

## Joint-preserving Surgery Improves Pain, Range of Motion, and Abductor Strength After Legg-Calvé-Perthes Disease

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### Abstract

**Background** Patients after Legg-Calvé-Perthes disease (LCPD) often develop pain, impaired ROM, abductor weakness, and progression of osteoarthritis (OA) in early adulthood. Based on intraoperative observations during surgical hip dislocation, we established an algorithm for more detailed characterization of the underlying pathomorphologies with a proposed joint-preserving surgical treatment.

**Questions/purposes** We asked if patients after LCPD treated with our algorithm experienced (1) reduced pain; (2) improved hip function; and/or (3) prevention of OA progression; we then determined (4) the intraoperative damage patterns; (5) the survival of the hip; and (6) factors predicting the need for a conversion to THA; radiographic progression of OA; a Merle d'Aubigné-Postel score below 15 at last followup; and/or the need for revision surgery.

**Methods** We retrospectively reviewed 53 patients after LCPD who underwent joint-preserving surgery (40 surgical

hip dislocations, eight acetabular osteotomies, four combined procedures, and one intertrochanteric osteotomy). We obtained Merle d'Aubigné-Postel scores to assess pain; OA was assessed using Tönnis grades. Survival and predictive factors were calculated with the univariate Cox regression. Fifty of the 53 patients were evaluated at a minimum of 5.1 years (mean, 8.2 years; range, 5.1–12.8 years).

**Results** Pain and hip function improved at followup from a median of 4 points to 5 points. The mean increase in Tönnis grades at last followup was 0.3 to 0.8. The survival of surgery at 5 years was 86%; 13 factors related to survival.

**Conclusion** Patients with symptoms resulting from pathomorphologic deformities after LCPD benefit from joint-preserving surgery with specific treatment of individual structural abnormalities.

**Level of Evidence** Level IV, therapeutic study. See the Guidelines for Authors for a complete description of levels of evidence.

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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### Introduction

Reasonable clinical and radiographic long-term results can be expected in 40% to 77% of all patients after Legg-Calvé-Perthes disease (LCPD) without the need for THA [8, 12, 30, 47]. However, in the remaining cases, the patients often develop symptoms in early adulthood including pain, impaired ROM, problems with ambulation, and progressive osteoarthritis (OA) [7, 22, 48]. Several pathomorphologies seemingly cause these problems: intraarticular femoroacetabular impingement (FAI) resulting from the aspherical femoral head [7, 35], extraarticular impingement of the greater and the lesser trochanter [17, 31], functional

retrotorsion of the femoral head [18], acetabular retroversion [9, 19], associated acetabular dysplasia [14, 15, 37], and/or joint incongruency [37].

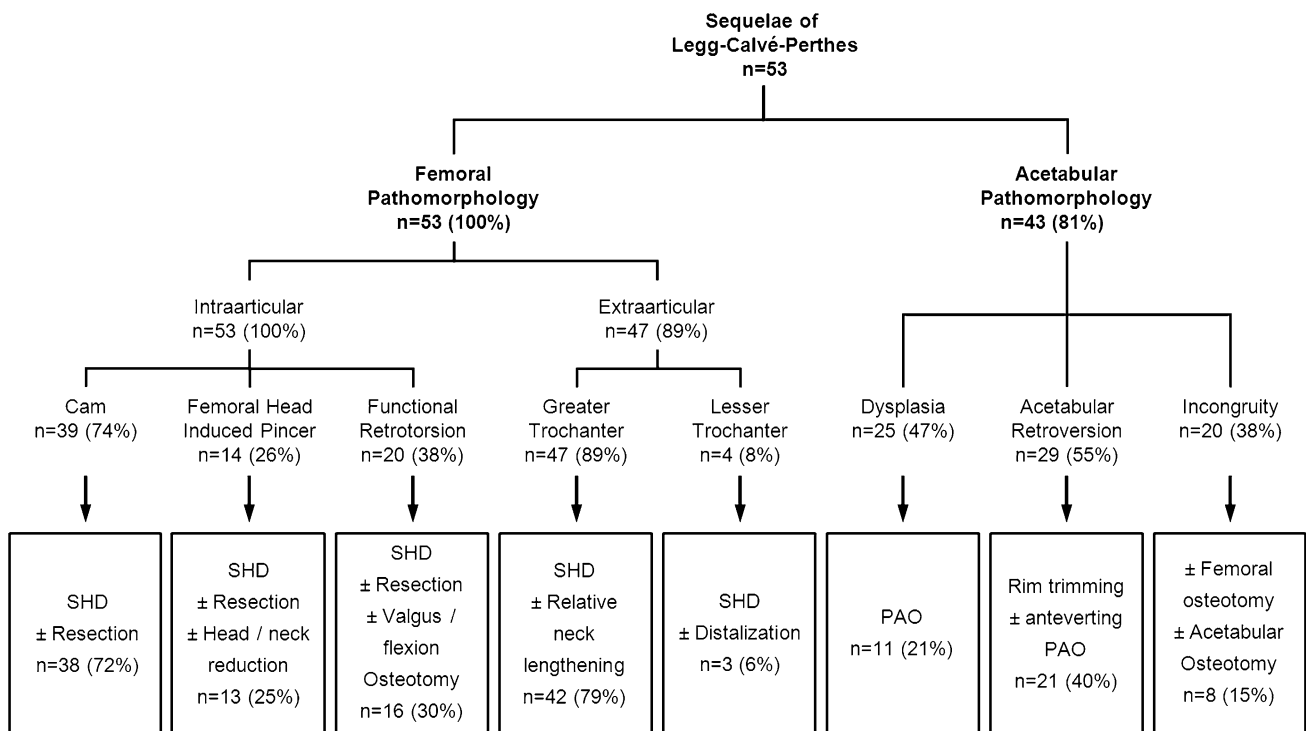
This variety of structural abnormalities can result in different pathomechanical problems that can be present in the same hip. It is crucial to address each problem appropriately [7, 11] to improve pain, ROM, and abductor weakness. Isolated treatments of a single mechanical problem do not improve pain or limp [13, 29]. Based on descriptions in the literature [7, 9, 14, 15, 17–19, 31, 35, 37] and previous preliminary reports on the evaluation of hips after LCPD from our institution [7, 11], we developed a treatment algorithm for these complex hips (Fig. 1). This algorithm offers a structured way to identify the underlying pathomechanical problem and offers a surgical treatment strategy to correct these structural abnormalities. This algorithm arose based on our intraoperative observations during surgical hip dislocation (SHD) [7] of these hips. This technique has opened the field for novel surgical treatment options for the sequelae of LCPD [11]. However, it is unclear whether treatment according to this algorithm has the potential to relieve pain, restore hip function, or stop progression of OA in hips with previous LCPD.

We therefore asked (1) if patients with LCPD after joint-preserving surgery had relief of pain; (2) improved hip function; and/or (3) prevention of progressive OA; we then determined (4) the survival of the surgery; (5) the

intraoperative damage patterns; and (6) factors predicting the need for a conversion to THA; the presence of radiographic progression of OA; a Merle d’Aubigné-Postel [24] score below 15 at last followup; and/or the need for revision surgery.

**Patients and Methods**

We retrospectively reviewed all 73 patients (73 hips) with LCPD in their history presenting with hip pain at our outpatient clinic between October 1997 and August 2005. All patients were evaluated for possible joint-preserving surgery. We excluded 20 patients (20 hips [27%]) with advanced OA (Grade 2 or greater according to Tönnis [43]) who underwent primary THA. This left 53 patients (53 hips) with no or minor radiographic hip OA (Grade 1 or less) [43] who underwent subsequent joint-preserving surgery (Table 1). The indications for surgery were: (1) pain; (2) impaired hip function (limp, positive anterior and posterior impingement test, impaired abductor strength); (3) decreased ROM; (4) abductor weakness; and (5) early degenerative changes. The contraindication was advanced OA > Grade 1 according to Tönnis. During the study time we treated all patients with joint preservation surgery if they had no advanced OA and met these indications. Using the classification of Stulberg et al. [37], there were three



**Fig. 1** The morphologic analysis with the corresponding surgical treatment algorithm of hips with pathomorphologic sequelae of Legg-Calvé-Perthes disease is shown. SHD = surgical hip dislocation; PAO = periacetabular osteotomy.

**Table 1.** Demographic data of patient series

Parameter	Value
Number of patients (hips)	53 (53)
Age at surgery (years)	21 ± 10 (7–47)
Sex (percent male of all hips)	55
Side (percent right of all hips)	38
Height (cm)	162 ± 17 (123–188)
Weight (cm)	62 ± 21 (25–107)
Body mass index (kg/m <sup>2</sup> )	23 ± 5 (16–33)
Previous surgery (percent)	57
Intertrochanteric varus osteotomy	15
Other intertrochanteric osteotomy	8
Pelvic osteotomy	23
Open reduction	6
Distalization of greater trochanter	2
Head trimming	2
Anterior capsulotomy	2

Values of continuous parameters are expressed as mean ± SD with range in parentheses.

hips (5%) with Class I, two hips (3%) with Class II, 32 hips (61%) with Class III, and 16 hips (31%) with Class IV. There were no hips with Class V. In 30 hips (57%), previous surgery was performed including 12 hips (23%) with femoral osteotomies, 12 hips (23%) with pelvic osteotomies, and in six hips (11%) with other surgical procedures (Table 1). All patients were invited to return for a minimum followup of 5 years. Three patients (three hips [6%]) were not available for followup. Of those, one patient (one hip [2%]) died from a cause unrelated to surgery without revision. The other two patients (two hips [4%]) were lost to followup. The remaining 50 patients (50 hips [94%]) were evaluated at the outpatient clinic with a minimum followup of 5.1 years (mean, 8.2 ± 2.1 years; range, 5.1–12.8 years). The study was approved by the local Institutional Review Board.

The preoperative clinical evaluation included the patient history, assessment of ambulation, abductor strength (MOM5) [23], anterior and posterior impingement test [42], and full goniometric ROM. As a clinical scoring system, the Merle d'Aubigné and Postel score was used [25]. Routine radiographic evaluations consisted of pre- and postoperative AP pelvic radiographs and a lateral crosstable radiograph of the proximal femur. Additional functional views have been used to predict coverage, containment, and congruency after periacetabular osteotomy (PAO) or proximal femoral osteotomies [10]. Abduction views were performed in cases of an acetabular deficiency before PAO if a clinical abduction of more than 20° was possible preoperatively [10]. Adduction views were performed in cases in which a valgus intertrochanteric osteotomy was planned

[10]. A gadolinium-enhanced MR arthrography was performed in all patients to quantify and localize cartilage and labral lesions [20, 21]. In nine patients we obtained an additional CT scan to assess the three-dimensional bone morphology. We analyzed the individual hip morphology using a systematic algorithm for analysis of the pathomorphologic sequelae of LCPD (Fig. 1). This analysis comprises both the description of femoral and acetabular pathomorphologies and their surgical treatment with respect to previously introduced surgical approaches and concepts [10, 11] for joint-preserving surgery. The aims of the surgery were to decrease pain, improve hip function, and delay secondary OA by eliminating intra- and extra-articular FAI, optimizing the abductor lever arm, and optimizing acetabular coverage and joint congruency.

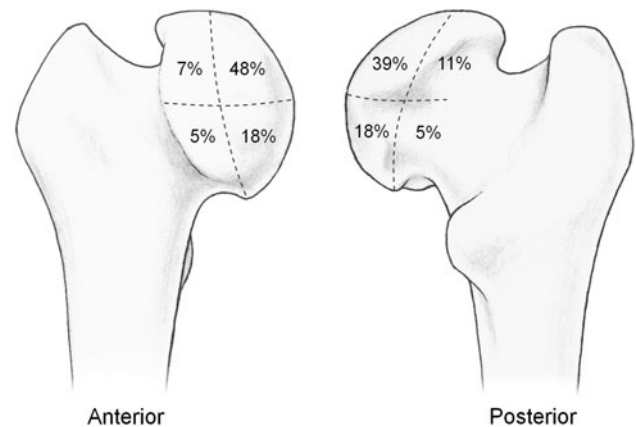
The intraarticular features comprise the typical asphericities related with LCPD subdivided into cam-type deformities (74%) and femoral head induced pincer-type deformities (26%) (Fig. 1). In cam-type deformities, the femoral head is still able to enter the acetabular cavity but creates a cam-type FAI. In femoral head-induced pincer-type deformities, the aspherical portion of the femoral head is too large to enter the joint creating a pincer-like type of FAI. The typical surgical treatment consisted of a SHD with trimming of the aspherical portion of the femoral head-neck junction. Rarely, a femoral head reduction osteoplasty (8%) to reduce the femoral head diameter is necessary. The intraarticular pathology can be aggravated by a functional retrotorsion (38%) in which the center of the articulating portion of the femoral head is posterior to the femoral neck axis. In those cases, an additional flexion and/or valgus osteotomy was necessary when femoral head-neck resection did not result in sufficient impingement-free ROM (30%).

The extraarticular features typically refer to abnormalities of the greater (89%) and the lesser trochanter (8%) (Fig. 1). The typically high-riding greater trochanter can lead to extraarticular impingement with the acetabulum and to decreased abductor muscle force. The high-riding greater trochanter can be corrected by advancing the trochanter (relative femoral neck lengthening) during SHD. The lesser trochanter can impinge extraarticularly with the ischium or the posterior acetabulum. The correction comprises distalization of the lesser trochanter.

Along with alterations of the proximal femur, secondary acetabular pathomorphologies occurred in 81% (Fig. 1). These alterations included acetabular deficiency (hip dysplasia, 47%) and acetabular malorientation (acetabular retroversion, 55%). The surgical treatment consisted of acetabular osteotomy or trimming of the acetabular rim, respectively. In 38%, an additional incongruity of the joint was corrected by either an acetabular and/or femoral osteotomy.

The allocation to one of the pathomorphologies of the algorithm was based on preoperative clinical and radiographic information and on a stepwise intraoperative evaluation. Typically, the first step to correct femoral pathomorphologies included the SHD with an osteotomy of the greater trochanter and a reduction of the stable portion of the former greater trochanter (relative neck lengthening). Next, ROM was reevaluated for previously inapparent intraarticular sources of FAI such as a femoral head-neck asphericity or acetabular rim prominence. An additional head-neck trimming was performed to resect the aspherical portion of the femoral head first. In case of a persistent intraarticular FAI, the acetabular rim was trimmed in a second step. We then evaluated the extraarticular impingement of the lesser trochanter, which could be treated by distalization of the lesser trochanter. In case of joint incongruency, functional radiographs were repeated intraoperatively to determine whether we would perform a proximal femoral osteotomy or to check the amount of correction for a PAO. Indications for a PAO were an associated secondary acetabular dysplasia [10], which was defined as a lateral center-edge angle of less than  $25^\circ$  [46]. Indications for a proximal femoral valgus osteotomy were a nonspherical femoral head with good congruence in an adduction view [10]. Often, the acquisition of these radiographs is not possible preoperatively as a result of the lack of hip motion resulting from the femoral pathomorphologies. Forty of the 53 hips (75%) were treated with a SHD, eight (15%) hips with an acetabular osteotomy, four (8%) hips with a combined SHD and acetabular osteotomy, and one hip (2%) with an isolated intertrochanteric osteotomy (Fig. 1). The intraoperative damage pattern was evaluated in the 44 hips (83%) that underwent SHD. This included the status of the articular cartilage and labrum, documented intraoperatively, and graded according to a previously described grading system [4]. Cartilage damage was objectified as malacia, debonding, cleavage, or defect. Labral damage was objectified as degeneration, full-thickness tear, detachment, or ossification. To describe the exact location of the chondrolabral damage on the acetabulum, we used the clock system. Six o'clock was located at the acetabular notch. All findings were converted to the right side with 3 o'clock consistently representing the most anterior portion of the acetabulum. To describe the exact location of the chondral damage on the femoral head, the head was divided into eight sectors of a sphere (Fig. 2) [40].

After SHD the hip was placed in a neutral position in a soft splint. The suction drains were removed after 48 hours. The patient was mobilized with crutches and partial weightbearing with 15 kg and restricted active and passive abduction and adduction to protect the trochanteric osteotomy. Active flexion was restricted if the lesser trochanter



**Fig. 2** The results for intraoperative femoral head damage are shown. To describe the exact location of the chondral damage on the femoral head, the head was divided into eight sectors of a sphere. The numbers represent the frequency of chondral damage in each of the eight sectors.

was advanced. The joint was mobilized on the second postoperative day on a continuous passive motion machine with a maximal flexion of  $90^\circ$  to avoid capsular adhesions. We used low-molecular-weight heparin for 8 weeks for prophylaxis of deep venous thrombosis. Eight weeks postoperatively, the patients were evaluated clinically and radiographically. By then, the trochanteric osteotomy usually was radiographically healed and gradual full weightbearing and muscular strengthening were started. The postoperative treatment regime did not change if an additional PAO or intertrochanteric osteotomy had been performed.

The next clinical and radiographic followup was generally set at 3 months, 1 year, and 2 years postoperatively. Relief of pain was assessed using the definition according to the Merle d'Aubigné-Postel pain subscore [24]. Improvement of hip function included the complete Merle d'Aubigné-Postel score [24], incidence of limp, percentage of maximal abductor strength force (M5) according to the British Medical Research Council grading [23], incidence of the anterior and posterior impingement tests [42], and full ROM.

One of us (CEA; not a treating surgeon) assessed 11 descriptive (six acetabular and five femoral) radiographic parameters pre- and postoperatively. The six acetabular parameters were: lateral center-edge angle [46], the acetabular index [44], the extrusion index [25], the crossover and the posterior wall sign [28], and the intactness of Shenton's line. The femoral parameters consisted of the centrum-collum-diaphyseal (CCD) angle, the alpha angle on the AP and crossstable lateral views [26], the sagging rope sign [2], and the trochanteric height. We assessed the trochanteric height by relating the height of the greater trochanter to the femoral head [37]. The head was divided

into four quadrants with the first quadrant at the inferior and the fourth quadrant at the superior border of the femoral head. A fifth quadrant was situated above the femoral head. In the literature, the interclass correlation coefficient or kappa values for the intra- (inter)observer reliability were 0.98 (0.92) for the lateral center-edge angle [41], 0.89 (0.92) for the acetabular index [41], 0.97 (0.91) for the extrusion index [41], 0.77 (0.6) for the crossover sign [41], 0.70 (0.62) for the posterior wall sign [41], and 0.86 (0.81) for the alpha angle [36]. No data exist for intactness of Shenton's line, CCD angle, sagging rope sign, and assessment of trochanteric height. From the 11 radiographic parameters describing the hip morphology, three (27%) changed postoperatively: the alpha angle in AP and crosstable radiograph both decreased, the incidence of a sagging rope sign decreased, and the mean grades for trochanteric height decreased (Table 2). Progression of OA was graded according to Tönnis [43].

We tested normal distribution of all continuous parameters with the Kolmogorov-Smirnov test. We determined differences in pain score between preoperative and followup using the Wilcoxon rank sum test. We determined differences in hip function using the paired Student's t-test for normally distributed data (ROM), the Wilcoxon rank sum test for data without normal distribution (Merle d'Aubigné-Postel score), the Fisher's exact test for binominal data (incidence of limp, anterior, and posterior impingement test), and the Kruskal-Wallis test for categorical data (abductor strength). We determined

differences in OA using the Kruskal-Wallis test. Survival of surgery was calculated with the following four end points: conversion to THA; radiographic progression of OA; a Merle d'Aubigné-Postel score below 15 at followup; and revision surgery for any reason (except hardware removal) using the method of Kaplan and Meier [16]. The following factors were evaluated as predictive factors using the univariable Cox proportional hazards model [6]: age, sex, previous surgery, preoperative OA, subluxation of the joint, Stulberg classes [37], preoperative pathomorphological features (Fig. 1), and all radiographic and clinical parameters (Tables 2, 3). Hazard ratios were calculated with 95% confidence intervals (CIs).

## Results

At the most recent followup, the median pain status represented by the pain subgroup of the Merle d'Aubigné score increased ( $p < 0.001$ ) from preoperatively 4 (range, 2–6) to 5 (range, 3–6) for the 45 hips that were not converted to THA. Fourteen patients (31%) presented pain-free and an additional 15 patients (33%) showed a reduction of pain compared with the preoperative status. In three patients (9%), pain was increased at last followup.

All parameters describing hip function except flexion improved at the most recent followup (Table 3). The median Merle d'Aubigné-Postel score increased ( $p < 0.001$ ), the incidence of limp decreased ( $p < 0.001$ ), the

**Table 2.** Preoperative and postoperative radiographic evaluation of all hips (n = 53)

Category	Parameter	Preoperative	Postoperative*	p value
Acetabular	Lateral center-edge angle (degrees)	27 ± 13.7 (2–62)	27 ± 13.4 (3–66)	0.510
	Acetabular index [44] (degrees)	11 ± 86.6 (–5–29)	11 ± 11.1 (–24–38)	0.682
	Extrusion index [25] (percent)	23 ± 14.1 (–17–48)	23 ± 14 (–14–57)	0.376
	Crossover sign [28] (percent positive)	65	48	0.087
	Posterior wall sign [28] (percent positive)	97	94	0.453
	Shenton's line (percent intact)	80	85	0.806
Femoral	CCD angle (degrees)	127 ± 8.8 (106–140)	129 ± 6.1 (116–140)	0.090
	AP alpha angle AP radiograph (degrees)	79 ± 20.5 (45–114)	52 ± 13 (39–91)	< 0.001
	Alpha angle crosstable radiograph [26] (degrees)	79 ± 27.2 (45–120)	44 ± 14.4 (27–96)	< 0.001
	Sagging rope sign (percent positive) [2]	78	29	< 0.001
	Trochanteric height [37] (%)			
	Quadrant 1	–	13	< 0.001
	Quadrant 2	6	57	
	Quadrant 3	17	17	
	Quadrant 4	44	11	
Quadrant 5	33	2		

Values of continuous parameters are expressed as mean ± standard deviation with range in parentheses; \* osteoarthritis values were obtained at the most recent followup; CCD = centrum-collum-diaphyseal.



**Table 3.** Clinical results preoperative and at followup of the hips with a preserved joint (n = 45 hips)

Parameter	Preoperative value	Followup value	p value
Merle d'Aubigné [24]	14 ± 1.4 (5–17)	16 ± 1.9 (13–18)	< 0.001
Limp (percent of all hips)	71	18	< 0.001
Abductor strength (percent of all hips with M5) [23]	37	76	0.002
Anterior impingement test [42] (percent of all hips)	91	59	< 0.001
Posterior impingement test [42] (percent of all hips)	71	21	< 0.001
Range of motion			
Flexion	93 ± 17.3 (50–130)	92 ± 15.7 (45–120)	0.741
Extension	3 ± 5.3 (0–20)	7 ± 5.9 (0–20)	0.017
Internal rotation	15 ± 10.7 (0–85)	21 ± 14.9 (0–60)	0.001
External rotation	22 ± 12.6 (0–45)	29 ± 15.6 (0–80)	0.010
Abduction	24 ± 11.17 (0–50)	29 ± 12.9 (0–50)	0.026
Adduction	19 ± 11.0 (0–45)	21.3 ± 8.7 (5–35)	0.029

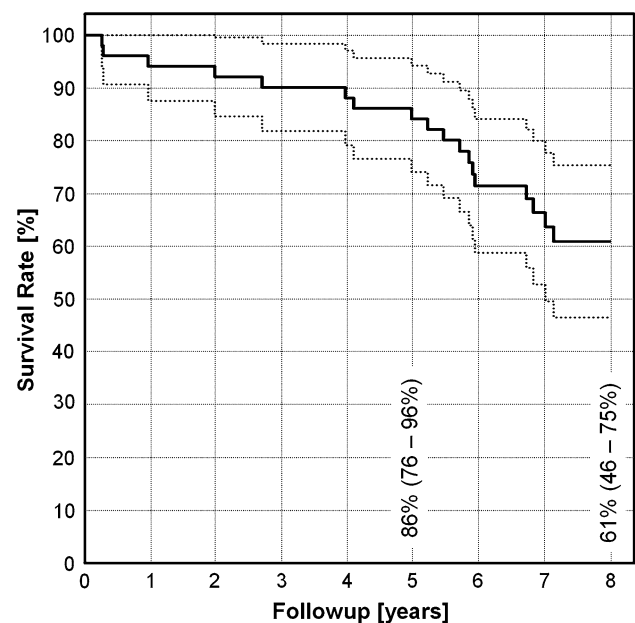
Values of continuous parameters are expressed as mean ± standard deviation, with range in parentheses; values for the Merle d'Aubigné score are expressed as median ± SEM with range in parentheses.

percentage of hips with a M5 abductor strength increased ( $p = 0.002$ ), the incidence of positive anterior and posterior impingement tests both decreased ( $p < 0.001$ ), and all amplitudes for ROM except flexion increased (Table 3).

The mean OA score increased ( $p = 0.004$ ) at most recent followup compared with the preoperative status. Preoperatively, 35 hips (66%) presented with Grade 0 and 18 hips (34%) with Grade 1 according to the classification of Tönnis [43]. At last followup, 19 hips (42%) of the remaining 45 hips without conversion to THA showed no signs of OA, 17 hips (38%) had osteoarthritic changes Grade 1, seven hips (15%) Grade 2, and two hips (5%) Grade 3 according to Tönnis [43].

The cumulative survival of surgery was 86% (95% CI, 76%–96%) at 5 years and 61% (46%–75%) at 8 years postoperatively (Fig. 3). Twenty-six hips (49%) reached an end point: five hips (9%) converted to THA, 13 hips (25%) showed progression of OA, one hip (2%) had a Merle d'Aubigné-Postel score of 13, and two hips (4%) had revision surgery. None of the patients had avascular necrosis of the femoral head secondary to surgery. In addition, there were three hips (6%) with combined progression of OA, a Merle d'Aubigné-Postel score ranging from 13 to 14, and two hips (4%) with progression of OA and revision surgery. The four hips with revision surgery were two acetabular redirection osteotomies, one intertrochanteric varus osteotomy as a result of loss of femoral head containment, and one patient with excision of heterotopic ossifications.

On the acetabular side, 38 hips (86%) had chondrolabral damage. There were 16 hips (36%) with cartilage malacia, eight hips (18%) with a debonding phenomenon, and two hips (5%) with a cleavage lesion of the cartilage. There were no hips with a full-thickness cartilage defect. The

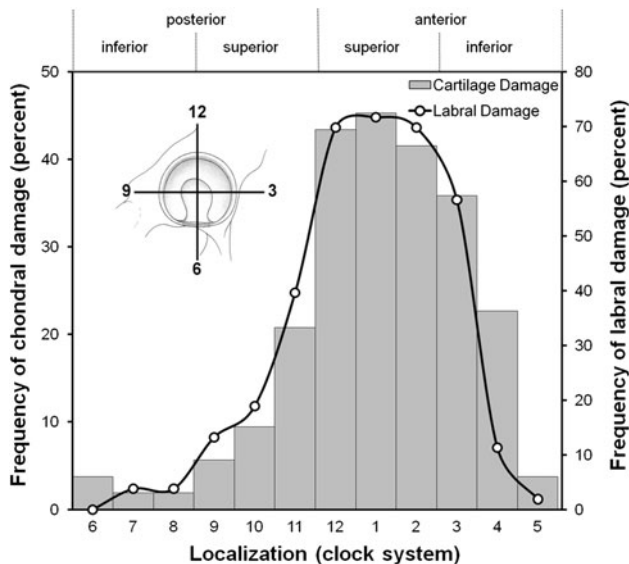


**Fig. 3** The Kaplan-Meier survival analysis is shown. End points were defined as conversion to a THA, reoperation for correction of acetabular coverage or femoral offset, progression of osteoarthritis, or an insufficient clinical result defined as end points. Values are expressed as cumulative survival of surgery with 95% confidence intervals in parentheses.

labrum was degenerated in 14 hips (32%) with a full-thickness tear in 21 (48%), a detachment in two (5%), and ossification in one hip (2%). The chondral damage was located more anteriorly ( $1.3 \pm 2.0$  o'clock) in comparison to the labral damage ( $12.8 \pm 1.9$  o'clock,  $p = 0.48$ ; Fig. 4). On the femoral side, 25 hips (57%) had evidence of chondral damage. There were 15 hips (34%) with chondral malacia, three hips (7%) with a debonding phenomenon,

one hip (2%) with a cleavage lesion, and six hips (14%) with a full-thickness cartilage defect. The chondral lesions were predominantly found in the medial half of the femoral head (Fig. 2).

We identified 11 predictors for failure (Table 4): one demographic, seven preoperative clinical or radiographic features, and three factors related to surgical treatment (Table 4).



**Fig. 4** The results for intraoperative chondrolabral damage of the acetabulum are shown. A clock system was used to describe the exact location of the chondrolabral damage on the acetabulum. Six o'clock was located at the acetabular notch. All findings were converted to the right side with 3 o'clock consistently representing the most anterior portion of the acetabulum.

## Discussion

Pathologic residual hip deformities after LCPD predispose for symptomatic malfunction of the joint and put the hip at high risk for degenerative OA [47]. It is important to address any possible source of extra- and intraarticular impingement, an associated acetabular dysplasia and/or joint incongruence to obtain pain relief, an improved ROM, and abductor strength. The ability of safely dislocating the hip with the recognition of FAI has revolutionized our surgical treatment protocol for surgical management of these conditions. We established a treatment algorithm to characterize the possible pathomechanical problems and proposed the appropriate surgical treatment for each problem. We therefore asked if patients undergoing joint-preserving surgery for symptomatic sequelae after LCPD according to this algorithm had (1) relief of pain; (2) improved hip function; and/or (3) no progression of OA; we determined (4) the survival of the surgery; (5) the intraoperative damage patterns; and (6) factors predicting an end point related to an unsatisfactory outcome. This was defined as the need for a conversion to THA; the presence of radiographic progression of OA; a Merle d'Aubigné-Postel [24] score below 15 at last followup; or the need for revision surgery.

Our study is subject to a number of limitations. First is the heterogeneity of the patient series, which includes an age range spanning four decades, a high percentage of hips with previous surgeries, and a relatively high number of patients undergoing different surgical procedures. This limits the power of the study. However, we included all patients who had surgery during the study period and in all, the healing stage of LCPD was completed. Nonetheless, we

**Table 4.** Predictive factors for poor outcome with corresponding hazard ratios

Category	Parameter	Hazard ratio (95% confidence interval)	p values
Demographic factors	Age > 40 years	6.7 (5.6–7.9)	< 0.01
Preoperative factors	Preoperative osteoarthritis (Tönnis $\geq$ 1) [43]	4.0 (2.9–5.1)	0.01
	Acetabular index > 14° [44]	2.7 (1.9–3.6)	0.02
	Severin classification > 3	5.7 (3.9–7.5)	< 0.05
	Merle d'Aubigné score < 14 points	2.8 (2.0–3.6)	0.01
	Range of motion		
	Internal rotation $\leq$ 10°	2.6 (1.7–3.4)	0.03
	External rotation < 20°	2.6 (1.7–3.4)	0.04
	Abduction < 20°	2.6 (1.6–3.5)	< 0.05
	Alpha angle > 56°	4.7 (3.2–6.2)	0.04
	Stulberg class > III	6.4 (4.7–8.2)	0.03
Postoperative factors	Broken Shenton's line	2.9 (1.9–4.0)	0.04
	Trochanteric height > Grade 3 [37]	2.7 (1.7–3.7)	< 0.05
	Alpha angle > 50°	7.8 (5.9–9.8)	0.04

**Table 5.** Selected publications for the outcome after joint-preserving hip surgery for the sequelae of LCPD or Perthes'-like hip deformities

Author	Number of hips	Mean age at surgery (years)	Type of surgery	Minimum (mean) followup (years)	Results
Anderson et al. [1]	14	20	SHD; proximal femoral osteotomy; trochanteric advancement	0.5 (3.8)	Improved Harris hip score, reduction of limp, improved center trochanteric distance, no hips with conversion to THA, description of chondrolabral damage pattern
Baksi [3]	31	N/A	Adductor tenotomy; cheilectomy of the femoral head	3.2–10	Relief of pain, increased range of motion
Clohisy et al. [5]	24	22	PAO; proximal femoral osteotomy	2.0 (4.5)	Improved Harris hip score, improved LCE angle, improved ACE angle, improved acetabular index, medialization of the hip center, slight increase in osteoarthritis
Eijer et al. [7]	12	21	SHD; various proximal femoral and acetabular osteotomies	1.1 (2.8)	Relief of pain, improved ROM, no new femoral head necrosis
Joo et al. [13]	15	17	Advancement of greater trochanter	2.3 (3.5)	No pain relief, no improvement of limp
Pecasse et al. [27]	15	30	Intertrochanteric osteotomy; advancement of greater trochanter; acetabular roof plasty	8.0 (11.3)	Relief of pain, fair Harris hip score, no improvement of ROM, mean survival time of 15.3 years
Shinoda et al. [32]	17	37	PAO	3.0 (6.6)	Improved Harris hip score, no increase in ROM, no decrease in leg length discrepancy, increased acetabular index, increased acetabular head index, progression of osteoarthritis
Shore et al. [33]	29	17	SHD; various proximal femoral and acetabular osteotomies	1.0 (3.0)	Improved WOMAC score, pain reduction, improved ROM and function, low failure rate
Vukasinovic et al. [45]	41	10–20	Chiari osteotomy	4.0 (7.2)	Improved Harris hip score, improvement of acetabular angle of Sharp, increase of LCE angle, improved femoral head coverage, improved acetabular depth ratio, increased Shenton's line continuity
Current study	53	21	SHD; PAO; various proximal femoral and acetabular osteotomies	5.0 (8.2)	Relief of pain, improvement of range of motion, improved hip abductor strength, slight progression of osteoarthritis

LCPD = Legg-Calvé-Perthes disease; SHD = surgical hip dislocation; PAO = periacetabular osteotomy; LCE = lateral center-edge; ACE = anterior center-edge.



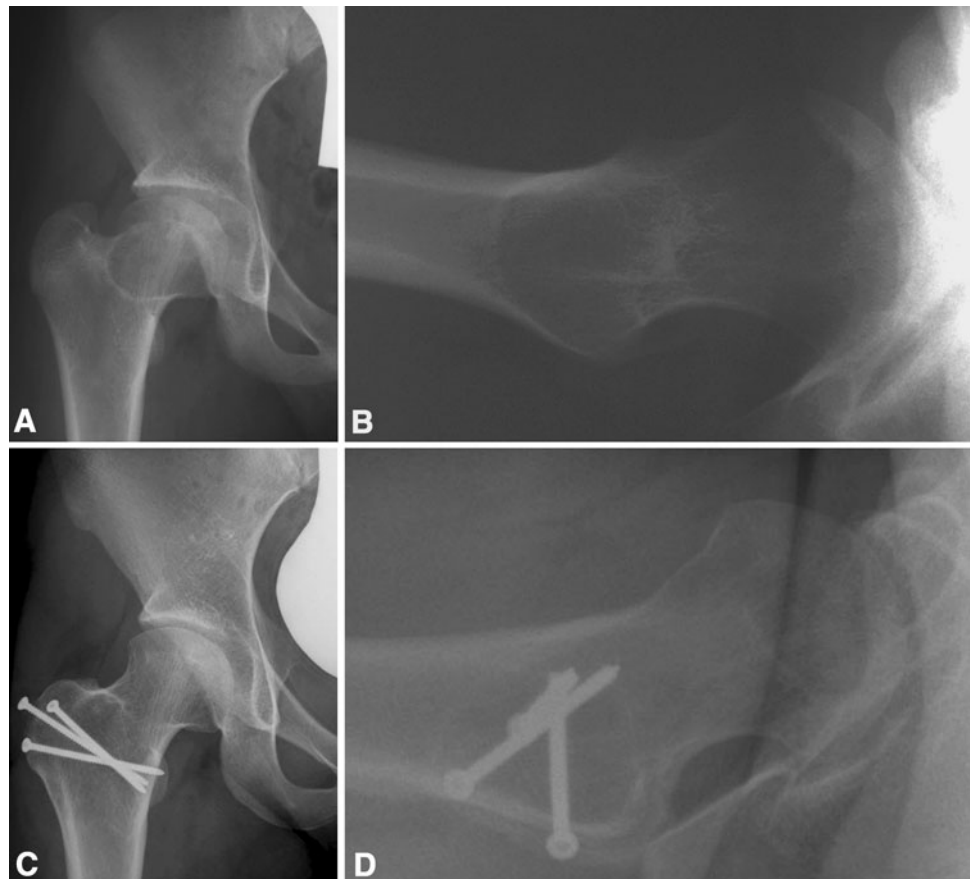
believe the heterogeneity facilitates the identification of predictors for our end points. Second, the surgical technique has evolved over time with growing experience and more precise assessment of the structural problem. Some of the classified pathomorphologies were not consistently addressed according to this proposed treatment algorithm and in some patients we judged an abnormality to be irrelevant. For example, we did not believe acetabular retroversion had to be corrected if impingement-free motion was present after reshaping of the femoral head, particularly with a borderline-type lateral acetabular coverage. Furthermore, some structural abnormalities were underestimated and not addressed. For example, in two patients with an additional borderline acetabular dysplasia, the femoral pathology was addressed only, which subsequently led to a loss of containment needing acetabular redirection osteotomy. Third, the retrospective nature of this study allowed us to only use the Merle d'Aubigné-Postel score, one that has not been validated. However, the three subgroups of the score (pain, walking ability, ROM) address the problems of patients with residual deformities after healed LCPD. Fourth, the description of the intra-articular damage only refers to hips that underwent a SHD, which covers 83% of our cases. Fifth, our univariate

analysis could be misleading because we have inadequate power to perform a multivariate analysis.

Our approach to treat symptomatic hips after LCPD decreases hip pain. This is consistent with other reports describing similar treatment strategies mainly based on a SHD [1, 7, 33]. This surgical approach offers the option to address any possible intra- and extraarticular source of FAI and can be combined with any form of concomitant femoral and acetabular osteotomies. The authors believe this comprehensive approach is the key for successful reduction of hip pain in these patients. Surgical treatment of an isolated structural deformity does not improve hip pain as shown with an isolated cheilectomy [29] of the aspherical femoral head portion or a simple trochanteric advancement [13].

We observed improved mean hip function at last followup. This included an increase in abductor strength together with a decreased prevalence of the anterior and posterior impingement signs. In addition, all amplitudes of hip ROM except flexion improved after surgery (Table 3). Although a similar effect on ROM has been described in some articles [3, 7], this is not the case with other surgical techniques for treatment of the sequelae of LCPD in the literature [27, 32] (Table 5). There are two main reasons why hip flexion did not change after surgery. First, hip

**Fig. 5A–D** The radiographs of a 16-year-old female patient are shown in the (A) AP projection and (B) crossstable projection. Next to the deformity of the femoral head (Grade III according to Stulberg), a high-riding trochanter, a positive sagging rope sign, and acetabular retroversion were present. The acetabular index was 4°. (C) A surgical hip dislocation with relative lengthening of the femoral head, distalization of the greater trochanter, and (D) osteochondroplasty of the femoral head neck junction was performed. The acetabular retroversion was not addressed to avoid joint instability. Eleven years postoperatively, the patient presented with a Merle d'Aubigné-Postel score of 18 points without signs of radiographic progression of osteoarthritis and full abductor strength.



flexion is the least restricted preoperative motion with LCPD, particularly in hips with low Stulberg classes [7, 39, 48]. Second, an additional acetabular osteotomy can adversely reduce the flexion amplitude even when the femoral pathomorphology was optimized.

Our observations suggest we are unable to stop the progression of OA in these hips. This can be attributed to several factors. A main factor is certainly the preexisting articular damage in these hips. In addition, the restoration of a normal hip anatomy even with extensive surgical corrections of the LCPD pathomorphology is rarely possible. As a result of the lack of comparable followup, the other studies evaluating the use of a SHD have not quantified the progression of OA in detail [1, 7, 33]. However, a similar trend of a slight progression of OA was observed with other joint-preserving techniques [5, 32]. It remains unclear if the progression of OA can be decelerated because of the lack of natural history controls.

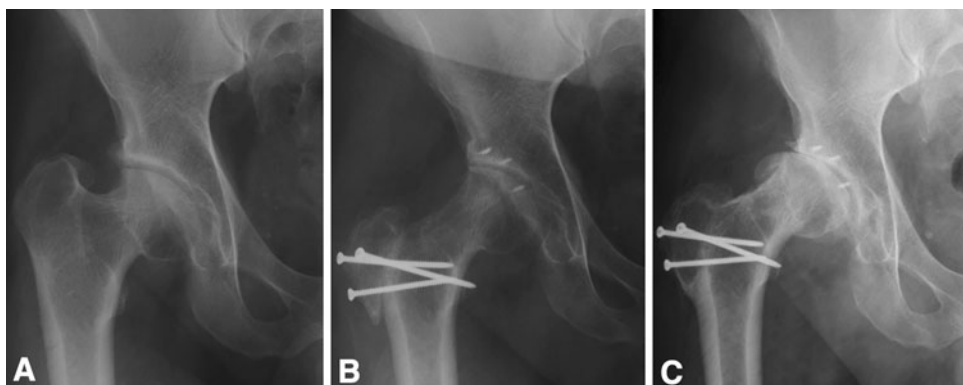
We found a survival rate of surgery of 86% at the minimum followup of 5 years and a 61% survival of surgery at the mean followup of 8 years. There are only limited comparable studies with a similar approach, none of them performing a survival analysis. Anderson et al. [1] report in their study with 14 hips at a mean followup of 3.8 years a progression of OA in four cases, a poor clinical outcome in three cases, and no conversions to THA. In a recent study by Shore et al. [33], 29 individuals were treated with SHD and various concomitant proximal femoral and acetabular osteotomies. In their study, the authors report four failures at a mean followup of 3 years. Of those, there was one patient presenting with a poor clinical result and three patients requiring THA [33]. In addition, seven patients underwent revision surgery. However, the improvement of the clinical scores and the ROM is a

consistent finding in all articles and matches with our results.

The chondrolabral damage on the acetabular side occurs typically in the anterosuperior quadrant, similarly to other hips with FAI [34, 38]. Our findings are consistent with other descriptions of smaller series in the literature [1, 7]. On the femoral side, the cartilage lesions are often found in the medial hemisphere, which is typically the location of the necrosis and osteochondral defects [1]. The large lateral aspherical portion is often less affected because it may not even contribute to the articulating process. It can therefore be used as a potential autologous osteochondral allograft for the medial femoral head portion.

We identified no literature reporting predictive factors of outcome in patients with LCPD undergoing joint-preserving surgery. We found 11 univariable predictors for poor outcome. As mentioned, this univariate analysis should be interpreted carefully because we have limited power to perform a multivariate analysis. The predictors can be divided into three main categories: preexisting joint damage, extent of the femoral and acetabular pathomorphology, and surgical correction. The preexisting joint damage is reflected by the degree of OA, the age, and the initial clinical score. The extent of the femoral and acetabular pathomorphology is reflected by a worse prognosis or hips with Stulberg > 3, hips with an accelerated offset problem (alpha angle > 50°), or a dysplastic morphology with subluxation (Severin grade > 3, acetabular index > 14°, and broken Shenton's line). The surgical correction has to include a sufficient offset creation (alpha angle < 50°), the restoration of an intact Shenton's line, and correct trochanteric height (Table 4).

Our data suggest the pathomorphologic features related to the sequelae of LCPD can be treated using our algorithm



**Fig. 6A–C** The radiographs of a 43-year-old patient with Legg-Calvé-Perthes disease are shown. (A) Preoperatively, the patient presented with pain, a severe Trendelenburg limp, and decreased abduction, internal, and external rotation. (B) A surgical hip dislocation with relative lengthening of the femoral head, distalization

of the greater trochanter and osteochondroplasty, and acetabular rim trimming with refixation of the labrum was performed. (C) Five years after surgery, the patient presented with severe progression of osteoarthritis and migration of the femoral head.

(Fig. 5). Patients with sufficient pain and disability in whom a primary THA often seems to be the only surgical option can benefit from a SHD together with the specific treatment of individual structural features. The severity of the deformation according to Stulberg et al. [37], the pre-operative grade of OA, the age of the patient, the accuracy of the correction, and the presence of a broken Shenton's line determine the midterm results of our treatment protocol (Fig. 6).

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