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The Position and Stability of the Prosthesis in Severely Deformed DDH Artificial Total Hip Replacement

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Objectives: To analyze the correlation of prosthesis position selection during total hip replacement with clinical short and middle-term effects of Crowe III and Crowe IV hip dislocation. **Methods:** Clinical data of 28 cases of dysplasia and dislocation of the hip joint combined with severe osteoarthritis were retrospectively analyzed. During 2-year follow-up, patients were rechecked by imaging regularly to analyze the imaging changes of acetabulum prosthesis position and bone graft fusion. Harris hip score was used to assess the recovery of hip function. The correlation of prosthesis position and short and middle-term effects was analyzed. **Results:** The filling rate of medullary cavity of prosthesis was above 75%. The initial position was fixed and stable. The stability rate of femur-prosthesis interface reached 100%. Compared with pre-replacement, hip function was significantly improved at 6 months post surgery ($p < 0.05$). **Conclusion:** These results indicate that total hip replacement for Crowe III and Crowe IV hip dislocation can effectively reconstruct the acetabulum, recover hip function, and stabilize prosthesis. Total hip replacement is characterized by good filling rate, high stability of femoral prosthesis interface, and stable initial fixation. The clinical repair effect is strongly associated with the position of the prosthesis.

Keywords: Arthroplasty, Replacement, Prosthesis Implantation, Hip Dislocation

Introduction

Hip dysplasia is mainly due to long-term biomechanical abnormalities caused by congenital developmental defects of the acetabulum, which gradually leads to subluxation of the femoral head, degeneration of cartilage in the weight-bearing area, and local necrosis of the femoral head, leading to severe osteoarthritis lesions [1, 2]. Hip dysplasia in adults is mainly due to the continuation of hip dysplasia in infancy and childhood. The reported incidence of such diseases abroad is 0.08% - 0.15%, and the incidence of such diseases in China is about 0.4% [3, 4].

The occurrence and development of the disease can cause severe joint pain and dysfunction. In younger patients it often causes lifelong disability due to severe disease and inability to receive good treatment. The disease is positively correlated with age, so clinical diagnosis of this disease should be made as soon as possible [5]. If the patient fails to receive regular treatment or the repair is not correct in childhood, the hip joint will continue to develop poorly, and hip joint pain and osteoarthritis will occur in adolescence or adulthood. Osteoarthritis patients progress to the advanced stage and develop into Crowe III, Crowe IV adult hip dysplasia. Artificial total hip replacement has a significant effect on pain relief, can effectively preserve joint function and maintain its stability. It is currently the most clinically effective treatment [6].

Crowe classification is mainly based on an evaluation system developed for the evaluation of the patient's total hip replacement repair effect according to the degree of dysplasia. When a patient develops severe osteoarthritis, different Crowe classifications choose different repair methods. The acetabulum of Crowe I and Crowe II patients showed mild developmental dysplasia, and no special treatment was required during treatment. Only general joint replacement was performed. Crowe III and Crowe IV patients are in a more serious condition. The physiological anatomy of the hip joint shows obvious deformity changes, and the treatment operation is complicated and difficult [7, 8].

The acetabular side showed abnormal thickening, tilting, shallowing, reduced diameter, and even the formation of false acetabulum. Changes in the hip joint structure will increase the difficulty of reconstructing the acetabulum and placing the prosthesis during the implementation of total hip replacement. Because of the poor development of the acetabulum, the femoral head has moved up and dislocated, and the posterior upper wall often has defects. When the prosthetic cup of the true acetabulum is placed horizontally during the operation, it cannot completely cover the host bone, and initial placement of the prosthetic cup is insufficient.

In order to better solve the above problems, some scholars have deepened the acetabulum, moved the center of rotation of the hip joint inward, and cut the autogenous femoral head to prepare a bone block in order to complete the structural bone graft and supplement the lack of acetabular bone block. According to Sun et al, deepening the acetabulum as well as femoral shortening has been showed significant good effects in 48 months follow-up of the total hip arthroplasty of Crowe IV patients [9]. Nowadays, autogenous bulk grafting is used to achieve femoral head anatomic cup placement and superolateral bone coverage, however, the treatment outcome often faces lack of graft integration which causes an early failure. Pizarro et al. demonstrated that bulk grafting of the femoral head combining with iliac osteotomy has shown satisfactory clinical and radiological outcomes in Crowe I to III patients [10]. This method effectively complements the missing bones, which is beneficial to restore the physiological anatomical position and mechanical relationship of the normal hip joint. It can also provide more bone reserves to lay the foundation for possible hip revisions in the future.

Structural bone grafts also have shortcomings, however. Complications such as bone graft collapse and bone graft absorption may also occur after surgery, which will affect the repair. The factors for successful treatment are not entirely due to advanced prosthesis placement technology. In our opinion, the operating skills and bone grafting techniques also have a significant impact on the repair success rate. Specially, in patients with advanced stage Crowe III and Crowe IV osteoarthritis hip joints, total hip replacement can be used to reconstruct the hip joint to restore its weight-bearing function and abductor function, effectively eliminating pain and promoting the recovery of walking function [11]. Thus, we aimed in this study, to investigate the correlation of prosthesis position and stability in 28 patients with Crowe III and Crowe IV hip dislocation.

Materials and Methods

Subject

A retrospective analysis was done based on the clinical data of 28 patients with hip dysplasia and joint dislocation and severe osteoarthritis admitted to the Department of Joint Surgery of the Second Affiliated Hospital of Inner Mongolia Medical University from December 2017 to December 2019, including 3 males and 25 females. According to the Crowe classification, 15 cases were type III and 13 cases were type IV. X-ray examination showed that the hip joint defect was dysplasia of the acetabulum in different degrees, increased acetabular angle, dislocated femoral head in different degrees, and degenerated hip join. This was accompanied by severe hip joint movement limitation and pain. It is consistent with the clinical diagnosis of hip dislocation and severe arthritis with hip dysplasia. All patients underwent total hip replacement treatment, and the implant material was a biological artificial total hip prosthesis.

Diagnosis criteria

Patients were diagnosed according to the classification criteria proposed by Crowe and other scholars. Based on pelvic radiographs, the displacement of the proximal femoral head was judged and divided into 4 types. Incomplete dislocation of the hip, with a degree of dislocation of less than 50%, is evaluated as Crowe I. Incomplete dislocation of the hip is evaluated as Crowe II at 50%-75%. And incomplete dislocation of the hip is evaluated as Crowe III. When the degree of incomplete dislocation is higher than 100%, that is, complete, dislocation is assessed as Crowe type IV [12].

Inclusion criteria

Inclusion criteria required: 1) all patients undergo total hip replacement for the first time without other comorbidities, 2) complete full-length DR film of the lower extremity,

3) before and after replacement hip joint DR film and CT three-dimensional reconstruction film, 4) clinical diagnosis in line with Crowe type III and Crowe type IV [11] type defects.

Exclusion criteria

Exclusion criteria was: 1) Patients with organic diseases that severely affect post-replacement functional exercise and motor function, 2) patients with poor local bone quality, such as poor bone fiber structure, 3) other diseases that affect lower limb activities, such as lumbar disc herniation, 4) failure to cooperate or complete examinations, 5) systemic disease such as coagulation dysfunction, heart, liver and kidney dysfunction, and lastly 6) Crowe type I, II and non-Crowe hip disorders [13].

Materials

The bioartificial total hip prosthesis used in this study was mainly the prosthesis produced by Johnson & Johnson. The femoral stem used Corail prosthesis (product lot number 8011952).

This femoral stem prosthesis was FDA-certified hydroxyl Apatite fully coated artificial hip joint prosthesis. The base material was titanium alloy. The design concept was to maximize the preservation of cancellous bone in order to facilitate the combination of hydroxyapatite coating and host bone, to optimize the proximal filling of the medullary cavity, and to enhance the initial mechanical stability of the prosthesis.

We adopted the Pinnacle acetabular cup system (product lot number 534166). The surface of the alloy acetabular prosthesis is coated with hydroxyapatite, and the wear-resistant Marathon high cross-linked polyethylene lining is adopted. The diameter of the femoral head can reach up to 36 mm. These materials improve joint mobility, reduce the risk of dislocation while maintaining sufficient thickness of polyethylene lining. The hydroxyapatite coating is approximately 60% of the minerals of human bones, and can be combined with human bones. The thickness of the coating is 155 ± 35 μm andis moderate. It will not be absorbed early due to being too thin and will not delaminate due to excessive thickness.

Restoration method

Restoration methods included: Measurement of the artificial prosthesis template before replacement, designate the prosthesis placement position, evaluate, and select the appropriate model. Choice of combined spinal-epidural anesthesia or general anesthesia, take the standard healthy side lying position, and choose the anterolateral side of the affected hip for the surgical approach. Surgeon exposed the proximal femur and acetabulum, separated the surrounding soft tissue, and cut at 1.0-1.5 cm above the femoral lesser trochanter bone, and removes the femoral head.

The surgeon determines the position according to the preoperative acetabular reconstruction plan, and polishes from small to large in the direction of 15° anterior inclination and 45° abduction. If the bone coverage of the acetabular prosthesis is less than 70%, it needs structural bone grafting to increase package capacity and coverage. After the acetabulum is polished, the selected acetabular prosthesis is placed, and the inner lining is added. The femur is externally rotated and adducted, and the medullary cavity is reamed according to the size of the medullary cavity measured before the operation. A femoral prosthesis of suitable model is selected and placed in the artificial acetabular prosthesis. For the femoral head, reduce the artificial hip joint to check its stability and mobility. Patients with shortened limbs need to completely loosen the surrounding soft tissues to extend the limbs. Strict aseptic operation during the operation is necessary to prevent damage to the femoral nerve, sciatic nerve and deep femoral artery. After replacement, antibiotics are infused for 1-5 days to prevent infection. After replacement, attention should be paid to prevent complications and perform functional exercises on the lower limbs. Paying attention to the correct way to proceed in a gradual manner to avoid premature weight bearing on hip joint function has an impact on restoration.

Observation indicators

Follow up for 2 years after discharge, and take regular lateral X-rays of the hip joint to determine the position of the acetabulum and femoral prosthesis, bone graft status, stability, length of both lower limbs, and medullary cavity filling rate of the femur-prosthesis. The interface stability and other conditions are evaluated, and the Harris hip score is used to evaluate the recovery of hip joint function.

Harris score of hip joint includes

1) Pain degree, 2) the degree of joint function recovery, 3) the degree of joint activity and flexibility, 4) whether the joints are deformed. Evaluate on a percentile system [14].

Prosthesis medullary cavity filling rate

The filling rate is obtained by measuring the femoral stem at 40 mm below the lesser trochanter, 20 mm above, and at the midpoint.

Statistical analysis

The paired t-test was used to determine the statistical significance between two groups. Fisher's Exact Test is used for assessing differences in the distribution of categorical variables between two or more independent groups. Statistical analysis is done in Stata 12.1 For all analyses, $p < 0.05$ was considered statistically significant.

Ethical statement

Ethical approval of Inner Mongolian University of Nationalities Ethics Committee was obtained (N0 YKD 20-18095).

Results

In this study, of the total 28 patients analyzed, 10.8% were males and 89.2% were females (Table 1). The participants' mean age was 38.65 years (SD ± 7.26).

Table 1. General characteristics of the study population (n = 28)

Variables	Mean ± SD
Age	38.65 ± 7.26
Gender	N (%)
Male	3 (10.8 %)
Female	25 (89.2 %)

In Table 2, the comparison of hip joint condition before and after total hip replacement is shown. Six months after the replacement, the hip joint function of all patients was significantly improved. The mean Harris hip score improved from 43.7 ± 7.5 points to 89.2 ± 5.7 points ($p < 0.000$) and limb shortening was reduced from 4.7 ± 2.5 cm to 0.4 ± 0.2 cm in the postoperative period.

Table 2. Comparison of hip joint before and after total hip replacement

Variables	Before replacement	6 months after replacement	p-value
	Mean ± SD	Mean ± SD	
Harris	43.7 ± 7.5	89.2 ± 5.7	0.000
Short limb length (cm)	4.7 ± 2.5	0.4 ± 0.2	0.000

Comparison of Harris score of hip joint and length of limb shortening of patients before and after replacement, the difference is significant ($p < 0.05$)

Next, we compared the filling rate of the procedure in Crowe III and IV patients. As seen in Table 3, compared with Crowe IV patients, the filling rate at the distal and middle-stem part was slightly higher in Crowe III patients, but not significantly. However, at the proximal stem level, the prosthetic medullary cavity filling rate of Crowe III patients was significantly higher than Crowe IV patients ($p > 0.023$).

Table 3. Comparison of prosthetic medullary cavity filling rate in Crowe III and IV type patients

Projects	Crowe III	Crowe IV	p-value
	(%)	(%)	
Stem filling rate	80	79	0.861
Filling rate of distal femoral stem	84	82	0.707
Middle part of femoral stem filling rate	79	76	0.612
Filling rate of proximal femoral stem	88	80	0.023

Comparing the filling rate of the medullary cavity of different prosthesis parts of the two types of patients, the difference is not significant ($p > 0.05$). Fisher's exact test was carried out.

The filling rate of the femoral prosthesis in the two types of femoral prosthesis was examined by imaging examination 6 months after replacement (Table 4). The distal position of the prosthetic stem is fixed by valgus on the outside of the femoral axis; the position above 3° on the inside is fixed by valgus. According to the evaluation of orthographic film after replacement, there were 4 cases of Crowe type III patients with neutral or perpendicular position, and 3 cases in Crowe type IV patients. After six months of follow-up, we have observed 6 cases of sinking with less than 2 mm for the femoral prosthesis in Crowe III patients and 3 cases with above of 2 mm. In Crowe IV patients, corresponding cases were lesser, but not significant.

Table 4. Comparison of displacement of femoral prosthesis in Crowe III and IV type patients

Item	Crowe III	Crowe IV	p-value
Distal displacement	(%)	(%)	
Neutral position becomes valgus (> 3°)	14.8	13.0	0.514
Neutral position becomes inversion (≤ 3°)	-	-	-
Eversion to neutral position (≤ 3°)	-	-	-
Sink			
2 mm or less	14.2	13.2	0.772
2 mm and above	15.0	13.3	0.353

There is no significant difference in the comparison of distal displacement and subsidence between the two types of patients ($p > 0.05$). Fisher's exact test was carried out.

Discussion

Patients with hip dysplasia and severe dislocation with osteoarthritis are generally more severe because of severe joint deformities and abnormal anatomical structures that increase the difficulty of repair. Artificial total hip replacement repairs hip dysplasia and osteoarthritis which can effectively relieve the patient's hip joint pain, correct deformity of the hip joint, improve its function, and improve the quality of life of patients [15].

The best and ideal position for the distal position of the femoral prosthesis is in a neutral position or mild valgus, with an angle of 3° or less, and a slight mild valgus is also acceptable, but the fixed angle of the prosthetic stem is 3° and above is not acceptable. Because of the deviation of the force line of the prosthesis stem, the stress in the femoral medullary cavity increases locally after weight bearing, and the femur will be painful and the prosthesis will move slightly, which will cause the prosthesis to loosen after a long time [16]. The current clinical evaluation criteria for prosthesis loosening is that the distal position of the prosthesis stem has an internal and eversion angle of more than 3° or a progressive sinking displacement of more than 2 mm [17].

Generally, hip replacement of younger patients with active physical lifestyle encounters recurring dislocation or implant failure. Compared with other studies [18], the average age of the patients who participated in this study was younger (38.65±7.26). In our study, all patients showed excellent clinical outcomes with higher improving scores six months after replacement (Harris score with the value of 89.2 ± 5.7). Moreover, Crowe type III patients had a neutral position fixation of 60%, mild valgus 26.67%, and valgus fixation 13.33%. Crowe type IV patients had a neutral position fixation of 53.85%, mild valgus 15.38%, and valgus fixation 15.38%. It shows that the stem of the femoral prosthesis matches the bone marrow cavity and displays an initial fixation effect. If the femoral prosthesis that sinks slightly within 1 year after weight bearing is restored to stability, it is also considered to be successfully fixed. In the end, bone ingrowth and fixation will be achieved, which is consistent with the results of related literature reports on early micro-sinkage of hip replacement [19-21].

In Bio-type artificial total hip joint prosthesis, the femoral stem adopts the Corail prosthesis which is a hydroxyapatite fully coated artificial hip joint prosthesis, and the base material is titanium alloy. By retaining the cancellous bone to the maximum, it is beneficial to the combination of the hydroxyapatite coating and the host bone, optimizing the filling of the proximal medullary cavity, and enhancing the initial mechanical stability of the prosthesis. When the acetabulum adopts the Pinnacle acetabular cup system, the surface of the alloy acetabular prosthesis is coated with hydroxyapatite, and the wear-resistant Marathon high cross-linked polyethylene lining is adopted.

The diameter of the femoral head can be up to 36 mm which improves joint mobility, reduces the risk of dislocation, while maintaining sufficient thickness of the polyethylene lining. The hydroxyapatite coating is approximately 60% of the minerals of human bones, and can be combined with human bones. The thickness of the coating is 155 ± 35 μm, and the thickness is moderate. It will not be absorbed early due to being too thin, and delamination will not occur due to excessive thickness. Relevant studies have found that DR orthographic films of patients after hip replacement show that most patients have hyperplasia of the acetabulum, confirming that the state of bone in growth in the later stage of the prosthesis is good [22-24].

In this study, the bone in growth fixation rate of Crowe type III patients was as high as 100%, the Crowe type IV bone ingrowth fixation rate was 85%, and the stable fiber fixation rate was 15%. It is consistent with the above research results. The true acetabulum of patients with Crowe type III and IV dislocation of the hip has incomplete development. Its structure has a thin anterior wall and a thicker posterior wall, showing an inverted triangle shape. At the same time, the acetabular rim is not well developed, and there is osteoporosis around the acetabulum. The acetabulum is relatively flat and the normal arc-shaped structure of the top is destroyed, and it is difficult to place the prosthesis in clinical surgery [25].

The placement of the prosthesis after the inner wall osteotomy forms invagination which is beneficial to increase the coverage of the host bone of the acetabular prosthesis. At the same time, the larger cup has a thicker inner lining to ensure the wear resistance of the prosthesis in the later stage of placement, but it has the shortcoming of lack of stability of the cup. The smaller prosthesis can stabilize the prosthesis by deepening the depth of the acetabulum. The small prosthesis has good adaptability to the true acetabulum of patients with hip dislocation and can obtain relatively satisfactory host bone coverage and stability. However, when the prosthesis model is small, the incidence of hip dislocation is high. Also, when the model is too small, the lining is relatively thin, the wear resistance is poor, and the service life is relatively short [26]. The above-mentioned treatment methods have certain limitations, so their clinical application is limited. Therefore, the replacement of total hip joint is receiving more and more attention in clinical development.

The main points of artificial total hip replacement are: 1) Reconstruction of the acetabulum. Its reconstruction is the key to total hip replacement. The main clinical principles are: restore its normal mechanical structure to avoid long-term loosening of the prosthesis, increase the prosthesis support to the bone to maintain its initial stability, and ensure that the acetabular cup is at the best abductor anterior angle to avoid dislocation. 2) Reconstruction of the femoral side. The morphology of the proximal femur of patients with hip dysplasia often has secondary changes. The medullary cavity is narrowed due to torsion, which increases the angle of femur anteversion. The key to the placement of femoral prosthesis lies in the restoration of the anteversion angle to help the femoral head return to the true acetabular level. Therefore, it is necessary to adjust the anterior inclination angle, and re-determine the placement of the anterior inclination angle based on the internal and external condyles of the femur and the patella, so as to avoid the occurrence of postoperative prosthetic dislocation due to excessive or small composite posterior anterior angle [27].

In this study, the Harris score of the hip joint increased from 43.7 points to 89.2 points after treatment, and the shortened limb length recovered from 4.7 cm to 0.4 cm. There was a significant difference between the data before and after treatment ($p < 0.05$). And the body filling rate of the femoral stem after treatment is as high as 75%. It shows that the patient's joint prosthesis is fixed and stable after hip replacement, which effectively restores the patient's hip joint function, and the effect is significant. Mainly because total hip replacement can be based on the patient's acetabular pathological changes, bone grafting is done in the severely defected part of the acetabulum. Through good bone grafting treatment, the host bone can be effectively fused with the bone graft block to ensure the rotation center of the hip joint: Crowe type III and IV hip dislocation patients have high dislocation of the femoral head, external rotation of the joint in either upward or downward displacement, the false acetabular joint is formed on the iliac bone, and the true acetabulum gradually becomes shallow, tilted and injured because of the lack of corresponding femoral head stimulation. Several studies demonstrated that the post-operative dislocation rate in Crowe IV patients had reached to 15-17.4% [28-30]. In our study, the displacement of the femoral prosthesis was 14.8 % in Crowe III patients, and 13.07% in Crowe IV patients.

However, our study has limitations. First, the research was limited by its small sample size, lower than we aimed. Surely, a larger sample size would have yielded more statistical power. Furthermore, this study has been conducted in one particular hospital in northern China. Therefore, future research should pursue a generalized study in multiple hospitals in various regions.

After the total hip joint prosthesis is placed in the true acetabular, the stability will decrease due to insufficient coverage. During the operation, the amputated femoral head can be prepared into a bone graft to complete the bone graft, and the cancellous bone can be fixed with screws to increase the coverage, ensure the stability of the placed acetabular prosthesis, and promote the recovery of the acetabular rotation center. At the same time, total hip replacement preserves the bone at the bottom and inner side of the hip joint to the greatest extent, provides complete bony support for the placement of the prosthesis, effectively prevents fractures of the acetabular, and ensures the best bony support possible in the later period. Re-revision occurs to lay the foundation for bone mass [31].

Conclusions

Total hip replacement has a significant effect on Crowe type III and Crowe type IV hip dislocations. It has the advantages of good prosthesis filling rate, high femoral-prosthesis interface stability rate, and initial internal fixation stability. It can effectively promote the hip joint functional recovery and recovery of limb length. With continuous improvement of clinical technology, improvement of prosthesis design and material improvement will further improve the repair effect.

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