ORIGINAL ARTICLE

Anatomical parameters of and differences in the proximal femoral cavity in adult patients with developmental hip dysplasia

Ran Zhao, Hong Cai, Hua Tian, Ke Zhang

Abstract

Objective: To explore the anatomical parameters proximal femoral cavity and developmental dysplasia of the hip.

Methods: The retrospective study was conducted at Peking University Third Hospital, Beijing, China, and comprised data of adult patients of either gender who underwent total hip arthroplasty from January 2009 to August 2015. Paients with a diagnosis of primary osteoarthrosis or aseptic necrosis of the femoral head were taken as the control group A, while patients with developmental dysplasia of the hip in group B were graded into subgroups I-IV using the Crowe classification. For each patient, the inner diameter of the proximal femoral medullary cavity was measured on preoperative radiographs using Noble's technique. Data was analysed using SPSS 20.

Results: Of the 835 hips, 571(68.4%) were in group A and 264(31.6%) in group B. The mean age of the patients at the time of surgery was 58.3 ± 12.3 years. Overall, there were 404(48.4%) hips of male patients; 59(22.3%) in group B. There were 431(51.6%) hips of female patients; 205(77.7%) in group B. In group B, 186(70.5%) hips were graded I, 38(14.4%) grade II, 22(8.3%)grade III, and 18(6.8%) hips were graded IV. There were significant differences in femoral offset, height of the femoral head, and canal flare index of the metaphysis between groups A and B ($p<0.05$). There was no significant difference in the morphology of the marrow cavity between subgroups II and III. The femoral offset, height of the femoral head, canal flare index of the metaphysis and medullary cavity isthmus were significantly smaller in the subgrop IV than group B ($p<0.05$). There was significantly greater stenosis in the diaphysis in subgroup IV than in the remaining subgroups ($p<0.05$).

Conclusion: The morphology of the marrow cavity was significantly different between patients with proximal femoral cavity and those with developmental dysplasia of the hip. Patients with developmental dysplasia grade IV had a narrower metaphyseal and diaphyseal cavity.

Keywords: Developmental hip dysplasia, Proximal femoral cavity, Morphology, Differences, Preoperative planning.

(JPMA 71: 2700; 2021) **DOI: https://doi.org/10.47391/JPMA.267**

Introduction

Total hip arthroplasty (THA) effectively relieves the pain associated with hip joint disease, and restores hip function. Among the preoperative diagnoses in patients undergoing THA, osteoarthritis secondary to developmental dysplasia of the hip (DDH) accounts for a large proportion.[1] THA for DDH is facing great challenges, especially for patients with proximal femoral medullary stenosis and an abnormally increased anteversion angle.[2] Preoperative radiograph is still the most commonly used auxiliary examination for prosthesis mould measurement during preoperative planning for THA. The current study was planned to investigate the differences in the medullary cavity morphology between patients with and without DDH.

Materials and Methods

The retrospective study was conducted at Peking University Third Hospital (PUTH), Beijing, China, and comprised data of adult patients of either gender who underwent THA from January 2009 to August 2015. The data included related to patients with a diagnosis of primary osteoarthrosis, avascular necrosis of the femoral head, or DDH.

Data was exluded in cases with imperfect imaging data and irregular radiographs. Data was also exluded for patients having non-DDH conditions that may influence the morphology or bone quality of the proximal femoral medullary cavity, such as a history of long-term hormone use, a history of proximal femoral osteotomy or internal fixation, or a history of proximal femoral bone tumours.

Paients with a diagnosis of primary osteoarthrosis or aseptic necrosis of the femoral head were taken as the control group A, while patients with DDH in group B were taken as the cases.

Preoperative medical records and anteroposterior (AP) and lateral radiograph films of the affected hip were accessed. The radiograph films were standard AP radiographs of the hip for which the patients were placed in the supine position at a distance of 100cm from the camera, centered at the level of the lesser trochanter. In

Department of Orthopaedics, Perking University Third Hospital, China.

Correspondence: Hong Cai. Email: caihong_76@126.com

the process of taking radiographs, a 2cm marker ball ws used to calibrate the magnification. The femoral head was internally rotated so that the femoral neck was presented in the coronal plane. After obtaining the radiographic images, the imaging information was converted into digital information and fed into a computer. A picture archiving and communication system was used for image processing.

The parameters of the proximal femur were measured using the technique cited in literature[3] (Figure-1a). The centre of the femoral head was determined using a Mose circle. The central axis of the femoral neck was determined by a line passing through the centre of the femoral head and dividing the upper and lower edges of the femoral neck. The central axis of the femoral shaft was determined by the midpoints of three vertical lines perpendicular to the direction of the femoral shaft. The neck-shaft angle (NSA) was measured as the angle between the central axis of the femoral neck and the central axis of the femoral shaft. The femoral offset was measured as the vertical distance from the centre of the femoral head to the central axis of the femoral shaft. The width of the medullary cavity at the intertrochanteric line (T) was measured by creating a vertical line of the central axis of the femoral shaft over the midpoint of the lesser trochanter, and the width of the medullary cavity along this vertical line was the width of the medullary cavity

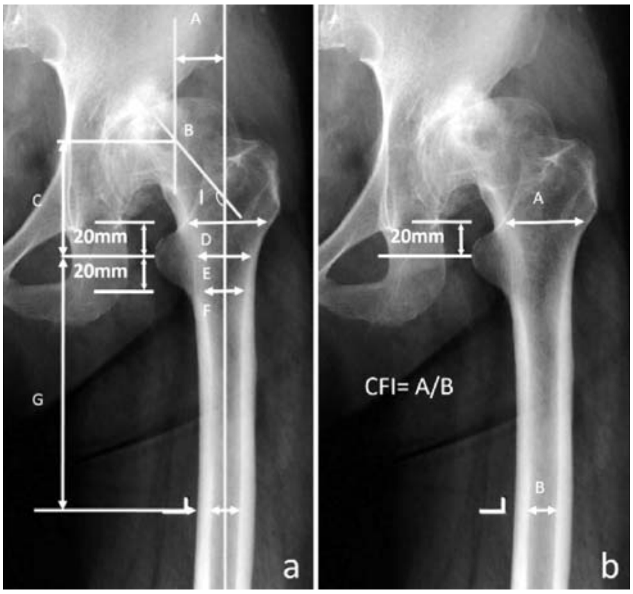

Figure-1: (a) A, femoral offset; B, center of femoral head; C, femoral head position; D, canal width 20mm above the mid-lesser trochanter line; E, canal width at the mid-lesser trochanter line; F, canal width 20 mm below the mid-lesser trochanter line; G, isthmus position below the mid-lesser trochanter line; H, isthmus diameter; I, neck-shaft angle. (b) The canal flare index (CFI) as defined by Noble et al.(3) is equal to A/B.

along the intertrochanteric line of the lesser trochanter. The width of the medullary cavity at 20mm above the intertrochanteric line of the lesser trochanter (T+20) was measured by creating a vertical line of the central axis of the femoral shaft 20mm over the intertrochanteric line of the lesser trochanter, and the width of the medullary cavity along this vertical line was the width of the medullary cavity at 20mm above the intertrochanteric line of the lesser trochanter. The width of the medullary cavity at 20mm below the intertrochanteric line of the lesser trochanter (T-20) was measured by creating a vertical line of the central axis of the femoral shaft 20mm below the intertrochanteric line of the lesser trochanter, and the width of the medullary cavity along this vertical line was the width of the medullary cavity at 20mm below the intertrochanteric line of the lesser trochanter. The femoral head height was defined as the vertical distance between the centre of the femoral head and the intertrochanteric line of the lesser trochanter. The isthmus height was defined as the vertical distance between the isthmus of the femoral shaft and the intertrochanteric line of the lesser trochanter. The isthmus diameter was defined as the diameter of the narrowest part of the femoral shaft. The canal flare index (CFI)(4) was calculated also (Figure-1b). CFI <3.0 was the chimney grade, CFI 3.0 to <4.7 was the normal grade, and CFI >4.7 was the funnel grade.

DDH was classified according to the Crowe classification,[5] which classifies DDH from grades I to IV based on the percent of subluxation of the femur from the acetabulum.

Data was analysed using SPSS 20. Kolmogorov-Smirnov test was used to test data normality, showing non-normal distribution. Mann-Whitney U test was used to conduct pairwise nonparametric tests between the control group and the DDH group and subgroups. $P<0.05$ was considered statistically significant.

Results

Of the 835 hips, 571(68.4%) were in group A and 264(31.6%) in group B. The mean age of the patients at the time of surgery was 58.3±12.3 years. Overall, there were 404(48.4%) hips of male patients; 59(22.3%) in group B. There were 431(51.6%) hips of female patients; 205(77.7%) in group B. In group B, 186(70.5%) hips were graded I, 38(14.4%)grade II, 22(8.3%)grade III, and 18(6.8%) hips were graded IV.

Anatomical parameters of proximal femoral medullary cavity in all the participants were calculated (Table-1).

There were significant differences in femoral offset, height of the femoral head, and CFI of the metaphysis

Table-1: Anatomical parameters of proximal femoral medullary cavity in control group and DDH groups.

[Median (Q1 - Q3)]	Control Group	Grade I	Grade II	Grade III	Grade IV
Femoral offset	38.6 (34.2, 43.2)	32.0 (28.3, 37.0)	31.5 (28.5, 36.5)	25.4 (23.3, 31.3)	25.6 (20.2, 28.6)
Femoral head position	59.7 (54.7, 64.7)	56.4 (51.5, 61.3)	55.8 (50.4, 60.4)	54.8 (52.5, 59.8)	47.8 (42.8, 51.7)
T+20	56.8 (52.2, 60.9)	52.9 (48.8, 57.0)	51.0 (46.0, 54.2)	47.9 (38.1, 51.1)	32.3 (26.2, 39.9)
T	28.8 (25.9, 31.7)	26.8 (24.1, 29.1)	26.7 (24.8, 29.0)	28.9 (26.8, 32.4)	22.9 (16.2, 24.8)
T-20	21.9 (19.9, 23.7)	19.9 (18.2, 21.8)	19.8 (17.8, 22.8)	20.5 (19.6, 23.4)	14.0 (12.1, 16.0)
Isthmus width	13.2 (11.7, 15.3)	12.0 (10.3, 13.9)	12.3 (10.4, 13.3)	12.7 (11.2, 13.6)	9.0 (7.9, 10.4)
Isthmus position	128.3 (119.0, 139.2)	124.0 (113.2, 133.1)	122.6 (115.7, 136.3)	131.6 (125.9, 139.5)	121.0 (105.5, 128.9)
NSA	132.8 (128.9, 136.3)	136.2 (131.8, 141.2)	138.1 (133.7, 143.1)	140.2 (135.1, 143.6)	132.2 (123.1, 137.4)
CFI	4.3 (3.7, 4.8)	4.5 (3.9, 5.1)	4.3 (3.5, 5.2)	3.8 (2.8, 4.3)	3.3 (2.6, 4.3)

DDH: Developmental dysplasia of the hip, CFI: Canal flare index,NSA: Neck-shaft angle, Q1: First quartile, Q3: Third quartile.

Table-2: Pairwise comparison for each anatomical parameter.

	Grade I	Grade II	Grade III	Grade IV
Femoral offset				
Control Group	<0.001	<0.001	<0.001	<0.001
Grade I			0.022	0.004
Femoral head posion				
Control Group	<0.001	<0.001	0.005	<0.001
Grade I				0.012
T+20				
Control Group	<0.001	<0.001	<0.001	<0.001
Grade I			0.004	<0.001
Grade II				0.016
T				
Control Group	<0.001			<0.001
Grade I				0.002
Grade III				<0.001
T-20				
Control Group	<0.001			<0.001
Grade I				<0.001
Grade II				<0.001
Grade III				<0.001
Isthmus width				
Control Group	<0.001	0.011		<0.001
Grade I				<0.001
Grade II				<0.001
Grade III				<0.001
NSA				
Control Group	<0.001	<0.001	0.002	
CFI				
Control Group				<0.001
Grade I			0.002	0.008

NSA: Neck-shaft angle, CFI: Ccanal flare index.

between groups A and B ($p<0.05$). There was no significant difference in the morphology of the marrow cavity between subgroups II and III. The femoral offset, height of the femoral head, canal flare index of the metaphysis and medullary cavity isthmus were significantly smaller in the subgrop IV than group B ($p<0.05$). There was significantly greater stenosis in the diaphysis in subgroup IV than in the remaining subgroups ($p<0.05$) (Table-2).

Discussion

DDH can cause changes in the proximal femoral medullary cavity, increasing the difficulty of surgery and the risk of surgical complications, such as prosthesis dislocation and loosening. A study diagnosed and studied DDH via pelvic radiograph in 1925.[6] Other studies have shown that the morphology of the femoral medullary cavity of patients with DDH can be characterised by a smaller femoral head, increased NSA, straight and narrow medullary cavity, and increased incidence of coxa valga.[7,8]

The NSA is an important parameter for the reconstruction of the normal anatomy in THA. Studies have shown that NSA in DDH varies from varus to valgus. Sugano et al.[9] reported coxa vara in 11% of patients with DDH and in 0% of patients in the control group, and DDH patients were more likely to have coxa vara than coxa valga. Liu et al.[10] reported that the NSA of Crowe I-III hips were similar to those of controls, while Crowe IV hips had significant varus of 122.8°. However, Steppacher et al.[11] showed that the NSAs in DDH were consistent with coxa valga. In the present study, although there was a significant difference between the Crowe I-III groups and the control group, the NSA was significantly smaller in patients with Crowe grade III DDH (121.4° ± 12.4°) than in patients in the control group, indicating coxa vara. In our measurement of Crowe grade IV hips, although not significantly different from the control group, the mean NSA reached 143.0° ± 8.4°, indicating coxa valga. We believe that this result is related to the more variable anatomic morphology of DDH patients compared to the control group. The abnormal morphology of the femoral head makes it difficult to find the centre of the femoral head, which also has a certain impact on the results. Although some patients with DDH have coxa vara or valga, it is more likely that patients with DDH have a normal NSA.[9,12]

Reconstruction of femoral offset is essential for THA and can effectively improve the stability of the hip joint, reduce wear of the prosthesis, improve the function of the prosthesis, and prolong the service life of the prosthesis.[13] The femoral offset is much smaller in patients with than without DDH, and it further decreases as the degree of dislocation increases.[12] In the present study, however, although the femoral offset gradually decreased from grade II to IV, there was no significant difference between any two groups. This was likely due to the small sample size or the greater variation in the medullary cavity morphology of DDH patients.

The present study found no significant difference in the medullary cavity morphology between DDH grades II and III. The metaphysis, isthmus and CFI of DDH patients were significantly lower than those of patients in the control group, indicating that the metaphysis of the medullary cavity was more strictured than the distal end, and that the medullary cavity tended to be chimney-shaped. This phenomenon is particularly true in patients with Crowe grades III and IV. Therefore, in patients with highly dislocated DDH, small straight-stem prostheses should be preferred during surgery. Notably, the AP radiograph often overestimates and the lateral radiograph often underestimates the diameter because of the rotation of the femur when taking the radiographs.[14]

In addition to bone structural changes, patients with DDH also have the risk of joint capsule hypertrophy, abduction, adductor muscle group contracture, femoral nerve and sciatic nerve variation, and nerve traction after reduction. DDH patients are also often relatively young and may require revision surgery in the future after receiving THA.[15] Therefore, a detailed preoperative plan should be established, and the patients' anatomical morphology should be thoroughly evaluated. During the operation, the soft tissue should be released as much as possible to protect the nerves, the proximal femur should be moved down, the length of the lower limbs should be restored, and the acetabular centre should be reconstructed into the true acetabular position to the greatest extent possible.

At PUTH, patients with Crowe grades I and II DDH are often treated with a primary THA stem to correct the length and anteversion of the lower femur. For patients with Crowe grades III or IV DDH, subtrochanteric osteotomy is often required to restore the femoral head to the normal anatomical site. Subtrochanteric osteotomy has demonstrated effective results in patients with DDH, with a survival rate of around 75% at 14 years.[16] Subtrochanteric osteotomy includes transverse, oblique, Z-shaped, and double-chevron osteotomy. Muratli et al.[17] evaluated the stability of these four techniques and found no difference in the stability of these technologies. We often choose transverse osteotomy and strictly abide by the principle of "less is better than more" to simplify the operation steps and avoid complications of joint relaxation and dislocation due to excessive osteotomy.

The current study has several limitations. First, it was a retrospective study. Second, it is difficult to measure femoral anteversion in a two-dimensional morphological study. The femoral anteversion angle increased significantly and varied widely among patients with DDH. In a study by Liu et al.,[10] femoral anteversion in patients with DDH ranged from -3.2° to 58.2° (average 22.2°), while that in normal patients averaged only 10.8°. This is difficult to calculate from radiographs, and the use of computed tomography (CT)-assisted measurements for preoperative planning of patients with grade III and IV DDH is recommended. Third, the small sample size of patients with Crowe grade III and IV DDH in the current study may have biased the findings.

Conclusion

There were significant differences in the femoral offset, femoral head height and T+20 level between DDH grades and the control group. The surgical treatment plan for patients with DDH should be individualised according to the development of the pelvic-medullary cavity to improve the matching of the mortar head and bed joints, to restore the body length of both lower limbs, and to improve the hip joint function.

Acknowledgment: We are grateful to the Ministry of Science and technology of China for financial assistance, and to Angela Morben, of Liwen Bianji, Edanz Editing China, for editorial assistance in the English language.

Disclaimer: None.

Conflict of Interest: None.

Source of Funding: Ministry of Science and technology of China.

References

1. Zhao R, Cai H, Liu Y, Tian H, Zhang K, Liu Z. Risk Factors for Intraoperative Proximal Femoral Fracture During Primary Cementless THA. Orthopedics. 2017; 40:e281-7.
2. Barrack RL, Burnett SJ. Preoperative planning for revision total hip arthroplasty. J Bone Joint Surg Am. 2005; 87:2800-11.
3. Noble PC, Alexander JW, Lindahl LJ, Yew DT, Granberry WM, Tullos HS. The anatomic basis of femoral component design. Clin Orthop Relat Res. 1988; 11:148-65.
4. Laine HJ, Lehto MU, Moilanen T. Diversity of proximal femoral medullary canal. J Arthroplasty 2000; 15:86-92.
5. Crowe JF, Mani VJ, Ranawat CS. Total hip replacement in congenital dislocation and dysplasia of the hip. J Bone Joint Surg Am. 1979; 61:15-23.
6. Classic. Translation: Hilgenreiner on congenital hip dislocation. J Pediatr Orthop. 1986; 6:202-14.

7. Robertson DD, Essinger JR, Imura S, Kuroki Y, Sakamaki T, Shimizu T, et al. Femoral deformity in adults with developmental hip dysplasia. Clin Orthop Relat Res. 1996;196-206.
8. Wells J, Nepple JJ, Crook K, Ross JR, Bedi A, Schoenecker P, et al. Femoral Morphology in the Dysplastic Hip: Three-dimensional Characterizations With CT. Clin Orthop Relat Res. 2017; 475:1045-54.
9. Sugano N, Noble PC, Kamaric E, Salama JK, Ochi T, Tullos HS. The morphology of the femur in developmental dysplasia of the hip. J Bone Joint Surg Br. 1998; 80:711-9.
10. Liu S, Zuo J, Li Z, Yang Y, Liu T, Xiao J, et al. Study of three-dimensional morphology of the proximal femur in developmental adult dysplasia of the hip suggests that the on-shelf modular prosthesis may not be an ideal choice for patients with Crowe type IV hips. Int Orthop. 2017; 41:707-13.
11. Steppacher SD, Zurmühle CA, Puls M, Siebenrock KA, Millis MB, Kim YJ, et al. Periacetabular osteotomy restores the typically excessive range of motion in dysplastic hips with a spherical head. Clin Orthop Relat Res. 2015; 473:1404-16.
12. Noble PC, Kamaric E, Sugano N, Matsubara M, Harada Y, Ohzono K, et al. Three-dimensional shape of the dysplastic femur: implications for THR. Clin Orthop Relat Res. 2003; 23:27-40.
13. Sakalkale DP, Sharkey PF, Eng K, Hozack WJ, Rothman RH. Effect of femoral component offset on polyethylene wear in total hip arthroplasty. Clin Orthop Relat Res. 2001; 11:125-34.
14. Greber EM, Pelt CE, Gililland JM, Anderson MB, Erickson JA, Peters CL. Challenges in Total Hip Arthroplasty in the Setting of Developmental Dysplasia of the Hip. J Arthroplasty. 2017; 32:S38-s44.
15. Faldini C, Nanni M, Leonetti D, Miscione MT, Acri F, Giannini S. Total hip arthroplasty in developmental hip dysplasia using cementless tapered stem. Results after a minimum 10-year follow-up. Hip Int. 2011; 21:415-20.
16. Bernasek TL, Haidukewych GJ, Gustke KA, Hill O, Levering M. Total hip arthroplasty requiring subtrochanteric osteotomy for developmental hip dysplasia: 5- to 14-year results. J Arthroplasty. 2007; 22:145-50.
17. Muratli KS, Karatosun V, Uzun B, Celik S. Subtrochanteric shortening in total hip arthroplasty: biomechanical comparison of four techniques. J Arthroplasty. 2014; 29:836-42.