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Original Research

Relative Femoral Neck Lengthening in Legg-Calvé-Perthes Total Hip Arthroplasty

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ABSTRACT

Background: Total hip replacement (THR) in patients with a history of Legg-Calvé-Perthes disease can be a technically challenging procedure due to the distorted hip morphology. We propose a technique in which THR is preceded by a modified relative femoral neck lengthening (RFNL) procedure. Hereby, we aim to restore the biomechanical parameters.

Methods: Twenty-eight patients underwent RFNL in preparation of a second-stage THR between December 2011 and September 2019. The mean age was 38.1 ± 11.4 years. Radiographs were analyzed for centrotrochanteric distance, lateral displacement of the greater trochanter, and leg length discrepancy to assess the biomechanical restoration. Complication rate, reoperation rate, and patient-reported outcome measures were measured.

Results: Mean centrotrochanteric distance increased from −18.7 ± 6.7 mm preoperatively to 1.9 ± 9.0 mm ($P < .001$) after RFNL and to 11.4 ± 10.4 mm after THR ($P < .001$). Mean lateral displacement of the greater trochanter increased from 34.2 ± 8.1 mm preoperatively to 42.4 ± 5.2 mm ($P < .001$) after RFNL and to 49.9 ± 8.3 mm after THR ($P < .001$). Leg length discrepancy decreased from 17.5 ± 10.5 mm to 2.7 ± 2.2 mm after THR ($P < .001$). Mean Harris Hip Score improved from 56.9 ± 17.6 preoperatively to 89.4 ± 10.7 at the latest follow-up ($P < .001$). Eight patients (8 hips) postponed THR because of sufficient clinical improvement, at a mean follow-up of 4.2 ± 2.1 years. Two hips needed a revision RFNL due to non-union (7.1%), and 1 hip replacement was revised due to a deep infection (5.0%).

Conclusions: RFNL prior to THR in patients with end-stage osteoarthritis following Legg-Calvé-Perthes disease allows for utilizing regular implants with straight access to the femoral canal, with restored biomechanics and restoration of leg length. The prominent overhanging greater trochanter is reduced to prevent postoperative extra-articular impingement.

Introduction

Legg-Calvé-Perthes disease (LCPD) is characterized by avascular necrosis of the proximal femoral epiphysis during childhood. Abnormal hip features include a short femoral neck, overgrowth of the greater trochanter (GT), varus hip morphology, and a dysplastic acetabulum [1,2]. Approximately 7% of patients with LCPD require a total hip replacement (THR) within 20 years [3].

Overgrowth of the GT decreases the abductor lever arm and can lead to extra-articular impingement [4]. Insufficient functioning of the hip abductors is associated with aberrant joint loading and poor

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function [5]. Relative femoral neck lengthening (RFNL) aims to increase the abductor lever arm by advancing the GT laterally and distally [6-8].

THR is a successful procedure to treat osteoarthritis in hips with a history of LCPD. Postoperative functional improvement is comparable to other patients undergoing THR. However, the procedure can be technically demanding with a higher revision and complication rate [1,9]. Fractures, due to the distorted anatomy of the proximal femur, and motor nerve palsies have been reported [10,11]. Modular implants can help to adjust offset, neck length, and version. However, concerns with regard to (modular) taper fretting, corrosion, and implant failure should be taken into account when using this type of implants in a young patient population [12]. In addition, the overhanging GT could hamper a straight access to the femoral canal, increasing the risk of varus positioning of the stem with early loosening.

Preoperative GT advancement with a modified RFNL procedure can improve the access to the femoral canal, potentially reducing the risk of extra-articular impingement with restoration of the hip biomechanics. We evaluated the results of this modified RFNL technique, which preceded a second-stage THR in patients with osteoarthritis following LCPD.

Material and methods

This is a retrospective, single-surgeon, case series review of a prospectively recorded database of patients with a history of LCPD treated between December 2011 and September 2019. All patients had clinically and radiographically (Tonnis grade ≥2) confirmed severe to end-stage osteoarthritis. This study was approved by the ethical committee (CTU2020082). All participants signed an informed consent and were informed that the modified RFNL procedure was the first stage of a two-stage treatment, with the anterior approach THR being the second stage.

Surgical technique

A slightly modified RFNL procedure as described by Ganz et al. was conducted by the senior author (K.C.) [13]. In lateral decubitus, a longitudinal incision is centered over the GT. A Gibson approach is used with a split following the interval between gluteus maximus and tensor fascia lata. The gluteus minimus is peeled off the posterior capsule in order to easily mobilize the muscle after the trochanter osteotomy. The vastus lateralis is peeled off the lateral cortex of the femur, distal to its insertion on the vastus ridge (Fig. 1).

The osteotomy should remain lateral to the insertion site of the piriformis. In order to achieve this, the leg is internally rotated. The osteotomy line is first marked with the electrocautery and incorporates the insertion sites of the abductors and the vastus ridge. The starting point is located 3-4 mm anterior to the posterior attachment site of the gluteus medius (Fig. 1). First, a cutting saw is used. Then an osteotome is put in the osteotomy site, and the mobile fragment of the GT is flipped in the anterior direction. Superior and anterior soft-tissue attachments are released with a

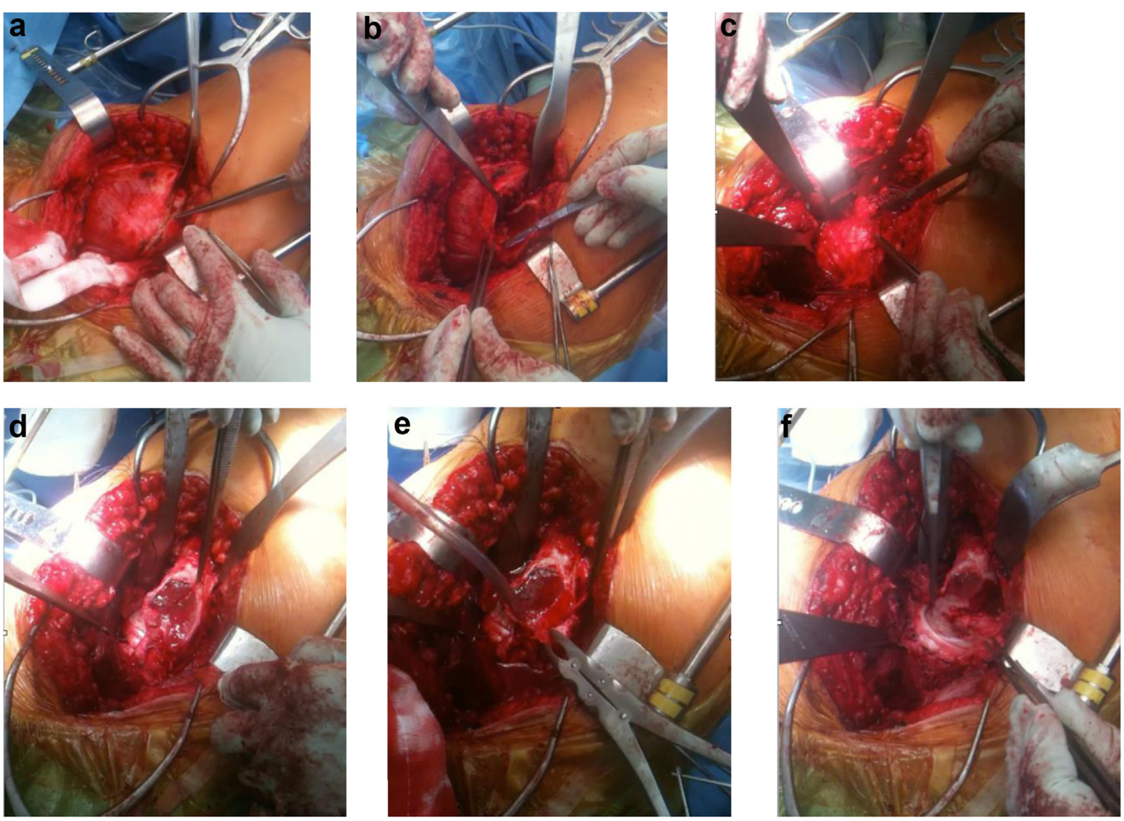

Figure 1. An RFNL of the right hip is shown, posterocranial view. Head of the patient is on the left side. (a) The electrocautery marking at the GT is shown. The thickness of the trochanter fragment should be between 1 and 1.5 cm. The vastus lateralis is peeled off the lateral cortex of the femur and left intact at the vastus ridge (indicated with forceps). A blunt retractor keeps the vastus lateralis elevated. (b) The osteotomy is done with the leg internally rotated. The posterior part of the gluteus medius tendon (indicated with the forceps) is split. (c) The entire anteroposterior capsule is exposed. The trochanter is mobilized anteriorly. The forceps indicates the position of the capsular incision anterosuperiorly, which allows identifying the base of the neck at the greater trochanter. (d) The trochanter mass is mainly bulky in the posterior and cranial directions. The forceps indicates the level of the posterior osteotomy. (e) The posterior osteotomy is done, and the cancellous bone is removed with the nibbler from the posterior inner surface of the posterior cortex. The external rotators remain attached to the posterior cortex. (f) After resection of the superior part of the overhanging trochanter, the base of the neck can be seen (marked with forceps). The surface of the remaining trochanter is reduced posteriorly and superiorly. The posterior capsule is held with the left hand forceps.

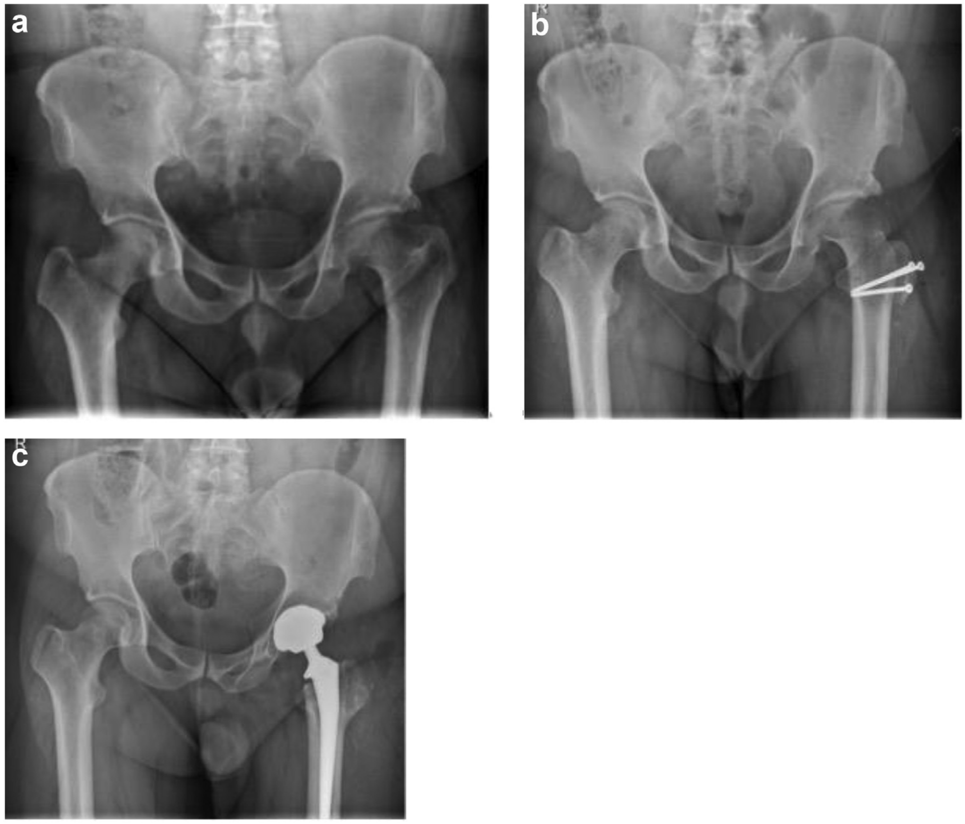

Figure 2. (a) A 32-year-old male patient with an overhanging and high-riding greater trochanter underwent a modified RFNL followed by a THR. (b) The trochanter is advanced distally in order to have the superior part of the fragment at the same level as the superior neck. This increases the abductor lever arm and allows for an improved access to the femoral canal. Of note is the less optimal screw fixation with convergence at the calcar. (c) A DAA THR is then performed reconstructing leg length and offset.

knife in order to fully mobilize the fragment. The leg is gradually externally rotated until the fragment has become fully mobile until the superior to anterior capsule become fully visible with anterior displacement of the trochanter fragment.

The trochanter advancement is now prepared. First, the level of the superior neck is identified by a small capsulotomy at the level of the anterosuperior neck. The strong capsular restraints remain intact, and the blood supply of the femoral head is not jeopardized. Second, the volume from the bulky GT is piecemeal reduced with sharp osteotomes and a nibbler. This minimizes the risk of extra-articular impingement after THR. The cancellous bone is removed from the inner surface of the posterior cortex, which thins out the posterior fragment and leaves the short external rotators attached. Next, the anterior part of the GT is removed until the base of the femoral neck is reached. This is done in a piecemeal way with inside out peeling of the bone from the periosteum (Fig. 1). The superior part of the trochanter should be at the level of the superior neck. Distally, the lateral femoral cortex is leveled out with the lateral part of the trochanter. No surgical dislocation or cam resection is performed as patients presented with signs of moderate to severe osteoarthritis are planned to undergo a second-stage THA.

The capsule is closed. The posterior cortex of the trochanter (with the sort external rotators attached) is advanced distally and fixed with Vicryl 2 (Ethicon, J&J, Warsaw, IN). The leg is again internally rotated. The osteotomized fragment is mobilized and advanced distally with a towel clip. The superior part of the fragment should be at the level of the superior neck. The fragment is fixed with three 2.5-mm cortical screws directed vertically, perforating the calcar bone just proximal to the lesser trochanter. Usually, the screw length is between 45 and 55 mm. In case the screw is measured to be longer, this can indicate the screw is in the neck or femoral head. Fluoroscopic guidance can be helpful in those cases.

Postoperatively, the patient is allowed to weight-bear 50% for 6 weeks until radiographic healing is present. Screws are removed after 3 months. The second-stage THR was conducted not earlier than 3 months following the RFNL procedure.

All THRs (n = 20) were performed through a direct anterior approach (DAA) with the patient in supine position on a regular surgical table [14,15]. A Pinnacle (n = 19) or Bantam (n = 1) socket (DePuy Synthes, Warsaw, IN) was used. A cementless (n = 16) or cemented (n = 4) Corail femoral stem with a Biolox Delta Ceramic head was used (DePuy Synthes, Warsaw, IN) (Fig. 2). Immediate weight-bearing with crutches for 1-2 weeks was allowed.

Radiological assessment

Radiographic evaluation was performed with supine anteroposterior pelvic radiographs. Radiographic parameters were measured by 2 authors (J.V. and J.D.). The mean measurement was used for analysis. Assessment was performed with OrthoView (Materialise, Leuven, Belgium), and a calibration marker was used to correct for magnification error.

The assessment of the biomechanical restoration was done according to the instructions presented in the study by Shohat et al. on preoperative and postoperative radiographs [16]. The articulo-trochanteric distance (ATD), the centro-trochanteric distance (CTD), and the lateral displacement of the GT (LDGT) were measured (Fig. 3). To evaluate leg length discrepancy, we measured the distance between the interteardrop line and the upper margin of the lesser trochanter [17].

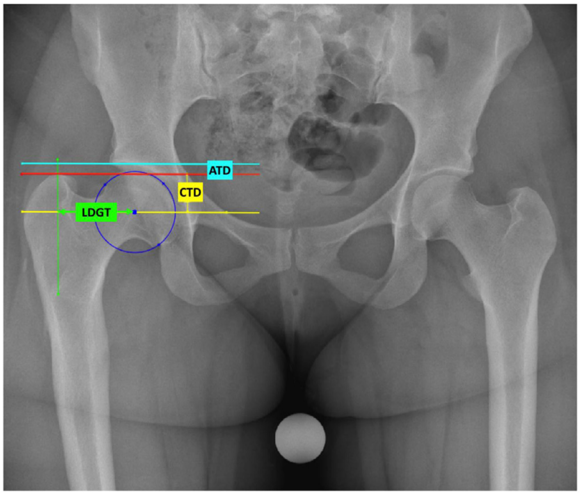

Figure 3. A schematic overview of the radiographic assessment of the biomechanical parameters [23]. First, a line parallel to the interteardrop line is drawn at the tip of the greater trochanter (red). Similarly, a line is drawn at the articular surface (cyan colored), and a line through the center of the femoral head (yellow). The articulo-trochanteric distance (ATD) (cyan) is defined as the perpendicular distance between the cyan and red line. A positive ATD means that the articular surface is proximal to the tip of the GT. A negative value means that the articular surface is below the GT. The centro-trochanteric distance (CTD) (yellow) is defined as the distance between the red and yellow line. A positive CTD indicates that the femoral head center is proximal to the tip of the GT. A negative CTD indicates that the center of the femoral head is below the GT. The lateral displacement of the greater trochanter (LDGT) (green) is the horizontal distance from the femoral head center to a vertical line starting at the tip of GT [23].

A femoral stem was considered to be in varus or valgus if the angle described by the intersection of the axis of the stem and the axis of the femoral shaft was >5° [18]. Non-union was defined as a persistent radiolucent line between the osteotomized fragment and trochanter or a migration of the fragment of ≥15 mm [19].

Outcomes

Outcome measures included patient-reported outcome measures (PROMs), complication rate, and reoperation rate. PROMs were obtained at the time of the patient's latest follow-up. These included the Harris Hip Score (HHS) [20], Hip Disability and Osteoarthritis Outcome Score (HOOS) [21], and 36-item Short Form Survey (SF-36) [22]. Preoperative values were retrieved from patient records. Length of follow-up was determined from the date of RFNL surgery until the last clinical follow-up.

The Clavien-Dindo classification was used to grade complications [23].

Statistical analysis

Statistical analysis was performed using SPSS v27 (IBM). Normal distribution of data was tested with the Kolmogorov-Smirnov test. For the radiological analysis, preoperative and postoperative values were compared using a paired samples t-test. A Fisher's exact test was used to compare categorical variables. A Mann-Whitney U test was used to compare continuous variables between these groups if there was no normal distribution of data, and an independent samples t-test was used if there was a normal distribution. A *P* value of <0.05 was considered significant.

Results

In total, 28 modified RFNL procedures were performed in 26 patients. Of these, 5 patients (6 hips, 21.4%) previously underwent a varus derotation osteotomy with a high-riding GT.

Eight patients (8 hips; 28.6%) have postponed the second-stage THR following the RFNL procedure. The mean follow-up of these patients was 4.2 ± 2.1 years.

Eighteen patients (20 hips; 71.4%) underwent the two-stage procedure, with a mean time of 14.7 ± 13.6 months between both procedures. The mean follow-up of patients that underwent THA was 3.9 ± 1.8 years. These patients were significantly older than those who postponed the second stage (41.0 ± 10.8 vs 30.8 ± 10.1; $P = .032$). Demographic details of the cohorts are outlined in Table 1.

Radiological results

Following RFNL, all biomechanical parameters changed significantly, as detailed in Table 2. The mean distal GT advancement after RFNL, as measured with the ATD and CTD, was 21.2 ± 7.5 mm and 20.6 ± 7.0 mm, respectively ($P < .001$). ATD (22.8 ± 10.4 mm) and CTD (1.9 ± 9.0 mm) values after RFNL were similar to those of the contralateral nonaffected hip, where a mean ATD of 22.4 ± 4.8 mm ($P = .8$) and a mean CTD of −2.6 ± 5.5 mm ($P = .5$) were measured. Following the THR, the mean CTD increased further to 11.4 ± 10.4

Table 1
Demographic and surgical data of the cohort.

Parameter	Whole cohort (n = 28)	RFNL group (n = 8)	RFNL + THR group (n = 20)	*P* value
Mean age @ RFNL, y ± SD (range)	38.1 ± 11.4 (16-58)	30.8 ± 10.1 (18-48)	41.0 ± 10.8 (16-58)	.032[b]
Mean age @ THR, y ± SD (range)	41.8 ± 10.6 (18-59)	-	41.8 ± 10.6 (18-59)	-
Gender				.6[c]
Male (n, %)	10 (35.7)	3 (37.5)	7 (35.0)	
Female (n, %)	18 (64.3)	5 (62.5)	13 (65.0)	
Mean follow-up, y ± SD (range)	4.0 ± 1.8 (1.9-8.7)	4.2 ± 2.1 (2.0-6.6)	3.9 ± 1.8 (1.9 ± 8.7)	.8[b]
Comorbidities				.5[c]
Obesity (BMI > 30), n (%)	2 (7.1)	-	2 (10.0)	
Cerebral palsy	1 (3.6%)	-	1 (5.0%)	
Ehlers-Danlos	1 (3.6%)	-	1 (5.0%)	
Achondroplasia	1 (3.6%)	-	1 (5.0%)	.5[c]
Previous hip surgery				
PAO, n (%)	3 (10.7)	1 (12.5)	2 (10.0)	.7[c]
Shelf, n (%)	3 (10.7)	1 (12.5)	2 (10.0)	.7[c]
VDRO, n (%)	6 (21.4)	1 (12.5)	5 (25.0)	.6[c]

VDRO, varus derotation osteotomy; PAO, periacetabular osteotomy.
[b] Independent samples t-test.
[c] Fisher's exact test.

Table 2
Radiological parameters preoperatively, after relative femoral neck lengthening, and after total hip replacement.

Parameters	Preoperative	After RFNL	P value[e]	After THR	P value[f]
ATD (mm ± SD)	1.5 ± 9.7	22.8 ± 10.4	<.001	-	-
CTD (mm ± SD)	−18.7 ± 6.7	1.9 ± 9.0	<.001	11.4 ± 10.4	<0.001
LDGT (mm ± SD)	34.2 ± 8.1	42.4 ± 5.2	<.001	49.9 ± 8.3	<0.001
LLD[d] (mm ± SD)	17.5 ± 10.5	-	-	2.7 ± 2.2	<0.001

[d] Leg length difference (LLD; positive value means short in comparison to unaffected side).
[e] Paired samples t-test comparing preoperative values and post-RFNL values.
[f] Paired samples t-test comparing post-RFNL values and post-THR values.

mm. The mean lateral advancement changed significantly by 7.2 ± 4.7 mm. After THR, the LDGT increased further to 49.9 ± 8.3 mm compared with the preoperative status ($P < .001$). LDGT of the contralateral hip measured 47.7 ± 6.7 mm ($P = .1$.) Leg length difference decreased from 17.5 ± 10.5 mm preoperatively to 2.7 ± 2.2 mm at the latest follow-up ($P < .001$). All patients had a final leg length difference ≤ 5 mm compared with that in the contralateral side.

All femoral stems were normally aligned without any radiographic sign of loosening at the latest follow-up.

Complications and reoperations

As summarized in Table 3, a total of 9 complications were identified in 9 hips (32.1%). Of these, 6 (21.4%) were Clavien-Dindo grade 1 complications, that is, asymptomatic Brooker type 1 (n = 4) or 2 (n = 2) heterotopic ossifications. There were 3 grade 3 complications requiring revision surgery (10.7%). Two (7.1%) patients with severe end-stage osteoarthritis required revision for GT nonunion following the RFNL procedure. They required revision with an iliac wing autologous bone graft and Acutrak screw fixation (Acumed, Remscheid, Germany). The GT healed within 3 months. One patient (5.0%) developed a deep infection after the second-stage THR. She underwent a two-stage revision THR.

There was no significant difference in complication rate between the group of patients who underwent RFNL and patients who underwent both RFNL and THR ($P = .2$).

Patient-reported outcome

PROM scores (preoperative and postoperative HHS) were available for 23 hips (82.1%), 6 in the RFNL group (75.0%) and 17 in the RFNL + THR group (85.0%). Preoperative HHS increased from a mean of 56.9 ± 17.6 points to 89.4 ± 10.7 at the latest follow-up ($P < .001$). Only postoperative values were available for HOOS and SF-36. Final PROM scores did not differ significantly between patients who underwent RFNL and patients who underwent RFNL and THR ($P > .05$) (Table 4).

Discussion

THR in patients with Legg-Calvé-Perthes deformities can be a challenging procedure due to the distorted anatomy of the hip. One might have difficulties with coaxial femoral stem placement because of overgrowth of the GT, regardless of the utilized surgical approach. Malalignment can detrimentally affect intermediate to long-term outcomes of THR [24]. The proposed 2-stage procedure can be a solution to this problem because none of the stems were malaligned, and all showed normal radiographic signs of ingrowth. Furthermore, the prominent overhanging GT might be a cause of postoperative extra-articular impingement, which could be a risk factor for dislocation or refractive groin pain [4]. In addition, a regular stem needs a good seating at the level of the calcar in order to reliably obtain good ingrowth. However, in LCPD, this can lead to a situation where the center of rotation is lower than the tip of the high-riding trochanter. As a result, surgeons often need to lengthen the leg, or modular implants with more distal fixation should be used. This can be challenging in these young patients with an often-narrow femoral canal. With the proposed 2-stage procedure, we were able to offset the abovementioned problems and utilize regular implants without risking extra-articular bony impingement.

RFNL in combination with open osteochondroplasty is a hip-preservation technique described to treat intra- and extra-articular impingement in patients with a history of LCPD [16,25,26]. Albers et al. have shown that the proportion of hips with a normal abductor strength improved from 17% to 91% after RFNL [25]. The improvement of abduction force is likely the result of the improved trochanteric height, resulting in a longer abductor lever arm. Other studies have suggested that the lever arm is mainly influenced by the LDGT [27]. In our study, we obtained a significant increase of both distal and LDGT. This also bears biomechanical advantages with improved joint loading [28]. Furthermore, we also believe that this improved loading allowed 8 of our patients to postpone the second-stage THR. Although these patients had cartilage degeneration and understood that the RFNL was a procedure in preparation of the second-stage THR, they were at an acceptable functional level. These patients remain in regular follow-up at our clinic.

The DAA for THR is becoming more popular with presumed advantages such as utilizing an intermuscular interval with enhanced recovery and low dislocation rates [29]. However, the DAA is also associated with technical difficulties, particularly on the femoral side [30]. The proposed 2-stage treatment can be used with

Table 3
Complications and reoperations for the whole cohort and each subgroup separately.

Parameter	Whole cohort (n = 28)	RFNL group (n = 8)	RFNL + THR group (n = 20)	P value[a]
Complications grade I				.4
Asymptomatic HO, n (%)	6 (21.4)	1 (12.5)	5 (25.0)	
Complications grade II	-	-	-	.5
Complications grade III				.7
Non-union GT, n (%)	2 (7.1)	-	2 (10.0)	
Deep infection, n (%)	1 (3.6)	-	1 (5.0)	
Complications grade IV	-	-	-	
Complications grade V	-	-	-	
Reoperations				
Revision RFNL, n (%)	2 (7.1)	-	2 (10.0)	.5
Revision THR, n (%)	-	-	1 (5.0)	-

HO, heterotopic ossification.
[a] Fisher's exact test.

Table 4
Patient-reported outcome measures at the latest follow-up for each subgroup separately.

	RFNL group (n = 6)	RFNL + THR group (n = 18)	P value[a]
HHS	87.7 ± 9.0	90.1 ± 11.4	.4
HOOS symptoms	77.5 ± 15.7	84.7 ± 14.3	.3
HOOS pain	80.9 ± 15.1	89.6 ± 10.5	.2
HOOS ADL	89.5 ± 10.1	89.1 ± 12.1	1.0
HOOS sports	69.9 ± 24.3	67.3 ± 27.5	1.0
HOOS QoL	60.5 + 18.8	71.7 ± 20.3	.3
Mean SF-36	87.6 ± 10.3	83.2 ± 15.6	.5

ADL, activities for daily living; QoL, quality of life.
[a] Mann-Whitney U test.

any surgical approach for THR but allows to easily conduct the DAA. By reducing trochanter volume, the proximal femur can easily be elevated beyond the posterior acetabular rim. In addition to the distal advancement of the overhanging GT, this ensures a straight and safe access to the femoral canal.

We acknowledge that this 2-stage treatment requires multiple procedures. In addition, the relative lengthening procedure can be technically demanding. However, in this young patient population, it can be beneficial to restore native biomechanics prior to “regular” component placement through a relatively straightforward surgical approach. The first goal was to improve biomechanics by advancing the GT and increasing abductor lever arm. Second, we aimed to facilitate femoral stem placement. Third, we aimed to avoid intraoperative and postoperative complications and the need for modular stem placement. Our clinical improvement was comparable to that in other studies reporting on THR in patients with sequelae of LCPD. A systematic review by Hanna et al. included six studies with similar improvement in clinical outcome scores [1]. A relatively high number of complications associated with femoral stem placement were reported in these studies (11% intraoperative fracture and 5% aseptic loosening) [1]. We report no femoral component malpositioning or periprosthetic fractures. However, we encountered complications associated with the learning curve of the procedure, such as a non-union of the GT (7.1%), which was solved with the use of different screws (Acutrak screws), allowing improved compression at the osteotomy site [17]. We report one deep infection (3.6%) in a patient, after which we adjusted our protocol and removed the screws in a separate intervention, instead of during THA. There was a relatively high incidence of heterotopic ossifications in our study cohort (25.0%), which is probably the consequence of the different surgical interventions. The high incidence of previous surgical interventions in this cohort also induces a higher risk of complications. More research is needed to compare the RFNL and THA as a staged procedure with a single procedure to reduce complications rate.

This study has some limitations. It is a retrospective review of a small cohort, and there was a lack of complete preoperative clinical PROMs data. For patients treated before 2017, only the HHS was preoperatively available. This occurred as we changed our follow-up protocol to include HOOS and SF-36. Second, the mean follow-up was 3.9 ± 1.8 years. Longer follow-up would be necessary to evaluate the long-term results. Third, assessment of abductor strength would have been appropriate to evaluate improvement of abductor muscle strength before and after RFNL. Finally, there is no comparison with patients with similar LCPD deformities undergoing only THR without RFNL.

Conclusions

RFNL prior to THR in patients with end-stage osteoarthritis following LCPD allows for utilizing regular implants with straight access to the femoral canal, with restored biomechanics and restoration of leg length.

Conflicts of interest

K. Corten receives royalties from, is in the speakers' bureau of or gave paid presentations for, and is a paid consultant for DePuy Synthes and MedEnvision and has stock or stock options in MedEnvision. R. Driesen is in the speakers' bureau of or gave paid presentations for Zimmer Biomet.

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