



## Original research

# Total hip arthroplasty with rectangular stems and subtrochanteric transverse shortening osteotomy in Crowe type IV hips: a retrospective study

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## ABSTRACT

**Background:** The complexity of femoral and acetabular anatomy and restoring anatomic center of hip rotation in Crowe type IV developmental dysplasia of the hip (DDH) complicates standard reconstruction. The aim of this study is to evaluate surgical techniques and clinical outcomes of subtrochanteric transverse shortening osteotomy with the use of cementless rectangular cross-section femoral implants in Crowe IV dysplastic hips.

**Methods:** A total of 26 hips of 25 consecutive patients with Crowe type IV DDH who underwent cementless total hip arthroplasty with subtrochanteric femoral transverse shortening osteotomy were retrospectively analyzed. The Harris Hip Score, Visual Analog Scale-pain, leg length discrepancy, and vertical and lateral migration of hip rotation center were recorded.

**Results:** Mean age, follow-up, and time of union were  $41 \pm 9.7$  years,  $7.1 \pm 1.2$  years, and  $3.7 \pm 1.1$  months, respectively. Mean Harris Hip Score significantly improved from  $38 \pm 5.7$  to  $86 \pm 6.1$  points post-operatively ( $P < .01$ ). Mean leg length discrepancy and Visual Analog Scale significantly decreased from  $4.3 \pm 1.3$  to  $1.2 \pm 0.6$  cm, and  $6.4 \pm 1.2$  to  $1.8 \pm 0.8$  points, respectively ( $P < .01$ ). One female patient had a dislocation due to acetabular liner wear, which was managed by liner and head change. One patient had Sudeck's atrophy, while another had pain on the lateral thigh, both of which were resolved with conservative management.

**Conclusions:** Combined transverse subtrochanteric femoral osteotomy and cementless total hip arthroplasty with rectangular cross-section femoral implants is technically demanding, effective, and safe in femoral shortening for treatment of Crowe type IV DDH.

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## Introduction

Management of adult Crowe type 4 developmental dysplasia of the hip (DDH) from childhood to adulthood has been a complex issue in terms of hip-preserving modalities or total hip arthroplasty (THA) for orthopaedic surgeons [1]. In addition, previous surgeries

such as Schanz osteotomy or periacetabular osteotomies have increased the complexity of further interventions. The most important step to achieve the normal or near-normal hip biomechanics has been suggested as transferring the hip joint center into the true acetabulum. In this context, acetabular cup placement in its true location is essential to prevent the increase in hip load and get better anatomical joint center, neck angle, offset, lever arm, range of motion, and reactive forces for longer hip arthroplasty survival [1,2]. On the femoral side, shortening is required for anatomic placement of the implants and to avoid neurovascular complications [3]. However, major complications include nonunion and unstable stem fixation after osteotomy of a small and anteverted femur [4]. Different types of osteotomies and femoral stem

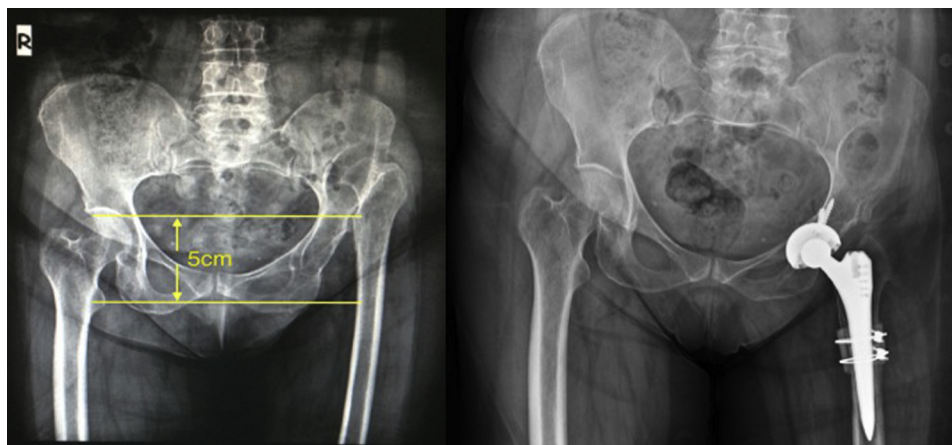
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**Figure 1.** Preoperative leg length discrepancy on pelvic radiography with a distance between lesser trochanters and postoperative radiograph of the same patient.

designs including cylindrical, conical, and special design (tapered) are used to overcome these problems.

Subtrochanteric osteotomies can be performed with various techniques, such as transverse, oblique, Z-shaped, and chevron-shaped, each of which have their own advantages and disadvantages [5–7]. The transverse type of bone cutting is a simple and effective technique with similar rotational stability compared to other types of osteotomies [5]. In addition, Krych et al [8] described their surgical technique for THA and fixed the transverse osteotomy site with split intercalary osteotomized bone obtained from the shortened distal fragment. Later on, Altay et al [9] used this fixation technique and reported that it provided initial intraoperative stability and promoted early bone healing. Gaining initial and secondary stability is critical to achieve clinical success of a hip stem implant [10]. Although higher union rates of osteotomy sites and longer survival rates have been reported with cylindrical and conical stems in several studies [11–14], highly successful outcomes have been obtained using tapered stems in relatively smaller series and short follow-up periods without any complication [1,8,15]. The latest generation of the rectangular cross-section tapered (ie, Zweymüller) femoral stems gain initial stability both axially and rotationally [1,2,16]. The initial stability ensures that osseointegration is possible leading to long-term secondary fixation and stability [10]. In addition, Zweymüller stem grit blasted surface enhances osseointegration and rapid secondary stability without the risk of coating delamination [15], and longer term results with Zweymüller stem have shown excellent secondary stability with high rates of radiographic osseointegration [1,6].

In the present study, we aimed to evaluate the surgical technique and clinical outcomes of subtrochanteric transverse shortening osteotomy and onlay split intercalary autograft with the use of cementless rectangular cross-section femoral implants in Crowe IV dysplastic hips.

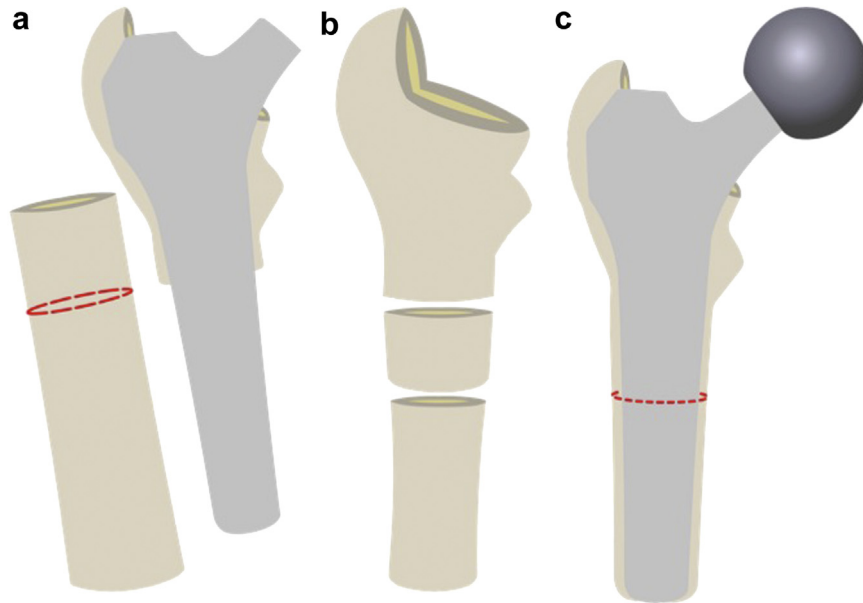
## Material and methods

A total of 26 hips of 25 consecutive patients with Crowe type IV DDH who underwent cementless THA with subtrochanteric femoral transverse shortening osteotomy between April 2005 and July 2013 were retrospectively analyzed. Patients with previous pelvic/femoral osteotomies were excluded. A written informed consent was obtained from each patient. The study protocol was approved by the Institutional Review Board. The study was conducted in accordance with the principles of the Declaration of Helsinki.

All patients were carefully examined preoperatively and at follow-up visits postoperatively. The Harris Hip Score (HHS) and Visual Analog Scale (VAS)-pain were used for the clinical preoperative and postoperative evaluation [8]. The final score ranges from 0 to 100 points in HHS and it is classified as excellent (between 90 and 100), good (80 to 90), fair (70 to 79), and poor (<70). In VAS, the final score ranges from 0 to 10, and as the score decreases, the pain severity is considered diminished. The presence of a Trendelenburg's sign was also recorded. Furthermore, the mean preoperative leg length discrepancy (LLD) was calculated measuring the anterior superior iliac spine to the medial malleolus (true measurement). Preoperative LLD was also calculated with a radiographic technique based on the measurement between the lesser trochanters, while it was calculated from the acetabular teardrop to the lesser trochanter postoperatively (Fig. 1). Standard anteroposterior and lateral hip radiographs in preoperative and postoperative assessments were obtained. Thereafter, change in the vertical and lateral migration of center of the anatomical hip rotation was measured on anteroposterior radiograph by considering the vertical distance from the hip rotation center to a line drawn through the distal edge of the teardrop, and for lateral distance a horizontal line drawn from the teardrop center to the hip rotation center. Femoral and acetabular templates were applied on hip and pelvis radiographs to estimate the component sizes to be used in surgery. Radiographic analysis of the prosthesis was performed according to DeLee and Charnley [17] classification for the acetabulum and Gruen et al [18] method for the femur postoperatively.

**Table 1**  
Properties of prosthetic implants.

	Number of hips (n = 26)
Stem type	
SL-Plus (Smith & Nephew Inc., Memphis, TN)	26
Stem size	
01 (128-mm length)	8
0 (132-mm length)	12
1 (136-mm length)	6
Cup type	
EP-Fit Plus REXPOL (Smith & Nephew Inc.)	26
Cup diameter (mm)	
40	16
42	10
Femoral head diameter (mm)	
22	26
Bearing surface	
Metal-on-polyethylene	26



**Figure 2.** Illustration of (a) transverse subtrochanteric osteotomy level, (b) the amount of resected bone fragment by measuring with the overlapping maneuver, and (c) stable construct with the implant.

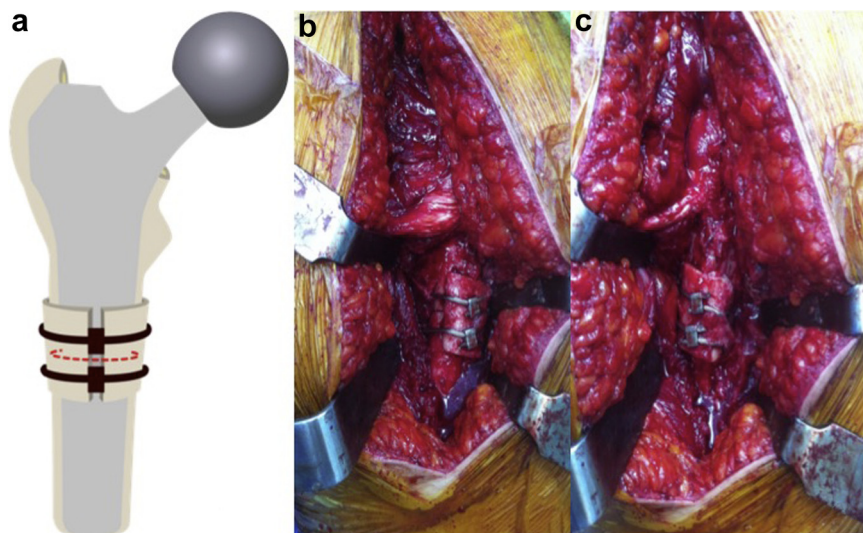
The bone union at the osteotomy site was defined as the image of callus formation on follow-up radiographs throughout the entire gap.

All cementless acetabular components were placed in native acetabulum and anatomical center of hip rotation was restored. Cementless press-fit Zweymüller dual-tapered rectangular stems (SL-Plus; Smith & Nephew Inc., Memphis, TN) were used in all patients for the femoral fixation, thus securing initial axial positioning and rotational stability with 4 corners embedding into the endosteal bone. Properties of the prosthetic implants are presented in [Table 1](#).

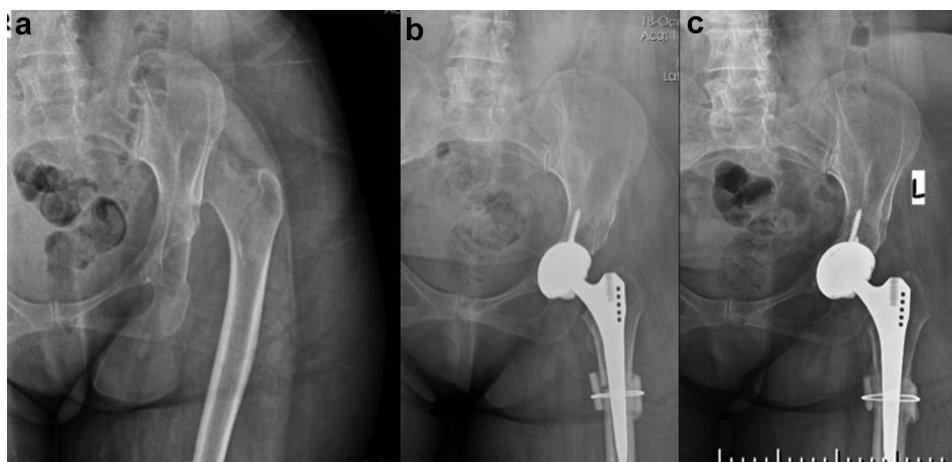
#### *Surgical technique*

Operations were performed in the lateral decubitus position with a posterolateral incision. The piriformis, short external

rotators, and quadratus femoris tendons were tenotomized at their insertion onto the greater trochanter. They are then tagged with a braided two No. 2 ETHIBOND EXCEL (Ethicon EMEA, Johnson & Johnson N.V., Belgium) sutures for identification and repair at the end of the procedure. The posterior joint capsule was exposed and then resected, the femoral head was dislocated, and the neck was osteotomized. Dissection of the inferior part of the elongated capsule allowed the exposure of the true acetabulum which was, then, cleared of soft tissues. The acetabulum was deepened posteromedially as much as possible to reach the medial inner cortex using the reamer. The acetabular component was impacted carefully to prevent a fracture of the thin acetabular wall. Also, we attempted to obtain an adequate hemispherical coverage. No augmentation was needed for the superior coverage of the acetabular component. Two screws were used for each acetabular component. After the acetabular component was fixed, the



**Figure 3.** (a) Illustration of the bone fragments wrapped around the osteotomy site by 2 cables and (b and c) intraoperative view of the resected bone wrapped around the osteotomy site.



**Figure 4.** (a) Preoperative and (b) early postoperative and (c) 3-mo radiographies of a DDH type IV patient. Bone union was observed at 3 mo of follow-up.

rasping of the femoral canal was started and continued to rasp with the Zweymüller trial stem, until the maximum cortical contact was reached. The torque test using the broach handle was performed to assess the stability, and intraoperative imaging was performed to confirm the appropriate femoral implant size. Also, a longitudinal line along the anterolateral femoral metadiaphysis was marked by electrocautery prior to osteotomy to determine the rotation after implantation. After removing the final rasp, a transverse osteotomy was performed 2–3 cm below the lesser trochanter (Fig. 2). The final rasp was reinserted to the proximal femoral fragment and reduced into the acetabular component. This maneuver was done to decide the amount of distal resection according to the overlapping of the distal femoral fragment on the proximal fragment with the hip reduced and femoral rasp seated in the proximal femoral fragment. The overlapping femoral segment was, then, resected by a second transverse osteotomy. While performing osteotomy, intermittent saline solution irrigation was applied to oscillating blades to avoid thermal injury to the bone. After placing prophylactic cerclage wires, intramedullary reaming was performed again to prepare the distal femoral canal and estimate the optimal size and rotation of the distal part of the femoral implant. During femoral rasping, the rotational alignment of both the proximal and the distal fragment was adjusted to allow approximately 10°–15° of anteversion of the femoral component. After compression of the osteotomy site was obtained with the femoral rasp, the femur was reduced to check the rotational and implant stability. The resected bone was divided into 2 parts in the midline. Once the femoral stem was fixed, resected bony fragments were wrapped around the osteotomy site and secured with one or the 2 titanium cerclage wires (Fig. 3). Intraoperative radiograph was repeated, following the definitive implantation of the stem (Fig. 4).

**Table 2**  
Demographic and clinical characteristics of patients.

	Mean (range) or n (%)
Gender	
Female	18 (72%)
Male	7 (28%)
Affected side	
Right	10
Left	14
Bilateral	1
Follow-up (y)	7.1 ± 1.2
Age (y)	41 ± 9.7

In total, 40- to 42-mm acetabular cups and 01 to 1 size femoral stems were used in all patients. Furthermore, 22-mm cobalt chromium femoral head sizes were used according to the acetabular size (Table 1). We were unable to use another head size or material other than cobalt chromium due to the available options supplied by the manufacturer. No rings or reconstruction cages were needed. Anterior soft tissue release was performed only in 2 patients to relieve anterior tension.

The patients were mobilized on the first postoperative day with partial weight-bearing and were allowed partial weight-bearing for 6 weeks postoperatively. Weight-bearing was increased carefully depending on the consolidation of the osteotomy site, and full weight-bearing was often permitted at 6-week follow-up visit, according to the radiographic consolidation of the osteotomy site.

#### Statistical analysis

Statistical analysis was performed using the IBM SPSS for Mac version 23.0 software (IBM Corporation, Armonk, NY). Descriptive data were expressed in mean ± standard deviation and number and frequency. The 2-tailed Wilcoxon signed-rank test for paired samples was used to compare preoperative and postoperative HHS and VAS scores, and vertical and lateral migration of the hip rotation center. A *P* value of <.05 was considered statistically significant.

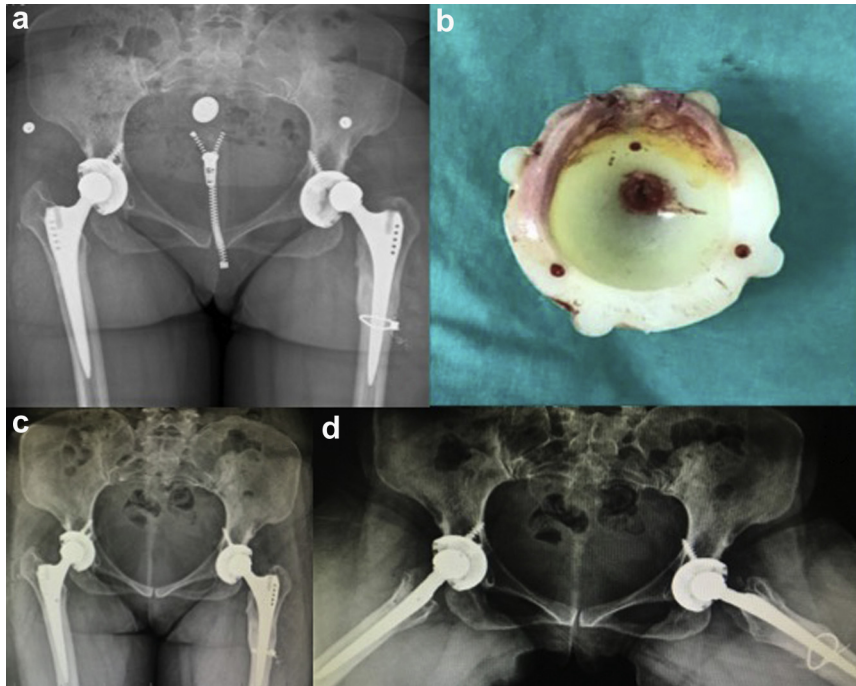
#### Results

Of the patients, 18 were females and 7 were males with a mean age of 41 ± 9.7 years. Bilateral THA was performed in 1 patient in 2 stages. The mean follow-up was 7.1 ± 1.2 years. Demographic and

**Table 3**  
Clinical and radiographic outcomes of patients.

	Preoperative (mean, average) (range)	Postoperative (mean, average) (range)	<i>P</i> value
Migration of hip rotation center (cm)			
Vertical (radiographic)	6.8 ± 2.1	1.5 ± 0.6	<.001
Lateral (radiographic)	3.5 ± 1.1	1.2 ± 0.3	<.001
HHS	38 ± 5.7	86 ± 6.1	<.001
VAS	6.4 ± 1.2	1.8 ± 0.8	<.001
Clinical LLD	4.3 ± 1.3	1.2 ± 0.6	<.001





**Figure 5.** A 40-year-old female patient with bilateral THA with subtrochanteric shortening osteotomy due to bilateral Crowe type IV DDH. (a) Left hip dislocation after 7 y, (b) due to acetabular liner wear, and (c and d) treated by acetabular liner and head change.

clinical characteristics of patients are shown in [Table 2](#). The mean operation time was  $100 \pm 22$  minutes. The mean time to union of the osteotomy site was  $3.7 \pm 1.1$  months. All osteotomy sites were eventually united. The mean preoperative HHS was  $38 \pm 5.7$ , while the mean postoperative HHS was  $86 \pm 6.1$  at final follow-up ( $P < .01$ ). The mean preoperative VAS scores were  $6.4 \pm 1.2$ , while the mean postoperative VAS scores were  $1.8 \pm 0.8$  at 6 months ( $P < .01$ ). The mean vertical and lateral migration of center of the anatomical hip rotation was decreased from  $6.8 \pm 2.1$  to  $1.5 \pm 0.6$  and  $3.5 \pm 1.1$  to  $1.2 \pm 0.3$ , respectively ( $P < .01$ ). Although all patients had a positive Trendelenburg's sign preoperatively, only 2 of them had a positive Trendelenburg's sign at 6 months and disappeared at 1 year. The mean clinical LLD decreased from  $4.3 \pm 1.3$  cm before surgery to  $1.2 \pm 0.6$  cm at the postoperative follow-up ( $P < .01$ ). The vertical and lateral migration of the hip rotation center reduced postoperatively ([Table 3](#)).

All hips were radiographically classified as Crowe type 4 high dislocations. The mean length of bone removed by femoral shortening osteotomy was  $3 \pm 0.4$  cm. All components showed bony ingrowth on radiographs without any radiolucency, loosening, or migration.

None of the patients experienced any intraoperative complications. One female patient had a dislocation due to acetabular liner wear after 7 years, which was managed by liner and head change ([Fig. 5](#)). One patient had pain on the lateral site of the femur where the cerclage wires applied after 5 years were then removed. One patient had Sudeck's atrophy with severe pain restricting rehabilitation at 1 month after surgery which resolved after 3-week physiotherapy. There was no infection, heterotopic ossification, deep venous thromboses, or sciatic palsy during the follow-up period. No patient was lost to follow-up.

## Discussion

In the present study, we evaluated the mid-term results of a shortening transverse subtrochanteric femoral osteotomy and

cementless THA with rectangular cross-section stems for treatment of Crowe type IV hips. One dislocation was revised due to severe wear of acetabular liner at 7 years, and 1 lateral thigh pain case was managed with removal of cerclage wire. Overall, our results included a mean 7.1-year survival rate of 96%. Clinical outcomes were excellent with a mean postoperative HHS and VAS of 86 and 1.8, respectively. This clinical score improvement is consistent in most recent studies with transverse subtrochanteric shortening osteotomy on THA for Crowe type IV hips [[9,14,19-21](#)].

Several methods have been described for femoral shortening osteotomy in Crowe type IV hips, including proximal femoral metaphyseal osteotomy with a greater trochanteric osteotomy and distal advancement, step-cut metaphyseal osteotomy, oblique metaphyseal osteotomy, V-shaped derotational osteotomy and proximal femoral shaft splitting, and distal femoral osteotomy [[12,22-24](#)]. However, these osteotomy procedures are complex and somewhat technically demanding [[25,26](#)]. Compared to these osteotomies, transverse osteotomy, which was performed in our series, has some advantages such as technical simplicity in terms of the osteotomy technique, adjusting the anteversion angle and minimal periosteal damage at the osteotomy site, and preserving the proximal femoral metaphysis [[27,28](#)]. However, transverse subtrochanteric shortening osteotomy has several potential complications such as osteotomy site nonunion and instability due to limited bony contact area and lack of inherent rotational stability [[6,29](#)]. Reikerås et al [[30](#)] reported that osteotomy site nonunions are caused by insufficient rotational stability of THA associated with transverse osteotomy. On the other hand, regarding osteotomy types, Muratli et al [[5](#)] reported a comparative biomechanical study and found that there was no inherent feature increasing the stability of the osteotomy types. In a meta-analysis, Li et al [[31](#)] demonstrated no significant difference between the transverse and modified techniques regarding complications and survival rate. In addition, autogenous bone graft and cerclage wires were applied in the current study to enhance the rotational stability and accelerate bone healing [[32](#)]; thus, all femoral osteotomies were healed,

**Table 4**

Overview of relevant literature in the treatment of Crowe type 4 hip dysplasia combined with subtrochanteric transverse femoral shortening osteotomy.

Study	Published year	Hips (n)	Osteotomy type	Augmentation	Stem type	Mean follow-up (y)	Union rate (%)	Preoperative function score	Postoperative function score	Results/complications	Survival (%)	Comments
Kenichi et al [33]	2013	34	Transverse	Structural autograft fixed with poly-L-lactic acid screws	Cemented HS 32 N narrow stem	5.2	100	JOA: 50.2 ROM: 93.1°	JOA: 84.6 ROM: 93.6°	3 dislocations	100	Subtrochanteric osteotomy combined with cemented THA is safe and reliable
Li et al [32]	2016	21	9 oblique, 12 transverse	1 oblique osteotomy fixed with allograft struts and cables	Cementless modular (S-ROM; DePuy)	4.1	100	HHS: 30.6	HHS: 91.2	1 deep vein thrombosis, 1 intraoperative fracture, 2 dislocations	100	Recommend the combined use of the subtrochanteric oblique osteotomy and the S-ROM stem
Park et al [23]	2007	24	Transverse	Morselized autogenous graft and resected femoral fragments with cable fixation	Cementless 7 tapered (BiContact, Duofit, C2), 14 modular (S-ROM; DePuy), 3 distal fix revisions (Lima)	4.7	88	HHS: 35.6	HHS: 81.7	3 intraoperative proximal femur fractures, 3 nonunions, 1 dislocation	83	
Reikeraas et al [34]	1996	25	Transverse	No augmentation	4 cemented, 21 cementless (Harris-Galante; Landos Corail)	3-7	100	HHS: 43	HHS: 93	1 sciatic palsy, 1 delayed union, 1 malunion	100	
Altay et al [9]	2018	41	Transverse	Intercalary cortical bone graft	Cementless and distally fluted Secur-Fit Plus (Stryker)	2.83	100	HHS: 47.7	HHS: 88	3 dislocations, 1 heterotopic ossification	100	
Togrul et al [35]	2010	21	Transverse	Endosteal bone pegs	10 cementless porous-coated (Synergy), 11 hydroxyapatite-coated (Secur-Fit)	3.43	100	MAP Pain: 2.9 MAP ROM: 4.4 MAP Walking: 3.7	MAP Pain: 5.2 MAP ROM: 5.4 MAP Walking: 5.5	2 early dislocations	100	Bone pegs should be added to osteotomy
Wang et al [36]	2017	76	Transverse	Autogenous cancellous bone graft from the resected femoral bone with 2 cables	Cementless modular (S-ROM)	10	98	HHS: 38.8 MAP: 6.7	HHS: 86.1 MAP: 15.9	3 dislocations, 2 transient nerve palsies, 1 nonunion, 4 intraoperative fractures, 2 moderate limps	98	Stable fixation of cementless implant is required
Ollivier et al [19]	2016	28	27 transverse, 1 step-cut	Cortical strut grafts	Cementless porous-coated modular	10	93	HHS: 43	HHS: 87	5 intraoperative femoral fractures, 3 dislocations, 2 nonunions	82	Durable and reliable results can be obtained with cementless modular stems
Shang et al [37]	2016	17	Transverse	N/A	Cementless (Zweymüller)	2.75	100	HHS: 34.0 ± 6.5 Pain: 15.7 ± 6.5 Function: 15.0 ± 3.8 Deformity: 1.4 ± 0.7 ROM: 1.4 ± 0.7	HHS: 85.0 ± 7.3 Pain: 39.0 ± 5.6 Function: 37.2 ± 9.8 Deformity: 3.2 ± 0.5 ROM: 3.5 ± 0.6	2 sciatic nerve injuries	100	Adequate soft tissue release and avoid over lengthening of the nerve
Mu et al [6]	2016	71		No augmentation	Cementless dual-tapered	5.88	97	HHS: 35.6	HHS: 82.9	19 intraoperative femoral fractures, 6 femoral nerve	91.4	Zweymüller implants are good options in DDH

(continued on next page)

Table 4 (continued)

Study	Published year	Hips (n)	Osteotomy type	Augmentation	Stem type	Mean follow-up (y)	Union rate (%)	Preoperative function score	Postoperative function score	Results/complications	Survival (%)	Comments
Zhu et al [20]	2015	21	61 transverse, 10 no osteotomy Transverse	Prophylactic cable fixation	rectangular (SL-Plus) Cementless nonmodular Wagner cone (Zimmer)	3.33	95	HHS: 52.4 ± 6.8	HHS: 90.5 ± 15.1	injuries, 2 sciatic nerve injuries, 2 dislocations 1 delayed union, 3 sciatic nerve injuries, 1 stem loosening	95	with antitorsional stability and low price Compared with modular prostheses and custom-made prostheses, the nonmodular conical stem obviated the complexities, high medical cost, and potential risk at the neck-stem interface
Hua et al [38]	2015	24	Transverse	Bone grafting and cable fixation	Cementless HA coated	3.5	100	HHS: 47.5 ± 8.7	HHS: 88.5 ± 3.1	3 trochanteric fractures, 1 sciatic nerve palsy	100	
Oinuma et al [39]	2014	12	8 transverse, 4 oblique	Morselized autogenous graft and resected femoral fragments with cable fixation	Cementless (8 S-ROM and 4 BiContact)	3.7	100	MAP: 9.2 (7-13)	MAP: 17 (16-18)	4 severe limps, 1 dislocation	100	
Yalcin et al [40]	2010	44	Transverse	Low contact plates and screws in 10 hips	Cementless standard stem	5.1	88	HHS: 36.2	HHS: 81.2	5 nonunions, 2 dislocations, 1 acetabular component displacement, 2 superficial infections	88	Torsional stability may be augmented with a plate and screws
Akiyama et al [41]	2011	15	Transverse	Intercalary cortical bone graft	Cemented stem	3-10	80	MAP: 8.1 ± 2.5	MAP: 15.1 ± 1.3	3 nonunions, 1 delayed union	80	An adequate intercalary cortical bone graft is needed to prevent nonunion
This study	2019	26	Transverse	Autogenous corticocancellous bone graft from the resected femoral bone with cables	Cementless Zweymüller dual-tapered stem (SL-Plus; Smith & Nephew)	7.1	100	HHS: 38 VAS: 6.4	HHS: 86 VAS: 1.8	1 Sudeck's atrophy, 1 dislocation	100	

JOA, The Japanese Orthopedic Association Hip Score, MAP, Merle d'Aubigné and Postel Score; ROM, range of motion; N/A, not applicable.

In the abovementioned studies, totally 484 hips were treated with transverse osteotomy, the average union rate was 96.1%, and the average stem survival rate was 89.2%.

and no nonunion or prosthesis instability was found at a mean of 7.1 years (Table 4). All patients showed successful autograft fusion which was found consistent with the studies of Muratli et al [5] and Li et al [31].

Furthermore, more satisfying results can be achieved by using the stems to eliminate the bending forces to the osteotomy site. The proper stem should also be placed tightly into the medullary canal [6,10]. Although S-ROM (modular cylindrical) stems are widely used owing to easy adjustment of the femoral anteversion with more satisfactory results [42], monoblock conical and tapered stems are not inferior to S-ROM regarding rigid fixation of the osteotomy site by eliminating the bending forces and providing easy anteversion in the femoral canal [6,36]. In addition, tapered femoral implants such as Zweymüller stems deliver stress from proximal to distal gradually; thus, stress shielding is not a common phenomenon except for zones 1 and 7 [43]. In our series, we selected Zweymüller dual-tapered implants for the reconstructions, intraoperative femoral fracture was not seen, and antirotational stability was achieved with the press-fit rectangular-shaped geometry.

The intraoperative femoral fracture rate during the femoral stem insertion has been reported to vary between 5.2% and 27.8% with cementless stems in Crowe type IV DDH, the main cause of fracture is tight impaction of the prosthesis into the medullary canal [6,19,23,36]. Intraoperative femoral fractures have been reported with Zweymüller stems, in particular, as they are fairly large proximally and have sharp edges. Perka et al [44] treated 121 dysplastic hips with Zweymüller prostheses and reported an 8% incidence of femoral fracture. Mu et al [6] reported 19 femoral fractures intraoperatively and 1 acetabular fracture with an incidence of 28%. In this series, we have not encountered any femoral fracture with Zweymüller stems during or after the procedure.

In a study by Little et al [45], the mean acetabular liner wear of 0.12 mm/y for <45° and 0.18 mm/y for >45° of cup inclination was reported. They also concluded that an increase in the acetabular cup inclination angle may lead to an increase in contact stress at the superior aspect of the polyethylene liner, thus resulting in further liner wear [45]. In our study, we encountered 1 hip dislocation due to severe wear of the polyethylene liner at the superior aspect, which was attributed to a cup inclination of >50°. On the contrary, encountering this complication in postoperative year 7 may be an advantage of smaller head size implantation [46].

In some studies, it has been reported nerve palsy has occurred after 3 cm, 4 cm, 5 cm, or 10% of femoral lengthening after THA in Type IV DDH [47–49]. According to Higuchi et al [48], leg lengthening greater than 5 cm was found to be a risk factor for sciatic nerve injury. On the other hand, Kerboull et al [50] showed that maximum leg lengthening regarding THA for Crowe type IV hips is 7 cm in a long-term study. However, there is no consensus on the maximum safe amount of limb lengthening to prevent significant sciatic nerve injury. We believe that the possible maximum range of limb lengthening depends on the length of the nerve and the anatomy. In our study, sciatic nerve tension and course was assessed by palpation intraoperatively after hip reduction. The mean leg lengthening was less than 4 cm and none of the patients had permanent or transient sciatic nerve injury following surgery.

Furthermore, the Trendelenburg's sign is an expected finding following THA in Crowe type IV hips, which is considered positive if the iliac crest is higher on the supported side. This is due to shortened and weakened hip abductors and previous pelvic/femoral osteotomies. Incidence in published literature ranges from 20% to 70% [50]. We observed the Trendelenburg's sign in 2 of the patients (7%), far lower than the rates reported in the literature, and the sign was no longer evident at 1 year in our 2 patients.

Nonetheless, there are some limitations to our study. First, we retrospectively evaluated the patients, which brings the possibility of selection bias, and there was no control group, thus limiting the strength of the current analysis. Second, this cohort was the set of consecutive patient series from a single surgeon in the second decade of his practice and a highly specific patient group. Third, the study population was also small due to the low incidence of Crowe type IV DDH. A larger sample size might be better for finding the prevalence of complications related to transverse subtrochanteric shortening osteotomy and rectangular cross-section femoral stem. Finally, the mean follow-up period of this study is 7 years, which may be relatively short for a primary arthroplasty series; therefore, further studies are needed to elucidate the long-term outcomes of this technique.

## Conclusions

In conclusion, our study results suggest that THA in combination with transverse subtrochanteric osteotomy and press-fit rectangular cross-section cementless stem can yield promising mid-term results in terms of the type of osteotomy, femoral stem, and their relationship, if it remains faithful to the surgical technique of stabilizing the osteotomy site. However, we recommend large-scale and long-term, prospective, clinical studies to confirm the efficacy and safety of this technique.

## References

- [1] Neumann D, Thaler C, Dorn U. Femoral shortening and cementless arthroplasty in Crowe type 4 congenital dislocation of the hip. *Int Orthop* 2012;36:499.
- [2] Ozden VE, Dikmen G, Beksac B, Tozun IR. Tapered stems one-third proximally coated have higher complication rates than cylindrical two-third coated stems in patients with high hip dislocation undergoing total hip arthroplasty with step-cut shortening osteotomy. *Orthop Traumatol Surg Res* 2017;103:569.
- [3] Cameron HU, Eren OT, Solomon M. Nerve injury in the prosthetic management of the dysplastic hip. *Orthopedics* 1998;21:980.
- [4] Migaud H, Putman S, Berton C, et al. Does prior conservative surgery affect survivorship and functional outcome in total hip arthroplasty for congenital dislocation of the hip? A case-control study in 159 hips. *Orthop Traumatol Surg Res* 2014;100:733.
- [5] Muratli KS, Karatosun V, Uzun B, Celik S. Subtrochanteric shortening in total hip arthroplasty: biomechanical comparison of four techniques. *J Arthroplasty* 2014;29:836.
- [6] Mu W, Yang D, Xu B, Mamtimin A, Guo W, Cao L. Midterm outcome of cementless total hip arthroplasty in Crowe IV-Hartofilakidis type III developmental dysplasia of the hip. *J Arthroplasty* 2016;31:668.
- [7] Bao N, Meng J, Zhou L, Guo T, Zeng X, Zhao J. Lesser trochanteric osteotomy in total hip arthroplasty for treating CROWE type IV developmental dysplasia of hip. *Int Orthop* 2013;37(3):385.
- [8] Krych AJ, Howard JL, Trousdale RT, Cabanela ME, Berry DJ. Total hip arthroplasty with shortening subtrochanteric osteotomy in Crowe type-IV developmental dysplasia: surgical technique. *J Bone Joint Surg Am* 2010;92:176.
- [9] Altay M, Demirkale İ, Çatma MF, Şeşen H, Ünlü S, Karaduman M. Results of Crowe type IV developmental dysplasia of hip treated by subtrochanteric osteotomy and total hip arthroplasty. *Indian J Orthop* 2018;52:374.
- [10] Karuppall R. Biological fixation of total hip arthroplasty: facts and factors. *J Orthop* 2016;13(3):190.
- [11] Mutlu T, Çiçek H, Yalçın N, Kiliçarslan K, Tuhanioğlu Ü. How do different designs of femoral stem affect total hip arthroplasty applied to Crowe type III and type IV dysplastic hips. *Hip Int* 2016;26:374.
- [12] Sun QC, Wang XH, Song BS, Zhu FB, Yan SG. [Total hip arthroplasty for Crowe type IV developmental dysplasia of the hip with S-ROM prosthesis]. *Zhongguo Gu Shang* 2013;26:153 [in Chinese].
- [13] Mu Jung J, Sang Kim C. Analysis of stress distribution around total hip stems custom-designed for the standardized Asian femur configuration. *Biotechnol Biotechnol Equip* 2014;28:525.
- [14] Grappiolo G, La Camera F, Della Rocca A, Mazziotta G, Santoro G, Loppini M. Total hip arthroplasty with a monoblock conical stem and subtrochanteric transverse shortening osteotomy in Crowe type IV dysplastic hips. *Int Orthop* 2019;43:77.
- [15] Delaunay C, Bonnomet F, North J, Jobard D, Cazeau C, Kempf JF. Grit-blasted titanium femoral stem in cementless primary total hip arthroplasty: a 5- to 10-year multicenter study. *J Arthroplasty* 2001;16:47.
- [16] Erdemli B, Yilmaz C, Atalar H, Güzel B, Cetin I. Total hip arthroplasty in developmental high dislocation of the hip. *J Arthroplasty* 2005;20:1021.



- [17] DeLee JG, Charnley J. Radiological demarcation of cemented sockets in total hip replacement. *Clin Orthop Relat Res* 1976;121:20.
- [18] Gruen TA, McNeice GM, Amstutz HC. "Modes of failure" of cemented stem-type femoral components: a radiographic analysis of loosening. *Clin Orthop Relat Res* 1979;141:17.
- [19] Ollivier M, Abdel MP, Krych AJ, Trousdale RT, Berry DJ. Long-term results of total hip arthroplasty with shortening subtrochanteric osteotomy in Crowe IV developmental dysplasia. *J Arthroplasty* 2016;31:1756.
- [20] Zhu J, Shen C, Chen X, Cui Y, Peng J, Cai G. Total hip arthroplasty with a non-modular conical stem and transverse subtrochanteric osteotomy in treatment of high dislocated hips. *J Arthroplasty* 2015;30:611.
- [21] Sofu H, Kockara N, Gursu S, Issin A, Oner A, Sahin V. Transverse subtrochanteric shortening osteotomy during cementless total hip arthroplasty in Crowe type-III or IV developmental dysplasia. *J Arthroplasty* 2015;30(6):1019.
- [22] Bruce WJ, Rizkallah SM, Kwon YM, Goldberg JA, Walsh WR. A new technique of subtrochanteric shortening in total hip arthroplasty: surgical technique and results of 9 cases. *J Arthroplasty* 2000;15:617.
- [23] Park MS, Kim KH, Jeong WC. Transverse subtrochanteric shortening osteotomy in primary total hip arthroplasty for patients with severe hip developmental dysplasia. *J Arthroplasty* 2007;22:1031.
- [24] Sun JY, Wei L. Subtrochanteric shortening with overlapping femoral resection in total hip arthroplasty for Crowe type IV adult dislocation of the hip. *Orthop Surg* 2009;1:207.
- [25] Cascio BM, Thomas KA, Wilson SC. A mechanical comparison and review of transverse, step-cut, and sigmoid osteotomies. *Clin Orthop Relat Res* 2003;(411):296.
- [26] Tözün İR, Akgül T, Şensoy V, Kılıçoğlu Öİ. The results of monoblock stem with step-cut femoral shortening osteotomy for developmentally dislocated hips. *Hip Int* 2016;26(3):270.
- [27] Rollo G, Solarino G, Vicenti G, Picca G, Carrozzo M, Moretti B. Subtrochanteric femoral shortening osteotomy combined with cementless total hip replacement for Crowe type IV developmental dysplasia: a retrospective study. *J Orthop Traumatol* 2017;18:407.
- [28] Swanson TV. The tapered press fit total hip arthroplasty: a European alternative. *J Arthroplasty* 2005;20:63.
- [29] Çatma MF, Ünlü S, Öztürk A, Aksekili AM, Ersan Ö, Ateş Y. Femoral shortening osteotomy in total hip arthroplasty for severe dysplasia: a comparison of two fixation techniques. *Int Orthop* 2016;40(11):2271.
- [30] Reikerås O, Haaland JE, Lereim P. Femoral shortening in total hip arthroplasty for high developmental dysplasia of the hip. *Clin Orthop Relat Res* 2010;468(7):1949.
- [31] Li C, Zhang C, Zhang M, Ding Y. Comparison of transverse and modified subtrochanteric femoral shortening osteotomy in total hip arthroplasty for developmental dysplasia of hip: a meta-analysis. *BMC Musculoskelet Disord* 2014;15:331.
- [32] Apivatthakakul T, Phaliphot J, Leuvitoonvechkit S. Percutaneous cerclage wiring, does it disrupt femoral blood supply? A cadaveric injection study. *Injury* 2013;44(2):168.
- [33] Kenichi OE, Iida H, Nakamura T, Okamoto N, Wada T. Subtrochanteric shortening osteotomy combined with cemented total hip arthroplasty for Crowe group IV hips. *Arch Orthop Trauma Surg* 2013;133:1763.
- [34] Reikeraas O, Lereim P, Gabor I, Gunderson R, Bjerkreim I. Femoral shortening in total arthroplasty for completely dislocated hips: 3-7 year results in 25 cases. *Acta Orthop Scand* 1996;67:33.
- [35] Togrul E, Ozkan C, Kalaci A, Gülşen M. A new technique of subtrochanteric shortening in total hip replacement for Crowe type 3 to 4 dysplasia of the hip. *J Arthroplasty* 2010;25:465.
- [36] Wang D, Li LL, Wang HY, Pei FX, Zhou ZK. Long-term results of cementless total hip arthroplasty with subtrochanteric shortening osteotomy in Crowe type IV developmental dysplasia. *J Arthroplasty* 2017;32:1211.
- [37] Shang DC, Zhong SC, Zhang XZ, Lu DP, Liu QL. [Surgical treatment for osteoarthritis secondary to Crowe type IV developmental dysplasia of hip in adults]. *Zhongguo Gu Shang* 2016;29:125 [in Chinese].
- [38] Hua WB, Yang SH, Xu WH, et al. Total hip arthroplasty with subtrochanteric femoral shortening osteotomy for high hip dislocation. *Orthop Surg* 2015;7:112.
- [39] Oinuma K, Tamaki T, Miura Y, Kaneyama R, Shiratsuchi H. Total hip arthroplasty with subtrochanteric shortening osteotomy for Crowe grade 4 dysplasia using the direct anterior approach. *J Arthroplasty* 2014;29:626.
- [40] Yalcin N, Kilicarslan K, Karatas F, Mutlu T, Yildirim H. Cementless total hip arthroplasty with subtrochanteric transverse shortening osteotomy for severely dysplastic or dislocated hips. *Hip Int* 2010;20:87.
- [41] Akiyama H, Kawanabe K, Yamamoto K, et al. Cemented total hip arthroplasty with subtrochanteric femoral shortening transverse osteotomy for severely dislocated hips: outcome with a 3- to 10-year follow-up period. *J Orthop Sci* 2011;16:270.
- [42] Li L, Yu M, Yang C, Gu G. Total hip arthroplasty (S-ROM stem) and subtrochanteric osteotomy for Crowe type IV developmental dysplasia of the hip. *Indian J Orthop* 2016;50:195.
- [43] Zweymüller KA, Schwarzingler UM, Steindl MS. Radiolucent lines and osteolysis along tapered straight cementless titanium hip stems: a comparison of 6-year and 10-year follow-up results in 95 patients. *Acta Orthop* 2006;77:871.
- [44] Perka C, Fischer U, Taylor WR, Matziolis G. Developmental hip dysplasia treated with total hip arthroplasty with a straight stem and a threaded cup. *J Bone Joint Surg Am* 2004;86-A:312.
- [45] Little NJ, Busch CA, Gallagher JA, Rorabeck CH, Bourne RB. Acetabular polyethylene wear and acetabular inclination and femoral offset. *Clin Orthop Relat Res* 2009;467(11):2895.
- [46] Tsikandylakis G, Mohaddes M, Cnudde P, Eskelinen A, Kärrholm, Rolfson O. Head size in primary total hip arthroplasty. *EFORT Open Rev* 2018;3(5):225.
- [47] Nercessian OA, Macaulay W, Stinchfield FE. Peripheral neuropathies following total hip arthroplasty. *J Arthroplasty* 1994;9:645.
- [48] Higuchi Y, Hasegawa Y, Ishiguro N. Leg lengthening of more than 5 cm is a risk factor for sciatic nerve injury after total hip arthroplasty for adult hip dislocation. *Nagoya J Med Sci* 2015;77:455.
- [49] Kerboull M, Hamadouche M, Kerboull L. Total hip arthroplasty for Crowe type IV developmental hip dysplasia: a long-term follow-up study. *J Arthroplasty* 2001;16:170.
- [50] Wang S, Zhou Y, Ma H, Du Y, Piao S, Wu W. Mid-term results of total hip replacement with subtrochanteric osteotomy, modular stem, and ceramic surface in Crowe IV hip dysplasia. *Arthroplast Today* 2017;4:363.