CLINICAL ARTICLE

Changes in Alignment of Ipsilateral Knee on Computed Tomography after Total Hip Arthroplasty for Developmental Dysplasia of the Hip

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Objective: To assess the changes in alignment of ipsilateral knee joint after total hip arthroplasty (THA) for patients with developmental dysplasia of the hip (DDH).

Methods: Thirty-four patients with DDH (38 hips) who underwent THA between February and December 2008 were included in the study: 4 men and 30 women with a mean age of 56.2 years. According to Crowe classification, 11 patients were grade I, 12 were grade II, 9 were grade III, and 6 were grade IV. Computed tomography scans were performed from the anterior superior iliac spine to the tibial tubercle before surgery and at last follow-up. Femoral anteversion angle, leg lengthening, and knee alignment, including patellar tilt angle, lateral patellar displacement, and tibiofemoral rotation angle, were measured on computed tomography scans, and their relationships were analyzed.

Results: The mean follow-up period was 51.5 months (range, 39–70 months). There were no intraoperative fractures, and no infections occurred during the follow-up period. One patient developed deep venous thrombosis and another suffered from femoral nerve palsy. The mean preoperative Harris Hip Score was 48.9 ± 7.5 and improved to 91.2 ± 8.3 by the last follow-up ($P < 0.001$). There was no sign of prosthetic loosening in all hips. Postoperatively, mean leg lengthening was 26.08 ± 21.81 mm ($P < 0.001$), femoral anteversion decreased 9.03° ± 12.80° ($P < 0.001$), and patellar tilt, lateral patellar displacement, and tibiofemoral rotation increased by 3.58° ± 4.96° ($P < 0.001$), 1.78 ± 3.36 mm ($P = 0.002$), and 2.56° ± 3.37° ($P < 0.001$), respectively. Postoperative increase in patellar tilt and lateral patellar displacement had significant linear relationships with the decrease in femoral anteversion ($r = 0.621$, $P < 0.001$ and $r = 0.437$, $P = 0.0037$, respectively). These results revealed that patellofemoral alignment would change more with the decrease in femoral anteversion. Postoperative increase in external rotation of the tibia had significant positive linear relationships with leg lengthening ($r = 0.34$, $P = 0.037$) and the decrease in femoral anteversion ($r = 0.693$, $P < 0.001$). These results revealed that the external rotation of the proximal tibia would increase with the leg lengthening or the decrease of femoral anteversion. Postoperative changes in patellar tilt and lateral patellar displacement had no significant linear relationships with leg lengthening ($P = 0.795$ and $P = 0.082$, respectively).

Conclusions: Total hip arthroplasty for DDH could induce changes in alignment of ipsilateral patellofemoral and tibiofemoral joints, with increases in patellar tilt and displacement, and increases in external rotation of the tibia. These secondary alterations still existed at medium-term follow-up after surgery, which should be considered during THA for patients with DDH. Extended follow-up is necessary to evaluate long-term changes in the knee joint.

Key words: Developmental dysplasia; Knee; Knee alignment; Total hip arthroplasty

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Introduction

Total hip arthroplasty (THA) is an effective method for relieving pain and improving function for adult developmental dysplasia of the hip (DDH) when end-stage osteoarthritis develops[1,2]. THA for DDH has been shown to result in excellent outcomes. However, anterior knee pain and changes at patellofemoral joints after THA in DDH patients have been reported[3,4]. Moreover, postoperative patella dislocation was observed recently in our follow-up study[5]. Therefore, some negative changes in the knee joints may be induced by THA, which should be considered during operations for patients with DDH, but these secondary changes are still not well defined at present. Abnormal alignment of the knee joint plays an important role in both the development and progression of osteoarthritis, and abnormal alignment of the knee joint is an independent risk factor for knee osteoarthritis progression[6]. Only when changes in the knee joints in such patients are fully defined can improvement measures be taken.

Generally, THA for patients with DDH differs from that for patients with common primary coxarthrosis because of acetabular and femoral anatomical abnormalities. For patients with DDH, upward displaced hips should be reduced to the anatomical center and femoral anteversion should be adjusted for ideal biomechanical load bearing, to correct leg length discrepancy, and to reduce the risk of impingement, dislocation, and other complications after THA[7]. The durability of arthroplasty in these patients is better with the restoration of an anatomic hip center[8]. Therefore, the anatomical hip structure changed significantly; two main changes were reduction in femoral anteversion and leg lengthening after THA operation in patients with DDH.

It has been suggested that anatomical changes at the hip joint are associated with abnormalities in the ipsilateral knee joint[9,10]. We had previously reported that the morphologies of the knees in patients with DDH changed compared with the knees in patients with normal hips[11]. Similarly, Zhang *et al.*[12] reported coronal plane malalignment of lower limbs in patients with unilateral DDH. According to these previous findings, we supposed that given the changes in the anatomical structure of the hip joints in patients with DDH who underwent THA, the alignment of the ipsilateral knee joint should be affected.

However, studies of THA in patients with DDH have mainly focused on surgical procedures and hip function; postoperative changes in the ipsilateral knee joints have generally not been evaluated. Previously, only a few studies reported changes in the knee joint alignment in patients with DDH who underwent THA. Tokuhara *et al.*[3] reported that THA influences the patellofemoral joint and can cause anterior knee pain; lateral patellar tilt measured on knee radiographs was increased at 2 weeks postoperatively, while the increase disappeared within 3 months postoperatively. Akiyama *et al.* reported that patellar tilt was increased on computed tomography (CT) scans at 46 days postoperatively[13] and the increased patellar tilt still existed 2 years after surgery[14]. However, the follow-up period is short and inconsistent results were observed in the above studies. In addition, although CT scans are routinely used in sports medicine for the evaluation of patellofemoral instability and knee deformity, few studies have used CT scans to evaluate the changes in alignment of the knee joint in DDH patients who have undergone THA[13]. To the best of our knowledge, no study has evaluated medium to long-term imageological changes in the patellofemoral alignment and no study has evaluated tibiofemoral rotational alignment in patients with DDH who have undergone THA.

Therefore, the present study aimed: (i) to determine the medium-term alterations in alignment of the ipsilateral knee joints based on CT scans in patients with DDH who underwent THA; (ii) to measure femoral anteversion angle, leg lengthening, and knee alignment, including patellar tilt angle, lateral patellar displacement, and tibiofemoral rotation angle, on CT scans preoperatively and at last follow-up; and (iii) to analyze their relationships.

Patients and Methods

Inclusion and Exclusion Criteria

This was a single center retrospective study of patients with DDH who underwent THA between February and December 2008. The inclusion criteria were: (i) adult patients with DDH having extreme impairment of daily activity; (ii) patients who underwent THA; (iii) outcome measures are Harris hip score (HHS), the amount of leg lengthening (LL), and the angle of femoral anteversion (FA); and (iv) retrospective study. The exclusion criteria were: (i) previous hip surgery; and (ii) lack of integral imaging data.

Patients' Data

Forty-eight consecutive THA were performed in forty-four patients with DDH between February and December 2008. A total of 10 patients were excluded from this study because of previous hip surgery (5 hips) or lack of preoperative CT scanning (5 hips). The remaining 34 patients (38 hips) were included in the study, including 4 men and 30 women with a mean age of 56.2 years (range, 29–76 years). According to Crowe classification[15], 11 (32.4%, 11/34) of these were Crowe grade I, 12 (35.3%, 12/34) were Crowe grade II, 9 (26.5%, 9/34) were Crowe grade III, and 6 (17.7%, 6/34) were Crowe grade IV. This study was approved by the local institutional review board. All investigations were conducted in accordance with the ethical principles of research. Informed consent for this study was obtained from all patients.

Computed tomography Scanning

Computed tomography evaluation was performed using the Hitachi Radix Turbo (Tokyo, Japan) (120 kVp, 200 mA, 5-mm collimation, 5 mm/s table speed, and 5-mm resolution index) device. CT scans were performed before surgery and at the last follow-up. By using axial sections passing from the anterior superior iliac spine to the tibial tubercle, all patients underwent 1-mm interval CT scans in the supine position, with the hips and knees fully extended and the lower limbs as horizontal and parallel as possible.

Surgical Procedure

All operations were performed by the senior surgeon (Zhu). The procedure has been described in detail in our previous studies[5,16,17]. Briefly, a posterolateral approach was used in all cases. The elongated capsule and all osteophytes around the acetabulum were removed to expose the true acetabulum. The acetabular component was placed at the level of the reamed anatomical location. The technique without femoral shortening osteotomy in patients with high dislocations was used to avoid leg length discrepancy. The femoral component was selected as the one that best matched the broached intramedullary canal with the anteversion carefully controlled. If it was difficult to reduce the hip, direct leverage was applied to the greater trochanter using an elevator, which obtained purchase on the bone below the acetabulum. When the modular femoral head reached the level of the acetabular component, the reduction was achieved by externally rotating the leg. During the procedure, the hip and knee were always held in flexion to relax the sciatic nerve and reduce the tension on the soft tissues. This position was maintained postoperatively for several days to avoid damage to the nerve.

Cementless prostheses were used in all hips, including 21 Secur-Fit stems and Trident cups (Stryker Corporation, New Jersey, USA), and 17 Wagner Cone stems and TM Continuum cups (Zimmer Biomet, Indiana, USA). Ceramic-on-polyethylene interfaces were chosen in 37 hips (21 from Stryker Corporation, New Jersey, USA and 16 from Zimmer Biomet Corporation, Indiana, USA); metal-on-polyethylene couple was chosen in 1 hip (Zimmer Biomet Corporation, Indiana, USA).

Postoperative Treatment

Antibiotics were routinely administered for 1 to 3 days to prevent infection. The rehabilitation program varied according to soft tissue tension. In general, patients were allowed partial weight-bearing from 1 day to 1 week after the surgery and then full weight-bearing at 1 to 6 weeks. If the soft tissue was very tight after leg lengthening, the hip and knee flexion position was maintained for several days postoperatively and then extended gradually over the course of 1 to 2 weeks. After regaining full extension, walking exercises with crutches and full weight-bearing were initiated.

Follow-up and Assessment

Outpatient follow-ups were performed 1, 3 and 6 months and 1 year after surgery. Subsequently, yearly follow-ups were performed. Clinical and imageological assessment were performed.

Harris Hip Score

The Harris Hip Score was used to assess the hip joint function of each patient prior to surgery and at each follow-up examination after surgery[18].

Radiographic Assessment

A series of radiographs of the pelvis were obtained at each follow-up visit and were carefully assessed for loosening of the prosthesis. The stability of the acetabular components was assessed radiographically using the method of DeLee and Charnley[19] and that of the femoral components using the method of Gruen *et al.*[20].

Amount of Leg Lengthening

The amount of leg lengthening was measured as the change in the vertical distance between the line joining the tear drops and the most medial tip of the lesser trochanter (Fig. 1).

Angle of Femoral Anteversion

The angle of femoral anteversion was measured according to the method of Pierchon *et al.*,[21] compensating for the rotational angle of the femur as defined by the intersection angle formed by the axis of the femoral neck and a tangent to the posterior borders of the medial and lateral condyles (Fig. 2).

Patellar Tilt Angle

The relationships of the patella relative to the femoral condyles are referred to as the patellar tilt angle (PTA) (Fig. 3A and 3B) and lateral patellar displacement (LPD) (Fig. 3C). The PTA is the angle between the slope of the lateral patellar facet and the line connecting the two most posterior points of the femoral condyles[22].

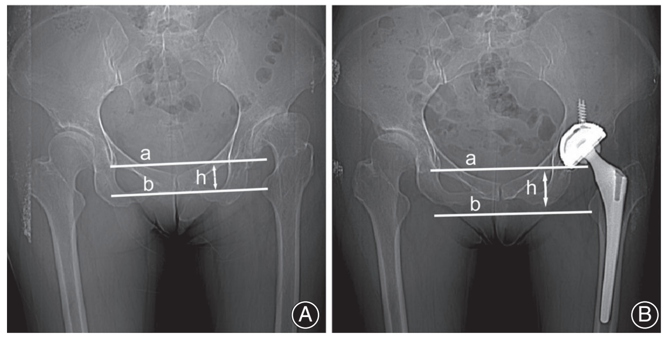

Fig. 1 The amount of leg lengthening was measured as the change in the vertical distance (h). A, The vertical distance (h) between the line joining the tear drops (a) and the most medial tip of the lesser trochanter (b) was measured on preoperative computed tomography (CT) scans. B, The vertical distance (h) between the line joining the tear drops (a) and the most medial tip of the lesser trochanter (b) was measured on postoperative CT scans.

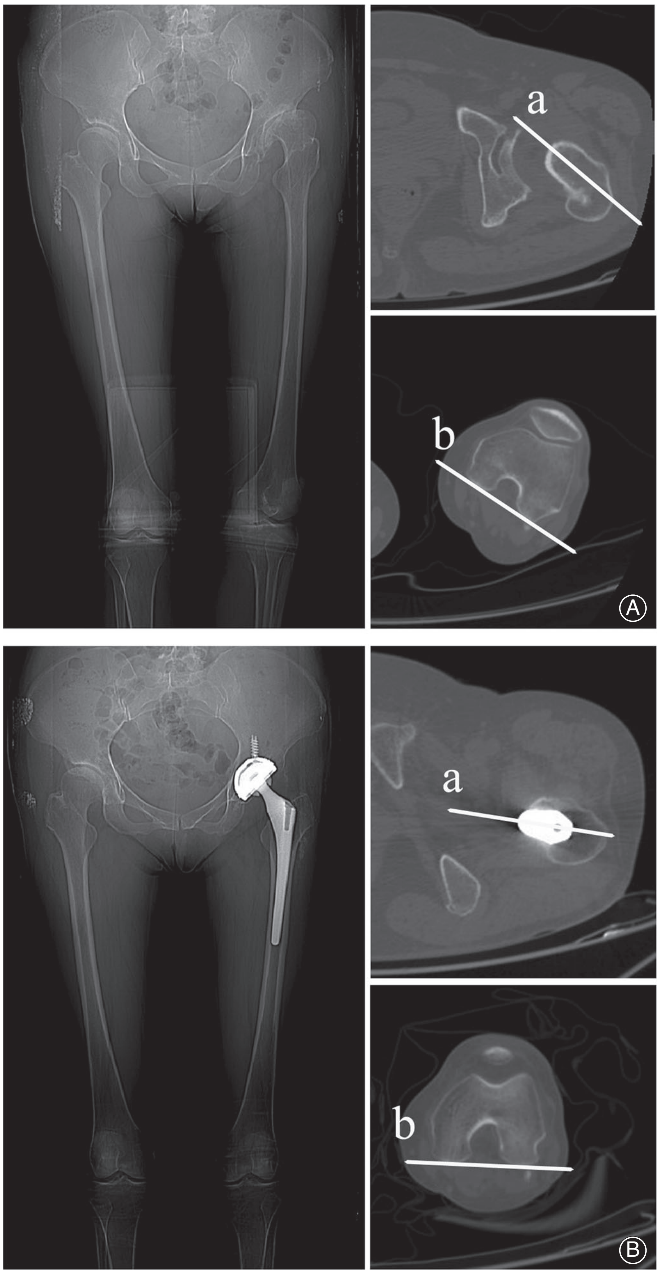

Fig. 2 Measurements of the femoral anteversion angle on computed tomography (CT) scans. A, The anteversion angle was measured by the axis of the femoral neck (a) and a tangent to the posterior borders of the medial and lateral condyles (b) on preoperative CT scans. B, The anteversion angle was measured by the axis of the stem neck (a) and a tangent to the posterior borders of the medial and lateral condyles (b) on postoperative CT scans.

Lateral Patellar Displacement

The LPD is the parallel distance between the highest tip of the medial femoral condyle and the medial tip of the patella[23].

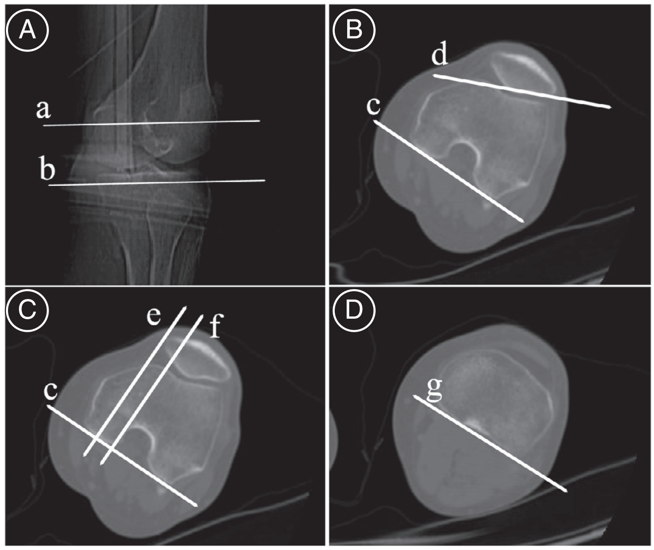

Fig. 3 Tibiofemoral alignment measurement on computed tomography scans. A, The section showing maximum transverse diameter of the patella (a) was chosen for the definition of the lateral patellar facet (d) and the medial tip of the patella (f). The section just proximal to the fibula head (b) was chosen for the definition of the line connecting the two most posterior points of the tibia condyles (g). B, PTA is the angle between the slope of the lateral patellar facet (d) and the line connecting the two most posterior points of the femoral condyles (c). C, LPD is the parallel distance between the highest tip of the medial femoral condyle (e) and the medial tip of the patella (f), perpendicular to line c. D, TFR is the angle between the line connecting the two most posterior points of the tibia condyles (g) and line c.

Tibiofemoral Rotation

Tibiofemoral rotation (TFR) is the angle between the line connecting the two most posterior points of the femoral condyles and the line connecting the two most posterior points of the tibia condyles[24](Fig. 3A and3D). A tangent on the posterior border of the tibia was placed distally to the femorotibial joint and proximal to the fibulotibial joint. The TFR angle represents the position of the proximal tibial epiphysis relative to the distal end of the femur in a non-weight bearing, resting position with the knee in full extension.

Clinical Complications

The clinical complications, such as intraoperative fracture, infection, deep venous thrombosis and the function of the sciatic and femoral nerves, were recorded.

Statistical Analysis

All statistical analyses were performed on a personal computer using SPSS software for Windows (version 17.0; SPSS, Chicago, IL, USA). The Shapiro–Wilk test was used to verify that preoperative and postoperative HHS, LL, FA, PTA, LPD, and TFR were normal distributions. Student's *t*-test

TABLE 1 Image measurement results

Parameters	Preoperation	Postoperation	Values changed	*t*-value	*P*-value*
LL (mm)	10.12 ± 25. 75	36.19 ± 7.05	26.08 ± 21.81	−7.37	<0.001
FA (°)	25.10 ± 14.20	16.07 ± 7.77	9.03 ± 12.80	4.35	<0.001
PTA (°)	16.01 ± 5.05	12.43 ± 4.87	3.58 ± 4.96	4.45	<0.001
LPD (mm)	3.42 ± 3.45	1.64 ± 4.81	1.78 ± 3.36	3.27	0.002
TFR (°)	4.06 ± 3.60	6.61 ± 4.70	2.56 ± 3.37	−4.67	<0.001

FA, femoral anteversion angle; LL, leg lengthening; LPD, lateral patellar displacement; PTA, patellar tilt angle; TFR, tibiofemoral rotation. * Student's *t*-test. All values are expressed as the mean ± standard deviation.

was used to compare preoperative and postoperative HHS, LL, FA, PTA, LPD, and TFR. Linear regression analyses were used to statistically evaluate the relationship between the changes of FA and LL with that of PTA, LPD, and TFR. A *P*-value of <0.05 was considered to represent a significant difference.

Results

Clinical Results

The mean follow-up period was 51.5 months (range, 39–70 months). No patients required revision during the follow-up period. The mean preoperative HHS was 48.9 ± 7.5 and improved to 91.2 ± 8.3 ($P < 0.001$) by the last follow-up.

Radiographic Results

The radiological stability of the acetabular and femoral components was assessed and there was no definite sign of prosthetic loosening in all hips. The detailed CT measurement results are listed in Table 1.

The Amount of Leg Lengthening

The preoperative and postoperative vertical distances between the line joining the tear drops and the most medial tip of the lesser trochanter were 10.12 ± 25.75 mm and 36.19 ± 7.05 mm, respectively. The average amount of LL was 26.08 ± 21.81 mm ($P < 0.001$).

The Angle of Femoral Anteversion

The preoperative and postoperative FA were 25.10° ± 14.20° and 16.07° ± 7.77°, respectively. The postoperative FA decreased 9.03° ± 12.80° ($P < 0.001$).

Patellar Tilt Angle

The preoperative and postoperative PTA were 16.01° ± 5.05° and 12.43° ± 4.87°, respectively. The postoperative PTA reduced 3.58° ± 4.96° ($P < 0.001$), which means that the patellar tilt increased.

Lateral Patellar Displacement

The preoperative and postoperative LPD were 3.42 ± 3.45 mm and 1.64 ± 4.81 mm, respectively. The

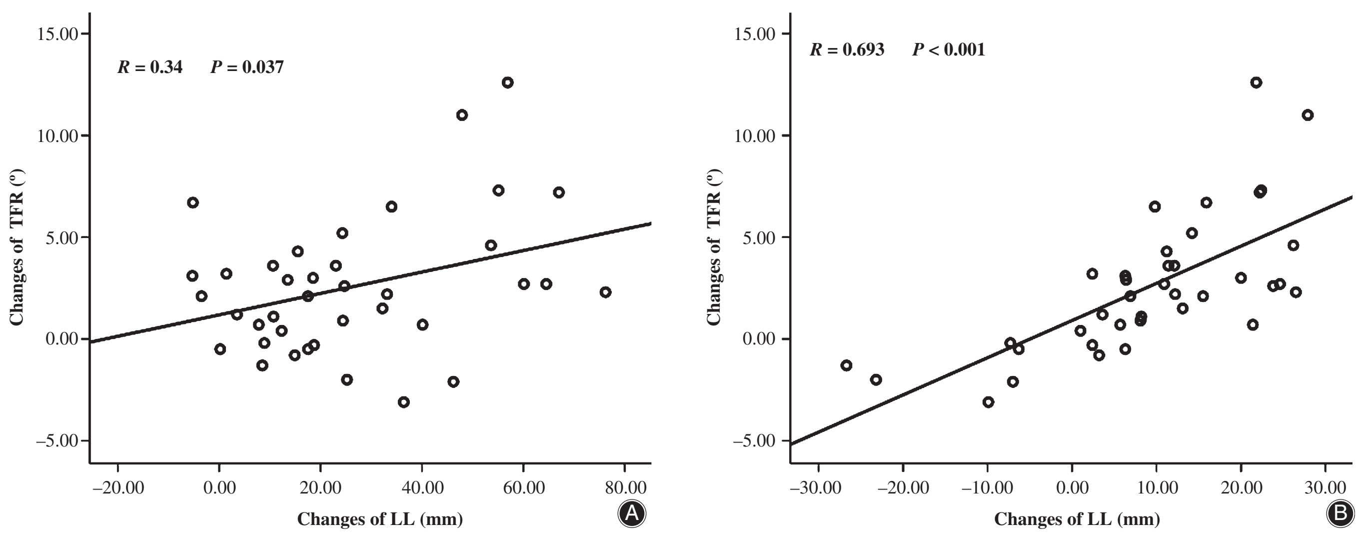

Fig. 4 The postoperative changes in tibiofemoral rotation had significant positive linear relationships with the changes in leg lengthening (A) and femoral anteversion (B).

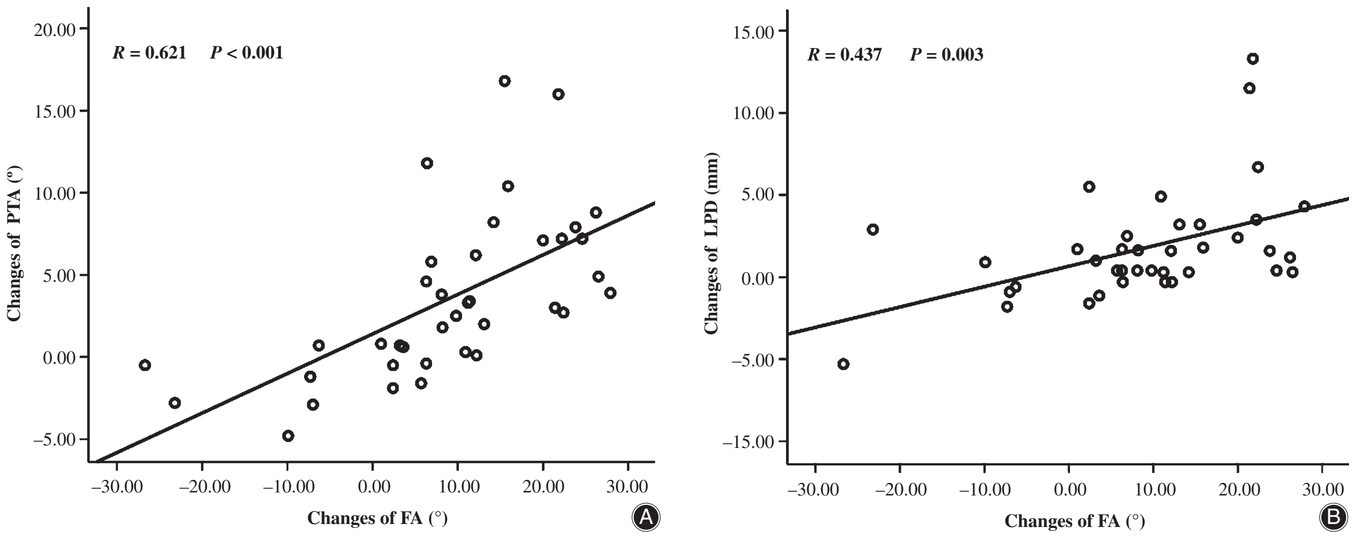

Fig. 5 The postoperative changes in patellar tilt angle (A) and patellar displacement (B) had significant positive linear relationships with the changes in femoral anteversion.

postoperative LPD reduced 1.78 ± 3.36 mm (P = 0.002), which means that the patella was displaced laterally.

Tibiofemoral Rotation

The preoperative and postoperative TFR were 4.06° ± 3.60° and 6.61° ± 4.70°, respectively. The average TFR increased 2.56° ± 3.37° (P < 0.001) postoperatively, which means that the proximal tibia rotated externally relative to the distal femur postoperatively.

Linear Regression Analyses

Linear regression and statistical tests were performed using the postoperative change in PTA, LDP, and TFR as dependent variables and the change in FA or the amount of LL as independent variables. The results revealed that the postoperative change in TFR had significant positive linear relationships with the amount of LL (r = 0.34, P = 0.037) and the change in FA (r = 0.693, P < 0.001), as shown in Fig. 4. These statistically significant results revealed that the external rotation of the proximal tibia would increase with the leg lengthening or the decrease of FA. The postoperative changes in PTA and LDP had significant linear relationships with the change in FA (r = 0.621, P < 0.001 and r = 0.437, P = 0.0037, respectively), as shown in Fig. 5. These results revealed that patellofemoral alignment would change more with the decrease in femoral anteversion. The postoperative changes in PTA and LDP had no significant linear relationships with LL (P = 0.795 and P = 0.082, respectively).

Complications

There were no intraoperative fractures, and no infections occurred during the follow-up period. One patient developed deep venous thrombosis in his right lower extremity on day 2 after the operation; this condition resolved after muscle contraction exercises and anticoagulation treatment with low molecular-weight heparin. One patient suffered from femoral nerve palsy with weakness of knee extension. This patient recovered completely after 3 months with conservative treatment, and the HHS was 87 at the last follow-up of 56 months.

Discussion

Recently, several studies have reported the changes in alignment of lower limbs after THA for DDH on radiographs[3,4,13]. However, the present study is the first to demonstrate that the patellofemoral and tibiofemoral relationships were changed on CT scans at medium-term follow-up (51.5 months) after THA operation on patients with DDH.

Patellofemoral Alignment

With respect to the patellofemoral alignment after THA for DDH, the present study demonstrated that the patellofemoral alignment changed, with the patella tilt increasing by 3.58° ± 4.96° and lateral displacement increasing by 1.78 ± 3.36 mm compared with preoperatively. It has been demonstrated that the patellofemoral relationship could be influenced by iliotibial band (ITB) tightness and leg rotation. ITB tightness increased with leg lengthening after THA in patients with DDH. As the ITB attaches to the lateral retinaculum of the patella, increasing the ITB tension could increase lateral tilt and translation of the patella[25,26]. Tokuhara observed an increased lateral patellar tilt phenomenon after THA in patients with DDH, which was related to the amount of leg lengthening and disappeared within 3 months[3]. However, in the current study, the lateral tilt phenomenon still existed after 51.5 months of follow-up, and no linear relationship was found between the change in PTA and variations in leg lengthening. Patellofemoral dysfunction has also been related to abnormal femoral rotation. Eckhoff (1994) reported that anterior knee pain in adults was associated with increased femoral anteversion[27]. Souza (2010) suggested that altered patellofemoral joint kinematics in women with patellofemoral pain appears to be related to excessive femoral rotation, and control of femur rotation may be important in restoring normal patellofemoral joint kinematics[28]. Similarly, the current study revealed a significant relationship between the changes in patellofemoral alignment and the decrease in femoral anteversion after THA for DDH patients.

Tibiofemoral Alignment

With respect to the tibiofemoral alignment, the present study is the first to report that the tibia rotates externally relative to the femur after THA for DDH, which is related to the change in leg lengthening and femoral anteversion. Several previous studies found that femoral malrotation changed the coronal alignment of the lower extremity and the center of force in the tibiofemoral joint, and the leg external rotation could switch its center of force towards the medial condyle[29,30]. These findings suggest that lower limb torsion disorders are not merely cosmetic issues but could be risk factors inducing gonarthrosis, which may alter the tibiofemoral kinematics and lead to abnormal pressure in the tibiofemoral compartment and cartilage damage. Kenawey's study demonstrated that when decreasing cadaveric femoral anteversion, the medial tibiofemoral compartment contact pressure was increased, but increasing the femoral anteversion decreased the medial pressure[31]. Duparc's study suggested that external rotation of the leg induces shear stresses on the medial compartment cartilage and alters the load distribution on the tibial plateaus[24]. Taken together, the present findings demonstrated that decreased femoral anteversion after THA for DDH patients may change the tibiofemoral alignment and increase the probability of gonarthrosis.

Combined Anteversion for Total Hip Arthroplasty

To avoid potential problems in the knee joint, we believe that the concept of "combined anteversion" might be helpful, which has been proved to reduce the risk of dislocation and impingement after THA for DDH in our previous studies[32,33]. Using the concept of "combined anteversion," it may be a wise choice not to fully correct the femoral anteversion by increasing the anteversion of the acetabular cup. Accordingly, the increases in patellar tilt and displacement and increases in external rotation of tibia after THA for DDH might be reduced.

Limitations of the Study

One limitation to this study is that the number of patients was relatively small, especially the number of Crowe III and IV, which makes the results less meaningful. However, high dislocation DDH is uncommon. This is the first study that demonstrated medium-term changes in ipsilateralti biofemoral rotational and patellofemoral alignment after THA for DDH.

Conclusion

Total hip arthroplasty is a proven method to treat DDH, but it can also be a potentially double-edged sword. THA operation for DDH could induce secondary changes in ipsilateral knee joint alignment, with alteration in both patellofemoral and tibiofemoral relationships. These abnormal phenomena should be further investigated. However, knee osteoarthritis may develop over a long period of time, and additional long-term studies are needed to evaluate whether THA operation may induce knee osteoarthritis in patients with DDH.

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