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Original article

Is step-cut shortening osteotomy a better choice than transverse osteotomy for total hip arthroplasty for Crowe type III-IV hip dysplasia?

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ABSTRACT

Introduction: Total hip arthroplasty for developmental hip dysplasia is a challenging surgery due to anatomic abnormalities. Crowe III and Crowe IV hip dysplasia generally necessitates a subtrochanteric shortening osteotomy. Transverse and step-cut osteotomy are the most common procedures for shortening of femur although there is still no consensus which one is a superior method. The objective of this study was to demonstrate whether transverse or step-cut osteotomy is superior in hips who undergo arthroplasty for high riding hip dysplasia.
Hypothesis: Our hypothesis was that higher rates of union would be achieved in patients with Crowe III-IV hip dysplasia when the step-cut osteotomy was performed compared to transverse osteotomies.
Material and methods: A total of 99 hips from 90 patients (9 bilateral, 81 unilateral; 79 female, 11 male), each with a minimum follow-up duration of two years, were included in this study. The hips were classified as Crowe III ($n = 16$) or IV ($n = 83$). All hips were implanted cementless. Transverse or step-cut osteotomy was chosen for osteotomy type. The clinical and functional outcomes were assessed using the Harris Hip Score (HHS), limb length discrepancy (LLD), and limping. The complications and management of these were noted. The union rates were compared between osteotomy types.
Results: The mean age at surgery was 48.8 (range, 21–79 years). The follow-up period was 64.3 months in average (range, 24 to 192 months). The mean Harris Hip Score before surgery was 35.6 (range, 18–50), and increased to 88.1 (range, 61–98) points at the most recent follow-up. The preoperative leg length discrepancy (LLD) measured 5.3 cm (with a range of 3 to 6.8), while the postoperative LLD reduced to 0.8 cm (with a range of 0 to 1.6). There were a total of 38 complications in 35 patients out of 99 cases, resulting in a complication rate of 38.4%. The most frequent complication observed was intraoperative femoral fractures, occurring in 13 cases. Residual limping was seen in 73.7% of all. Step-cut osteotomy was performed in 64 hips (35 CDH stem [Zimmer Biomet, Warsaw, IN, USA], 29 Wagner Cone stem [Zimmer Biomet, Warsaw, IN, USA]) and, transverse in 35 hips (22 CDH, 13 Wagner Cone). Six hips had nonunion problem and all of them were operated with a step-cut osteotomy (z-score: −7.12 and $p < 0.00001$, Mann-Whitney U Test).
Conclusion: Transverse osteotomy may be a better option while performing a shortening subtrochanteric level osteotomy for total hip arthroplasty for Crowe III-IV hips.
Level of evidence: Level III; observational retrospective cohort study.

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1. Introduction

Total hip arthroplasty is the preferred treatment method for secondary osteoarthrosis in Crowe type III and IV adult dysplastic hips. However, these hips present many technical challenges due to long-lasting abnormalities of both the femur and acetabulum and it may be necessary to address problems both intraoperatively and postoperatively. Complications are more frequent compared to simple total hip arthroplasties. The most common complications include limb length discrepancy (LLD), sciatic nerve palsy, nonunion, intraoperative and postoperative fractures, infection, heterotopic ossification, and dislocation [1]. Dysplastic femurs typically exhibit a narrower canal, shorter femoral necks, a posteriorly positioned greater trochanter, thin cortices resulting from a lack of stress remodeling, and excessive femoral anteversion [2,3]. Moreover, the soft tissue around the hip joint is extremely contracted and abductor muscle group is less effective due to chronic dislocation. The current recommendation for acetabular reconstruction for the increased longevity and durability of total hip arthroplasty is to reconstruct the hip center anatomically in the true acetabulum which is shallower and has bone stock deficiency especially in the anterolateral aspect [4,5]. However, moving the hip center into the true acetabulum may pose the risk of excessive limb lengthening and iatrogenic nerve injury when the increase in lengthening exceeds 4 cm [6].

Subtrochanteric femoral shortening osteotomy (STO) is necessary to avoid these neurovascular risks and facilitate easier reduction in most of the cases. The most feared and major complication is nonunion in this osteotomy [7]. Nonunion rates of up to 20% have been reported in the literature [8]. Various types of STO have been described and proposed to overcome this issue and reduce the risks over time: transverse, step-cut, oblique, chevron, Z-shaped [9–11]. Although each method has its own advantages and disadvantages, there is no consensus in the literature regarding the preference for a specific method. Transverse osteotomy is a more practical method technically, also permits intraoperative derotation and adjustment, but is criticised to be inherently unstable in rotation [12]. Step-cut osteotomy is technically demanding, time-consuming, complex, but due to the high torsional stability and possessing more contact surface area of the osteotomized surfaces, it is considered that the probability of femoral union is higher with that technique [13,14].

In this retrospective study, we aimed to review the challenges and complications encountered during 99 cementless total hip arthroplasties combined with transverse or step-cut shortening osteotomies performed for Crowe III and IV dysplastic hips. We also examined how we managed these cases, the outcomes and the union rate after the STO, with a minimum 2-year follow-up period. Our hypothesis was that higher union rates would be achieved in patients when the step-cut osteotomy method was preferred during surgery.

2. Material and methods

This retrospective observational study was approved by the local ethics committee. The surgeries were performed by three different surgeons between 2007 and 2019. The preoperative X-rays of the hips of the patients who underwent cementless total hip arthroplasty were evaluated and if the hips were classified as Crowe type III or IV, they were included in this study. The patients who had less than a two-year follow-up were excluded. All the hips required either transverse or step-cut subtrochanteric shortening osteotomy (STO). One of the senior surgeons (DG) performed transverse osteotomies while the other two seniors (ME, NS) applied step-cut STO based on their surgical experience and preference. The indications for arthroplasty were pain, functional impairment uncontrolled by conservative management, severe limping, and stiffness.

Table 1
Baseline parameters.

Demographic data Parameter	
Age	48.8 (21–79)
No. of hips	99
Gender	
Male	11
Female	79
Side	
Right	50
Left	49
Follow-up (months)	64.3 (24–192)
Shortening osteotomy	
Step-cut	64 (35 CDH, 29 Wagner Cone)
Transverse	35 (22 CDH, 13 Wagner Cone)
Approach	
Posterolateral	43
Lateral	56
Crowe type	
III	16
IV	83
Stem type	
I (CDH)	57
II (Wagner Cone)	42

2.1. Patient population

A total of 126 hips were assessed for eligibility in this study. All 87 hips classified as Crowe IV underwent STO. However, it was observed that STO was not performed in 23 out of 39 hips classified as Crowe III. Four Crowe IV hips were lost to follow-up before six months. Consequently, these 27 hips were excluded from the study. The remaining 99 hips of 90 patients (9 bilateral, 81 unilateral; 79 female, 11 male) were included in this study (Fig. 1). Bilateral hip surgeries were staged with at least three months interval in between. One patient had Schanz valgus osteotomy previously before hip arthroplasty. The demographic data of the patients are presented in Table 1.

All acetabulums were implanted using Trilogy IT acetabular shell (Zimmer Biomet, Warsaw, IN, USA). All femoral stems were cementless, and two types of femoral stems were applied based on the surgeon's experience and preference: (I) proximal fixation straight CDH stems ($n = 57$) (Congenital Dysplastic Hip) (Zimmer Biomet, Warsaw, IN, USA) and (II) diaphyseal fixation cylindrical Wagner Cone Prosthesis™ stems ($n = 42$) (Zimmer Biomet, Warsaw, IN, USA).

2.2. Surgical technique

A percutaneous adductor tenotomy ($n = 21$) was performed to release excessive adductor contracture if it was deemed necessary in the supine position before the patient was positioned into the lateral decubitus. The posterolateral surgical approach was utilised in 43 surgeries and the direct lateral Hardinge approach in 56 surgeries. The incision was extended distally along the femur for the STO. The femoral neck was resected, the femoral canal was reamed and rasped sequentially according to the preferred femoral stem. Traction was applied to the femur with the rasp in the canal in a caudal direction and it was determined whether a shortening osteotomy was needed in Crowe III hips. If needed, iliopsoas tenotomy ($n = 11$) was added. The proximal limb of the STO (transverse or step-cut depending on the choice of the surgeon) was applied 1–2 cm distal to trochanter minor (Figs. 2 and 3). The

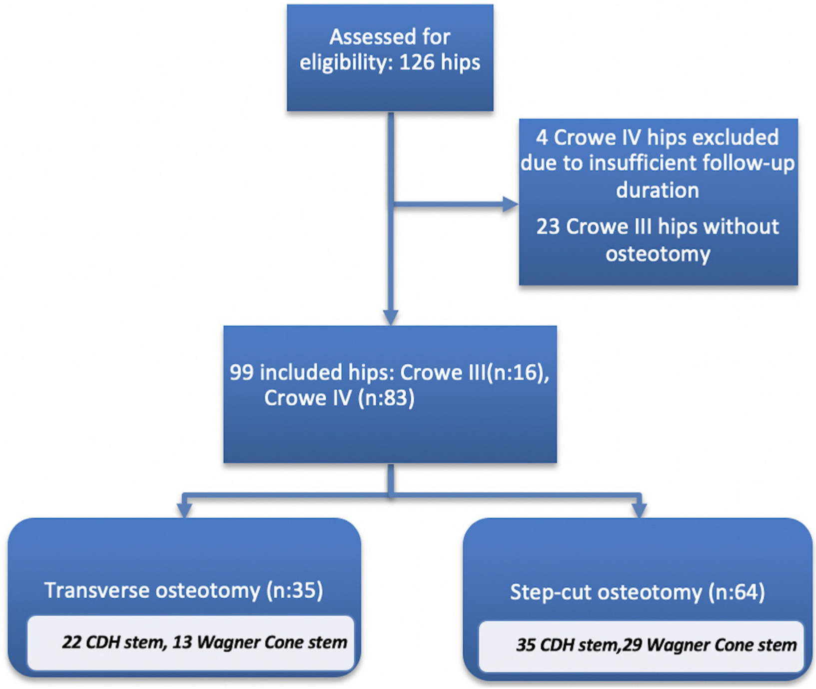

Fig. 1. The consort diagram of the study.

proximal femoral fragment was distracted proximally for acetabular exposure. True shallow acetabulum was found by the guidance of the capsule and ligamentum teres. The medial protrusio technique which requires deeper reaming of the medial and posterior acetabulum as described by Dorr et al. was preferred for increasing the coverage of the acetabular component without acetabular bone grafting [15]. The porous cementless acetabular cup was then installed in the true acetabulum with the support of augmentation screws in each hip. The trial femoral stem was inserted into the proximal fragment and a trial hip reduction was applied. Then, the tensor fascia lata muscle was assessed for tightness and pie-crusted if there was any flexion contracture or tightness. The amount of overlapped femoral stem and distal femur was determined and the amount length of overlapping bone (2–5 cm) was excised. The distal femur was under reamed with a straight reamer again to prevent a mismatch between proximal and distal femoral medulla. The original stem was inserted into the femur making sure that there was no gap in the osteotomy site. The tension of the sciatic nerve was palpated during the surgery. The intercalary excised segment was divided into two pieces and wrapped medially and laterally around the osteotomized site using two or three cables as strut autografts ($n = 98$). If the osteotomy site was determined unstable in rotation or for preventing proximal femur fragment escape, a mini plate-screw system could be added ($n = 1$).

2.3. Postoperative protocol

Active range of motion hip and knee exercises were initiated on the first postoperative day. The patients were allowed to toe-touch weight bearing with a walking aid the next day following the arthroplasty. The patients were routinely followed up at 2 weeks, 6 weeks, 3 months, 6 months, the end of year one postoperatively and annually thereafter. The clinical and functional outcomes were evaluated through Harris Hip Score (HHS) [16]. Limb length discrepancy (LLD) and limping was noted both preoperatively and postoperatively. The radiological assessment was done with pelvis anteroposterior and true lateral view of the affected hip roentgenograms in each visit. The patients were allowed to fully weight bear approximately at 6–8 weeks depending on the union of osteotomy area. The union was assessed with Masonis criteria [17]. Absence of enough callus and bone bridge on at least 3 of 4 cortices around the osteotomy site defined a nonunion if seen for longer than six months after the index surgery.

The complications were noted if there was any. Complications were grouped into three groups: intraoperative, early postoperative (in the first month) and late complications (after first month). Fracture, nonunion, heterotopic ossification, infection, dislocation, femoral or acetabular failure, vessel injury, nerve injury were the defined complications.

2.4. Statistical analysis

The data from the patients was processed via Microsoft Excel 2019 spreadsheet (Microsoft Corp., Redmond, WA, USA) for statistical analysis. Descriptive analysis such as mean, range was obtained using the Excel sheet. Statistical significance was assumed at p-values of 0.5. Mann-Whitney U Test was used as non-parametric data to determine the association between femoral STO and complications. Spearman's correlation test (non-parametric) was used to assess the association between femoral stem type, age, Crowe type and complications.

3. Results

The mean age at surgery was 48.8 (range, 21–79 years). The follow-up period was 64.3 months in average (range, 24 to 192 months). Fifty of the hips had right-sided THA and the remaining 49 hips had left-sided THA. Crowe type was III and IV in 16 and 83 hips, respectively. Fifty-seven patients had straight type I stems and 42 patients had cylindrical type II stems. Step-cut STO was performed in 64 hips (35 type I stems, 29 type II stems) and, transverse STO in 35 hips (22 type I stems, 13 type II stems). Acetabular cup size was a mean of 46 mm and head size was mostly 28 and 32 mm. Baseline parameters are shown in Table 1.

The mean Harris Hip Score was 35.6 (range, 18–50) preoperatively and improved to 88.1 points at latest follow-up (range,

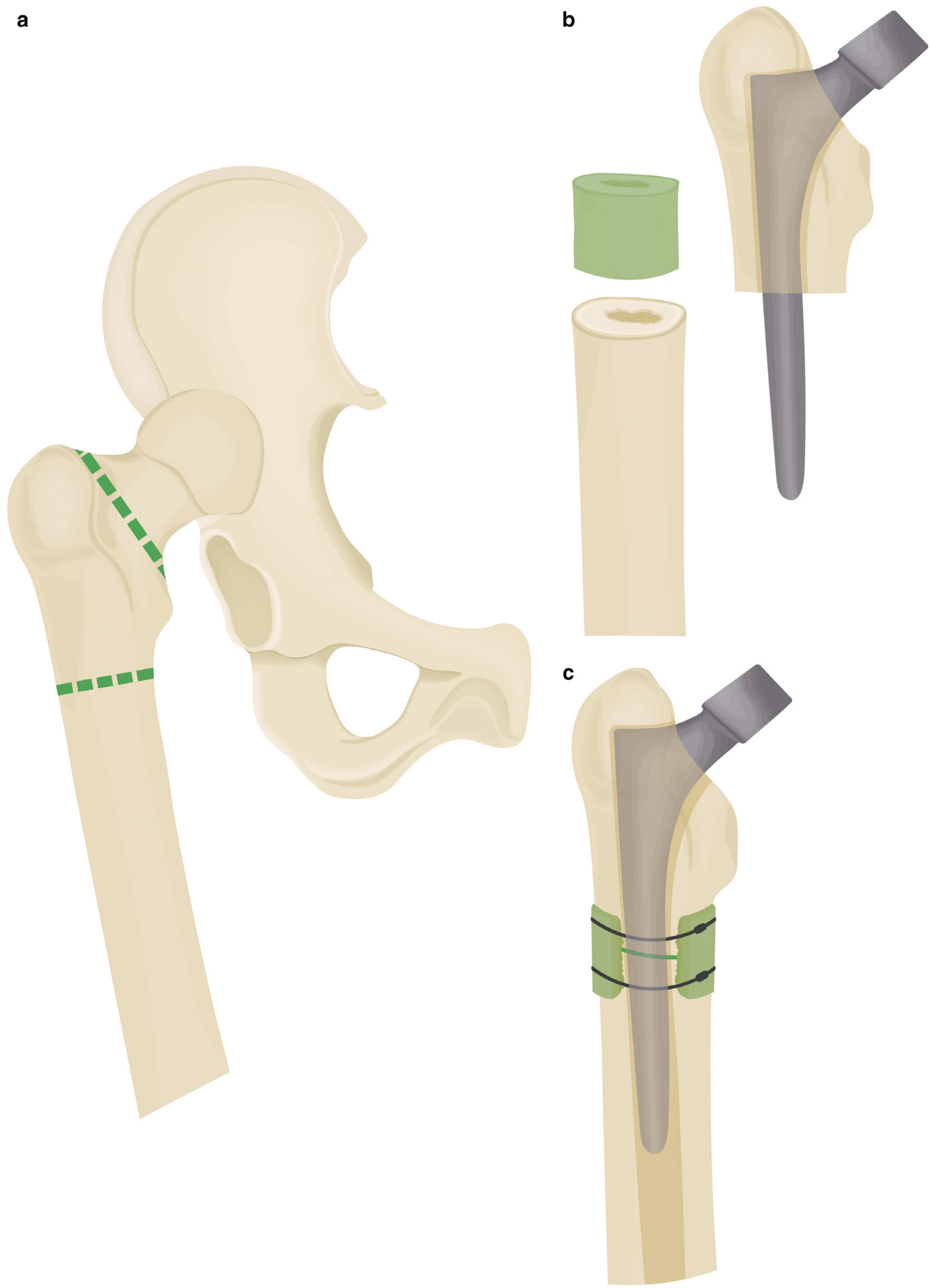

Fig. 2. The illustration of transverse shortening subtrochanteric osteotomy. a: Crowe IV hip dislocation; b: transverse osteotomy is done; c: after insertion of femoral stem and stabilisation with cables and autografts.

61–98). Preoperative LLD was 5.3 cm (range, 3–6.8) and 0.8 cm (range, 0–1.6) postoperatively. The mean amount of shortening with osteotomy was 3.3 cm (range, 2–5). The mean limb lengthening was measured as 3.2 cm (range 2.5–4.1). Moderate to severe limping was observed in all hips before the surgery. Twenty-six (26.3%) of those were limp free, 61 (61.6%) had slight limp and 12 (12.1%) had moderate limp postoperatively despite of significant improvement both clinically and radiologically at one year of follow-up.

3.1. Complications

The total complication rate was 38.4% (38 out of 99) in 35 patients. Complications are shown in Table 2.

3.2. Intraoperative complications

Most of the complications were observed intraoperatively. The most common intraoperative complication was 10 Vancouver type

Table 2
Complications.

Case	Osteotomy type	Stem type	Complication type	Management	Reoperation
Intraoperative complications					
No. 6	Step-cut	II	Vancouver type A fracture	Cable osteosynthesis	
No. 54	Transverse	II	Vancouver type A fracture	Cable osteosynthesis	
No. 52	Step-cut	I	Vancouver type A fracture	Trochanteric grip or plate and cable osteosynthesis	
No. 61	Step-cut	II	Vancouver type A fracture	Trochanteric grip or plate and cable osteosynthesis	
No. 71	Step-cut	I	Vancouver type A fracture	Trochanteric grip or plate and cable osteosynthesis	
No. 73	Step-cut	I	Vancouver type A fracture	Trochanteric grip or plate and cable osteosynthesis	
No. 76	Step-cut	I	Vancouver type A fracture	Trochanteric grip or plate and cable osteosynthesis	
No. 84	Step-cut	II	Vancouver type A fracture	Trochanteric grip or plate and cable osteosynthesis	
No. 109	Transverse	II	Vancouver type A fracture	Trochanteric grip or plate and cable osteosynthesis	
No. 115	Transverse	II	Vancouver type A fracture	Trochanteric grip or plate and cable osteosynthesis	
No. 70	Step-cut	I	Vancouver type B fracture	Plating	
No. 78	Step-cut	II	Vancouver type B fracture	Plating	
No. 120	Transverse	II	Vancouver type B fracture	Plating	
No. 50	Transverse	II	Proximal femoral escape	Plating	
No. 33	Step-cut	I	A. profunda femoris injury	Intraoperative repair of the vessel	
No. 79	Step-cut	I	Acetabulum posterior wall fracture (*previous Schanz osteotomy)	Plate osteosynthesis	Acetabulum revision (50 mm sized acetabulum, allograft femoral head to the medial side, cage, cemented dual mobility cup)
Early postoperative complications					
No. 4	Step-cut	I	Early dislocation	Closed reduction	Plating + strut graft for nonunion
No. 105	Transverse	II	Early dislocation	Closed reduction	
No. 22	Step-cut	I	Early dislocation	Open reduction	
No. 26	Step-cut	I	Early dislocation	Open reduction	
No. 87	Transverse	I	Early dislocation	Open reduction	
No. 36	Step-cut	II	Early dislocation	Open reduction (+4 mm femoral head change)	Early redislocation and acetabulum revision with highly crosslinked 20° liner
No. 47	Transverse	II	Early dislocation	Open reduction	Early redislocation and liner change (highly crosslinked 20° liner)
No. 101	Transverse	II	Early dislocation	Open reduction and acetabular component revision	
No. 83	Step-cut	II	Periprosthetic fracture in the second month	Plating with strut allograft	Debridement, liner change, IV antibiotherapy for acute periprosthetic joint infection
No. 91	Transverse	I	Central acetabular protrusion in the postoperative fifth day	Acetabular component revision, medial acetabular wall grafting with femoral head allograft	
No. 77	Step-cut	I	Acetabular failure in the second postoperative day	Revision with a acetabular cage and cemented all polyethylene liner	
No. 86	Transverse	I	Acetabular failure in the first week	Revision with a multihole acetabular cup	
No. 66	Step-cut	I	Sciatic nerve palsy	Conservative	
Late complications					
No. 2	Step-cut	I	Femoral nonunion	Plating + strut graft	
No. 4	Step-cut	I	Femoral nonunion	Plating + strut graft	
No. 66	Step-cut	I	Femoral nonunion	Plating + strut graft	
No. 76	Step-cut	I	Femoral nonunion	Plating + Fibula autograft	
No. 78	Step-cut	II	Femoral nonunion	Plating + Fibula autograft	
No. 98	Step-cut	I	Femoral nonunion	Femoral component revision + grafting + plating	
No. 55	Step-cut	II	Heterotopic ossification	Radiotherapy + Indometacin tb + Resection in the 18th month	
No. 96	Step-cut	I	Acetabular loosening in the third year after arthroplasty	Isolated acetabular revision	
No. 112	Transverse	II	Dislocation in the second year	Open reduction and liner change (highly crosslinked 20° liner)	

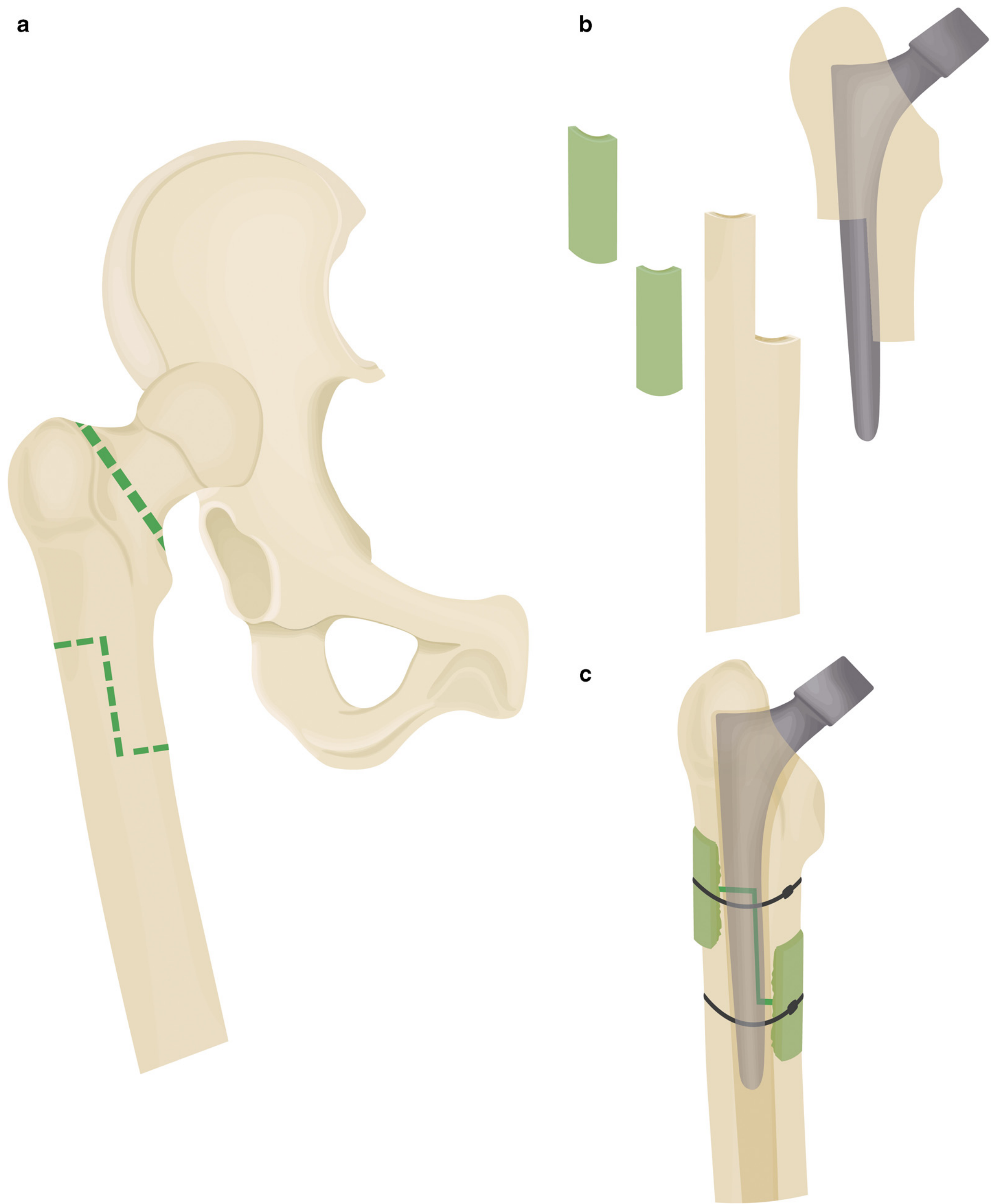

Fig. 3. The illustration of step-cut shortening subtrochanteric osteotomy. a: Crowe IV hip dislocation; b: step-cut osteotomy is done; c: after insertion of femoral stem and stabilisation with cables and autografts.

A femoral fractures proximal to the osteotomy site. Two of them were treated with cables alone, whereas a trochanteric grip or plate was combined with cables in 8 of those hips. Three patients had Vancouver type B femoral shaft fractures which extended distally and were localised below the osteotomy site and treated with locked plating. One hip with a transverse osteotomy had proximal femoral fragment escape due to abductor strength after femoral stem implantation and this issue was handled by improving the stability of the STO with additional plating (Fig. 4). One patient experienced a vascular injury when the arteria profunda femoris was iatrogenically injured and required repair by a cardiovascular surgeon intraoperatively.

One patient who was previously treated with Schanz osteotomy sustained an acetabular posterior wall fracture intraoperatively and necessitated osteosynthesis via plate and screws. However, an early failure of the cup was encountered in the postoperative 2nd day and further required acetabular revision surgery with medial femoral head allograft, cage and cemented dual mobility system.

3.3. Early complications

Eight patients had early dislocation. Closed reduction was performed in 2 hips and open reduction in 6 patients. One patient underwent revision surgery with a +4 mm femoral head. Another patient was revised for insufficient acetabular version with isolated acetabular component revision. After reduction, two patients experienced redislocation in the latter period. One of them was revised with acetabular component revision with highly crosslinked 20° liner. Acetabular liner was changed without acetabular revision in the other redislocated hip.

One patient had early periprosthetic Vancouver type B femoral shaft fracture and was treated with plating and strut grafting. The

Fig. 4. The transverse osteotomy and additional plating of a patient for preventing proximal femoral fragment escape. a: preoperative X-ray; b: early postoperative X-ray; c: union, X-rays in the ninth month after surgery.

same hip was also infected and treated with liner change, debridement and 6 weeks of antibiotherapy. Three patients had acetabular failure in the early postoperative period and were revised. One patient had temporary sciatic nerve palsy and fully recovered nerve function at the end of the 3rd month (Table 2).

3.4. Late complications

Six femoral osteotomies had nonunion problem. Bony union was obtained by plating and strut grafting in three cases (Fig. 5), by plating and fibular autografting in two cases (Fig. 6) and femoral stem revision in the last one. All nonunion cases united by 3.8 months (range, 3–6 months).

One patient had asymptomatic Brooker type II heterotopic ossification which was treated with radiotherapy, indometacin tablets and resection in the 18th month. One patient had acetabular loosening in the third postoperative year and the patient underwent a successful isolated acetabular revision surgery. One patient had late dislocation in the second postoperative year and liner change was performed in the open reduction surgery.

Nonunion rate was 6.06 (6 out of 99). Dislocation rate was 9.09 (9 out of 99), and femoral fracture rate was 13.13 (13 out of 99). One patient experienced both a dislocation and a nonunion (case No. 78), and 2 patients had both trochanteric fracture and osteotomy nonunion (case No. 4, case No. 66).

No statistically significant differences were observed in terms of complications or nonunion with respect to the type of femoral stem ($p > 0.05$). Similarly, no significant associations were found between age, Crowe type, and complications ($p > 0.05$) (Table 3).

There was no association between femoral head size and dislocation. One patient with head size of 22 did not have a hip dislocation. There were 5 dislocation cases with head size of 28 mm and 4 dislocations with head size of 32 mm. There was also no significant association between stem type and femoral fracture. There were 5 femoral fractures with type I stems and 8 fractures with type II stems intraoperatively.

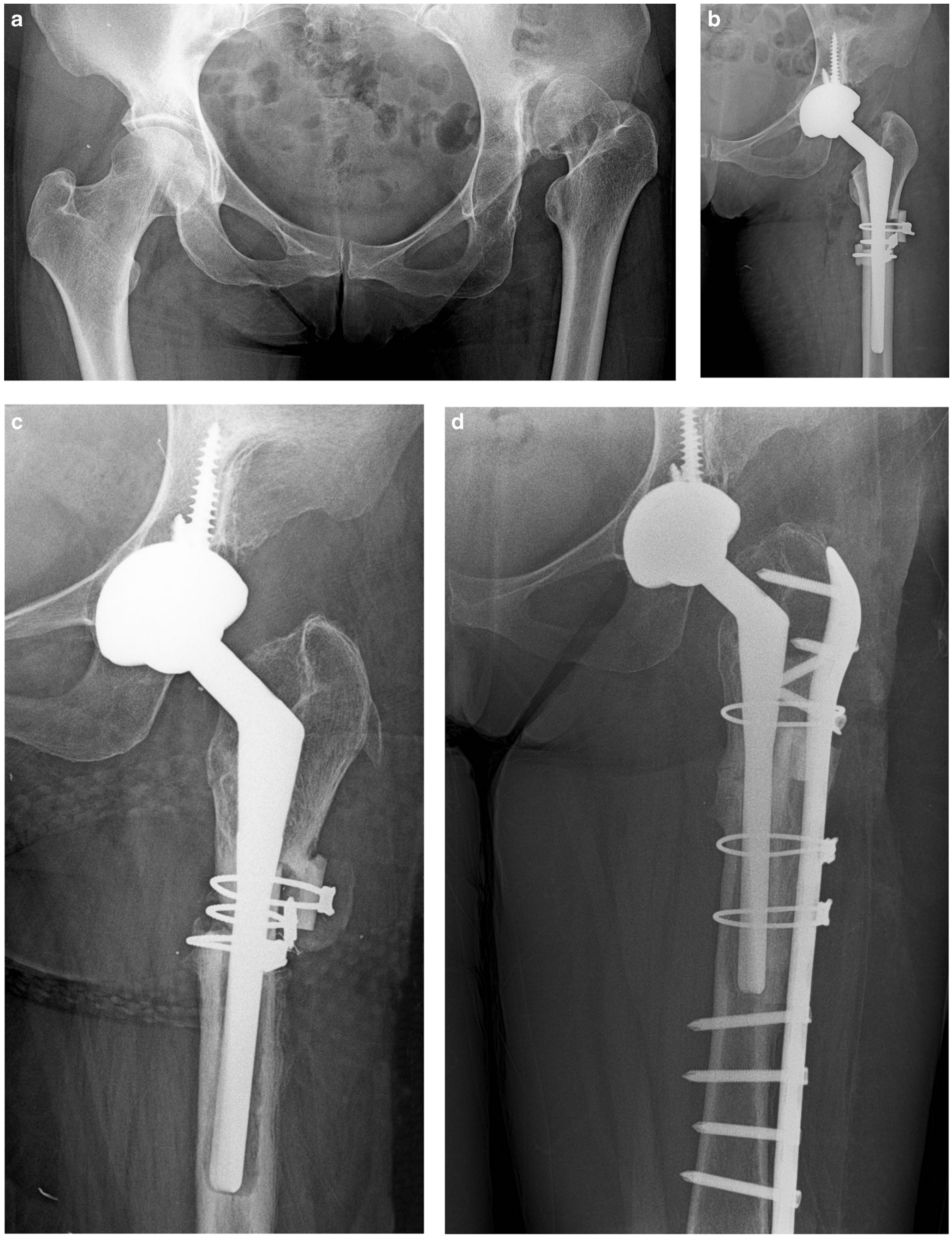

Fig. 5. The nonunion after a step-cut osteotomy patient, treated with plating with strut grafting. a: preoperative X-ray; b: early postoperative X-ray; c: nonunion; d: plating with strut grafting and union, postoperative second year after the index surgery.

Table 3
Association between complications, nonunion and femoral stem type, age, and Crowe type.

Association between	Spearman's R_s	p
Femoral stem type and complications	0.11262	0.26708
Age and complications	0.03136	0.758
Crowe type and complications	0.06061	0.55121
Femoral stem type and nonunion	0.18784	0.06263

However, there was a strong association between femoral STO type and nonunion (z-score: −7.12 and $p < 0.00001$, Mann-Whitney U Test). Step-cut osteotomy caused more nonunion cases than transverse osteotomy, 6 and 0 respectively. All nonunion cases were operated with a step-cut osteotomy.

4. Discussion

Total hip arthroplasty for neglected hip dysplasia is one of the most difficult surgeries in orthopedics. It has a higher complication rate due to distorted anatomy compared to simple THA although successful clinical and functional outcomes are achievable. Total hip arthroplasty for Crowe III-IV dysplastic hip patients yields favorable results in terms of clinical and functional scores. Harris Hip Score (HHS), WOMAC score are commonly used in the literature, and it has been observed that successful outcomes are achieved in the postoperative period compared to the preoperative period [18,19]. In the current study, the clinical and functional outcomes were assessed using HHS, revealing a significant improvement (from a mean preoperative 35.6 to a

Fig. 6. The nonunion after a step-cut osteotomy patient plating with fibula autografting. a: preoperative X-ray; b: early postoperative X-ray; c: nonunion; d: plating with fibula autografting and union, postoperative second year after the index surgery.

postoperative score of 88.1), consistent with the findings in the literature [20]. Seventy-three patients in this study still experienced some degree of limping at the one-year follow-up. LLD can also persist postoperatively as in our study [21]. Predicting whether walking difficulties and limping will improve after surgery is challenging due to underlying long-lasting abductor weakness and shortening. Therefore, patients should be informed in detail preoperatively about residual limping and LLD.

All acetabular cups in this case series were placed in the true acetabulum. Severe soft tissue contractures, LLDs, and pathomorphologic changes make reduction and maintenance challenging. Subtrochanteric osteotomy addresses these problems while reducing sciatic nerve tension. There is no consensus on which method should be applied, although subtrochanteric level osteotomies are generally preferred. Several types of STO for Crowe III-IV hips have been described: transverse, step-cut, oblique, z-subtrochanteric, double chevron [22]. Each method has its own set of advantages and disadvantages. In our study, we utilized transverse or step-cut osteotomies at the subtrochanteric level. Delayed union or nonunion represents one of the most concerning complications associated with STO. Nonunion rates following STO vary in the literature (0–7%) [7,18]. In our study, we observed a nonunion incidence of 6.06%. Differing from the literature, all cases of nonunion occurred in hips where a step-cut osteotomy was performed. The easiest way for a STO is transverse osteotomy. Transverse osteotomy offers practicality and technical simplicity, while preserving the proximal femoral metaphysis and causing minimal damage to the periosteum, thereby increasing the likelihood of union. However, a primary concern associated with transverse osteotomy is the added risk of torsional instability [22]. Furthermore, excess anteversion can be more easily corrected by rotating the osteotomized fragments when using a transverse osteotomy, as compared to step-cut and chevron osteotomies. Conversely, step-cut osteotomy theoretically offers greater torsional stiffness and an increased probability of union, attributed to the larger surface area of contact of the osteotomized fragments [14]. Step-cut STO is generally thought to be time-consuming and laborius [23]. Reikeraas et al. proposed that step-cut osteotomy may lead to a reduction in circumferential contact between the endosteal cortex and the femoral stem, potentially resulting in stem fixation failure and the development of varus malalignment [24]. Hence, it is imperative to execute precise bone cuts in terms of both shape and size circumferentially, ensuring the maintenance of ideal contact geometry. This, however, is a technically demanding task. MacLachlan and Ries reported that they encountered challenges in achieving optimal bone apposition during their experience with step-cut osteotomy. They attributed this outcome to the absence of specialized instruments for precise osteotomy [25].

The learning curve for this surgery is steep due to its complexity, and ensuring a consistently smooth contact surface may not always be achievable. Additionally, it is essential to acknowledge the potential mismatch between the proximal femoral and distal femoral medulla, highlighting the need for meticulous distal reaming, particularly in cases of prior Schanz osteotomy. Due to these reasons, we believe that we have observed a higher incidence of nonunion in our cases. To the best of our knowledge, this represents the first case series in which transverse osteotomy has been found to be associated with higher union rates in comparison to step-cut osteotomy, despite the widely acknowledged technical challenges and complexity associated with step-cut STO highlighted in nearly all existing literature. Nonunion cases in this study were managed and healed with solid union by plating and strut graft in 3 patients, plating and fibular grafting in 2 patients, and femoral stem revision in 1 patient.

Muratli et al. investigated biomechanically transverse, step-cut, oblique, z-subtrochanteric osteotomy methods on composite Sawbone femurs and could not find significant superiority of one method to the others in terms of stability [12]. They also showed grafting did not add any increase in stability biomechanically but the results could be different if it was an in vivo or cadaver study. Yildiz et al. biomechanically compared step-cut and oblique osteotomy, revealing that neither of the osteotomy types exhibited clear superiority in terms of both rotational and axial forces [26]. Li et al. also could not show a significant difference between osteotomy types in their meta-analysis [22].

The incidence of femoral fractures exhibited variation and was reported to be as high as 27% in the literature, with the majority of fractures occurring at the proximal femoral level [27,28]. In this study, the most frequent complication observed was femoral fractures, occurring in 13 cases (13.1%), consistent with findings reported in the literature. Among these cases, 10 patients experienced Vancouver A fractures, while 3 patients experienced Vancouver B fractures. Importantly, all affected hips successfully healed without any instances of nonunion. A mismatch of diameters of proximal femoral segment and distal femoral segment after STO, a derotational correction and the utilization of standard femoral stems designed for individuals without dysplastic hips can be counted as the main causes of femoral fracture complication. Press-fit implantation of stems can also lead to a fracture. Step-cut osteotomy also has stress loading in points where vertical and horizontal osteotomy lines merge [29]. This stress concentration led to a spike fracture at the proximal edge during the osteotomy in one of the step-cut STO patients in this study, necessitating treatment with cables.

Careful patient selection, good preoperative planning, selection of a suitable prosthesis for the patient and if necessary, supply of a small acetabular cup, careful and meticulous surgical technique should be maintained to minimize complications. Additionally, the experienced hip surgeons should perform these complex hip arthroplasties to lower complication rates and improve prosthesis survival in specialized centers [30]. In this case series, which encompassed 99 hips, treatment was administered by three experienced hip surgeons, resulting in an overall complication rate of 38.4%.

This study has some limitations. First, it is a retrospective case series. It has a small sample size despite the fact that it is one of the largest case series on this uncommon issue. Another notable limitation is the variability introduced by three different surgeons, varying surgical approaches, and the use of different femoral stems in the procedures. Although both stems are designed for arthroplasty in dysplastic hips, their fundamental features are different from each other. Wagner Cone stem has a rough-blasted surface with longitudinal 8 ribs, provides good rotational stability [31,32]. On the other hand, Biomet's CDH stem (now unavailable) is straight and has proximal porous coating characteristics. Both groups had a higher number of type 1 stems. While the nonunion rate was 8.77% in cases where a type 1 stem was used, it was observed to be 2.38% in cases where a type 2 stem was used. However, there was no statistically significant difference in nonunion rates between the two stem types, and successful outcomes were achieved with both stem types. Therefore, despite the majority of nonunion cases involving the use of CDH stem (5 out of 6), the primary cause of nonunion was identified as the step-cut STO. Additionally, the relatively short follow-up duration is a constraint in the context of an arthroplasty study.

5. Conclusion

Step-cut subtrochanteric osteotomy is a much more complicated, technically demanding osteotomy and led to significantly higher nonunion in our series. Transverse osteotomy may represent the best choice for subtrochanteric osteotomy in Crowe III-IV dysplastic hips.

Disclosure of interest

The authors declare that they have no competing interest.

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Author contributions

NT: study design, data collection, writing of article, statistics.
ME: study design, data collection, writing of article supervision.
ACE: data collection, corrections.
LB: statistics, corrections.
SB: data collection.
NS: study design, writing of article.
DG: study design, writing of article.

Declaration of artificial intelligence use

No artificial intelligence tool has been used at any stage of this article.

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