CLINICAL ARTICLE

Risk Factors for Intraoperative Periprosthetic Femoral Fractures in Patients with Hip Dysplasia Undergoing Total Hip Arthroplasty with Uncemented Prostheses

Bo Liu, MD[†], Si-kai Liu, MD[†], Tao Wu, MD, Ze-ming Liu, MD, Xiao Chen, MD, Meng-nan Li, MD, Hui-jie Li, MD, Yong-tai Han, MD

Department of Osteonecrosis and Hip Surgery, The Third Hospital of Hebei Medical University, Shijiazhuang, China

Objectives: To determine the potential risk factors for intraoperative periprosthetic femoral fractures in patients with developmental dysplasia of the hip (DDH) undergoing total hip arthroplasty (THA).

Methods: This was a retrospective study. Patients who were diagnosed with DDH and undergoing THA (by artificial joint replacement) at our hospital from January 1999 to December 2019 were included in this study. Clinical and radiological factors were obtained from their medical records, such as age, sex, Crowe classification, morphological features of proximal femur, and features of surgical procedure. The outcome of interest was the occurrence of intraoperative periprosthetic femoral fracture, which was recorded and classified according to the Vancouver classification system. According to the fracture status, the patients were divided into two groups: the fracture group and the non-fracture group. Multivariate logistic regression model was built to identify the risk factors for these fractures.

Results: A total of 1252 hips were finally included. Intraoperative periprosthetic femoral fractures were identified in 62 hips. The incidence of intraoperative periprosthetic femoral fractures in patients with DDH undergoing THA was 4.95%. There were 22 patients (proportion = 35.48%, incidence = 1.76%) with Type A fractures, 38 (proportion = 61.29%, incidence = 3.04%) with Type B fractures, and two (proportion = 3.23%, incidence = 0.16%) with Type C fractures. Six independent risk factors for intraoperative periprosthetic femoral fractures were identified: osteoporosis (OR = 3.434; 95% CI, 1.963–6.007), previous surgical history (OR = 4.797; 95% CI, 2.446–9.410), Dorr Type A canal (OR = 3.025; 95% CI, 1.594–5.738), retained femoral neck length (OR = 1.121; 95% CI, 1.043–1.204), implanted metaphyseal-diaphyseal fixation stems (OR = 3.208; 95% CI, 1.562–6.591), and implanted stem with anteversion design (OR = 2.916; 95% CI, 1.473–5.770).

Conclusions: The overall incidence of intraoperative periprosthetic femoral fractures in patients with DDH undergoing THA was 4.95%, which was at a moderate level compared to patients with other diseases undergoing THA. Six independent risk factors were identified: osteoporosis, previous surgical history, Dorr Type A canal, insufficient neck osteotomy level, implantation of metaphyseal-diaphyseal fixation stem, and implantation of a stem with an anteversion design. Comprehending these risk factors might help surgeons prevent the occurrence of these intraoperative periprosthetic femoral fractures in patients with DDH.

Key words: Developmental dysplasia of the hip; Intraoperative fractures; Periprosthetic femoral fractures; Risk factor; Total hip arthroplasty

Address for correspondence Yong-tai Han, MD, Department of Osteonecrosis and Hip Surgery, The Third Hospital of Hebei Medical University, 139 Ziqiang Road, Shijiazhuang, Hebei Province, China 050051, Tel: +86 18533112816; Fax: +86 311 87023626; Email: cthhmu@foxmail.com
[†]These two authors contributed equally to this work.

Introduction

Developmental dysplasia of the hip (DDH) encompasses a wide spectrum of pathology ranging from a complete fixed dislocation at birth to asymptomatic acetabular dysplasia in adults[1]. DDH is an epidemiologic conundrum. Woodacre et al. reported that the incidence of DDH in the United Kingdom was 4.9 per 1000 live births in the time period from January 1998 to December 2008[2]. Moreover, female sex, breech presentation, positive family history, and first or second pregnancy were confirmed as risk factors[2]. Nelson et al. suggested that there might be a possible delay in diagnosis of infantile DDH[3], which means some asymptomatic patients could not be detected in infantile period or childhood. Therefore, treatment of adult DDH is still a great challenge for orthopaedic surgeons. Generally, operative reduction is not the routine treatment strategy for adult DDH. This is because degenerative change of the hip joint might occur earliest in patients with DDH[4] and secondary hip osteoarthritis can commonly be found[5]. Total hip arthroplasty (THA) with artificial joint prosthesis implantation is nearly the most optimized treatment for these patients[6]. Commonly, DDH patients undergoing THA are expected to be pain-free and reach functional restoration. Sun et al.[7] reported that 50%–70% of patients with DDH finally developed moderate to severe hip osteoarthritis and that most of them had undergone THA. Wyles et al.[4] reported that 33% of adult DDH patients eventually underwent THA.

However, some complications of THA might compromise the prognosis of these patients. Intraoperative periprosthetic fractures, especially femoral fractures, are the most common and important complications[8]. The incidence of intraoperative periprosthetic fractures varies between different populations and indications of THA. But it is certain that uncemented hip arthroplasty is associated with increased incidence of intraoperative periprosthetic fractures[9–11]. Abdel et al. investigated a total of 32,644 individuals undergoing THA, and reported that the incidence of intraoperative periprosthetic femoral fractures was 3.0% when uncemented stem was used[9]. Hong et al. reviewed 271 patients treated with bipolar hemiarthroplasty after traumatic displaced femoral neck fractures, and found the incidence of intraoperative periprosthetic femoral fractures (for uncemented stem) was 14.7%. The treatment of intraoperative periprosthetic femoral fracture is commonly a major challenge for surgeons. For stable fractures such as Vancouver type A and B1, conservative treatment and non-weight-bearing treatment could be effective[11]. However, in order to ensure fracture healing and prevent stem loosening, internal fixation such as cerclage cable is commonly performed in patients with intraoperative periprosthetic femoral fracture[11]. If the femoral component is considered to be unstable, immediate revision with a lengthened femoral component should be performed to achieve the stable fixation of femoral component[11]. Otherwise, early aseptic loosening might commonly occurred, which could eventually result in treatment failure[11].

As previously described[5,12,13], patients with DDH commonly have abnormal anatomical features of the hip joint. These features include dysplasia of both the acetabulum and proximal femur, such as decreased acetabular diameter, shallowed acetabular depth, and morphological changes in the proximal femur[5]. Coxa valgus deformity (a change in the neck–shaft angle), increased anteversion degrees, and narrowed diaphyseal canal diameter are commonly identified in patients with DDH[1,14,15]. These pathoanatomical changes might eventually affect the implantation of femoral components. Nevertheless, most femoral components are designed for patients without these pathoanatomical changes[16–18]. Therefore, when THA is performed in patients with DDH, the mismatch between the femoral component and abnormal medullary canal of the patient might result in the occurrence of intraoperative periprosthetic femoral fracture[19]. For instance, Lamb et al. carried out a study including 793,823 primary total hip arthroplasties between 2004 and 2016. They found that females and indications other than primary osteoarthritis (including DDH) were associated with increased risk of intraoperative periprosthetic femoral fractures[20].

The best treatment for these intraoperative periprosthetic femoral fractures is prevention, meaning that surgeons must know the etiology of these periprosthetic femoral fractures prior to the surgical process and take proper intraoperative actions to prevent them from occurring. There are some reports regarding the risk factors for intraoperative periprosthetic femoral fracture in patients undergoing THA[15,21]. However, as we have already explained, conditions in patients with DDH might be quite different from those in "normal" patients. The pathoanatomical changes in the hip joint might affect the incidence and risk factors for intraoperative periprosthetic femoral fractures[22,23]. There are limited reports involving these specific patients. Therefore, we carried out this study and tried to identify potential risk factors for intraoperative periprosthetic femoral fractures in this special situation. In this study, a total of 1252 uncemented hip arthroplasties were reviewed. All of these arthroplasties were performed in patients with DDH. The main aims in this study were: (i) to estimate the incidence of intraoperative periprosthetic femoral fractures; (ii) to demonstrate the clinical characteristics of patients with intraoperative periprosthetic femoral fractures; and (iii) to determine the potential risk factors for intraoperative periprosthetic femoral fractures in patients with DDH. We believe these findings might be helpful for preventing these serious intraoperative complications in patients with DDH.

Patients and Methods

Study Population

This was a retrospective study. Patients who were diagnosed with DDH and underwent THA (by artificial joint replacement) at our hospital from January 1999 to December 2019 were included in our study.

Inclusion Criteria And Exclusion Criteria

The inclusion criteria were as follows: (i) patients who were diagnosed with DDH and had radiological findings consistent with DDH; (ii) patients who underwent THA surgery with artificial joint implantation; (iii) medical records and radiological examinations were available for identifying the demographic information, anatomical characteristics, and surgical procedure characteristics; (iv) intraoperative periprosthetic femoral fracture can be definitely identified or excluded; and (v) patients were retrospectively included and analyzed by a multivariate logistic regression model.

The exclusion criteria were as follows: (i) age less than 18 years; (ii) sepsis found during surgery (instead of prosthetic implantation, a spacer was implanted or a cleaning infection operation was performed); (iii) unipolar or bipolar hemiarthroplasty; (iv) cemented prosthesis implantation; (v) and lack of medical records or radiological data.

Demographic and General Information

The demographic and general information of the patients was identified based on their medical records, including age, sex, smoking and alcohol abuse, medically diagnosed osteoporosis, and previous surgical history. Note that bone mineral density was measured by the dual energy X-ray absorptiometry in this study. According to the criterion from the National Osteoporosis Foundation[24], a patient was considered to have osteoporosis if his or her bone mineral density was 2.5 standard deviations (SDs) or more below that of the mean level for a young adult reference population, or if the T-score was at or below −2.5 SDs. If a patient received bilateral total hip arthroplasties, he or she was considered by two independent individuals. The study was approved by the Institutional Review Board of the Third Hospital of Hebei Medical University and was conducted in accordance with the Declaration of Helsinki and regulations of the Health Insurance Portability and Accountability Act. As this was a retrospective study and all patient information was deidentified before analysis, informed consent was not required except for patients whose radiological images would be published.

Radiological Measurements

For each patient, anterior–posterior view X-ray examinations of the pelvis and both lower extremities were performed before and after surgery. Computed tomography (CT) scan of both hips was also performed.

Crowe Classification

On the preoperative anterior–posterior X-ray examination images, the Crowe classification[25] was determined by the ratio between the femoral head subluxation height and the femoral head diameter. Grade 1: subluxation <50%; Grade 2: subluxation = 50%–74%; Grade 3: subluxation = 75%–100%; Grade 4: subluxation >100% (complete dislocation). Crowe classification was used to evaluate the subluxation height of femoral head in patients with DDH.

Neck–shaft Angle

The neck–shaft angle was defined as the angle between the femoral neck axis and the femoral shaft axis[11]. The neck–shaft angle was measured on the preoperative coronal view of CT scans. The neck–shaft angle (as well as anteversion, canal flare index, Dorr classification, and cortical index) was used to describe the morphological characteristic of proximal femur.

Anteversion

The anteversion was defined as the angle between the femoral neck axis and thetransepicondylar axis on axial view of CT scans[11]. The anteversion was measured on the preoperative axial view of CT scans.

Canal Flare Index and Dorr Classification

Canal flare index (CFI) was defined as the ratio of the canal diameter 20 mm above the level of the lesser trochanter midpoint and the canal diameter at the level of the isthmus. According to the range of CFI, Dorr classified the proximal femoral medullary canal into three types[26]: Type A: CFI > 4.7; Type B: CFI = 3.0–4.7; Type C: CFI < 3.0.

Cortical Index

The cortical index was recorded on preoperative anterior–posterior X-ray examination images as the quotient of femoral diaphysis width (DW) minus intramedullary width (MW) divided by DW 10 cm distal to the lesser trochanter[27].

Retained Femoral Neck Length

The retained femoral neck length was defined as the shortest distance between the middle point of the osteotomy line and the intertrochanteric line on the postoperative anterior–posterior X-ray examination images[28,29]. Retained femoral neck length reflects the proximal femoral osteotomy level, and might affect the incidence of intraoperative periprosthetic femoral fractures.

All radiological measurements were performed by one experienced surgeon. To test the intraclass coefficient (ICC), we randomly selected 20 patients and repeated the radiological measurements with a 2-week interval. The results showed good reliability, with all ICCs >0.9.

Surgical Procedure

All surgeries were performed by the same group of experienced surgeons. The approaches and prostheses were decided by the surgeon. Most of the patients received their surgeries via a posterior approach. The surgical process was described briefly as follows: after the initial incision was made, the hip joint was exposed and dislocated. Then, the osteotomy was performed. Next, the femoral head was removed and the acetabulum component was implanted. After preparation of the medullary canal, the femoral stem was inserted with proper anteversion. Finally, the joint was reduced.

The femoral components chosen for this study included TriLock from DePuy, S-Rom from DePuy, Link

Classic Uncemented from LINK, and M/L Taper from Zimmer. To evaluate the potential impact on periprosthetic femoral fractures, these femoral components were classified according to the design of the stem. These included fixation segments (metaphyseal fixation, metaphyseal-diaphyseal fixation, and diaphyseal fixation), anteversion designs (e.g. Ribbed Stem from LINK), and modular designs with adjustable anteversion (e.g. S-Rom from DePuy).

Outcomes of Interest

Intraoperative fracture involving any part of the ipsilateral femur was considered a periprosthetic fracture. Intraoperative periprosthetic femoral fractures could be identified either during the surgical process or on radiological examination immediately after surgery. According to the fracture status, the patients were divided into two groups: the fracture group and the non-fracture group.

Vancouver Classification

The intraoperative periprosthetic femoral fractures were classified according to the Vancouver[30,31] classification system. Type A: fractures of the trochanteric region; stem stable (Type A-G: fracture of the greater trochanter; Type A-L: fracture of the lesser trochanter). Type B: fractures around or just distal to the stem (Type B1: stem stable; Type B2: stem loose, good bone stock; Type B3: stem loose, poor bone stock). Type C: fractures well distal to the stem; stem stable. Vancouver classification was commonly used, which helped determine the stability of intraoperative periprosthetic femoral fractures.

Statistical Analysis

Excel 2016 for Windows (Microsoft Corporation, Seattle, WA, USA) and SPSS 19.0 statistical software for Windows (IBM, Armonk, NY, USA) were used for the statistical analyses. Continuous variables are expressed as the mean ± SD. Categorical variables are expressed as frequencies. Student's t test was performed if the data followed a normal distribution. Otherwise, the Mann–Whitney U test was performed for comparisons between continuous variables. The chi-square test was performed for comparisons between categorical variables. A multivariate logistic regression model was built to identify the potential risk factors for intraoperative periprosthetic femoral fractures. A stepwise regression method was used. A P-value less than 0.05 was considered to be statistically significant.

Results

Overall Incidence and Classification

A total of 1252 hips were finally included in the current study. Among all 1252 hips, intraoperative periprosthetic femoral fractures were identified in 62 hips. The overall incidence of intraoperative periprosthetic femoral fracture was 4.95%. The incidence and classification of periprosthetic femoral fractures are shown in Table 1.

Vancouver Classification

Most of the periprosthetic femoral fractures were classified as Vancouver Type B ($n = 38$, incidence = 3.04%, proportion = 61.29%), followed by Vancouver Type A ($n = 22$,

TABLE 1 General information on patients with hip dysplasia undergoing total hip arthroplasty					
Patient characteristics	Patients without intraoperative periprosthetic femoral fractures ($n = 1190$)	Patients with intraoperative periprosthetic femoral fractures ($n = 62$)	Total ($n = 1252$)	Statistics value	P
Sex (n, [%])				1.432[*]	0.231
Male	199 (16.72)	14 (22.58)	213 (17.01)		
Female	991 (83.28)	48 (77.42)	1039 (82.99)		
Age (years)	50.04 ± 17.65	57.05 ± 17.66	50.39 ± 17.71	−2.997[*]	0.003
Body Mass Index (kg/m²)	25.34 ± 5.50	25.71 ± 4.74	25.36 ± 5.46	−0.609[*]	0.543
Smoking (n, [%])				1.856[†]	0.173
No	1124 (94.45)	56 (90.32)	1180 (94.25)		
Yes	66 (5.55)	6 (9.68)	72 (5.75)		
Alcohol Consumption (n, [%])				1.551[†]	0.213
No	1052 (88.40)	58 (93.55)	1110 (88.66)		
Yes	138 (11.60)	4 (6.45)	142 (11.34)		
Osteoporosis (n, [%])				28.390[†]	<0.001
No	990 (83.19)	35 (56.45)	1025 (81.87)		
Yes	200 (16.81)	27 (43.55)	227 (18.13)		
Previous surgical treatment (n, [%])				27.184[†]	<0.001
No	1104 (92.77)	46 (74.19)	1150 (91.85)		
Yes	86 (7.23)	16 (25.81)	102 (8.15)		

[*] Mann–Whitney U test.; [†] chi-square test.

PERIPROSTHETIC FRACTURES IN DDH PATIENTS

TABLE 2 Results of radiological measurements in patients with hip dysplasia undergoing total hip arthroplasty

Patient characteristics	Patients without intraoperative periprosthetic femoral fractures (n = 1190)	Patients with intraoperative periprosthetic femoral fractures (n = 62)	Total (n = 1252)	Statistics value	P
Crowe Classification (n, [%])				8.550[†]	0.036
Grade 1	459 (38.57)	15 (24.19)	474 (37.86)		
Grade 2	369 (31.01)	18 (29.03)	387 (30.91)		
Grade 3	199 (16.72)	17 (27.42)	216 (17.25)		
Grade 4	163 (13.70)	12 (19.35)	175 (13.98)		
Neck–shaft angle (°)	150.97 ± 10.59	147.19 ± 11.78	150.78 ± 10.68	−2.531[*]	0.011
Anteversion (°)	17.51 ± 4.35	16.82 ± 4.36	17.48 ± 4.35	−1.147[*]	0.251
Canal flare index	3.91 ± 0.83	4.03 ± 0.98	3.92 ± 0.83	−0.953[*]	0.341
Dorr classification (n, [%])				8.259[†]	0.016
A (CFI >4.7)	254 (21.34)	22 (35.48)	276 (22.04)		
B (CFI 3.0–4.7)	736 (61.85)	28 (45.16)	764 (61.02)		
C (CFI <3.0)	200 (16.81)	12 (19.35)	212 (16.93)		
Cortical index	0.66 ± 0.08	0.65 ± 0.08	0.66 ± 0.08	−0.791[*]	0.429
Retained femoral neck length (mm)	11.38 ± 3.16	12.68 ± 4.33	11.45 ± 3.24	−2.527[*]	0.012

CFI, canal flare index.; [*] Mann–Whitney U test.; [†] chi-square test.

incidence = 1.76%, proportion = 35.48%). Only two patients (n = 2, incidence = 0.08%, proportion = 3.23%) were identified with Vancouver Type C fractures. Stratified by subtype, there were five patients (proportion = 8.06%) with Type A-L fractures, 17 patients (proportion = 27.42%) with Type A-G fractures, 25 patients (proportion = 40.32%) with Type B1 fractures, 12 patients (proportion = 19.35%) with Type B2 fractures, one patient (proportion = 1.61%) with Type B3 fractures, and two patients (proportion = 3.23%) with Type C fractures.

Demographic and General Information
In the non-fracture group, there were 199 hips from males and 991 hips from females, while in the fracture group, there were 14 hips from males and 48 hips from females (χ^2 = 1.432, P = 0.231). The average age in the non-fracture group was significantly lower than that in the fracture group (50.04 ± 17.65 years vs 57.05 ± 17.66 years, Z = 2.997, P = 0.003). No difference was found regarding the BMI of the patients (25.34 ± 5.50 vs 25.71 ± 4.74, Z = 0.609, P = 0.543). No significant differences were found regarding smoking (χ^2 = 1.856, P = 0.173) or alcohol status (χ^2 = 1.551, P = 0.213) between the two groups. Compared to the patients without periprosthetic femoral fractures, those who suffered from periprosthetic femoral fractures were more likely to have osteoporosis (χ^2 = 28.390, P < 0.001). A total of 102 patients had a previous surgical history of ipsilateral hip, including periacetabular osteotomy, proximal femoral osteotomy, and both. The proportion of previous surgical history was different between the two groups

(χ^2 = 27.184, P < 0.001). The demographic and general information of all the patients is shown in Table 2.

Radiological Measurements
Five parameters regarding the anatomical characteristics of the proximal femur and one surgical procedure parameter were investigated to demonstrate their potential impact on periprosthetic femoral fractures (Table 3).

Crowe Classification
The proportions for each Crowe type between the two groups were different (χ^2 = 8.550, P = 0.036). There were 459 (38.57%) Grade 1 hips, 369 (31.01%) Grade 2 hips, 199 (16.72%) Grade 3 hips, and 163 (13.70%) Grade 4 hips in the non-fracture group. There were 15 (24.19%) Grade 1 hips, 18 (29.03%) Grade 2 hips, 17 (27.42%) Grade 3 hips, and 12 (19.35%) Grade 4 hips in the fracture group.

Neck–shaft Angle
The average neck–shaft angle was 3.78° lower in the fracture group than that in the non-fracture group (150.97° ± 10.59° vs 147.19° ± 11.78°), and there was significant difference in the two groups (Z = 2.531, P = 0.011).

Anteversion
The anteversion angle was 17.51° ± 4.35° in the non-fracture group and 16.82° ± 4.36° in the fracture group. No significant differences were found between the two groups regarding anteversion (Z = 1.147, P = 0.251).

TABLE 3 Characteristics of the surgical procedure in patients with hip dysplasia undergoing total hip arthroplasty

Patient characteristics	Patients without intraoperative periprosthetic femoral fractures ($n = 1190$)	Patients with intraoperative periprosthetic femoral fractures ($n = 62$)	Total ($n = 1252$)	Statistics value	P
Approach (n, [%])				0.010[†]	0.919
Posterior	1117 (93.87)	58 (93.55)	1175 (93.85)		
Anterior	73 (6.13)	4 (6.45)	77 (6.15)		
Femoral stem fixation segment (n, [%])				19.888[†]	<0.001
Metaphyseal	542 (45.55)	11 (17.74)	553 (44.17)		
Metaphyseal-diaphyseal	582 (48.91)	48 (77.42)	630 (50.32)		
Diaphyseal	66 (5.55)	3 (4.84)	69 (5.51)		
Anteversion design of stem (n, [%])				29.229[†]	<0.001
No	1099 (92.35)	45 (72.58)	1144 (91.37)		
Yes	91 (7.65)	17 (27.42)	108 (8.63)		
Modular stem with adjustable anteversion (n, [%])				0.057[†]	0.812
No	1124 (94.45)	59 (95.16)	1183 (94.49)		
Yes	66 (5.55)	3 (4.84)	69 (5.51)		
Femoral osteotomy (n, [%])				0.032[†]	0.859
No	1174 (98.66)	61 (98.39)	1235 (98.64)		
Yes	16 (1.34)	1 (1.61)	17 (1.36)		

[†] chi-square test.

Canal Flare Index and Dorr Classification
In terms of the CFI, no statistically significant difference was found between the two groups (3.91 ± 0.83 vs 4.03 ± 0.98, $Z = 0.953$, $P = 0.341$). However, the proportions for each type of Dorr classification were different ($\chi^2 = 8.259$, $P = 0.016$). In the non-fracture group, 254 (21.34%) Type A hips, 736 (61.85%) Type B hips, and 200 (16.81%) Type C hips were identified. In the fracture group, there were 22 (35.48%) Type A hips, 28 (45.16%) Type B hips, and 12 (19.35%) Type C hips.

Cortical Index
The cortical index was 0.66 ± 0.08 in the non-fracture group and 0.65 ± 0.08 in the fracture group. No significant differences were found between the two groups regarding cortical index ($Z = 0.791$, $P = 0.429$).

Retained Femoral Neck Length
In the fracture group, there was a significantly higher retained femoral neck length than in the non-fracture group (11.68 ± 4.33 vs 11.38 ± 3.16), and there was significant difference in the two groups ($Z = 2.527$, $P = 0.012$).

Characteristics of the Surgical Procedure
Because of the potential impact on periprosthetic fractures, surgical procedures for these patients were also investigated. For both groups, most patients received hip arthroplasty via the posterior approach (1117/1190 vs 58/62, $\chi^2 = 0.010$, $P = 0.919$). The anterior approach was performed in only 73 hips in the non-fracture group and four hips in the

fracture group. The implanted femoral components were classified by three characteristics. Stratified by the stem fixation segment, the proportion of metaphyseal–diaphyseal fixation stem was significantly higher in the fracture group than in the non-fracture group ($\chi^2 = 19.888$, $P < 0.001$). The anteversion design of the stem was also found to influence the incidence of periprosthetic fractures. The proportion of stems with the anteversion design was significantly higher in the fracture group than in the non-fracture group ($\chi^2 = 29.229$, $P < 0.001$). However, implantation of modular stems with adjustable anteversion seemed to have no influence on periprosthetic fractures ($\chi^2 = 0.057$, $P = 0.812$). Femoral osteotomy was performed on 17 hips, but no significant difference was found between the two groups ($\chi^2 = 0.032$, $P = 0.859$). The characteristics of the surgical procedure are shown in Table 4.

Independent Risk Factors
Six independent risk factors for intraoperative periprosthetic femoral fractures were identified via multivariate logistic regression. Among them, three factors were patient-related, and the other three factors were surgery-related. Osteoporosis ($OR = 3.434$; 95% CI, 1.963–6.007) and previous surgical history ($OR = 4.797$; 95% CI, 2.446–9.410) were risk factors for periprosthetic femoral fractures. In terms of the Dorr classification, compared to Type B patients, patients who were classified as Dorr Type A were more likely to experience a periprosthetic femoral fracture ($OR = 3.025$; 95% CI, 1.594–5.738). Retained femoral neck length was another risk factor related to the surgical process. With every

PERIPROSTHETIC FRACTURES IN DDH PATIENTS

TABLE 4 Independent risk factors for periprosthetic femoral fractures in patients with hip dysplasia undergoing total hip arthroplasty

Risk factor (independent)	Odds ratio	95% Confidential interval	P
Osteoporosis			
No (ref.)			
Yes	3.434	1.963–6.007	<0.001
Previous surgical treatment			
No (ref.)			
Yes	4.797	2.446–9.410	<0.001
Dorr classification			
Type B (ref.)			
Type A	3.025	1.594–5.738	0.001
Type C	1.427	0.685–2.973	0.343
Retained femoral neck length (mm)	1.121	1.043–1.204	0.002
Femoral stem fixation segment			
Metaphyseal (ref.)			
Metaphyseal-diaphyseal	3.208	1.562–6.591	0.002
Diaphyseal	1.685	0.428–6.631	0.455
Anteversion design of stem			
No (ref.)			
Yes	2.916	1.473–5.770	0.002

Only variables in the equation are shown in the table.

additional millimeter increase in retained femoral neck length, the possibility of periprosthetic femoral fracture increased by 12.1% ($OR = 1.121$; 95% CI, 1.043–1.204). The design of the femoral component also influenced periprosthetic femoral fractures. Compared with patients who were implanted with metaphyseal fixation stems, patients with metaphyseal–diaphyseal fixation stems suffered a 3.208-fold higher possibility of periprosthetic femoral fractures ($OR = 3.208$; 95% CI, 1.562–6.591). The anteversion design of the stem also increased the incidence of periprosthetic femoral fractures ($OR = 2.916$; 95% CI, 1.473–5.770). The independent risk factors for intraoperative periprosthetic femoral fractures are summarized in Table 5.

The final logistic regression equation was as follows:

$$Y = -6.241 + 1.234 \times X1 + 1.568 \times X2 + 1.107 \times X3 + 0.114 \times X4 + 1.166 \times X5 + 1.070 \times X6$$

$X1$, Osteoporosis; $X2$, Previous Surgical Treatment; $X3$, Dorr Classification (Type A); $X4$, Retained Femoral Neck Length (mm); $X5$, Femoral Stem Fixation Segment (Metaphyseal-Diaphyseal); $X6$, Anteversion Design of Stem.

The covariate was assigned 0 if it was a reference value. Otherwise, the covariate was assigned 1 in the regression equation.

Discussion

Incidence and Classifications of Intraoperative Periprosthetic Femoral Fractures

The overall incidence of intraoperative periprosthetic femoral fractures in this study was 4.95%. This is at a moderate level compared to some other studies[30,32,33]. Similar to our incidence, Ohly et al.[32] reported that the prevalence of intraoperative periprosthetic femoral fractures was 5.4%, and Li et al.[33] reported that the prevalence was up to 10%. In these studies, most intraoperative periprosthetic femoral fractures were classified as Vancouver Type A and Type B. Similar regularity was also found in our study, which means that nearly all of the intraoperative periprosthetic femoral fractures were classified as Vancouver Type A and Type B. These two types consisted of 96.77% of all intraoperative periprosthetic femoral fractures. This finding indicates that even though the anatomical features of the hip joint are quite different in patients with DDH, some incident mechanisms of periprosthetic femoral fractures are similar. For example, implanting an over-sized femoral stem might cause a periprosthetic femoral fracture at the stem level (Vancouver Type B).

Risk Factors for Intraoperative Periprosthetic Femoral Fracture

There are some risk factors in common in both normal patients and DDH patients. However, we also found some unique risk factors that could only be identified in patients with DDH. These findings help distinguish our study from previous studies[30,34]. In this study, a total of six independent risk factors were identified. The first one was osteoporosis (Fig. 1). It has already been well-established that osteoporosis is closely related to trabecular structure changes and bone strength decreases[11,21]. This bone strength decrease might result in failure of the stem press-fit[28]. In this situation, an over-sized femoral component might be incorrectly chosen by surgeons to achieve stable fixation, causing a periprosthetic fracture[11]. Similarly, Lindberg et al.[35] reported that elderly females with moderate to severe osteoporosis

PERIPROSTHETIC FRACTURES IN DDH PATIENTS
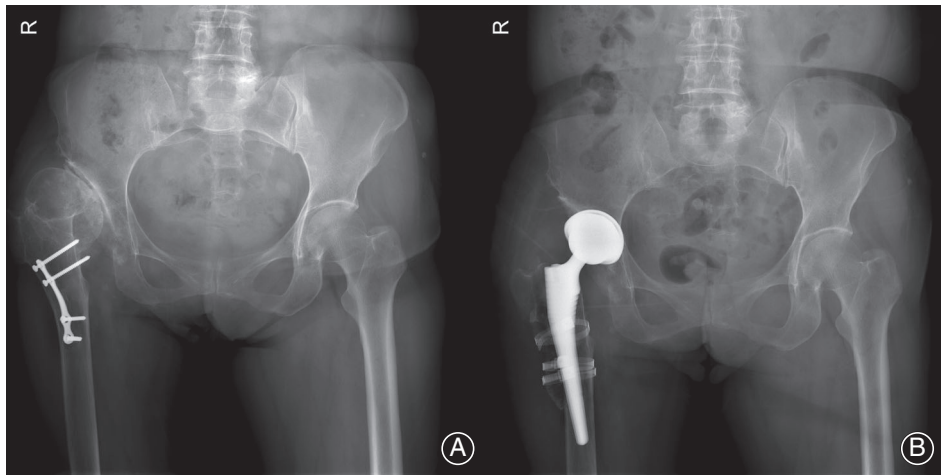
Fig. 1 (A) A 67-year-old female patient with developmental dysplasia of her right hip (Crowe Type IV). She had undergone a proximal femoral osteotomy 21 years ago. She was also diagnosed with osteoporosis 5 years ago (T-score = −2.9). The radiological exam revealed that the femoral cortical bone on the right side was significantly thinner than that on left side. (B) The patient received unilateral total hip arthroplasty (right side). A postoperative radiograph revealed a Vancouver B2 periprosthetic femoral fracture. The previous surgical history and the osteoporosis were the potential reasons for this periprosthetic femoral fracture.

had a certain risk for periprosthetic femoral fracture. Liu et al.[11] also found that decreased bone mineral density is closely related to the occurrence of periprosthetic femoral fractures. Therefore, for patients with osteoporosis, surgeons should be careful during the surgical process to avoid the use of violent surgical manoeuvres[11]. Alternatively, some anti-osteoporosis drugs might be utilized before surgery to improve the trabecular structure and bone strength[34]. These factors might help reduce the incidence of periprosthetic femoral fractures.

A previous surgical history of the ipsilateral hip joint was also a risk factor in our study (Fig. 1). In patients with DDH, the common previous surgical treatments included periacetabular osteotomy, proximal femoral osteotomy (in some cases, combined with internal fixation implantation), and open reduction[1,8]. A previous surgical history might change the normal anatomical structure of the soft tissue around the hip joint[27]. As a consequence, difficulties might be found during the process of acetabular and femoral exposure[27]. A previous surgical history was also associated with bone remodeling, bone loss, or even osteolysis around the surgical site[29]. In particular, proximal femoral osteotomy changes the normal structure of the medullary canal, making it difficult to perform canal identification, drilling, and prosthetic insertion[35]. All these factors might increase the incidence of intraoperative periprosthetic femoral fracture. Several studies have also found similar phenomena. Zhang et al.[27] reported that a previous surgical history is related to an increased incidence of periprosthetic femoral fracture. Liu et al.[11] also found that individuals with a surgical history had an approximately 3-fold increased risk of periprosthetic femoral fracture.

Another risk factor associated with intraoperative periprosthetic femoral fracture is the morphological features of the proximal femoral medullary canal. However, we did not find correlations between the canal flare index and the occurrence of periprosthetic femoral fracture. We did observe a nearly 3-fold increased fracture risk for patients with Dorr Type A canals (Fig. 2) compared to those with Dorr Type B canals. This may be related to the statistical method we used because the canal flare index is a continuous variable. According to the range of the canal flare index, Dorr classified the morphological features of the proximal femoral medullary canal into three types. Dorr Type B canals are the most common type[11]. However, in contrast to our study, Gromov et al.[34] reported that Dorr Type C canals are related to a 5.2-fold increased incidence of periprosthetic femoral fractures. Nash[36] also reported that compared with patients with Dorr Type A canals, those with Dorr Type B and Type C canals are at higher risk of periprosthetic femoral fracture. They explained that this phenomenon might be a consequence of correlations between osteoporosis and Dorr type: osteoporosis and poor bone quality might be associated with Dorr-type femurs, and the finding that advanced age and osteoporosis are risk factors for periprosthetic fracture may reflect the reduced cortical thickness indices and the lower Dorr type (Dorr Type B and especially Dorr Type C)[34,36]. However, in our study, all these patients were diagnosed with DDH. Therefore, a narrowed diaphyseal canal diameter might commonly be identified in these patients[5,37−39]. This narrowed diaphyseal canal diameter might affect the Dorr type of patients. Meanwhile, a narrowed diaphyseal canal diameter might be difficult when implanting the femoral stem,
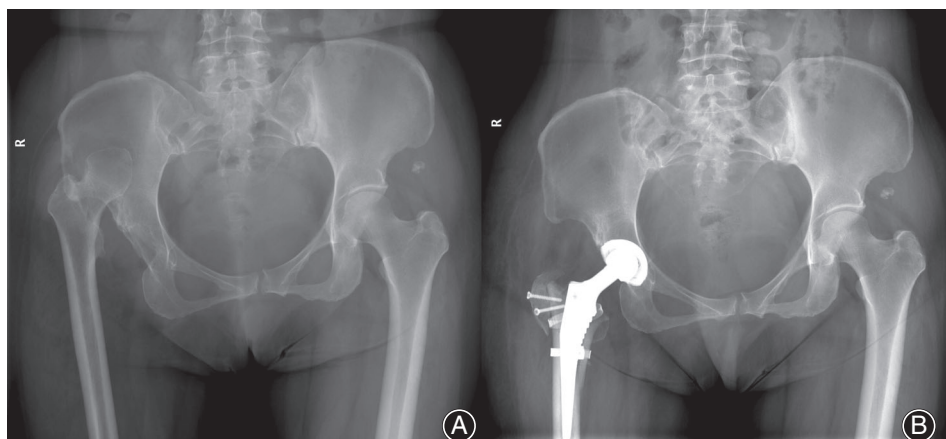
Fig. 2 (A) A 53-year-old female patient with developmental dysplasia of her right hip (Crowe Type IV). The patient had a Dorr Type A canal (Canal Flare Index = 4.9) on the affected side. (B) The patient received unilateral total hip arthroplasty (right side). A postoperative radiograph revealed a Vancouver B2 periprosthetic femoral fracture. The special medullary cavity morphology (Dorr Type A) was considered to be the cause of this periprosthetic femoral fracture.
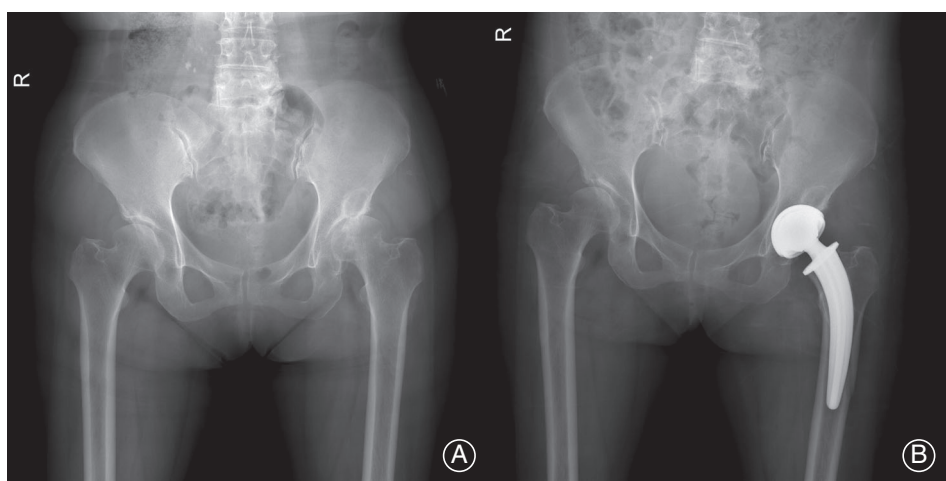
Fig. 3 (A) A 57-year-old female patient with developmental dysplasia of her left hip (Crowe Type I). (B) The patient received unilateral total hip arthroplasty (left side). The retained femoral neck length (the shortest distance between the midpoint of the retained femoral neck and the intertrochanteric line) was 25.6 mm. A postoperative radiograph revealed a Vancouver B1 periprosthetic femoral fracture. The excessive retained femoral neck length, as well as the using of a stem with anteversion design, were considered to be the cause of this periprosthetic femoral fracture.

leading to the occurrence of periprosthetic femoral fractures[11]. This might be the reason that Dorr Type A canals were a risk factor for intraoperative periprosthetic femoral fracture in this study.

There are another three risk factors related to surgery. The first one is the retained femoral neck length (Fig. 3). For most femoral components, the standard osteotomy level (retained neck length) is located 1–1.5 cm superior to the less trochanter. This helps preserve some calcar bone and maintain the correct position of the stem[29]. However, abnormal morphological features of the proximal femur could commonly be identified in patients with DDH[8,29,40]. For example, an increased neck–shaft angle and over-anteversion were observed. When a standard femoral component is implanted into a proximal femur with an increased neck–shaft angle and over-anteversion, a mismatch between the femoral component and proximal femur might be identified, causing an occurrence of intraoperative periprosthetic femoral fracture[7]. Hence, an appropriate decrease in retained femoral neck length might help eliminate the effect of abnormal anatomical changes in the proximal femur in patients with DDH[6]. In other words, the femoral neck should be removed

completely when a "standard" femoral component is implanted. Otherwise, the femoral component with diaphyseal fixation and adjustable anteversion should be considered[16].

The fixation segment of the femoral stem was also investigated in this study. According to the press-fit level at the proximal femur and the length of the stem, the femoral stem could be generally divided into three groups[41]. The first kind is metaphyseal fixation stems, such as TriLock from DePuy and M/L Taper from Zimmer. These stems are commonly designed with a proximal spray coating and relatively short stem length[41]. The second kind is the metaphyseal–diaphyseal fixation stem. These stems have been widely used in the past several decades. For example, Corail from DePuy is a classic femoral component designed with full-coating hydroxyapatite and a standard stem length[41]. The last kind is the stem characterized as diaphyseal fixation. The stability of these stems is independent of the integrity of the proximal femur[41]. Additionally, these stems are often designed with adjustable anteversion (e.g. S-Rom from DePuy, Wagner Cone from Zimmer). In patients with Crowe Type IV DDH, these stems might be used to overcome the abnormal over-

anteversion of the femoral neck as well as provide distal fixation when proximal femoral osteotomy is performed[16]. We found that compared with patients implanted with a metaphyseal fixation stem, patients implanted with a metaphyseal–diaphyseal fixation stem had a 3.2-fold higher risk of intraoperative periprosthetic femoral fractures. This is probably because most metaphyseal–diaphyseal fixation stems are designed for patients with normal anatomy of the proximal femur[41]. In patients with DDH, the anatomical characteristics of the proximal femur changed. Narrowed diaphyseal canal diameter and increased canal flare index might be commonly identified[5]. In this situation, when a metaphyseal–diaphyseal fixation stem is implanted, metaphyseal–diaphyseal mismatch (Fig. 4) between the stem and patient medullary canal commonly occurs, increasing the incidence of intraoperative periprosthetic femoral fractures[6]. In contrast, when a metaphyseal fixation stem is inserted, due to the contactless design of the distal stem, there is no stress distribution in the diaphyseal part of the femur[6]. Therefore, the incidence of intraoperative periprosthetic femoral fracture is expected to be decreased.

The last risk factor for intraoperative periprosthetic femoral fractures in patients with DDH is the anteversion design of the stem[6]. This special design is often seen in femoral neck bone-preserving stems (e.g. the ribbed stem from LINK and the collum femoris preserving stem from LINK, Figs 3 and 5). It helps the femoral component to be successfully inserted into the proximal femoral medullary canal[11]. However, in patients with DDH, over-anteversion of the femoral neck is commonly identified (e.g. $17.48° \pm 4.35°$ in this study). The mismatch of the anteversion between the prosthesis and the patient's proximal femur anatomy might cause intraoperative periprosthetic femoral fractures[16].

According to the previous discussion, we provide advice for preventing intraoperative periprosthetic femoral fractures in patients with DDH undergoing THA. First, for patients with serious osteoporosis and previous surgical treatment (especially proximal femoral osteotomy, which

Fig. 4 (A) A 25-year-old female patient with bilateral developmental dysplasia of the hip (Crowe Type IV). (B) The patient received bilateral total hip arthroplasty. A postoperative radiograph revealed periprosthetic femoral fractures on both sides. There was a Vancouver Type A fracture on the left side and a Vancouver Type B fracture on the right side. Metaphyseal–diaphyseal mismatch between the stem and patient medullary canal might be the potential cause of the fractures.
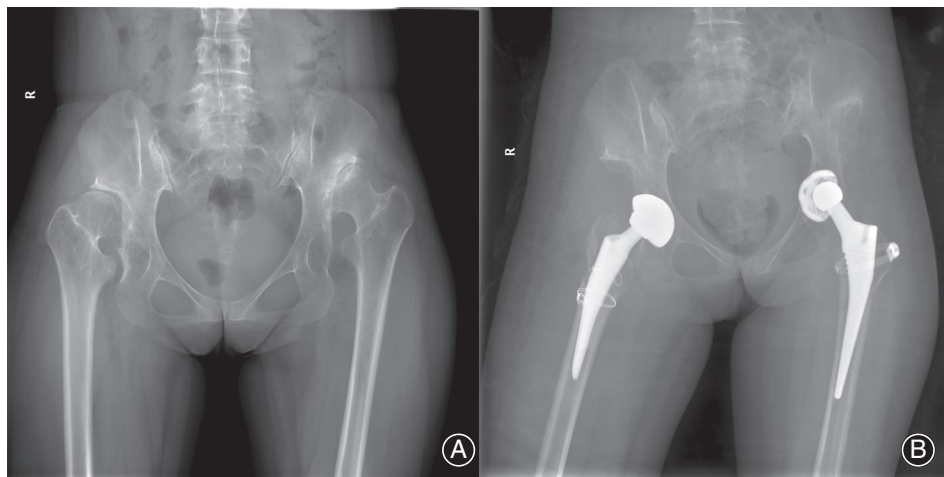
Fig. 5 (A) A 36-year-old female patient with bilateral developmental dysplasia of the hip (Crowe Type IV). (B) The patient received bilateral total hip arthroplasty. A postoperative radiograph revealed a Vancouver A periprosthetic femoral fracture (left side). On this side, a ribbed stem was used. The anteversion design of the stem might influence the occurrence of a periprosthetic femoral fracture.
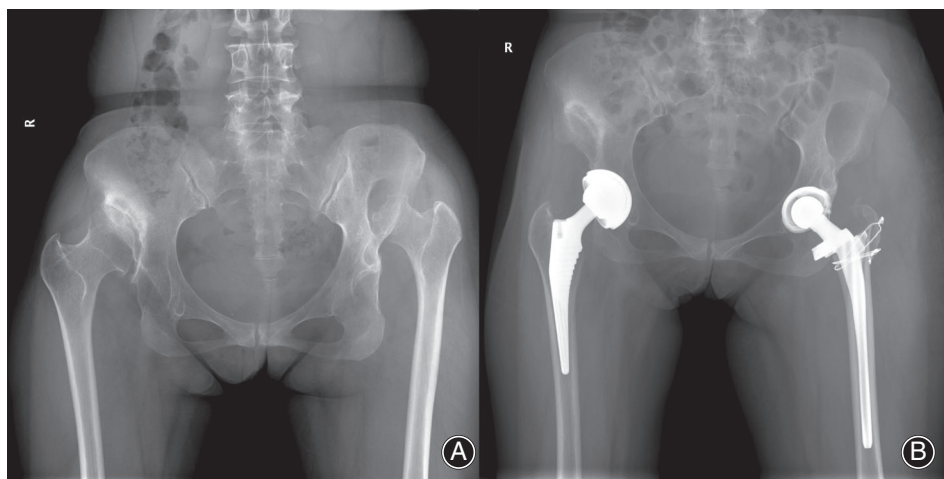
could change the normal anatomical features of the proximal femur), thorough soft tissue release and gentle manipulation (particularly when preparing the medullary canal) should be performed during surgery to prevent periprosthetic femoral fractures. Anti-osteoporosis drugs could also be used to improve bone strength. Second, when a Dorr Type A canal with a narrowed diaphyseal canal diameter is identified, a metaphyseal fixation stem should be chosen to prevent potential metaphyseal–diaphyseal mismatches. Finally, completely removing the deformed femoral neck and implanting the femoral component without an anteversion design might also help reduce the occurrence of intraoperative periprosthetic femoral fractures.

Limitations

There are some limitations of our study. First, as a single-centre study with all surgeries performed by the same group of surgeons, the effect of the surgical skills of surgeons could not be evaluated. Second, some anatomical and geometric characteristics of the proximal femur were measured on standard X-ray images. Therefore, the projection position might have an effect on the measurement accuracy. Third, the Crowe classification, as well as the femoral osteotomy performing during surgery, might have a potential impact on the occurrence of periprosthetic femoral fractures in patients with DDH. However, the proportions of each Crowe type were different between patients with and without periprosthetic femoral fractures. In this study, these two factors were not found to be independent risk factors for periprosthetic femoral fractures. This may be due to the collinearity between the variables. Alternatively, the limited sample size might have also contributed to the failure to detect these potential risk factors. Finally, this study focused only on the risk factors for intraoperative periprosthetic femoral fractures, while the treatment and prognosis of patients were not investigated.

Conclusion

The current study showed that the incidence of intraoperative periprosthetic femoral fractures in patients with DDH undergoing THA was 4.95%. Six independent risk factors were identified: osteoporosis, previous surgical history, Dorr Type A canal, insufficient neck osteotomy level, implantation of metaphyseal–diaphyseal fixation stem, and implantation of a stem with an anteversion design. Comprehending these risk factors might help surgeons prevent the occurrence of these intraoperative periprosthetic femoral fractures in patients with DDH.

Authorship Declaration

All authors listed meet the authorship criteria according to the latest guidelines of the International Committee of Medical Journal Editors, and all authors are in agreement with the manuscript.

References

1. Loder RT, Skopelja EN. The epidemiology and demographics of hip dysplasia. ISRN Orthop, 2011, 2011: 238607.
2. Woodacre T, Ball T, Cox P. Epidemiology of developmental dysplasia of the hip within the UK: refining the risk factors. J Child Orthop, 2016, 10: 633–642.
3. Nelson SE, DeFrancesco CJ, Sankar WN. Operative reduction for developmental dysplasia of the hip: epidemiology over 16 years. J Pediatr Orthop, 2019, 39: e272–e277.
4. Wyles CC, Heidenreich MJ, Jeng J, Larson DR, Trousdale RT, Sierra RJ. The John Charnley award: redefining the natural history of osteoarthritis in patients with hip dysplasia and impingement. Clin Orthop Relat Res, 2017, 475: 336–350.
5. Kotlarsky P, Haber R, Bialik V, Eidelman M. Developmental dysplasia of the hip: what has changed in the last 20 years. World J Orthop, 2015, 6: 886–901.
6. Shi XT, Li CF, Han Y, Song Y, Li SX, Liu JG. Total hip arthroplasty for Crowe Type IV hip dysplasia: surgical techniques and postoperative complications. Orthop Surg, 2019, 11: 966–973.
7. Sun C, Zhang Y, Li LT, Ding H, Guo T, Zhao JN. Long-term outcomes of Total hip arthroplasty with transverse subtrochanteric shortening osteotomy and modular stem in Crowe IV developmental dysplasia. J Arthroplasty, 2021, 36: 630–635.
8. Barton C, Scott E, Khazi ZM, Willey M, Westermann R. Outcomes of surgical Management of Borderline hip Dysplasia: a systematic review. Iowa Orthop J, 2019, 39: 40–48.
9. Abdel MP, Watts CD, Houdek MT, Lewallen DG, Berry DJ. Epidemiology of periprosthetic fracture of the femur in 32 644 primary total hip arthroplasties: a 40-year experience. Bone Joint J, 2016, 98: 461–467.
10. Hong CC, Nashi N, Tan JH, Manohara R, Lee WT, Murphy DP. Intraoperative periprosthetic femur fracture during bipolar hemiarthroplasty for displaced femoral neck fractures. Arch Orthop Trauma Surg, 2018, 138: 1189–1198.
11. Liu B, Ma W, Li H, Wu T, Huo J, Han Y. Incidence, classification, and risk factors for intraoperative Periprosthetic femoral fractures in patients undergoing Total hip arthroplasty with a single stem: a retrospective study. J Arthroplasty, 2019, 34: 1400–1411.
12. Sloan M, Kamath AF. Capsular augmentation in Colonna arthroplasty for the management of chronic hip dislocation. J Hip Preserv Surg, 2018, 5: 34–38.
13. Terjesen T. Residual hip dysplasia as a risk factor for osteoarthritis in 45 years follow-up of late-detected hip dislocation. J Child Orthop, 2011, 5: 425–431.

14. Shi XT, Cheng CM, Feng CY, Li CF, Li SX, Liu JG. Crowe type iv hip dysplasia treated by THA combined with osteotomy to balance functional leg length discrepancy: a prospective observational study. Orthop Surg, 2020, 12: 533–542.
15. Ding ZC, Zeng WN, Mou P, Liang ZM, Wang D, Zhou ZK. Risk of dislocation after Total hip arthroplasty in patients with Crowe Type IV developmental dysplasia of the hip. Orthop Surg, 2020, 12: 589–600.
16. Yang Y, Yu QP, Wang SL, et al. Outcomes after Total hip arthroplasty using a Cementless S-ROM modular stem for patients with high hip dislocation secondary to hip pyogenic arthritis. Orthop Surg, 2019, 11: 460–466.
17. Sakellariou VI, Christodoulou M, Sasalos G, Babis GC. Reconstruction of the acetabulum in developmental dysplasia of the hip in total hip replacement. Arch Bone Joint Surg, 2014, 2: 130–136.
18. Zuo W, Ma JH, Cui W, Guo WS, Sun W. Comparison of Total hip arthroplasty after two types of failed hip preserving procedures with primary Total hip arthroplasty. Orthop Surg, 2020, 12: 162–169.
19. Maldonado DR, Ortiz-Declet V, Chen AW, et al. Modified shelf Acetabuloplasty endoscopic procedure with allograft for developmental hip dysplasia treatment. Arthrosc Tech, 2018, 7: e779–e784.
20. Lamb JN, Matharu GS, Redmond A, Judge A, West RM, Pandit HG. Risk factors for intraoperative Periprosthetic femoral fractures during primary Total hip arthroplasty. An analysis from the National Joint Registry for England and Wales and the Isle of Man. J Arthroplasty, 2019, 34: 3065–3073.e1.
21. Lee SJ, Yoo JJ, Kim HJ. Cementless Total hip arthroplasty involving trochanteric osteotomy without subtrochanteric shortening for high hip dislocation. Clin Orthop Surg, 2017, 9: 19–28.
22. Musielak B, Idzior M, Jóźwiak M. Evolution of the term and definition of dysplasia of the hip: a review of the literature. Arch Med Sci, 2015, 11: 1052–1057.
23. Gong L, Zhang YY, Yang N, Qian HJ, Zhang LK, Tan MS. Raloxifene prevents early Periprosthetic bone loss for postmenopausal women after Uncemented Total hip arthroplasty: a randomized placebo-controlled clinical trial. Orthop Surg, 2020, 12: 1074–1083.
24. Cosman F, de Beur SJ, LeBoff MS, et al. Clinician's guide to prevention and treatment of osteoporosis. Osteoporos Int, 2014, 25: 2359–2381.
25. Crowe JF, Mani VJ, Ranawat CS. Total hip replacement in congenital dislocation and dysplasia of the hip. J Bone Joint Surg Am, 1979, 61: 15–23.
26. Feyen H, Shimmin AJ. Is the length of the femoral component important in primary total hip replacement. Bone Joint J, 2014, 96: 442–448.

27. Zhang Z, Zhuo Q, Chai W, Ni M, Li H, Chen J. Clinical characteristics and risk factors of periprosthetic femoral fractures associated with hip arthroplasty: a retrospective study. Medicine (Baltimore), 2016, 95: e4751.

28. Hu H, Liu Z, Liu B, *et al*. Comparison of clinical outcomes, radiological outcomes and bone remodeling outcomes between proximal coated single-wedge new stem and full coated dual-wedge classic stem in 1-stage bilateral Total hip arthroplasty. Med Sci Monit, 2020, 26: e921847.

29. Liu Z, Hu H, Liu S, Huo J, Li M, Han Y. Relationships between the femoral neck-preserving ratio and radiologic and clinical outcomes in patients undergoing total-hip arthroplasty with a collum femoris-preserving stem. Medicine (Baltimore), 2019, 98: e16926.

30. Berry DJ. Epidemiology: hip and knee. Orthop Clin North Am, 1999, 30: 183–190.

31. Karam J, Campbell P, Desai S, Hunter M. Periprosthetic proximal femoral fractures in cemented and uncemented stems according to Vancouver classification: observation of a new fracture pattern. J Orthop Surg Res, 2020, 15: 100.

32. Ohly NE, Whitehouse MR, Duncan CP. Periprosthetic femoral fractures in total hip arthroplasty. Hip Int, 2014, 24: 556–567.

33. Li M, Hu Y, Xie J. Analysis of the complications of the collum femoris preserving (CFP) prostheses. Acta Orthop Traumatol Turc, 2014, 48: 623–627.

34. Gromov K, Bersang A, Nielsen CS, Kallemose T, Husted H, Troelsen A. Risk factors for post-operative periprosthetic fractures following primary total hip arthroplasty with a proximally coated double-tapered cementless femoral component. Bone Joint J, 2017, 99: 451–457.

35. Lindberg-Larsen M, Jørgensen CC, Solgaard S, Kjersgaard AG, Kehlet H. Increased risk of intraoperative and early postoperative periprosthetic femoral fracture with uncemented stems. Acta Orthop, 2017, 88: 390–394.

36. Nash W, Harris A. The Dorr type and cortical thickness index of the proximal femur for predicting peri-operative complications during hemiarthroplasty. J Orthop Surg (Hong Kong), 2014, 22: 92–95.

37. Fassihi SC, Lee D, Tran AA, *et al*. Total hip arthroplasty in an adult patient with pelvic dysmorphism, unilateral sacroiliac joint autofusion, and developmental hip dysplasia. Arthroplast Today, 2020, 6: 41–47.

38. Du YQ, Sun JY, Ma HY, Wang S, Ni M, Zhou YG. Leg length balance in Total hip arthroplasty for patients with unilateral Crowe Type IV developmental dysplasia of the hip. Orthop Surg, 2020, 12: 749–755.

39. Zhang Y, Zhang X, Zhou Y. Direct anterior approach: the outlook of Total hip arthroplasty in Crowe Type III-IV hip dysplasia. Orthop Surg, 2020, 12: 1016–1018.

40. Liu ZY, Zhang J, Wu ST, *et al*. Direct anterior approach in Crowe Type III-IV developmental dysplasia of the hip: surgical technique and 2 years follow-up from Southwest China. Orthop Surg, 2020, 12: 1140–1152.

41. Shin YS, Suh DH, Park JH, Kim JL, Han SB. Comparison of specific femoral short stems and conventional-length stems in primary Cementless Total hip arthroplasty. Orthopedics, 2016, 39: e311–e317.