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

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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

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**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. 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. Moreover, female sex, breech presentation, positive family history, and first or second pregnancy were confirmed as risk factors. Nelson et al. suggested that there might be a possible delay in diagnosis of infantile DDH, 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 and secondary hip osteoarthritis can commonly be found. Total hip arthroplasty (THA) with artificial joint prosthesis implantation is nearly the most optimized treatment for these patients. Commonly, DDH patients undergoing THA are expected to be pain-free and reach functional restoration. Sun et al. 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. 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. 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. Abdel et al. investigated a total of 32,444 individuals undergoing THA, and reported that the incidence of intraoperative periprosthetic femoral fractures was 3.0% when uncemented stem was used. 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. 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. 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. Otherwise, early aseptic loosening might commonly occurred, which could eventually result in treatment failure.

As previously described, 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. Coxa valga deformity (a change in the neck–shaft angle), increased anteversion degrees, and narrowed diaphyseal canal diameter are commonly identified in patients with DDH. These pathoanatomical changes might eventually affect the implantation of femoral components. Nevertheless, most femoral components are designed for patients without these pathoanatomical changes. 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. 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.

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. 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. 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.

**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.

**Patients and Methods**

**Orthopaedic Surgery**

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**PERIPROSTHETIC FRACTURES IN DDH PATIENTS**
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, 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 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 axis11, 24, 25. The neck–shaft angle was measured on the preoperative coronal view of CT scans. The neck–shaft angle (as well as anteverision, canal flare index, Dorr classification, and cortical index) was used to describe the morphological characteristic of proximal femur.

Anteverision
The anteverision was defined as the angle between the femoral neck axis and the transepicondylar axis on axial view of CT scans11. The anteverision 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 ischium. According to the range of CFI, Dorr classified the proximal femoral medullary canal into three types26: 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 trochanter27.

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. 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 anteverision. 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 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,
incidence = 1.76%, proportion = 35.48%). Only two patients \( (n = 2) \) in the fracture group had lower in the fracture group (150.97 \pm 10.59 \degree vs 147.19 \pm 11.78 \degree, \( Z = 2.527, P = 0.011 \)). The average age in the non-fracture group (17.65 years) was significantly lower than that in the fracture group (17.76 years, \( Z = 2.997, P = 0.003 \)). No difference was found between the two groups (\( Z = 2.531, P = 0.036 \)). 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. No significant differences were found regarding smoking (\( \chi^2 = 1.856, P = 0.173 \)) or alcohol status (\( \chi^2 = 1.551, P = 0.213 \)) 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 (\( \chi^2 = 28.390, P < 0.001 \)). 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 (\( \chi^2 = 27.184, P < 0.001 \)). 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 (\( \chi^2 = 8.550, P = 0.036 \)). 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° \pm 10.59° vs 147.19° \pm 11.78°), and there was significant difference in the two groups (\( Z = 2.531, P = 0.011 \)).

#### Anteversion

The anteversion angle was 17.51° \pm 4.35° in the non-fracture group and 16.82° \pm 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, [%])                       |                                                                           |                                                                       |                  |                  |         |
| Posterior                               | 1117 (93.87)                                                             | 58 (93.55)                                                            | 1175 (93.85)     | 0.010‡           | 0.919   |
| 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 (χ² = 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 the patients were also investigated. For both groups, most patients received hip arthroplasty via the posterior approach (1117/1190 vs 58/62, χ² = 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 (χ² = 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 (χ² = 29.229, P < 0.001). However, implantation of modular stems with adjustable anteversion seemed to have no influence on periprosthetic fractures (χ² = 0.057, P = 0.812). Femoral osteotomy was performed on 17 hips, but no significant difference was found between the two groups (χ² = 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
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, 1.594–5.738). The anteversion design of the stem also increased the incidence of periprosthetic femoral fractures (OR = 1.204; 95% CI, 1.141–1.27). Similarly, Lindberg et al. reported that the prevalence of intraoperative periprosthetic femoral fractures was 5.4%, and Li et al. 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. 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. This bone strength decrease might result in failure of the stem press-fit. In this situation, an over-sized femoral component might be incorrectly chosen by surgeons to achieve stable fixation, causing a periprosthetic fracture. Similarly, Lindberg et al. reported that elderly females with moderate to severe osteoporosis

**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. Similar to our incidence, Ohly et al. reported that the prevalence of intraoperative periprosthetic femoral fractures was 5.4%, and Li et al. 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).

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

| Risk factor (independent) | Odds ratio | 95% Confident interval | P |
|--------------------------|------------|------------------------|---|
| Osteoporosis              | 3.434      | 1.963–6.007            | <0.001 |
| Previous surgical treatment | Yes       | 4.797                  | 2.446–9.410 |
| Dorr classification       |            |                        | <0.001 |
| Type A                   | 3.025      | 1.594–5.738            | 0.001 |
| Type B                   | 1.427      | 0.685–2.973            | 0.343 |
| Retained femoral neck length (mm) | 1.121 | 1.043–1.204 |
| Femoral stem fixation segment |            |                       | 0.002 |
| Metaphyseal (ref.)       |            |                        | 0.002 |
| Metaphyseal-diaphyseal   | 3.208      | 1.562–6.591            | 0.002 |
| Diaphyseal               | 1.685      | 0.429–6.631            | 0.455 |
| Anteversion design of stem | Yes       | 2.916                  | 1.473–5.770 |

Only variables in the equation are shown in the table.
had a certain risk for periprosthetic femoral fracture. Liu et al.\textsuperscript{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\textsuperscript{11}. Alternatively, some anti-osteoporosis drugs might be utilized before surgery to improve the trabecular structure and bone strength\textsuperscript{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\textsuperscript{1,8}. A previous surgical history might change the normal anatomical structure of the soft tissue around the hip joint\textsuperscript{27}. As a consequence, difficulties might be found during the process of aceta
dular and femoral exposure\textsuperscript{27}. A previous surgical history was also associated with bone remodeling, bone loss, or even osteolysis around the surgical site\textsuperscript{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\textsuperscript{15}. All these factors might increase the incidence of intraoperative periprosthetic femoral fracture. Several studies have also found similar phenomena. Zhang et al.\textsuperscript{27} reported that a previous surgical history is related to an increased incidence of periprosthetic femoral fracture. Liu et al.\textsuperscript{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\textsuperscript{11}. However, in contrast to our study, Gromov et al.\textsuperscript{34} reported that Dorr Type C canals are related to a 5.2-fold increased incidence of periprosthetic femoral fractures. Nash\textsuperscript{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)\textsuperscript{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\textsuperscript{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.
leading to the occurrence of periprosthetic femoral fractures. 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. However, abnormal morphological features of the proximal femur could commonly be identified in patients with DDH. 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. 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. 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.

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. 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. The second kind is the stem characterized as diaphyseal fixation. The stability of these stems is independent of the integrity of the proximal femur. 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 stable distal fixation when proximal femoral osteotomy is performed. 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. 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. 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. 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. 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. 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. However, in patients with DDH, over-anteversion of the femoral neck is commonly identified (e.g. 17.48° ± 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.

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
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 peri-prosthetic 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 anteverision design might also help reduce the occurrence of intraoperative peri-prosthetic 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 performed during surgery, might have a potential impact on the occurrence of peri-prosthetic femoral fractures in patients with DDH. However, the proportions of each Crowe type were different between patients with and without peri-prosthetic femoral fractures. In this study, these two factors were not found to be independent risk factors for peri-prosthetic 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 peri-prosthetic femoral fractures, while the treatment and prognosis of patients were not investigated.

**Conclusion**

The current study showed that the incidence of intraoperative peri-prosthetic 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 anteverision design. Comprehending these risk factors might help surgeons prevent the occurrence of these intraoperative peri-prosthetic 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.

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