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Morphological research at the proximal femur on the three-dimensional reconstruction leaded by MRI for the adult developmental hip dysplasia

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Abstract

The three-dimensional reconstruction is beneficial to observe the injured portion better. It provided the all-around treatment choices. Our study aimed to discuss the effect of the three-dimensional reconstruction leaded by MRI on the morphology. The iconographical assessment was performed for patients by LCEA (Front and rear view), acetabular inclination (AI) (Front and rear view), and anterior central margin angle (ACEA). Patients with dysgenesis at different degree was detected through HE and IHC. The principal component analysis was performed by DDH leaded under MRI. The baseline characteristics of patients was consistent basically. The center of caput femoris was lateral obviously in patients with DDH mild form and proximal notably in patients with DDH heavy type under MRI. There was more extensive vascularization and inflammatory cell infiltration in the synovial membrane of hip joint in the development of DDH from the moderate type to heavy type. The staining strength of SP and CGRP in patients with heavy type DDH was significantly higher than those in patients with moderate type DDH and control group. The patients with DDH were treated through the three-dimensional reconstruction leaded by MRI which could improve the intertrochanteric osteotomy combined with periacetabular osteotomy. The thighbone is adjusted moderately so as to improve the coverage of caput femoris and recover or maintain the limb alignment.

Key words: MRI, DDH, three-dimensional reconstruction

Introduction:

The developmental dysplasia of the hip (DDH) was one kind of structural disease. Its features are that making acetabulum shallower, covering incompletely and stabilizing the caput femoris. This kind of abnormal bone structure could lead to the changes in stresses of articular cartilage and labrum so as to increase the risk of hip osteoarthritis (OA) up to 4.3% [1-2]. The hip joint preserving operation of DDH can make acetabulum redirected relatively to the caput femoris for preventing or releasing the development of hip osteoarthritis (OA) so as to provide more integrated coverage. The medullary space of thighbone at the proximal hip joint with abnormal growth was smaller, narrower and shorter as demonstrated by literatures [3-4]. But even if these malformations are solved completely, there is occasionally special malformation such as S-ROM, hardly-inserted ready-assembled femur stalk, especially highly-dislocated hip joint in some patients with DDH hip joint. The morphological parameter at the proximal thighbone is detected by SD-CT scanning from a recent literature. The outline in the transverse section of proximal thighbone is irregular and oval-shaped [5]. The feature of every section in the proximal medullary space was described through the inside and outside width and front and back width based on the concept. The true morphological feature of the corresponding section could be observed by the adopted method. But their study did not make much contribution to the prosthesis design for the patients with DDH due to the vertical axis of cross section in medullary space being rotated from inside and outside lateral to front and rear [6-7]. At the present, diagnosis and corrected operation on DDH is focused on the acetabulum. But there is abnormal shape of thighbone in several cases of DDH. It was commonly reported that there was thighbone leaning too much forward, corneal asphericity of caput femoris and coxa vara being increased. The variability of 3D shape of thighbone in DDH cases further may be conducive to identify the formation of abnormal joint between the thighbone and acetabulum, and how the mechanism of the intra-articular damage was facilitated by every kind of structure [8-9]. To

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know the shape variability in this kind of patients could also illuminate better the comparability and difference of shape and morphology in the patients with DDH and patients with other poorly-defined proximal thighbone lesion (such as femoroacetabular impingement). Besides, the shape variability in the distal thighbone may be related with DDH patients because it probably impacted the lower limb alignment and load transmitting from ground to hip joint. More knowledge on the shape of the proximal and distal thighbone in patients with DDH could be adopted for preoperative planning. It provided the understanding on the survival rate of all kinds of long-term joint in the related patients with DDH. The statistical shape modeling (SSM) was one kind of statistical tool based on crowd. It could be quantized the shape change objectively. The SSM was involved with the distribution of corresponding point in shape of one group representing the interested group so as to represent the position and the related extent of variability on the individual shape in this group [10-11]. The SSM had been adopted to understand the shape variability in the population with all kinds of orthopedics further. But it was not adopted on the population with DDH.

The series of two-dimension (2D) image based on normal X ray photographic images or computed tomography (CT) or magnetic resonance imaging (MRI) was adopted to classify the geometric construction of hip joint. A group of limited discrete character was adopted on the present clinical measurement on the acetabulum (such as side of acetabulum border) and thighbone (such as deviation from the best-fitting circle). The MRI was also an optimal imaging tool for diagnosis of the soft tissue injury including acetabular labrum tear, parietal region tear, cartilage damage and muscle damage. The MRI could identify the soft tissue in joint, bone chip and posterior unossified acetabular neck injury. It had unique performance in the traumatic dislocation of the hip with skeletal immaturity. The effect of MRI on traumatic dislocation of the hip in adolescents and children had been reported from previous studied [12-13]. Although the evaluation of MRI on the closed reduction in adolescents and children was useful, it is not considered as the standard imaging mode of the upper closed reduction scanned by CT. The MRI was supposed to be superior to the CT scanning on the pathological evaluation for the soft tissue structures. And it was same as or better than the CT scanning for the detection on the bone injury in the adolescents and children with traumatic posterior dislocation of the hip.

But the 2D description on geometrical shape may misidentify (or not identify) malformation. The 3D description on geometrical shape could not be described adequately. It could probably interfere with the diagnosis and treatment. The relation between the variation of 3D shape and clinical measurement could be adopted to consummate further the most entire description for DDH pathological diagnosis tool if it was confirmed. The main purpose in our study was to develop the SSM of thighbone in the patients with symptomatic DDH so as to improve the understanding on the geometric pathology of DDH. The most common variation type of 3D type was described [14-15]. The second purpose of our study was to test the correlation between the description of shape variation by SSM and the measured value obtained from 2D X-ray film and measured value on the function of hip joint ROM.

Materials and Methods

Inclusion criteria of patients

This retrospective study was approved by the ethic committee of our hospital. All patients signed the informed consent. The forty-five cases of patients with traumatic dislocation of the hip from Jan 2016 to Oct 2018 in our hospital was studied retrospectively. Whether the activity of the location of pain was limited, hip joint was not moved normally, greater trochanter was confirmed by X-ray examination or CT scanning examination. The patient under nineteen years old which could be evaluated by MRI after restoration was included. The eighteen patients which could be checked by MRI were excluded. So, 27 patients were included in our study and 16 patients (59.3%) received CT scanning after restoration.

Research on the patient's imaging

The research program on all patients' imaging was not uniform. The six cases of patients (37.5%) imaging were obtained at the external agency before they were transferred in our hospital in the sixteen cases of patients through MRI scanning. Ten cases of patients (62.5%) received MRI scanning. Although patients received different MRI scanner, thin slice (thickness of slice less than 1mm) was adopted on all images for collection axially. The three-dimensional reconstruction software was adopted in the procession of imaging investigation by two experienced radiologists. The CT image was re-formatted into coronal plane and sagittal plane. The four cases of patients were performed through scanning in outward hospital before they were transferred in our hospital in the twenty-seven cases of patients through MRI scanning. The imaging scheme of different agency was different.

The all kinds of different imaging system were adopted for scanning including 3T (8/27) and 1.5T (19/27) imaging system. The all-imaging study had diagnostics quality equally considered by the two experienced radiologists including multiple planes of T1 weighted sum and T3 weighted sum imaging sequence. Whether the patients were requested through CT and/or MRI scanning in our research institution was decided by attending physician. The joint space was broadened of part cases in the sixteen cases of patients being through CT and MRI inspection simultaneously due to several reasons for postponing MIR inspection. The fracture was not found out through CT scanning.

The population statistical data, damage mechanism and clinical management in the electronic medical record was inquired and all CT and MRI inspection was agreed by the two orthopedic radiologists. The CT inspection was applied blind when the MRI inspection was explained by the two orthopedic radiologists, and vice versa.

Morphological description

The iconographical measuring result on describing DDH was obtained from a series of MRI image. The acetabulum shape was described by LCEA (Front and rear view), acetabular inclination (AI) (Front and rear view), and anterior central margin angle (ACEA). The shape of caput femoris was described by α angle (Dunn view) and head and neck eccentricity (HNO) (Dunn view). The other description of shape of caput femoris was including collodiaphysial angle (NSA) (Front and rear view), overall femur inclination Angle and top and bottom Angle of rotor. The standardized radiological image in retrospective control group was not obtained. So the femoral version, Upper and lower rotor versions was only measured. The control value of the other iconographical description was based on the previous enunciable literature [16-17].

Three-dimensional reconstruction and pretreatment

The geometric construction in the proximal and distal thighbone in DDH group and the thighbone in control group was rebuilt and decollated from the data of MRI images. The femoral shaft was established through linear interpolation between the undermost and upmost slice in the proximal and distal image set respectively. The total thighbone was cut off from the six centimeters of the distal end of the most medial projection of the lesser trochanter and the six centimeters of the proximal lateral condyle respectively in order to compare the uniform shape with DDH group. The geometrical shape in the proximal and distal thighbone in control group was established. As previously mentioned, these geometrical shapes were conducted with linear interpolation subsequently. The trigonometric survey and smoothing procession were performed to reduce the segmentation and linear interpolation artifact. Every thighbone was scaled solidly into handpicked “primary” thighbone so as to eliminate the total variability of thighbone shape. Then the thighbone was aimed through iterative nearest point optimization algorithm. The root means square distance between the surface of minimum Amira (iteration RMS<0.0001). At the last, the thighbone was converted into bivariate volume with bounding box of 512×512×512 and resolution of isotropic voxel with 1.0mm×1.0mm×1.0mm.

Histological staining

The hematoxylin and eosin (HE) (Sigma-Aldrich,St Louis,MO,USA) staining and IHC staining of SP and CGRP was conducted using SP primary antibody (1:1000 diluent, product catalog number: ab14184, Abcam, Cambridge, UK) and CGRP primary antibody (1:3000 diluent, product catalog number: ab36001, Abcam) and biotinylated second antibody (EnVision system ; Dako,Glostrup,Denmark). The Image-Pro Plus of 6.0 version software (Media Cybernetics, Rockville, MD, USA) was adopted to measure the immunoreactivity. The result was represented as average optical (AOD). The AOD was integrated optical density of every view under microscope with the actual synovial membrane.

Modeling of statistical shape

The surface of Amira was disposed in the ShapeWorks software. Each surface was converted into distance transform. The 3D shape was defined including physical distance 19 of overall original point in the image volume relative to every unit in the shape space. The volume was cut automatically into cuboid volume with 124×98×442. The gradient descent energy function was adopted in ShapeWorks. The 8192 of corresponding particles were places on every thighbone. The collected entropy of the distribution of particles on the surface of each shape was equilibrated. Then sixteen of particles’ configuration as DDH group and control group was adopted. The individual average shape was generated.

Results

Patient baseline characteristics

The diagnosis on DDH was based on the criterion of hip joint. The acute angle was less than 45 degree.

The center edge angle was less than 20 degree. The perihip osteotomy (PAO) or osteochondroplasty (OCP) was performed on the patients with moderate DDH. The total hip arthroplasty (THA) was performed on the patients with serious DDH. The fixation or hemiarthroplasty was performed on the patients in the control group in 24 hours after injury. The clinical and lab examination data of patients in all groups was shown in table 1. The analysis on the baseline characteristics of patients was consistent basically.

Comparison of three-dimensional reconstruction leaded by MRI

There was obvious lateral in the center of caput femoris under MRI in the patients with slight type of DDH (I type, 103.5±8.6 mm; II type, 101.5±6.6 mm; III type, 102.1±11.2mm) ($p<0.001$) compared with healthy control group (87.5±5.1 mm) in the inside and outside (ML) direction. There was obviously proximal in the center of caput femoris under MRI in the patients with serious type of DDH (I type, 62.4±7.3 mm; II type, 50.0±7.0 mm; III type, 43.2±7.5 mm) ($p<0.001$) (figure 1).

Morphological clinical description leaded by MRI

There was more vascularization and inflammatory cell infiltration in the synovial membrane of hip joint in the development procession from the moderate type to serious type of DDH as shown by H&E staining (figure 2A-C). The blue arrow represented blood vessel or hyperplastic blood capillary in the tissue of synovial membrane. It was selected retrograde when the view was selecting according to the condition of staining expression due to the different expression position of SP and CGRP. The strength of SP and CGRP staining in the patients with serious type of DDH was higher than in the patients with moderate type of DDH and control group from IHC staining SP (figure 2D-F) and CGRP (figure 2GF-I) analysis. The similar result was observed in the comparison on the expression of neuropeptide gene in tissue of synovial membrane in these groups.

Principal Component Analysis of DDH leaded by *MRI*

The former eight kinds of Principal Component Analysis (PCA) in DDH group were not fake based on the parallel analysis. It was in 90.9% of total square deviation (VAF) (figure 3). In practical terms, 28.6% of VAF was captured in model 1, 23.6% of VAF was captured in model 2 secondly, 16.4% of VAF was captured in model 3, 8.1% of VAF was captured in model 4, 6.6% of VAF was captured in model 5, 2.8% of VAF was captured in model 6, 2.0% of VAF was captured in model 7, and 1.7% of VAF was captured in model 8. The former seven kinds of model were remarkable for parallel analysis in the control group. It was in 91.6% of total VAF. In practical terms, variation in model 1 in DDH group was most remarkable in the width of thighbone. The variation of proximal thighbone, length of the collodiaphysial angle and femoral neck was described principally in model 2. The variation of distal thighbone, size of caput femoris and femoral offset was described in model 3. The shape variation collected in model 4 to 8 was fine mainly including the variation of shape in the proximal thighbone. The variation of collodiaphysial angle and femoral condylar width was described in model 1 in control group. And the variation of height and width of greater trochanter was described in model 2. The shape variation described in PCA model 3 was also related with the overall thighbone edition significantly ($P<0.001$).

Discussion

The collodiaphysial angle is important extramedullary parameter in the proximal thighbone. The average NSA in healthy adult (5089 of hip joints) was 128.8 degree. The average NSA in the patients with osteoarthritis (1230 of hip joints) was 131.5 degree. The NSA of men was 129.6°±5.9° and the NSA of women was 131.9°±6.8° from large-scale CT study on eight hundred cases of adult hip joints. In general, the collodiaphysial angle of patients with DDH was larger than normal population [18-19]. On the contrary, there was no significant difference on this parameter between the normal group and the Crowe I and Crowe II-III group from our study. Besides, it was funny that the collodiaphysial angle in Crowe IV group (122.8±11.4°) was significantly less than that in the other DDH group and normal control group. The value from the previous report on the NSA in the Crowe I and Crowe II/III group was less than the value from our study. The adopted method was similar. So, the difference was probably the reason for the difference of DDH in the different regions. The length of the head and neck of DDH group was shorter than in control group from our study. It was more obvious in the Crowe IV group. The value in the Crowe IV group was shortest, the length of the head and neck was shorter when the degree of dislocation was higher based on the three-dimensional data for analyzing the morphological parameter in the proximal thighbone. Their recovery was similar to our study [20].

The level of CGRP in synovial membrane and SF was elevated equally along with the development of DDH as shown by IHC staining and HE staining. The obvious proinflammatory ability of CGRP and

the correlation between the CGRP and cell factors such as IL-1β, TNF-α and IL-10 in SF of patients with moderate or serious type of DDH was observed by real-time PCR. The CGRP neure had crucial effect on perceiving the pain of hip joint from an item of previous study [21]. In conclusion, not only CGRP probably could participate in the hyperalgesia of the hip joint in the patients with DDH, but also it could participate in the hypothesis for adjusting the inflammatory infiltration from our obtained results. It could probably impact on the pathological procession of DDH.

The main purpose of our study was to perform the morphological research at the proximal femur on the three-dimensional reconstruction leaded by MRI for the adult developmental hip dysplasia. The X-ray plain film was a kind of routine examination method clinically. But the real anatomical characteristics of hip joint in DDH could be displayed by the X-ray plain film generally due to the flexion contracture and rotational malalignment of hip joint. The three-dimensional study could conquer this barrier. So, the expression difference in different parts was confirmed by our study. The maximum amount of variability among the thighbone in DDH was femoral version from our obtained result. It was most obvious in the proximal thighbone. Besides, the maximal morphological difference was found at the proximal of thighbone compared with the average control shape. The bigger front rake of thighbone and bigger length of femoral neck was displayed in the thighbone in DDH. There was considerable variability in the geometric construction of thighbone in the relatively limited and clearly defined patients' samples based on the geometric characteristic of acetabulum. The potential action of thighbone on the symptom development and disease development in patients with DDH was highlighted. The correlation between the variation in 3D model and the measured value of common clinical morphology was reported in certain literature [22].

There was correlation between the 3D shape and measuring global version, as well as the commonly-used measurement (LCEA or NSA) on the diagnosis of DDH from our study. The correlation between the complicated 3D morphology and the 2D radiological measuring was probably conducive to improve the total understanding on the shape variability and heterogeneity in the population with DDH. And it provided new method for diagnosis and evaluation [23].

There was obvious difference between the femoral version of PCA model 2 and model 3 from the present result of SSM. It indicated that it was one of the main modalities on the shape difference of thighbone in the population with DDH. The position of the average shape of the maximum deviation from in PCA model 2 was proximal of thighbone from our result. It indicated that the variability of femoral version was more obvious due to the rotation of the proximal thighbone relative to the distal thighbone. Although it was not same as the protrusion of proximal variability, there was significance difference on the distal femoral version collected at the PCA model 3 which was indicated by the SSM result in DDH group. The diametral medullary cavity reaming index could be considered as the direct reference for the design of fitted femur stalk in the DDH thighbone group from certain literature. The proportional range between the proximal and distal width of sleeve was 1.31 to 3.17 according to the product manual of S-ROM. So, the structure of hip joint was analyzed specifically according to the condition of three-dimensional reconstruction [24].

The formation of extreme femoral version and OA of hip joint was confirmed adequately with the worse postoperative denouement after the hip arthroscopy clinically. But the 3D description on the shape variation was not concluded in the most of previous study on this kind of population. It only included the proximal thighbone and the limited sample capacity was inspected. So, the amount of variability in the version was difficult to be quantified. The increasing on the top rake in the thighbone with DDH was attributable to the measuring on the rotor top and bottom which was already indicated. Although the variability of DDH was impacted with the proximal morphology obviously, the abnormality of DDH was integrated effect between the variation of the distal and proximal thighbone [25]. It was supported by our results. The thighbone was moderately adjusted probably through the three-dimensional reconstruction on the operative decision leaded by MRI, as the same as through the rotator cuff osteotomy combined with periacetabular osteotomy so as to improve the recovery of thighbone, recover or maintain the limb alignment.

In conclusion, the thighbone was moderately adjusted probably through the three-dimensional reconstruction on the operative decision leaded by MRI, as the same as through the rotator cuff osteotomy combined with periacetabular osteotomy so as to improve the recovery of thighbone, recover or maintain the limb alignment. However, the main limitation of our study is the small number of patients enrolled. In the future, large cohort study is required to confirm our findings to provide more evidence for the effect of the three-dimensional reconstruction leaded by

MRI on the morphology

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Table and Figure legends

Table 1. **comparison of patient baseline characteristics**

	control group	patients with slight DDH	patients with serious DDH	p
quantity of patients	32	35	32	> 0.05
age	30.3±2.3	28.2±3.1	29.2±4.2	> 0.05
men/women	22/10	21/14	22/10	> 0.05
BMI （kg/m2）	24.8±2.4	23.2±4.3	23.4±2.1	> 0.05
duration	-	2.5	4.3	> 0.05
CRP (mg/L)	10.9 ± 6.5	12.1±2.9	11.79±3.8	> 0.05
erythrocyte sedimentation rate (mm/1st hr)	19.6±4.7	16.2±3.0	17.8±6.7	> 0.05
Harris grade of hip joint	-	74.6±9.9	62.8±12.4	> 0.05
analogous scale	-	38.2±13.2	57.8±10.3	> 0.05

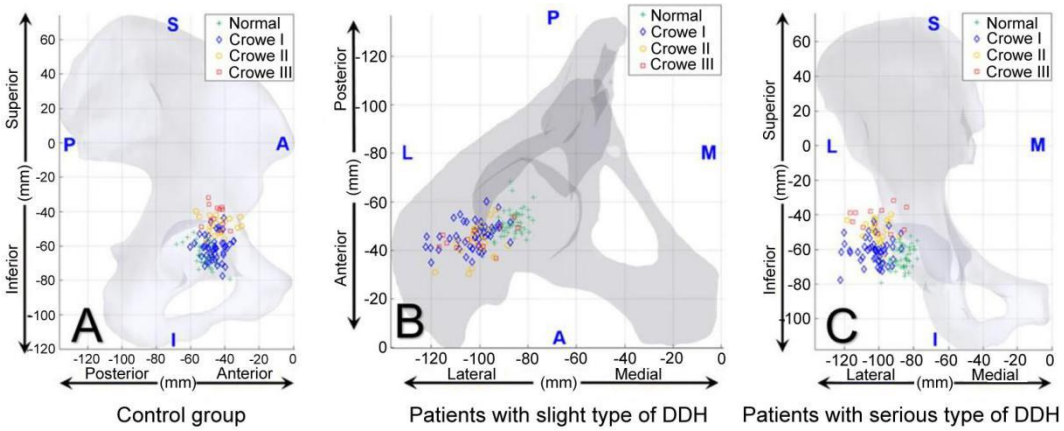

Figure 1. **comparison on the 3D pelvis model of MRI and 3D displacement distribution of the center of caput femoris in the patients with different types in every groups**

Figure A: control group. Figure B: patients with slight type of DDH. Figure C: patients with serious type of DDH.

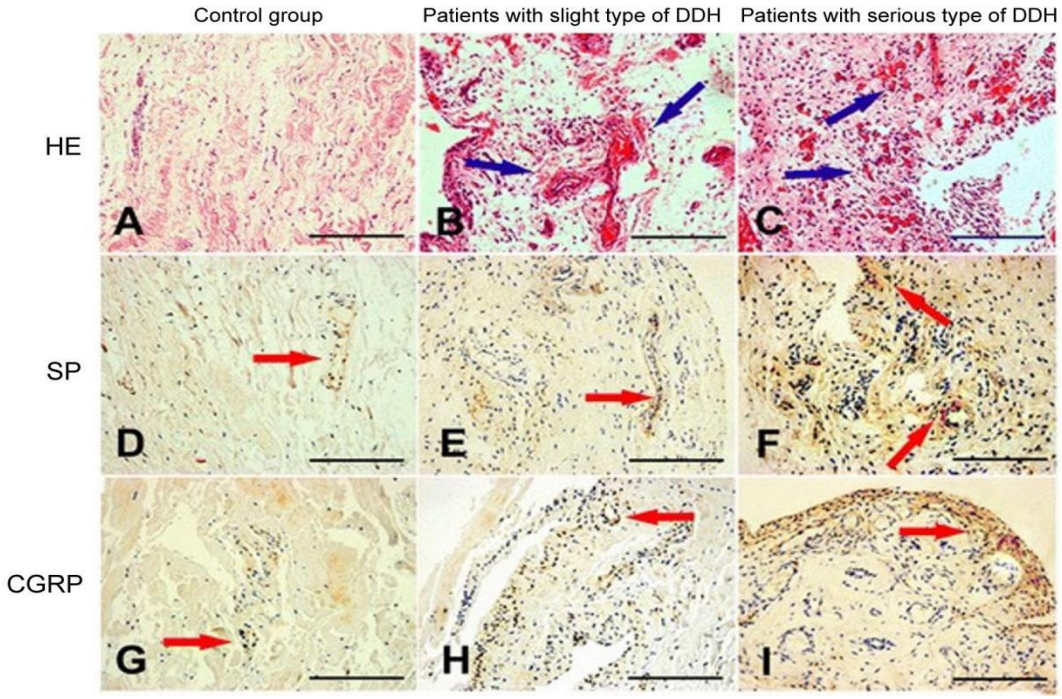

Figure 2. **Morphological clinical description leaded by MRI.**

Figure A-C: hematoxylin and eosin staining (HE) in groups. IHC staining SP (figure 2D-F) and CGRP (figure 2GF-I). plotting scale: 1:100μm.

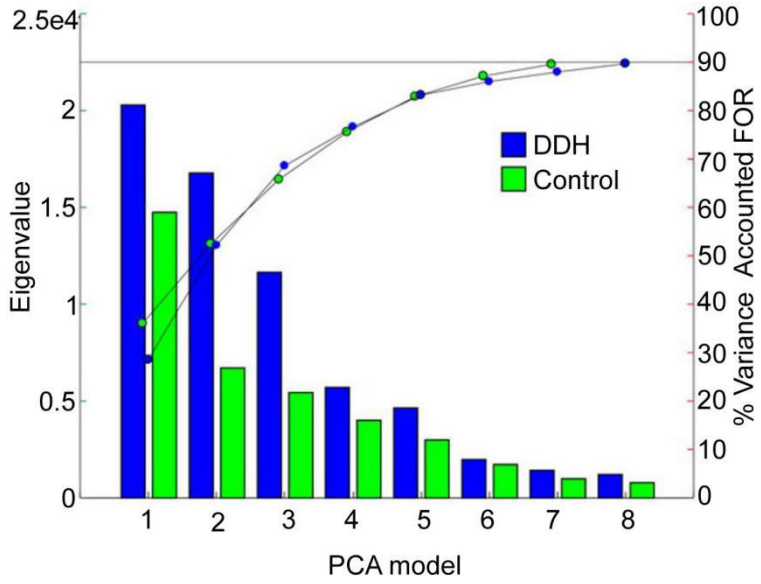

Figure 3. **Principal Component Analysis of DDH leaded by MRI.**

The screen image of accumulated shape variation in the important PCA model was shown in DDH group (blue) and control group (green). The ranking of the corresponding characteristic value (left axis) was based on PCA model. The confirmed accumulated shape variation was shown at right axis. The SSM and PCA was performed for every groups respectively. The DDH was independent reciprocally with the control PCA.