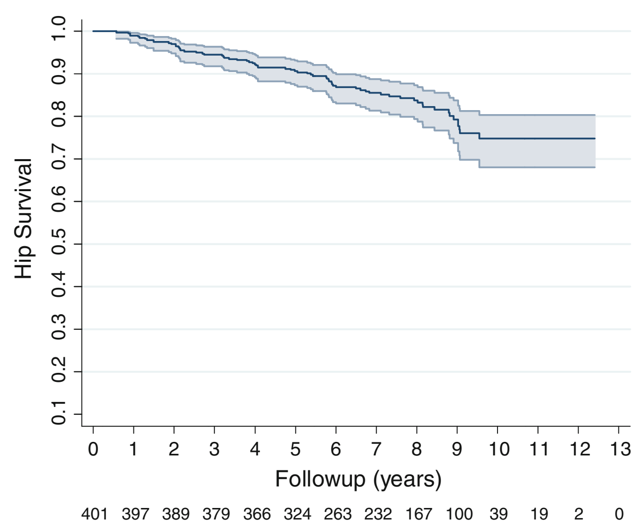

Fig. 2 A graph shows the Kaplan-Meier survivorship curve (with 95% CI) with conversion to THA as the end point for 401 hips after PAO. Each decrease in curve corresponds to a conversion to THA. The number of hips remaining for every year of followup is given below the x axis. Hip survival rate is 74.8% (95% CI, 68.1%–80.4%) at 12.4 years.

Consistent with the literature [21, 35], we found increasing age independently predicted failure after PAO with an adjusted hazard ratio of 2.10 (95% CI, 1.29–3.41). These observations support an upper age limit for performing PAO. However, one clinical study reported a 10-year hip survival rate of 90.8% in PAO patients older than 40 years [16], and another study reported no radiographic differences in the progression of OA 5 years after PAO when comparing patients 55 years or older to a group of younger patients [36]. Conclusions may be influenced by cultural differences in expectations and functional demands after PAO. The adjusted hazard ratios for joint degeneration in terms of Tönnis Grade 2 osteoarthritis or a joint space width of 3 mm or less found in our study is in agreement with the existing literature [20, 23, 33, 35, 44]. Today, hips with a Tönnis grade of 2 or more do not commonly undergo PAO, and we found even Tönnis Grade 1 hips had a lower long-term survival rate compared with Tönnis Grade 0 hips. Our data suggest the postoperative center-edge angle of Wiberg should be between 30° to 40°. We found the risk of failure to be doubled if acetabular reorientation was not confined to this interval. Steppacher et al. [35] also found insufficient coverage as a risk factor for

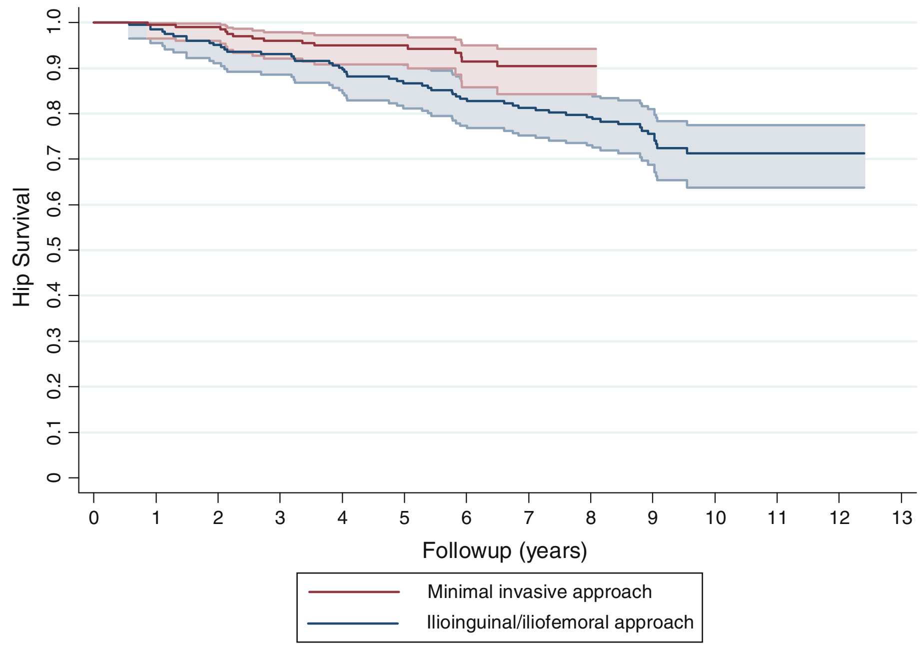

Fig. 3 A graph shows the Kaplan-Meier survivorship curves (with 95% CIs) with conversion to THA as the end point for 401 hips after PAO divided according to surgical approach. Hip survival rate after 8 years is clearly improved after the implementation of the minimally invasive technique in 2003 to 90.4% (95% CI, 84.3%–94.2%) compared to the traditional approach at 79.3% (95% CI, 73.1%–84.3%).

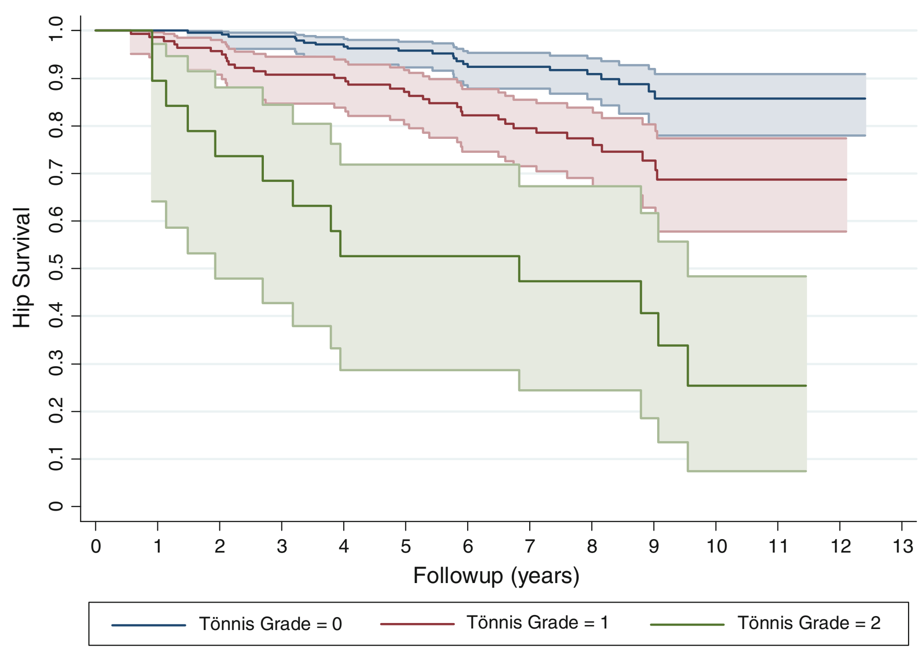

Fig. 4 A graph shows the Kaplan-Meier survivorship curves (with 95% CIs) with conversion to THA as the end point for 401 hips after PAO divided according to the preoperative Tönnis grade of osteoarthritis. Ten-year hip survival rates for Tönnis Grades 0, 1, and 2 are 85.7% (95% CI, 78.0%–90.9%), 68.7% (95% CI, 57.7%–77.3%), and 25.4% (95% CI, 7.5%–48.4%), respectively.

conversion to THA. Further, acetabular overcorrection has been associated with risk of femoroacetabular impingement after PAO [25]. Lack of hip congruence and instability are thought to induce repeated impaction between the femoral head and the acetabular labrum leading to labral tearing, increased local contact stresses, and degeneration. The biomechanical consequences of incongruence of the hip can therefore explain why postoperative hip incongruence predicted failure with an approximately doubled risk of conversion to THA. Okano et al. [27] also found postoperative hip congruence important for the function of the hip after PAO. Hips with Legg-Calvé-Perthes disease are characterized by inherent, severe incongruence; however, our analysis failed to show an increased risk for failure. In the existing literature, Clohisy et al. [9] reported 92% being satisfied at followup (mean, 4.3 years; range, 2.0–9.3 years) and no conversions to THA in 24 hips with Perthes-like deformities. Shinoda et al. [31] followed 17 hips for 3 to 19 years (mean, 6.6 years) and reported one conversion to THA. An os acetabuli is considered a sign of overload of the acetabular rim zone and may cause progressive degeneration of the

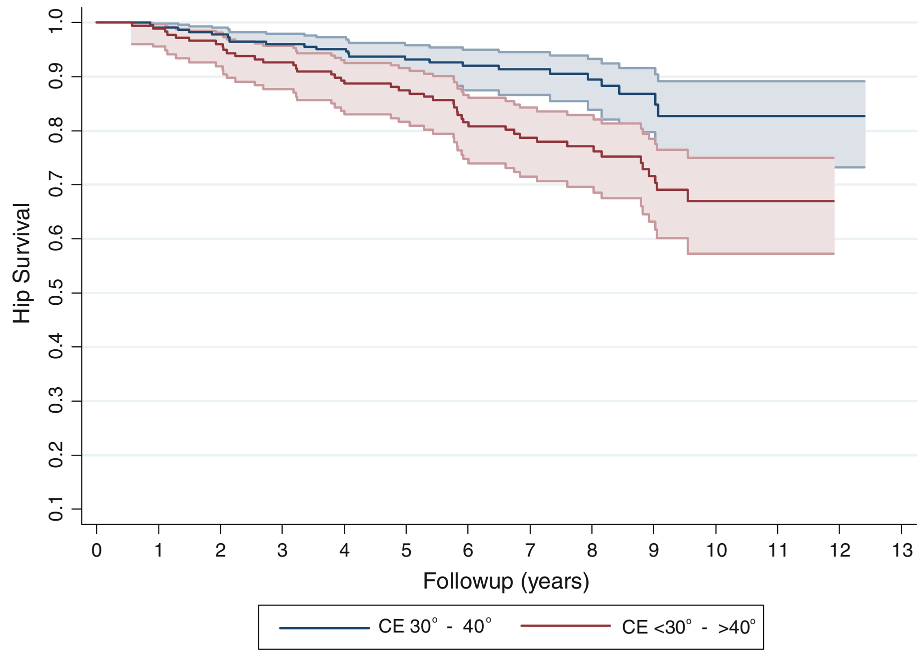

Fig. 5 A graph shows the Kaplan-Meier survivorship curves (with 95% CIs) with conversion to THA as the end point for 401 hips after PAO divided according to the achieved center-edge (CE) angle postoperatively. Correction of the acetabulum to a center-edge angle of between 30° and 40° (82.7% [95% CI, 73.3%–89.1%]) shows a higher 10-year survival rate than correction to a center-edge angle of less than 30° or more than 40° (67.0% [95% CI, 57.3%–75.0%]).

Table 6. Studies reporting predictors of failure using risk estimate statistics and survival rate after PAO

Study	Age at surgery (years)*	Number of hips with PAO	Number of failed hips†	Followup (years)*	Predictors of failure	Hip survival rate
Matheney et al. [21]	26.7 (10–45)	135	17	9	Age > 35 years, poor congruency	5 years: 96% 10 years: 84%
Steppacher et al. [35]	29.3 (13–56)	68	27	20.4 (19–23)	Age, preoperative score, positive impingement test, limb, osteoarthritis grade, insufficient acetabular coverage	5 years: 93.2% 10 years: 84.6% 20 years: 60.5%
Troelsen et al. [41]‡	29.9 (14.1–57.0)	116	17	6.8 (5.2–9.2)	Severe dysplasia, presence of os acetabuli, osteoarthritis, excessive lateral and proximal dislocation	5 years: 90.5% 9.2 years: 81.6%
Millis et al. [23]	43.6 (40–51)	87	21	4.9 (2–13)	Osteoarthritis	
Current study	33.9 (13.2–61.4)	401	69	7.9 (3.9–12.4)	Age, osteoarthritis, suboptimal achieved center-edge angle, reduced postoperative joint space width incongruence	12.4 years: 74.8%

* Values are expressed as mean, with range in parentheses; †failure in terms of conversion to THA; ‡reports the outcome of part (n = 116) of the same cohort as in the current study; PAO = periacetabular osteotomy.

joint [17, 19, 29], and we previously reported an os acetabuli predicted failure [41]. However, in the current study, after adjusting for the risk imposed by the grade of osteoarthritis, the pre- and postoperative center-edge angle, and sex, the presentation of an os acetabuli no longer predicted failure. Finally, CT conveys detailed information on the three-dimensional pathomorphology of hip dysplasia. It has been widely utilized to aid preoperative planning, but the prognostic value of the findings remains unexplored and could potentially convey important information about how to select patients who will benefit most from PAO.

Hip survival using Kaplan-Meier analysis showed a cumulative survival rate of 74.8% at 12.4 years. This is slightly less than reported in two other studies reporting long-term followup in smaller study cohorts [21, 35]. In Denmark, it is possible to perform complete followup of all patients by inquiry into The National Registry of Patients as all patients (and treatments) can be traced by the unique social security number of the patients. Thus, none of the patients living in Denmark would be lost to followup, making number of conversions to THA reliable. We have previously reported good hip survival rates (97% after

5 years) in patients operated on since April 2003 using the minimally invasive approach. Improvement in the surgical technique with sparing of the soft tissue, reduced blood loss, less impact at the blood supply to the acetabulum, together with refinement in patient selection have increased the hip survival rate [39, 40]. There is a learning curve when performing PAO [10, 12, 14, 15, 28, 43], and the cumulated experience of the senior author (KS) has added to the increased hip survival rate of 91% at 8 years after the introduction of the minimal invasive technique used since 2003.

The WOMAC questionnaires revealed 44 preserved PAOs with a pain score 10 or more (15.9%). Most studies reporting the outcome of a clinical scoring system after PAO have used the Merle d'Aubigné-Postel score or Harris hip score. Matheney et al. [21] reported similar findings, with clinical failure in 13% of the preserved PAO hips defined by a WOMAC pain score of 10 or more at mean followup of 9.7 years. The use of contemporary WOMAC total scores is still rare in followup of PAO.

In conclusion, PAO overall preserved three of four hips at 4 to 12 years' followup and the majority of the patients with preserved hips reported no or low pain. Patients should be carefully selected for joint-preserving surgery as higher age and preoperative Tönnis grade of osteoarthritis above 1 impose increased risk of failure. Also, failure to achieve proper acetabular correction and hip congruence will increase the risk of failure after PAO, and preoperative radiographs should be assessed to judge whether this can be achieved.

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