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Effects of different pelvic osteotomies on acetabular morphology in developmental dysplasia of hip in children

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Abstract

Developmental dysplasia of hip seriously affects the health of children, and pelvic osteotomy is an important part of surgical treatment. Improving the shape of the acetabulum, preventing or delaying the progression of osteoarthritis is the ultimate goal of pelvic osteotomies. Re-directional osteotomies, reshaping osteotomies and salvage osteotomies are the three most common types of pelvic osteotomy. The influence of different pelvic osteotomy on acetabular morphology is different, and the acetabular morphology after osteotomy is closely related to the prognosis of the patients. But there lacks comparison of acetabular morphology between different pelvic osteotomies, on the basis of retrospective analysis and measurable imaging indicators, this study predicted the acetabular shape after DDH pelvic osteotomy in order to help clinicians make reasonable and correct decisions and improve the planning and performance of pelvic osteotomy.

INTRODUCTION

Developmental dysplasia of the hip(DDH)leads to loss of the normal anatomical relationship between the femoral head and acetabulum due to developmental defects of the acetabulum, resulting in abnormal morphology and position of the hip joint [1-3].DDH is the most common hip deformity in children.The global incidence rate is 1‰–

2‰. Surgical correction is still the most challenging problem for pediatric orthopedic surgeons[4, 5].Delayed diagnosis of DDH means that more complex and higher failure rates of treatment are needed, so early diagnosis and treatment are important[6].The main goal of DDH treatment is to achieve and maintain concentric reduction of the femoral head and acetabulum, to ensure te normal development of the hip joint, and to avoid osteonecrosis of the femoral head and reoperation[7, 8].Surgical treatment of DDH is usually determined according to the age, imaging examination and clinical symptoms of the child. In patients with progressive acetabular dysplasia, pelvic osteotomyis necessary to minimize the risk of hip dislocation in adults[9].Common surgical procedures for DDH patients include pelvic osteotomy, open reduction, capsular arthroplasty and femoral osteotomy[10].To restore the anatomical morphology and mechanical structure of the pelvis and ensure normal development and life of children, pelvic osteotomy is almost inevitable[11, 12].Morphology of the acetabulum after pelvic osteotomy is closely related to prognosis of DDH. Many researchershave proposed their own methods of pelvic osteotomy that have their own characteristics, indications and clinical effects. There are three common types of pelvic osteotomy: redirectional, reshaping and salvage [11]. On the basis of retrospective analysis and measurable imaging indicators, this study predicted the acetabular shape after DDH pelvic osteotomy in order to help clinicians make reasonable and correct decisions and improve the planning and performance of pelvic osteotomy.

NORMAL ACETABULAR MORPHOLOGY IN CHILDREN

The hip joint consists of a round head of the femur and a cup-shaped acetabulum, which forms a unique ball and fossa shape that helps stabilize the joint and allows a dynamic range of rotational motion[13].The normal acetabular structure consists of the upper ilium, the anterior pubic bone and the posterior ischial bone. In early infants, the acetabulum consists of a cartilage complex composed of Y-type and acetabular cartilage. The acetabular cartilage is located at the outer two thirds of the acetabular fossa, and the Y-type cartilage is located at the junction of the pubic bone, ischium and ilium[14, 15].With the growth and development of infants, the ossification center in acetabular cartilage appears and develops successively;the pubic ossification center develops and forms the anterior wall of the acetabulum;the ossification center of the ischium develops and forms the posterior wall of the acetabulum;and the ossification center of the ilium develops and forms the superior wall of the acetabulum. The cartilage complex of the normal acetabulum fuses at the age of 12–16 years, completely forming the fossa of the joint, and covering the entire femoral head.The stress direction determines whether the growing hip joint tends to concentric growth, and determines the morphology and structure of the acetabulum under stress[16].The acetabular cup usually faces downward, lateral and anterior, opposite to the upper, medial and lateral direction of the femoral head, forming a stable spherical joint structure of the hip joint[17].Acetabular cartilage is interrupted in the center of the acetabular fossa and is also known as lunate cartilage because it is similar to a crescent shape. Lunate cartilage is located on the lateral and superior articular surface of the acetabulum, which is thickerand stronger than femoral head cartilage[18].The glenoid labrum is a fibrocartilage structure that surrounds the outer edge of the bony structure of the acetabulum, which functionally deepens the acetabular cup and improves the stability of the hip joint[19, 20].

ACETABULAR MORPHOLOGY DURING DDH

Morphological changes of the acetabulum and proximal femur during DDH includes acetabular cartilage degeneration, acetabular fossa shallower, acetabular roof tilted, acetabulum lost its normal and nearly round shape[21, 22]. Subluxation or dislocation of the hip is characterized by widening of teardrops, loss of lateral depression of the acetabulum, elongation of the posterior upper edge of the acetabulum, increase of the ratio of long diameter to short diameter of the acetabulum, and loss of normal concentric circle relationship between the proximal femur and the acetabulum[5, 23].Due to the reduction of the contact area between the acetabulum and femoral head, the load of the acetabulum increases, and the structure of the acetabulum propagates laterally under stress, resulting in excessive anteversion of the femoral neck and varying degrees of hip varus[24, 25].The structural changes of the hip joint also cause compensatory changes in the pelvis and spine, leading to a variety of clinical symptoms. It was believed that dislocation of the hip joint during DDH was caused by insufficient depth and excessive tilt of the acetabulum, which could not accommodate the femoral head. However, recent studies have shown that the development between the acetabulum and femoral head follows the Wolff rule[26].Accordingly, the arrangement of bone trabeculae is affected by the dynamic distribution of bone load, and the mechanical pressure on the bone is conducive to stimulating bone development. When the acetabulum loses the centripetal pressure from the femoral head, the structural development of the acetabulum is affected, andthe depth, width and inclination of the acetabulum become abnormal, and even acetabular cartilage degenerates. With the development of DDH, the anatomical morphology of the acetabulum iscompletely lost and the hip joint is totallydislocated. In the case of total dislocation of the hip, the normal acetabulum loses the pressure from the femoral head, resulting in hypertrophy of the articular pelvis, and the hypertrophic pelvis adheres to the joint capsule and ligaments, which further affects the reduction of the femoral head.

EVALUATION OF ACETABULAR MORPHOLOGY BY COMPUTED TOMOGRAPHY

Computed tomography (CT) is a widely used method forevaluation ofthe hip joint. Because acetabular dysplasia is not just a simple malrotation or anterolateral defect, three-dimensional (3D) CT imaging can help doctors to determine the exact shape of the acetabulum[27].Because of the simplicity and speed of obtaining images, CT has become an important method for the diagnosis of hip joint structural changes, preoperative evaluation and postoperative re-examination[25].The traditional 3D reconstruction of CT can observe the acetabular morphology of DDH in many directions, accurately measuringthe acetabulum, and carrying out further quantitative analysis, so as to better evaluate the pathological changes of DDH and morphology of the acetabulum after osteotomy. Some parameters that cannot be measured by conventional X-ray films can be measured by3D CT, such as bony acetabular index and anteversion. Therefore, CT and 3D reconstruction scanning have important guiding significance for clinicians. The bone reconstruction model of 3D CT provides an omnidirectional and multiangle observation index for clinicians to observe the pathological changes of the hip joint and the curative effect of surgery, and has value for guiding surgical planning and prediction of postoperative acetabular shape[28].Li *et al*[29] used computer-aided design for quantitative dynamic analysis of hip joint morphology, and found that it was a better guide for surgical planning and evaluation oftreatment results. Someclinical studieshave found that the value and safety of using 3D CT to guide pelvic osteotomy is higher than that of ordinary CT [30].In addition, 3D CT can also be combined with finite element analysis method to carry out biomechanical analysis of acetabular morphology after DDH, which has important guiding significance for the evaluation of surgical efficacy and improvement of surgical methods of DDH[31].

EVALUATION OF ACETABULAR MORPHOLOGY BY X-RAY FILM

X-ray film can dynamically observe the changes of bone structure during childgrowth and development, which is the most basic imaging method to evaluate the structural changes of the hip joint, and is important for guiding screening and evaluation of acetabular morphology[32-34]. The following are the main parameters in the evaluation of acetabular morphology by X-ray film[35, 36]: degree of acetabular anteversion, central edge angle (CEA), Acetabular index (AI), sharp angle, angle of iliac wall, and acetabular coverage. The normal acetabulum is usually tilted forward, and it is of clinical importance when the angle is increased by >7° compared with normal [24]. CEA is an important index to describe the shape of the acetabulum[37, 38].It is normal when the CEA is > 25°, but abnormal when it is < 20°, suggesting that the acetabulum is incomplete. When CEA is between 20° and 25°, it is necessary to closely follow up and observe its changing trends. AI is an objective measurement index of acetabular dysplasia, which can be used to judge the severity and therapeutic effect of DDH. The normal range of AI before age 2 years is 20°–25°, and AI >30° after 2 years is considered abnormal [38, 39].The sharp angle reflects the development of the acetabulum and coverage of the hip joint on the femoral head. It is used to diagnose and predict the progress of hip dislocation. The normal value is 33°–38°. Dynamic observation is needed when the value is 42°–47°, and abnormality can be diagnosed when it is > 47°[40].The angle of the iliac wall is the angle between the line from the anterior inferior iliac spine to the outer upper edge of the acetabulum and the Y-shaped cartilage line on both sides of the acetabulum. The normal value of the infant is about 55°. The iliac wall angle increases slowly with infant age, and there is little difference between the normal value and the outlier range, so it is necessary to compare the two sides on the X-ray film[41].The acetabular coverage rate[42]reflects accommodation of the acetabulum to the femoral head. It is the ratio of the distance from the inner edge of the femoral head to the vertical line of the upper edge of the acetabulum to the diameter of the femoral head, and the normal value is > 75%.X-ray film is a simple, fast and economic examination method, which can quickly diagnose DDH from a large number of pelvic films, effectively reduce the misdiagnosis rate and evaluating the shape of the pelvis and acetabulum after surgery.

PELVIC OSTEOTOMYAND ACETABULAR MORPHOLOGY

The ability of acetabular remodeling has an age limit, and previous studies have shown that the acetabulum can be remodeled under the age of 5years[43]. Acetabular dysplasia over a certain age needs to be corrected by pelvic osteotomy. Different methods of pelvic osteotomy depend on the age of DDH patients and the degree of deformity[44, 45].Normal development of the acetabulum depends on the femoral head under the concentric circle position, but DDH changes the biomechanical structure of the hip joint, which limits the morphological development of the acetabulum in children, so the purpose of the operation is to restore the concentric reduction of the hip joint[46]. Pelvic osteotomy can improve deformity of the acetabulum, increase the stress area of the hip joint, restore the coverage of acetabular cartilage, and reconstruct the biomechanical relationship of the hip joint[47]. When acetabular dysplasia is associated with subluxation or dislocation, pelvic osteotomy is necessary to minimize the risk of hip dislocation in adults[11].The older the onset of DDH, the worse the prognosis. It is generally believed that osteotomy has a lot of complications in patients aged> 8 years [48].The effects of different pelvic osteotomy on acetabular morphology are different, which provides a basis for different patients to formulate specific osteotomy methods[49].The current imaging technology has been able to measure the relevant indicators of acetabular morphology, but the operations processof different patients can't be total the same, so it is difficult to measure acetabular morphology accurately by different osteotomies. Previous researchers used the lateral CEA to assess acetabular developmental defects, but Daniel *et al* [50]found that acetabular deficiency in borderline hip dysplasia can be underestimated by lateral CEA alone. Some researchers used 3D printing technology to measure the relevant indexes of acetabular morphology after different osteotomies. The real proportional anatomical model can accurately measure the AI before and after surgery, and it provides conditions for optimizing the surgical plan and improving the method. Researchers had described many types of pelvic osteotomy. Different pelvic osteotomies have different advantages and indications, and the shape of the acetabulum after osteotomy is also different. There are three common types of pelvic osteotomy: redirectional, reshaping and salvage [11]. We will describe the effects of the different types of pelvic osteotomy on the morphology of the acetabulum.

REDIRECTIONAL OSTEOTOMY

Redirectional osteotomy of the pelvis changes the direction of the acetabulum, increases the contact area between the acetabulum and the femoral head, and increases the area of hyaline cartilage in the weight-bearing area of the acetabulum. It is characterized by repositioning the acetabulum to improve the anterolateral acetabular cover without changing the size and shape of the hip, which is an incomplete osteotomy[51]. The common redirectional osteotomies include Salter, periacetabular and triple pelvic osteotomy.

Salter osteotomy

Salter osteotomy is a classic method of pelvic osteotomy, which belongs to the osteotomies that change the direction of the acetabulum. It was first proposed by Salter in 1961[52]. The osteotomy line of Salter is from the anterior inferior iliac spine to the great ischial notch, and the entire acetabulum is turned forward and outward with the pubic symphysis as the fulcrum. It changes the overall orientation of the acetabulum to increase the inclusiveness of the acetabulum to the femoral head, and the shape and volume of the acetabulum remain unchanged[3].Therefore, Salter osteotomy is suitable for the following[52, 53]: (1)children aged 18 mo to 6 years with unossified pubic symphysis; (2) anterolateral acetabular defect as the main defect; and (3)AI is basically normal. Salter osteotomy requires internal fixation support, so the wedge-shaped bone removed from the ilium is placed into the fracture line and fixed with Kirschner wire to increase stability of the acetabulum after osteotomy. In the Salter procedure, the rotation angle and distance of the distal iliac bone are not only the difficulties of the operation, but also the key to its effectiveness. Previous studies have shown that Salter osteotomy changes the acetabular center with the movement of the distal bone mass, and the AI decreases yearly. At 3–4 years after the operation, the AI is stable to about 15°, the CEA increases yearly, and returns to the normal range for about 5 years, and the postoperative obturator area is significantly reduced[54].

Periacetabular osteotomy

Periacetabular osteotomy, also known as GANZ osteotomy, is suitable for patients with hip pain and when the femoral head is located in the center of the acetabulum, and the degree of hip deformity and arthritis is low.It was first proposed by Ganz in 1983[55].The periacetabular osteotomy procedure is mainly to amputate the pubic bone, ischium and ilium, and under the condition of maintaining the continuity of the pelvis, rotate the acetabulum to make the acetabulum cover the femoral head to the best extent[56].Because periacetabular osteotomydoes not destroy the acetabular blood supply and the pelvic ring, it can improve the biomechanical relationship between the acetabulum and femoral head, reduce the probability of postoperative acetabular necrosis, and avoid the occurrence of hip arthritis[45]. Andrew *et al*[57] found that among athletes with symptomatic hip dysplasia who received periacetabular osteotomy, all acetabular parameters were improved, and the return to exercise rate of competitive athletes was > 70%. Periacetabular osteotomy allows the acetabulum to be relocated in multiple directions to correct the deficiency of the anterior coverage of the femoral head, so even severe acetabular deformities can be satisfactorily corrected by accurate rotation and internal displacement of the acetabular center. Because periacetabular osteotomy maintains the integrity of the posterior column of the acetabulum, better initial stability is obtained[55, 58]. Through long-term follow-up, researchers have found that in the patients treated with periacetabular osteotomy, the fracture healed well, the lateral coverage of the femoral head, AI angle and Sharp angle were significantly improved, the cartilage area of the acetabular weight-bearing area was increased, and the gait and hip joint function were significantly improved.

Triple pelvic osteotomy

Triple pelvic osteotomy, which includes osteotomy of the ilium, pubis and ischium around the acetabulum, is a complete redirected osteotomy, which solves the problems of limited movement of bone mass and lateralization of the hip joint after osteotomy[59, 60].This complete redirected osteotomy increases the range of motion of the acetabulum by cutting off the pubic bone, ischium and ilium, so that the rotated acetabulum can completely contain the femoral head and achieve concentric reduction of the hip joint. At present, there are three common triple pelvic osteotomy procedures, which are LeCoeur, Steel and Tonis[61].By amputating the ilium and the superior and inferior branches of the pubis near the symphysis pubis, the LeCoeur procedure limits the rotation of the acetabulum because the position of the amputated pubis and ischium is far from the acetabulum[11].Steel osteotomy cuts the ischial bone at the ischial tubercle through the posterior approach, and the pubic bone and ilium through the anterior approach. Because the osteotomy is close to the acetabulum, the range of acetabular adjustment is better than that of LeCoeur. The position of the Tonnis osteotomy is closer to the acetabulum than the Steel osteotomy is, so the acetabular rotation is greater[62].Like other redirected osteotomies, triple pelvic osteotomy is a rotational osteotomy that does not change the size and shape of the acetabulum[63]. The premise of this operation is that the structure of the hip joint is intact, which is mainly suitable for older children with more severe acetabular dysplasia, and it is an unstable osteotomy that requires solid internal and external fixation[59, 64]. Triple pelvic osteotomy can improve the CEA, lateral coverage of the femoral head, and stress distribution of acetabular cartilage, and can effectively correct acetabular deformities.

RESHAPING OSTEOTOMIES

Compared with pelvic redirectional osteotomies, pelvic reshaping osteotomies are incomplete, which increases the coverage of the acetabulum and femoral head by bending acetabular vertices[65]. Therefore, this kind of operation is also called acetabuloplasty. Because it is an incomplete osteotomy, the position of the bone mass after operation is stable and usuallydoes not require internal fixation. There are three common methods of reshaping osteotomies, namely, Pemberton, Dega and SanDiego. Researchers[49]compared the effects of these three osteotomies on acetabular morphology using 3D-printed models, and found that Pemberton and Dega increased the upper and anterior coverage of the acetabulum, resulting in retroversion of the acetabulum, while SanDiego increased the posterior coverage of the acetabulum, resulting in acetabular anteversion.

Pembertonpelvic osteotomy

Pemberton pelvic osteotomyis a periarticular osteotomy, also known as Pemberton acetabuloplasty, which was first proposed by Pemberton in 1968[66, 67].Pemberton pelvic osteotomyhas a wide range of adaptation, and can be used in children under 12 years old, but because it affectsdevelopment of the pelvis and pubic symphysis, caution is needed in children under 6 years old. Pemberton pelvic osteotomy takes the Y-type cartilage around the acetabulum as the rotation fulcrum and controls the shape of the acetabulum by adjusting the position of the bone cortex on the posterior side of the ilium. It increases the coverage of the anterior edge of the acetabulum, and significantly increases the coverage of the outer upper edge and posterior edge of the acetabulum[68]. Pemberton pelvic osteotomycan adjust acetabular direction, correct acetabular deformity and increase acetabular depth according to the degree of acetabular defect.Therefore, it can reduce AI, increase the coverage of acetabulum and femoral head, stabilize the hip joint, and reduce deformity of the acetabulum[69,70]. Because the Pemberton procedure can reduce AI, it is suitable for cases where the acetabulum needs to be corrected by > 15 °and the acetabulum is shallow and steep.

Degapelvic osteotomy

Dega osteotomy is one of the commonly used osteotomies in the treatment of DDH. It was first proposed and applied in clinic Dega in 1958[71, 72]. The Dega procedure is a typeofacetabuloplasty to change the shape and inclination of the acetabulum, mainly to increase the lateral coverage of the acetabulum, which can change the volume of the acetabulum without damaging the Y-type cartilage [73]. Dega operation uses the iliac bone of incomplete osteotomy above the Y-type cartilage as a hinge to change the direction and inclination of the acetabulum. Its advantage is that the position of iliac osteotomy can be adjusted according to the location of the acetabular defect, so that acetabular defects in different parts can be corrected[74].Aretrospective analysis[75]showed that AI decreased significantly in patients who underwent Degaacetabuloplasty, and postoperative Sharp angle was also improved, which can improve AI and inclusiveness of the femoral head.

San Diego pelvic osteotomy

SanDiego osteotomy is a modified Dega osteotomy to improve lateral and posterior acetabular coverage[11, 76].The SanDiego operation is an incomplete osteotomy. The medial iliac bone cortex is intact except for the anterior and posterior sides, and the ischial and pubic corticesarealso continuous[51].In iliac osteotomy, the wedge-shaped bone can be used to stretch the osteotomy surface, so this kind of monocortical osteotomy enables doctors to change the shape of the acetabulum by changing the size and position of the bone graft, thus solving the problem of insufficient acetabular coverage[76].Because San Diego osteotomy mainly increases coverage of the acetabulum, the shape of the acetabulum tilts forward after osteotomy, the volume of the acetabulum decreases, and the depth of the acetabulum increases.

SALVAGE PELVIC OSTEOTOMIES

If DDH is untreated or inadequately treated, it aggravates the deformity of the hip joint,which eventually develops into a nonfunctional joint with pain symptoms [77].At that time, the change in the bony structure of the hip joint is more serious, the shaping ability of the bone decreases, the shape of the femoral head and acetabulum are difficult to reduce by simple methods, and in severe cases, cartilage injury of the hip joint occurs[78].At that time, surgeons should pay attention to recovery of hip joint function and perform salvage surgery, so as to delay the progress of arthritis and reduce the probability of osteonecrosis of the femoral head. The common salvage pelvic osteotomiesare Chiari and Shelf.

Chiari pelvic osteotomy

Chiari osteotomy, also known as intrapelvic osteotomy, was first proposed and applied by Chiari *et al* in 1974[79].Chiari osteotomy changes the weight-bearing line of the hip joint and increases the weight-bearing area by moving the position of iliac osteotomy. It is a type of joint capsule plasty, which belongs to single-plane osteotomy[80]. Therefore, Chiari operation is suitable for older children with abnormal acetabular–femoral head index, non concentric reduction of the femoral head, acetabular deformity and lack of plastic potential[81, 82]. The Chiari procedure cuts the ilium from front to back from the area between the acetabulum and the anterior inferior iliac spine along the ischial notch, and then the bone mass of the distal end of the ilium is moved inward and upward. In this process, it is necessary to ensure the coverage of the acetabulum to the femoral head and avoid the impact between the femoral head and ilium[51, 78].The coverage of the acetabulum depends on the width of the ilium. In order to achieve satisfactory coverage of the lateral acetabulum, it is usually necessary to move the distal bone completely inward to the width of the ilium. If there is insufficient containment of the anterior side of the femoral head, iliac alar osteotomy can be performed, then coverage on the anterior side of the femoral head was improved. The Chiari procedure distributes the weight-bearing area of the acetabulum by expanding the inclusion of the acetabulum to the femoral head, but the damaged acetabular cartilage and glenoid labrum may still be located in the weight-bearing area after salvage surgery. Therefore, although this operation can better restore the acetabular–femoral head index, it cannot solve the defect in front of the acetabulum, and shortens the transverse diameter of the pelvis, resulting in unsatisfactory surgical results [83].

Shelf pelvic osteotomy

Shelf osteotomy, also known as acetabular extension, is mainly suitable for older children with femoral head and acetabular mismatch and hip dislocation.The anterior, posterior and lateral weight-bearing surface of the acetabulum is enlarged by osteotomy of the ilium and bone grafting at the fracture line, so the acetabular coverage of the femoral head is increased[11]. Shelf operation is a salvage operation, which is suitable for older children who have failed nonoperative treatment of DDH[84]. Shelf acetabuloplasty has a favorable, stimulatory effect on acetabular growth[85].The operation does not change the direction or biomechanical structure of the acetabulum, but increases the volume, so it can improve stability of the hip joint. After Shelf osteotomy, the central marginal angle of the hip joint increases, the coverage of the acetabulum to the femoral head increases, and the acetabular shaping is improved[86].

CONCLUSION

Pelvic osteotomy is an important method for surgical treatment of DDH. There are three common types of pelvic osteotomy: redirectional, reshaping and salvage. The choice of pelvic osteotomy depends on the patient's age, acetabular development and disease severity. No operation is the best, and no operation is suitable for all cases. It is particularly important for pediatric orthopedic surgeons to choose the osteotomy with which they are most familiar and which is most suitable for patients. Different methods of pelvic osteotomy have different effects on acetabular morphology, and the acetabular morphology is closely related to prognosis. It is still one of the most challenging problems for pediatric orthopedic surgeons to master the principles of various pelvic osteotomies and to understand the morphological changes in the acetabulum after pelvic osteotomy. At present, the evaluation of acetabular morphology after pelvic osteotomy mainly depends on ordinary X-ray or 3D CT reconstruction, but the measurement of acetabular morphology is not accurate because of the nonreplicability of different patients and the individual differences of observers. In the future, the acetabular morphology of different pelvic osteotomymethods will be measured by 3D printing, and the morphological changes in the acetabulum before and after surgery will be accurately measured by real proportional anatomical models, so as to provide a basis for optimizing the surgical plan and improving the osteotomy method.

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