VIDEO OF ORTHOPAEDIC TECHNIQUE

Restoration of Proximal Femoral Anatomy during Total Hip Arthroplasty for High Developmental Dysplasia of the Hip: An Original Technique

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Objective: To introduce a modified osteotomy method for proximal femur reconstruction (PFR) in total hip arthroplasty (THA) for high developmental dysplasia of the hip (DDH).

Method: A retrospective study was performed in a series of 24 patients (26 hips) with Crowe III/IV DDH who underwent THA and simultaneous PFR. We used an animated video to illustrate and help understand the procedure for this technique. Patients were reviewed clinically and radiographically with an average follow-up of 31 months. The Harris hip score (HHS) was recorded preoperatively and at 3 and 12 months postoperatively.

Results: All patients achieved primary bone union. No revision was needed up to the latest follow-up. One patient had a dislocation due to self-fall and received manual reduction under general anesthesia. No patient had intraoperative femoral fractures, sciatic nerve injury, or infection. The mean HHS improved from 33.48 ± 9.06 preoperatively to 84.61 ± 4.78 immediately after surgery and 90.84 ± 4.96 at 12 months.

Conclusion: Proximal femur reconstruction is a simple and practical technique for femoral remolding during THA in patients with high DDH.

Key words: Developmental dysplasia of the hip; Proximal femur reconstruction; Total hip arthroplasty; Video technique note

Introduction

Developmental dysplasia of the hip (DDH) is a leading cause of hip arthritis, especially in young adults, and total hip arthroplasty (THA) remains the gold standard of treatment when end-stage arthritis leads to significant pain and loss of function[1]. Although its clinical efficacy is widely recognized, difficulties have been met in the performance of THA in DDH patient[2,3]. Hip deformity significantly increases the difficulty of surgery. The two related problems are: (i) determining how to restore the center of hip rotation in the true acetabulum; and (ii) determining how to obtain prosthesis stability in a dysplastic hip.

High dislocation and severe contracture of soft tissue lead to difficulty in reducing the hip and pose a major risk of neurologic traction injury. Subtrochanteric femoral shortening osteotomy is an approach that makes reduction easier. A variety of types have already been documented in the published literature[4–9]. Osteotomies involving the femoral neck, the distal femur, and the great and the lesser trochanter have been reported in previous studies[10,11]. However nonunion

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and complexity in performance remain major concerns in these procedures[7,12].

With increasing degree of dysplasia, femur deformities are frequently encountered, such as larger anteversion, shorter neck, smaller intramedullary canal size, and a straight contour that the anterior bow of the femur has displaced further distally[13]. The decreased canal width and thinner cortical diameters make them more prone to fracture[14] and add to the difficulty of obtaining a stable implantation of an adequately sized femoral component[11]. Poorly fitted and incorrectly placed prosthesis installations can cause loosening of the prosthesis, fractures, and dislocation, and increase the risk of nerve injury[15]. Reproducing the femoral offset and limb length yielded favorable clinical outcomes in THA for DDH patients[16,17]. Better hip alignment decreases the reaction forces exerted on the hip joint and could, thus, reduce the loosening rate.

To address these difficulties, we have improved the osteotomy technique and developed a simple and reliable solution for the proximal femur reconstruction (PFR). This technique allows surgeons to expand the canal volume in a stepless way and reduce the femur lenght at a discretionary extent. We have previously demonstrated that this technique has comparable clinical effects to standard subtrochanteric transverse osteotomy[18]. In the present study, the specific surgical procedure and detailed clinical outcomes are reported for a consecutive case series, with an animated video demonstration included.

Method

After obtaining approval from our investigational review board, a retrospective chart review was performed in our institute from April 2015 to January 2018. Patients who had had correction of femur deformity with the PFR osteotomy technique in THA surgery were identified through review of operative records. The inclusion criteria were: (i) painful osteoarthritis secondary to severe DDH (Crowe Grade III–IV); (ii) age from 18 to 65 years; and (iii) had received THA surgery with PFR technique applied in the operation. The exclusion criteria were: (i) coxa synarthrosis; (ii) previous history of hip surgeries (including peri-acetabular osteotomy and rotational femur osteotomy); (iii) skeptic arthritis; and (iv) primary or secondary abnormal muscle strength (e.g. poliomyelitis, cerebral infarction sequelae, and Parkinson's disease).

Surgical Technique

Anesthesia and Position

All surgeries were performed under general anesthesia with the patient lying in the lateral position.

Approach and Exposure

A posterolateral incision was used for exposure and the proximal femoral reconstruction procedure. The joint capsule and fibrous scar tissue were carefully and completely removed, and the inferior part of the elongated capsule was dissected to access the true acetabulum. The femoral neck was resected along with the femoral head. The femoral head was preserved for further autografts in later procedures.

Osteotomy

To determine the osteotomy length on the femoral side, Marker 1 was placed in the great trochanter at the protruded level, and Markers 2, 3, and 4 were placed every 1–1.5 cm below. The whole length of the marking region was approximately 4–6 cm. An oblique osteotomy was performed following the osteotomy line, and the distal osteotomy line was oblique to the lateral cortex. In this way, the gluteus minimus muscle, the gluteus medius muscle, the bone fragment and the vastus medialis muscle were retained in an integrated structure. Leg length difference was measured preoperatively to determine whether to perform the femur shortening osteotomy procedure. A simple horizontal osteotomy is adequate for this adjustment (Fig. 1).

Acetabular Procedure

After completing the proximal femoral osteotomy, the proximal fragment was distracted laterally and proximally for an easier soft tissue dissection and adequate exposure of the acetabulum. Restoration of the anatomical hip center was attempted. Structural autologous bone grafting was performed in cases of unneglectable bone defects. The acetabulum was then prepared, deep in a posterior and medial direction, using reamers. Primary stability was obtained by press-fitting the acetabular component. One to three screws were used for augmenting the primary stability of the acetabular cup.

Femoral Procedure

The femur cavity was measured by CT before surgery. If the cavity diameter was smaller than the smallest cavity broach, a femoral shaft wire cerclage was needed 2-cm distal from osteotomy level, and a longitudinal slot was made on the femoral cortex with a saw. The direction and insertion length of the broach were maintained (Fig. 2A,B). The temporary femoral neck and head were inserted before hip joint reduction, and then the joint stability was evaluated.

Proximal Femur Reconstruction, Joint Reduction and Fixation

Then we inserted the femoral stem (Fig. 2D), the femoral head, and reduced the hip joint. We fit the slot at the great trochanter to the shape of the proximal femoral broach (Fig. 2E). The position of the proximal femoral osteotomy fragment was adjusted according to the tension of the gluteus medius muscle (Fig. 2F). Three to four cerclage wires were used to fix the osteotomy fragment. Several small slots were made at the surface of the osteotomy fragment with a saw to keep the wire in the right position. Bone autografts were performed from the preserved femoral head for better bone union (See attached video clip Video S1).

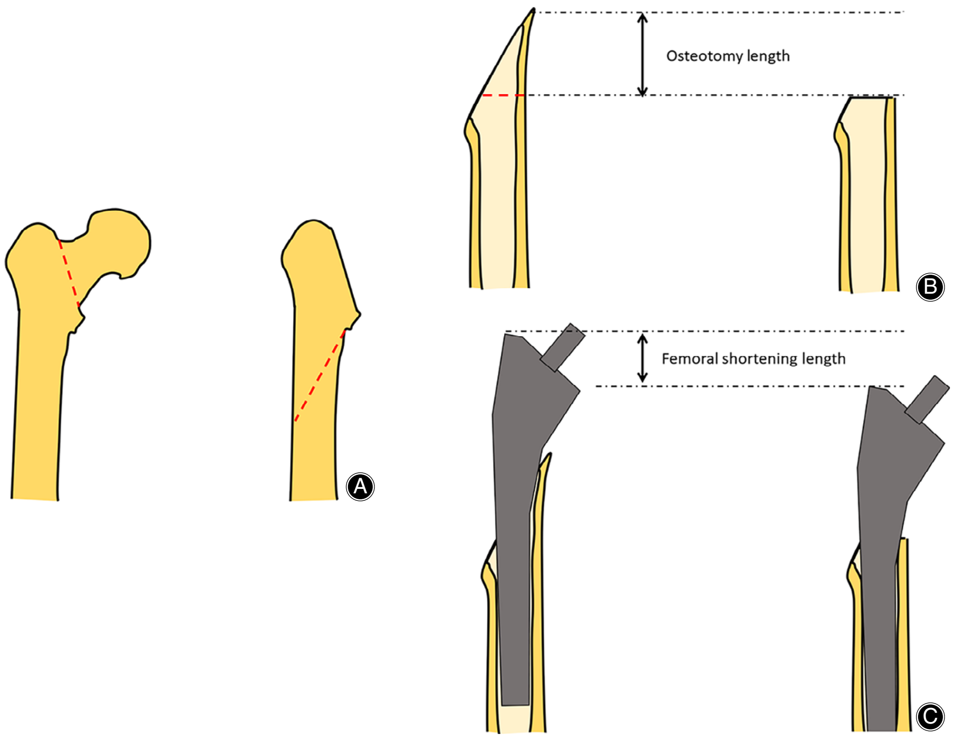

Fig. 1 Schematic diagram for femoral osteotomy procedure. (A) Resect the femoral neck and perform the oblique great trochanter osteotomy following the dotting line. (B) Make a horizontal osteotomy according to the opposite side lower limb length. (C) Insert the stem into the medullary canal. The insertion could be deeper after the femoral shortening which, therefore, facilitates low limb length adjustment and joint reduction. However, the femoral shortening length might not be equal to the osteotomy length due to the medullary canal fit-press.

Postoperative Care

The patients underwent a routine rehabilitation program with partial weight-bearing as tolerated as early as the first day after surgery. Active and passive motion exercises were encouraged. There is no specific need for external mobilization or bed rest. The patients were allowed to walk with full weight-bearing 4–6 weeks after surgery. The patients were asked to have a reevaluation in the clinic at 4 weeks after surgery. The patients were allowed to stop using their walking aids only if there was evidence of bony union on physical examination or radiological check (such as continuous osteotylus across the osteotomy line).

Outcome Measures

The outcomes of this patient cohort were recorded and compared as follows. The data were retrieved from the medical records and hospital PACS system. Missing data were obtained through phone calls.

Harris Hip Score

The Harris hip score (HSS) system was used to assess the functional results of the hips. A questionnaire was conducted for all patients before and after surgery. The patients were also evaluated 3 months and 12 months after surgery.

Visual Analogue Scale

Pain was evaluated using a visual analogue scale (VAS: 0 = no pain at all, 10 = worst pain imaginable). The evaluation was performed on admission before surgery and at 1-year follow-up after surgery.

Radiographic Measures

The leg length correction was measured on the AP view (distance from lesser trochanter to a horizontal line based on the teardrop or, if not visible, on the ischial tuberosity). The femur migration was measured as the decreased distance between the tip of the great trochanter to the horizontal line before and after surgery.

Lower limb discrepancy was measured before and after surgery on a long-leg view X-ray. We define the lower limb length as the distance between the anterior superior spine and the malleolus medialis. The discrepancy was calculated by comparing the length between both lower limbs.

Prosthesis Loosening and Osteolysis

Prosthesis loosening and osteolysis were assessed using pelvic X-Ray film around the cup. Screw breaks, formation of translucent bands, and acetabular displacement are considered to be manifestations of acetabular loosening. They were also assessed with anteroposterior and lateral radiographs around the femoral stem.

Bone Union

Bone union was assessed at each follow-up point. Radiographic bone union was determined by a single radiologist (CM) who was blinded to the aim and protocol of this study. Bone union was defined as the complete disappearance of fracture lines confirmed through anteroposterior and lateral views.

TABLE 1 Individual patients' information

Name	Gender (M/F)	Age	Side (L/R)	Crowe classification	Prothesis	Bearing surface	Operation time (min)	Femur migration (cm)	Pre-op Harris score	Post-op Harris score	Post-op 3-month Harris score	Post-op 12-month Harris score	Follow-up (months)
Z. GR.	F	55	L	III	T.O.P + LCU	CoC	120	4.4	28	81	84	86	48
L. AP.	F	24	L	IV	T.O.P + LCU	CoC	100	6.0	44	90	92	94	47
C. M.	F	49	L	IV	CombiCup + LCU	CoC	110	6.5	33	87	90	90	47
C. BH.	F	48	L	IV	CombiCup + LCU	CoC	120	6.5	36	91	95	93	46
Z. XL.	F	52	L	III	CombiCup + LCU	CoC	115	4.5	30	81	85	87	45
X. M.	F	43	L	IV	CombiCup + LCU	CoC	90	7.6	21	55†	93	96	44
			R	IV	CombiCup + LCU	CoC	100	7.1	60	85	96	96	37
Y.HM.	F	48	R	III	CombiCup + LCU	CoC	90	4.6	34	84	89	90	40
H. SX.	F	48	L	IV	VERSYS LD/FX	CoP	110	5.4	41	84	91	89	38
R. DR.	F	69	L	III	VERSYS LD/FX	CoP	110	4.6	22	77	79	86	36
S. ZS.	M	74	L	IV	CombiCup + LCU	CoC	110	5.1	28	78	88	84	32
X. CZ.	M	44	R	IV	Trilogy + CLS	MoP	90	7.1	28	86	90	92	31
X. QZ.	F	48	R	III	CombiCup + LCU	CoC	80	5.4	29	83	95	90	30
Z. RX.	F	53	R	IV	CombiCup + LCU	CoC	90	5.2	24	76	89	88	30
M. L.	F	44	R	IV	CombiCup + LCU	CoC	80	6.0	28	79	94	94	29
D. ZM.	F	27	R	III	CombiCup + LCU	CoC	80	5.5	48	90	94	99	27
H. ZA.	M	61	L	IV	CombiCup + LCU	CoC	90	6.5	34	88	94	88	26
W.WR.	F	47	L	III	CombiCup + LCU	CoC	100	5.3	27	78	79	84	24
Z. PP.	F	32	L	IV	CombiCup + LCU	CoC	100	6.5	22	47†	96	95	22
			R	IV	CombiCup + LCU	CoC	90	6.0	47	90	96	95	20
C. HY.	F	53	L	III	Trident HA + Accolade	CoP	90	5.1	38	90	94	96	19
W. Y.	F	24	R	IV	CombiCup + LCU	CoC	80	5.9	38	92	96	96	19
R. SH.	F	54	L	IV	CombiCup + LCU	CoC	100	6.0	36	88	96	96	19
X. YC.	M	44	R	IV	CombiCup + LCU	CoC	100	5.0	28	83	90	88	14
Z. Y.	F	48	R	III	CombiCup + LCU	CoC	90	4.6	33	85	86	88	14

† These patients received staged bilateral surgery; therefore, the first post-op Harris score was affected by the contralateral side.; Accolade, stem prothesis, Skyer; CLS, Cementless Spotorno, Zimmer Biomett™; CoC, ceramic on ceramic; CombiCup, acetabular cup, Link™; CoP, ceramic on (crosslinked) polyethylene; LCU, LCU stem prothesis, Link; MoP, metal on polyethylene; T.O.P, trabeculae oriented pattern, acetabular cup, Link; Trident HA, Trident hemispherical cup, Skyer; Trilogy, cetabular Hip System, Zimmer Biomet; VERSYS LD/FX, Cemented and Press-Fit Hip Prostheses, Zimmer Biome.

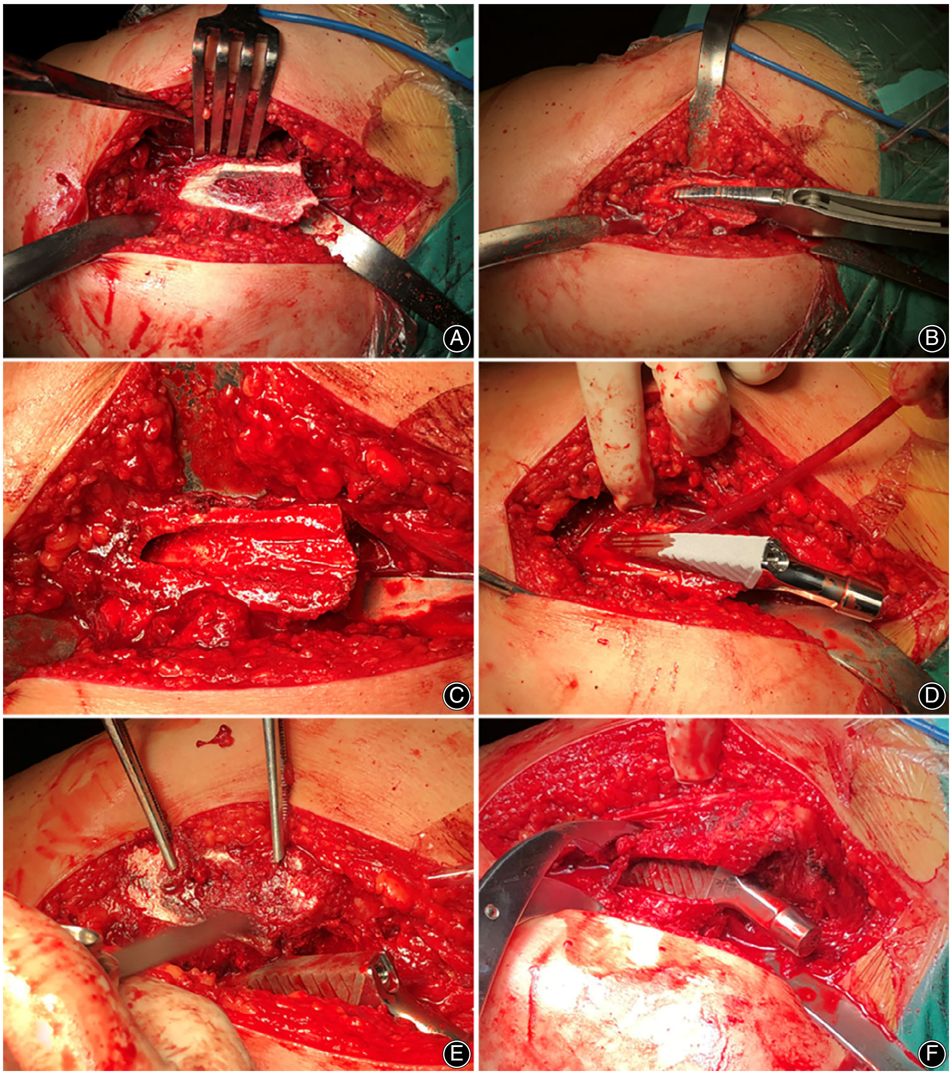

Fig. 2 Femoral procedures of the surgery. (A) Expose the isthmus after a long oblique osteotomy. (B and C) Ream and recanalization of the proximal femur. (D) Insert a fully porous-coated uncemented stem into femoral isthmus as internal scaffold to gain both axial and rotational stability, ignoring the osteotomized fragments. (E) Remold the great trochanteric fragment with an oscillating saw to fit the stem. (F) Restore the proximal anatomy by press-fitting the reshaped and canalized fragment back to the stem prosthesis as a shell.

Complications

Complications were noted during and after the surgery, including any neurovascular injury, intraoperative periprosthetic fracture, acute or chronic infection, deep venous thrombosis, and dislocation.

Statistics

Student's *t*-test was used for statistical analysis. We used SPSS 13.0 software (SPSS, Chicago, US) for analyzing all the statistical data and a *P*-value <0.05 was considered significant for all the parameters.

Results

General Results

Between 2015 and 2018, 26 primary THA in 24 patients were performed with PFR by a senior surgeon (XFS) for hip pain secondary to high DDH in our institution. The age at which the patients received surgery was 47.3 ± 12.07 years. Nine (34.6%) patients were classified as Crowe Type III. The rest (65.4%) were Type IV. The average operation time was 97.4 (range, 80–120) minutes. The follow-up was 31.36 ± 10.75 months. The demographic and clinical data are summarized in Table 1.

Clinical Results

All patients had significant clinical improvement for perceived pain, function, and mobility, as assessed using the Harris hip score questionnaire.

Harris Hip Score

Despite the 2 patients who had two-stage bilateral surgery (X.M. and Z. PP.), the Harris hip score improved from 33.48 ± 9.06 preoperatively to 84.61 ± 4.78 immediately after surgery ($P < 0.01$) and 90.84 ± 4.96 ($P < 0.01$) 3 months after surgery.

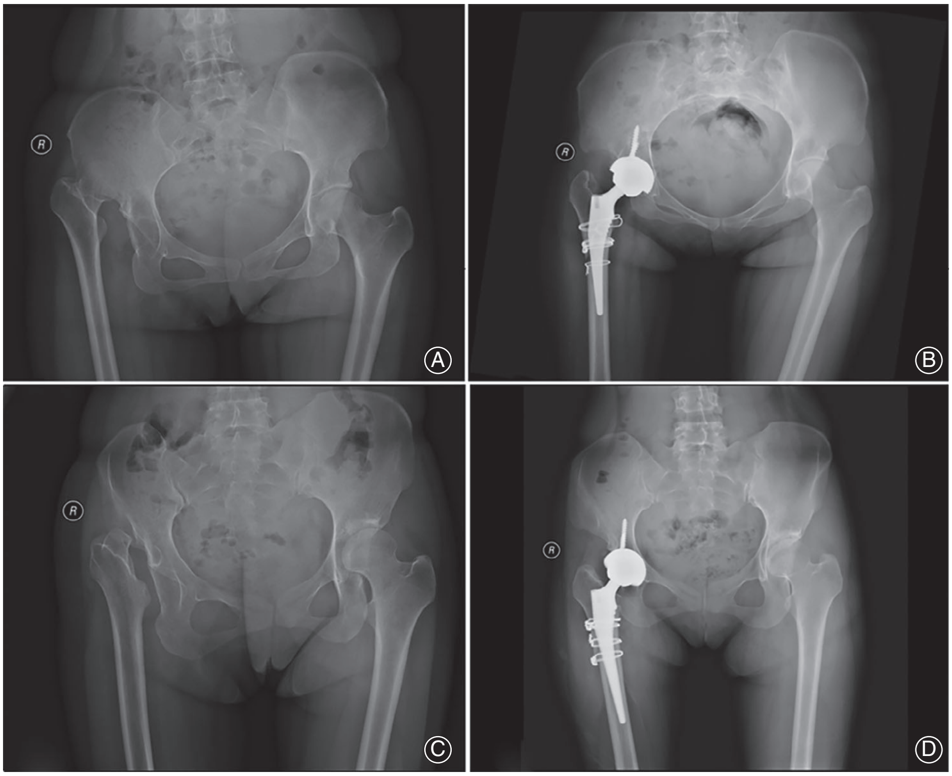

Fig. 3 Representative preoperative and postoperative X-ray comparisons of reviewed developmental dysplasia of the hip (DDH) patients. (A and B) Case 13, a 53-year-old female with Crowe IV DDH received THA and simultaneous proximal femur reconstruction (PFR) surgery ((A) before operation; (B) 3 months after surgery). (C and D) Case 20, a 27-year-old female with Crowe IV DDH ((C) before operation; (D) last follow-up, 27 months).

Visual Analogue Scale
The VAS score dropped from 6.92 ± 0.93 preoperatively to 1.19 ± 0.80 ($P < 0.01$) 1 year after surgery. The percentage of improvement was significant for mobility among all three direction parameters. At the latest follow-up, all patients had no or only slight and occasional pain. Patients did not require medication and their activity was not compromised.

Radiological Results

Femur Migration
Comparing the preoperative and postoperative X-ray, the femur migration was 5.70 ± 0.87 cm.

Lower Limb Discrepancy
The lower limb discrepancy deceased from 5.34 ± 1.96 cm preoperatively to 1.02 ± 0.77 cm postoperatively.

Prosthesis Loosening and Osteolysis
At the latest follow-up, no prosthesis loosening, stem sinking or periprosthesis osteolysis were found.

Bone Union
All cases underwent one-stage union. The average bony union time was 4.35 ± 1.24 months (Fig. 3).

Complications
No periprosthesis facture occurred during the surgery. No infection was reported up to the latest follow-up. Four patients developed intermuscular vein thrombosis and received prolonged anticoagulation treatment. One patient had a dislocation 1 month after surgery due to self-fall. She underwent reduction under general anesthesia and was instructed to stay in bed for 3 months. At 1-year follow-up, she was able to carry out daily activities such as walking, climbing stairs, and putting on socks. The continued follow-up was uneventful.

Discussion

Dealing with femur deformity during THA surgery is technically demanding. Challenges have been met, such as implanting the stem into a small dysplastic medullary cavity, and decreasing possible neurovascular structure injury after excessive limb lengthening. In this study, we introduced a modified osteotomy method to restore the shape of dysplastic proximal femurs.

Different types of subtrochanteric osteotomy have been reported, including transverse (subtrochanteric transverse osteotomy, STO), oblique chevron, and T-shaped (Table S1).[5–8,19–21] In 2014, Ahmed et al. introduced a short oblique subtrochanteric osteotomy with good clinical results.[4] Ozan et al. report satisfying mid-term survival for transverse subtrochanteric osteotomy in THA surgery.[22] They have similar geometric designs with PFR, but the core concepts are different. The STO and its modifications only aimed to facilitate restoring the hip center and leg length. In addition, the PFR intends to restore the proximal femur construction and provides favorable biomechanical results.[23,24] One big advantage of the PFR technique is the ability to restore the normal offset with a common stem prosthesis by adjusting the thickness of the great trochanter osteotomy. Theoretically, the lever arm length of abductor muscles was the most important factor influencing the abductor function.[25] The increased abductor lever arm helps to improve abductor muscle efficiency and is reflected in the Harris score in the aspect of joint motion. Although the offset can also be rebuilt with an S-ROM stem during the STO, the S-ROM modular hip system has disadvantages in terms of osteolysis and stress-shielding.[26] In addition, corrosion at the femoral neck-stem taper and soft tissue adverse reaction to metal debris formation in modular femoral stems are noteworthy.[27]

A variety of similar osteotomy methods are reported in the published literature. Lee et al. reported on an osteotomy just behind the great trochanter.[28] It seems that a smaller osteotomy is easier to perform, but, in fact, smaller bone grafts are more difficult to firmly fix and are prone to nonunion. In our procedure, a great trochanter fragment was severed from the proximal femur. The canal cavity was reshaped the fragment was then fixed press-fitting to the stem prosthesis as a shell. The shape was, therefore, matched regardless of the various deformities of the proximal femur (Fig. 2E,F). Furthermore, secondary dysplasia of the femoral canal was frequently encountered in patients with previous medical interventions. Reaming and inserting a stem in the neutral position could be more than difficult under such conditions, even with a subtrochanteric osteotomy. In the reviewed case series, obliteration of the femoral canal was also encountered. The sclerotic bone was simply removed with a small oscillating saw under direct vision after long oblique osteotomy to facilitate the recanalization of the proximal femur.

The PFR technique also provides better exposure to the anterior structures in front of the femur. In patients with high DDH, there is a decrease in tissue excursion with subsequent difficulty in reducing the head in the true acetabulum. In addition to the osteoarthritic scar adhesion, disused adductor contracture hinders the reduction of the proximal femur. It has been a challenge for surgeons to expose and release the contracted soft tissue in front of the femur in a posterior approach. However, after the PFR osteotomy, the exposure becomes easy and can be directly visualized (Fig. 2A). In the reviewed case series, the average operation time is 97.4 minutes. For exposure, releasing the adductors and then reducing the hip after PFR osteotomy has been a time-saving procedure compared to traditional methods.

It has remained controversial whether there is a need to shorten osteotomy for high DDH patients.[19,29,30] It is believed that appropriate proximal femur shortening facilitates joint reduction and prevents neurovascular injury from excessive limb lengthening.[2,7,8,11] Without sciatic nerve tractive irritation, the patient can easily straighten the lower limbs, which is beneficial for early weight-bearing activities and functional exercise.[31] However, others found that shortening osteotomy aggravates the lower limb discrepancy after the restoration of pelvic inclination because the absolute length for the affected femur is even shorter than for the normal side.[30] There are also concerns about compromise of the stem's long-term survival.[7,8,19–21] Based on our experience, the decision should depend on the tension of the gluteus medius after joint reduction and limb lengthening. This PFR osteotomy allows the surgeon to stepwisely adjust the femur length by sliding the great trochanter fragment. In our cases, the average femur migration was 5.7 cm, and all patients were able to walk partially weight-bearing and free from sciatic nerve symptoms 3 days after surgery. To protect the neurovascular structure from excessive traction, we recommend femur shortening if the scheduled migration is over 6 cm.

Doubts had been raised about the union rate after PFR. Previous studies have reported a nonunion rate of STO ranging from 3.3% to 7.1% in patients with high hip dislocation.[20,21,32] Our union rate is 100%. The high union rates may be attributed to the factors of biology and biomechanics. The proximal femoral metaphysis has more sufficient blood supply than the subtrochanteric area, which facilitates bone healing at the osteotomy site. Second, the osteotomy line is longer in the PFR than those in the STO.[33] It is assumed that larger bone contact enables better bone union. Third, we also used autogenous bone grafting to fill the gap and enhance bone integration. Finally, we established mechanical stability among the fragment, femoral stem, and femoral isthmus, which is crucial for bone union.

Another main concern is the sinking of the stem. Because the osteotomy is made along a long and oblique line, and the proximal stem and femoral shaft is reattached only using several double-loop cerclage wires, the instant stability of the stem is questioned. In our study, patients were allowed to partial weight-bear as soon as they woke up. They were able to walk full weight-bearing approximately 3 months after surgery. At the radiologic follow-up up to 24 months, no stem sinking was found. This might be attributed to the use of a fully porous-coated uncemented stem. The fixation technique is similar to the universally recognized management of Vancouver type B2 and B3 periprosthetic femoral fractures, press-fitting the stem into the femoral isthmus as an internal scaffold to gain both axial and rotational stability and ignoring the osteotomized fragments[34] (Fig. 2D).

Several limitations of this study should be acknowledged. The number of included subjected was relatively small. In addition, it is a retrospective, single-arm, non-controlled study, which limited the examination efficiency. In this study, we only aimed to introduce the core concept of femur reconstruction and the modified technique of subtrochanteric osteotomy. There was no analysis of inter-observer reliability in the radiographic assessment. The determination of bone union was not robust based on the X-ray. Our final assessment of union was acceptable given the radiographic appearances as well as absence of symptoms. The longest follow-up of this present series is 48 months up to now. The long-term survival of these complex arthroplasties needs further investigation.

In conclusion, the PFR technique is a reliable solution for femoral procedures during THA in patients with high

DDH. The complication rate is low, and results are good and compare favorably with other results in the published literature. Its advantages include simple osteotome geometry, stepwise femoral shortening, instant stem stability, perfect shape matching of the proximal femur, and a good bone union rate at the osteotomy site.

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Supporting Information

Additional Supporting Information may be found in the online version of this article on the publisher's web-site:

Table S1 Overview of previous studies of total hip arthroplasty (THA) with subtrochanteric osteotomy using different femoral stem.
Video S1 Supplementary Video.

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