

Coronal and Sagittal Balance of Spine in Patients with Developmental Dysplasia of the Hip

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Abstract

Objective: To explore the spino-pelvic alignment changes in patients with Developmental dysplasia of the hip (DDH) and the effect of Total hip arthroplasty (THA) on the spino-pelvic alignment.

Methods: In this study, patients with DDH are selected as the study group and healthy adults are selected as the control group. The differences of sagittal spino-pelvic parameters between patients with DDH and healthy adults are compared by independent sample *t*-test. Paired sample *t*-test is performed for spine-pelvis parameters before and after THA. Pearson correlation analysis is used to analyze the correlation about coronal spine-pelvic parameters. SPSS 22.0 software is used for statistical analysis, and $p < 0.05$ is the result of statistical significance.

Results: In this study, there are 48 patients with DDH in study group, with an average age of 43.1 ± 10.3 years old, consist of 42 females and 6 males. $SVA = -4.1 \pm 33.9$ mm, $PI = 42.9 \pm 18.9^\circ$, $PT = 4.6 \pm 15.6^\circ$, $SS = 38.2 \pm 13.9^\circ$, $LL = 53.3 \pm 12.6^\circ$, $TK = 22.8 \pm 9.2^\circ$, $TLK = 6.7 \pm 5.7^\circ$. There are 214 subjects in control group, $SVA = -11.3 \pm 28.9$ mm, $PI = 45.6 \pm 9.4^\circ$, $PT = 9.9 \pm 6.8^\circ$, $SS = 35.5 \pm 7.1^\circ$, $LL = 48.4 \pm 10.8^\circ$, $TK = 27.7 \pm 10.4^\circ$, $TLK = 5.7 \pm 10^\circ$. The differences of SVA, PT, LL and TK were statistically significant.

Before THA, $IO = 6.7 \pm 4.6^\circ$, $SO = 6.4 \pm 5.4^\circ$, $HO = 5.3 \pm 5.8^\circ$, $L5O = 6.1 \pm 5.5^\circ$, $Cobb\ angle = 11.0 \pm 10.7^\circ$; After THA, $IO = 3.5 \pm 3^\circ$, $SO = 3.7 \pm 3.4^\circ$, $HO = 3.7 \pm 3.6^\circ$, $L5O = 4.3 \pm 4.7^\circ$, $Cobb\ angle = 6.8 \pm 7.7^\circ$. The Cobb angle is related to SO and IO respectively ($r = 0.610$, $r = 0.570$).

Conclusions: Due to acetabular dysplasia and dislocation of hip joint, patients with DDH will have changes in sagittal and coronal spino-pelvic alignment. In sagittal plane, PT is decreased, TK is decreased and LL is increased. And THA cannot correct the sagittal spino-pelvic alignment in patients with DDH. In coronal plane, there are Leg length discrepancy (LLD) and hip dislocation in patients with DDH, which together lead to coronal pelvic obliquity (PO). The overall coronal imbalance tendency caused by PO leads to compensatory scoliosis. And THA can significantly improve the degree of PO and compensatory scoliosis in patients with DDH.

Introduction

Developmental dysplasia of the hip (DDH) is a kind of disease covering abnormal hip development in infancy and development [1–4], which is one of the important reasons of hip osteoarthritis in adults. It refers to the structural dysplasia of the femoral head and acetabulum, which leads to the loss of the stability of the hip joint and the subluxation or complete dislocation [5, 6]. The change of spine balance is closely related to patients' life function and quality of life.

Spine, pelvis and lower limbs are important parts of the human body. Spine and lower limbs are connected to the pelvis through sacroiliac joints and hip joints. Therefore, the pelvis is an important transition area. If pathological changes occur in pelvis, it will lead to corresponding compensatory

changes in the other two parts. As a result, the overall coronal and sagittal alignment of the human body will change.

In 1983, Offerski and Macnab [7] defined a series of syndromes of changes in sagittal spino-pelvic balance and pain caused by hip diseases as secondary hip spine syndrome. Piazzolla et al. [8] found that in patients with hip diseases, the preoperative pelvic parameters of patients with hip diseases and low back pain were greater than those of patients without low back pain. However, there are few studies focus on changes of sagittal spino-pelvic alignment in patients with DDH.

Besides, coronal spino-pelvic balance in patients with DDH also need to be further study. Through observation, we found that there is pelvic obliquity (PO) in patients with DDH. In order to evaluate PO, we need some new parameters. Wang et al. [9] further defined the angle between the line connecting the bilateral transition point of S1 superior articular process and the sacral wing and the horizontal line as sacral obliquity (SO), which can reflect the obliquity of the sacrum. The angle between the line connecting the highest point of bilateral iliac crest and the horizontal line is defined as iliac obliquity (IO), which can reflect the obliquity of iliac. SO and IO were proved as simple and reliable coronal imaging parameters of pelvis and lower limbs, which can be used to evaluate the coronal balance of pelvis.

This study attempts to explore and analyze the change on sagittal and coronal spino-pelvis parameters in patients with DDH.

Methods

This study is a single center retrospective study. Patients with DDH undergoing total hip arthroplasty (THA) in our hospital from January 2009 to December 2019 were chosen as the study group (the preoperative and postoperative standing full-length X-ray spine films and standing full-length lower limb X-ray films is necessary, and the hip should be seen clearly without occlusion or absence to meet the requirement for measurement).

Healthy adults who underwent physical examination in our hospital were chosen as the control group. And they all took standing full-length spine X-ray film (This study is a retrospective study, which collects images from existing clinical data without medical intervention to normal people, so it does not involve medical ethics issues).

The imaging parameters of all patients included in the study were measured by two experienced surgeons to reduce the error. It is worth mentioning that there are some difficulties in measuring pelvic sagittal parameters due to the poor collinearity of hip axis in patients with DDH.

The following parameters were measured in the surgimap system.

Sagittal parameters:(1) Sagittal vertical axis (SVA), (2) Lumbar lordosis (LL), (3) Sacral slope (SS), (4) Pelvic tilt (PT), (5) Pelvic incidence (PI), (6) Thoracic kyphosis (TK), (7) Thoracic lumbar kyphosis (TLK).

Coronal parameters:(1) Cobb angle, (2) Coronal balance distance (CBD), (3) Sacral obliquity (SO), (4) Iliac obliquity (IO), (5) Hip obliquity (HO), (6) L5 obliquity (L5O), (7) Leg length.

Some important concepts

CBD: Horizontal distance from central sacral vertical line to C7 plumb line (Fig. 1).

SO: The angle between the line connecting the bilateral transition point of S1 superior articular process and the sacral wing and the horizontal line as sacral obliquity, which can reflect the obliquity of the sacrum (Fig. 1).

IO: The angle between the line connecting the highest point of bilateral iliac crest and the horizontal line is defined as iliac obliquity, which can reflect the obliquity of iliac (Fig. 1).

HO: The angle between midpoint line of femoral head and horizontal line (Fig. 1).

L5O: The angle between upper endplate of L5 vertebral body and horizontal line (Fig. 1).

Data analysis

The differences of sagittal spino-pelvic parameters between patients with DDH and healthy adults were compared by independent sample *t*-test. Paired sample *t*-test was performed on sagittal and coronal spino-pelvic parameters before and after THA. Pearson correlation analysis was used to analyze the correlation between coronal spino-pelvic parameters in patients with DDH. SPSS 22.0 software was used for statistical analysis, $p < 0.05$ was the result with statistical significance.

Results

In this study, the study group includes 48 patients with DDH. There are 42 females and 6 males, with a mean age of 42.8 ± 10.4 years. In patients with DDH, SVA= -4.1 ± 33.9 mm, PI= 42.9 ± 18.9 °, PT= 4.6 ± 15.6 °, SS= 38.2 ± 13.9 °, LL= 53.3 ± 12.6 °, TK= 22.8 ± 9.2 °, TLK= 6.7 ± 5.7 °. There are 214 subjects in the control group, SVA = -11.3 ± 28.9 mm, PI= 45.6 ± 9.4 °, PT= 9.9 ± 6.8 °, SS= 35.5 ± 7.1 °, LL = 48.4 ± 10.8 °, TK= 27.7 ± 10.4 °, TLK= 5.7 ± 10 ° (Table 1). The differences of SVA, PT, LL and TK were statistically significant. There was no significant difference in sagittal spino-pelvic parameters before and after THA (Table 2).

The length of lower limb on the longer side was 782.8 ± 49.4 mm, which is longer than that on the shorter side (766 ± 50.2 mm). Preoperative IO= 6.7 ± 4.6 °, SO= 6.4 ± 5.4 °, HO= 5.3 ± 5.8 °, L5O= 6.1 ± 5.5 °, Cobb angle is 11.0 ± 10.7 °. Postoperative IO= 3.5 ± 3 °, SO= 3.7 ± 3.4 °, HO= 3.7 ± 3.6 °, L5O= 4.3 ± 4.7 °, Cobb

angle was $6.8 \pm 7.7^\circ$ (Table 3). Cobb angle was correlated with SO and IO ($r = 0.610, r = 0.570$) (Table 4) (Fig. 2&Fig. 3).

Table 1
Comparison of sagittal spine-pelvic parameters in patients with DDH and normal population

	DDH	Healthy adults	<i>p</i>
SVA(mm)	-4.1±33.9	-11.3±28.9	0.132
PI(°)	42.9±18.9	45.6±9.4	0.340
PT(°)	4.6±15.6	9.9±6.8	0.024*
SS(°)	38.2±13.9	35.5±7.1	0.206
LL(°)	53.3±12.6	48.4±10.8	0.014*
TK(°)	22.8±9.2	27.7±10.4	0.004**
TLK(°)	6.7±5.7	5.7±10	0.340
☒: * $p < 0.05$, ** $p < 0.01$			

Table 2
Comparison of sagittal spine-pelvic parameters in patients with DDH preoperatively and postoperatively

	Pre-op	Post-op	<i>p</i>
SVA (mm)	-4.1±33.9	-3.4±36.2	0.912
PI(°)	42.9±18.9	43.4±17.0	0.873
PT(°)	4.6±15.6	6.3±10.1	0.301
SS(°)	38.2±13.9	37±17.5	0.712
LL(°)	53.3±12.6	52.4±11.9	0.666
TK(°)	22.8±9.2	21.7±11.3	0.512
TLK(°)	6.7±5.7	6.8±6.1	0.843

Table 3
Comparison of coronal spine-pelvic parameters in patients with DDH preoperatively and postoperatively

	Pre-op	Post-op	<i>p</i>
Cobb	11.0±10.7	6.8±7.7	0.001**
CBD	14.2±10.6	13.7±12.5	0.821
IO	6.7±4.6°	3.5±3°	0.001**
SO	6.4±5.4°	3.7±3.4°	0.001**
☒: ** <i>p</i> <0.01			

Table 4
Correlation analysis of coronal spine-pelvic parameters of in patients with DDH

	cobb	SO	IO	HO	L50
CBD	0.082	-0.074	0.037	0.289*	0.015
Cobb		0.610**	0.572**	-0.189	0.801**
SO			0.873**	-0.057	0.771**
IO				-0.011	0.742**
HO					0.111
L50					1
☒: * <i>p</i> <0.05, ** <i>p</i> <0.01					

Discussion

Spine, pelvis and lower limbs are important parts of the human body. Spine and lower limbs are connected to the pelvis through sacroiliac joints and hip joints. Therefore, the pelvis is an important transition area. If pathological changes occur in one part of them, it will lead to corresponding compensatory changes in the other two parts. Therefore, for patients with DDH, pathological changes of hip may lead to corresponding changes of spine and pelvis.

In this study, the SVA of patients with is - 4.1 ± 33.9mm; SVA of healthy adults is-11.3 ± 28.9 mm, which means the C7 plumb line of patients with DDH and healthy adults falls behind the posterior upper angle of sacrum. SVA is important to evaluate sagittal balance. General speaking, C7 plumb line should fall

above the posterior upper angle of the sacrum. If SVA > 50mm, it is called sagittal imbalance. In this study, patients with DDH can maintain sagittal balance.

In patients with DDH, PI = $42.9 \pm 18.9^\circ$, PT = $4.6 \pm 15.6^\circ$, SS = $38.2 \pm 13.9^\circ$, LL = $53.3 \pm 12.6^\circ$, TK = $22.8 \pm 9.2^\circ$, TLK = $6.7 \pm 5.7^\circ$. In the control group, PI = $45.6 \pm 9.4^\circ$, PT = $9.9 \pm 6.8^\circ$, SS = $35.5 \pm 7.1^\circ$, LL = $48.4 \pm 10.8^\circ$, TK = $27.7 \pm 10.4^\circ$, TLK = $5.7 \pm 10^\circ$. It can be seen that PT decreases, TK decreases and LL increases in patients with DDH. The reason may be that the femoral head in patients with DDH is dislocated backward and upward, resulting in poor hip axis collinearity, resulting in the decrease of PT.

When the femoral head is dislocated backward, the position of the upper body relative to the femoral head is forward. There is a tendency of sagittal imbalance. In order to compensate it, the curvature of the spine changes, LL increases, TK decreases. Spine is in a state of hyperextension to compensate the tendency of sagittal imbalance.

Matsuyama et al. [10] and Hasegawa et al. [11] reported SS increased in patients with high dislocation DDH. In this study, the average SS of patients with was higher than that of healthy adult, but the difference was not statistically significant. Theoretically, PI = PT + SS. When PI is constant, PT decreases, which will lead to the increase of SS.

In addition, the effect of THA on spine-pelvic sagittal alignment in patients with DDH has also attracted more attention. Murphy et al. [12] showed that there was no significant change in PT 1 year after THA. Ishida et al. [13] reported that the pelvis of patients with hip dysplasia tends to tilt backward after THA. Eyvazov [14] and Weng [15] reported that there was no significant difference in spine-pelvic parameters after THA. The results of this study are consistent with those of Eyvazov and Weng. There is no significant change in sagittal spino-pelvic parameters of patients with DDH after THA (Figure.4).

In addition to sagittal balance, coronal spino-pelvic balance in patients with DDH is also important for patient's life quality.

After measuring the length of both lower limbs of patients with DDH, it was found that in this study, the average length of lower limbs on the longer side was $782.8 \pm 49.4\text{mm}$, the average length of lower limbs on the shorter side was $766 \pm 50.2\text{mm}$, $p < 0.01$, and the average HO = $5.3 \pm 5.8^\circ$. It shows that there is leg length discrepancy (LLD) in patients with DDH.

For people with LLD, pelvic obliquity may occur to compensate for coronal balance.

Song et al. [16] believe that people with LLD will have continuous pelvic obliquity to compensate, and the average LLD is between 2 cm and 15.8 cm. Aiona et al. [17] believe that pelvic obliquity is one of the main compensatory mechanisms of people with LLD. And for patients with DDH, their hip is in a state of dislocation, which may lead to pelvic obliquity, too. Therefore, LLD and hip dislocation can contribute to pelvic obliquity together.

Besides, LLD may also have an impact on development of DDH. Tallroth et al. [18] pointed out that LLD may be related to the pathological state of hip joint. When LLD occurs, the hip coverage on the longer side becomes worse, and shorter side may deteriorated. And it can result in aggravation of hip dysplasia. The relationship between LLD and DDH is complex. They can interact with each other.

In this study, 86.1% of DDH patients had a higher position of the femoral head (dislocation side), but a lower position of the pelvis. It shows that the dislocation of hip plays a dominant role in coronal pelvic obliquity. However, this does not mean that the contribution of LLD can be ignored.

In the study, we found that the preoperative Cobb = $11.0 \pm 10.7^\circ$, IO = $6.7 \pm 4.6^\circ$, SO = $6.4 \pm 5.4^\circ$, L50 = $6.1 \pm 5.5^\circ$. This shows that patients with DDH do have pelvic obliquity and scoliosis. Through the correlation study, we found that the Cobb angle was correlated with SO and IO ($r = 0.610$, $r = 0.570$). The result suggests that there is a correlation between scoliosis and pelvic obliquity in patients with DDH. We can hypothesize the scoliosis may be the compensatory method of pelvic obliquity.

In general, CBD more than 30mm is regarded as coronal imbalance. In this study, the preoperative CBD of DDH patients was 14.2 ± 10.6 mm, which showed that there was no overall coronal imbalance in patients with DDH. This may be due to the tendency of coronal imbalance was compensated by scoliosis.

When DDH occurs, there will be pelvic obliquity, which may lead to coronal imbalance tendency. And spine will compensate it, manifested as compensatory scoliosis.

Next, we want to explore the effect of THA on spino-pelvic coronal alignment. In patients with DDH, preoperative IO = $6.7 \pm 4.6^\circ$, SO = $6.4 \pm 5.4^\circ$, HO = $5.3 \pm 5.8^\circ$, L50 = $6.1 \pm 5.5^\circ$, Cobb angle was $11.0 \pm 10.7^\circ$. After THA, IO = $3.5 \pm 3^\circ$, SO = $3.7 \pm 3.4^\circ$, HO = $3.7 \pm 3.6^\circ$, L50 = $4.3 \pm 4.7^\circ$, Cobb angle was $6.8 \pm 7.7^\circ$. This study showed that THA can significantly reduce Cobb angle, SO and IO in patients with DDH. THA can directly improve the pelvic obliquity of patients with DDH and indirectly reduce the degree of compensatory scoliosis through acetabular reconstruction (Figure.5).

Conclusion

Due to acetabular dysplasia and dislocation of hip joint, patients with DDH will have changes in sagittal and coronal spino-pelvic alignment. In sagittal plane, PT is decreased, TK is decreased and LL is increased. And THA cannot correct the sagittal spino-pelvic alignment in patients with DDH. In coronal plane, there are Leg length discrepancy (LLD) and hip dislocation in patients with DDH, which together lead to coronal pelvic obliquity (PO). The overall coronal imbalance tendency caused by PO leads to compensatory scoliosis. And THA can significantly improve the degree of PO and compensatory scoliosis in patients with DDH.

Abbreviations

SVA	Sagittal vertical axis
LL	Lumbar lordosis
SS	Sacral slope
PT	Pelvic tilt
PI	Pelvic incidence
TK	Thoracic kyphosis
TLK	Thoracic lumbar kyphosis
CBD	Coronal balance distance
SO	Sacral obliquity
IO	Iliac obliquity
HO	Hip obliquity
L5O	L5 obliquity
LLD	Leg length discrepancy
DDH	Developmental dysplasia of the hip

Declarations

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Not applicable.

Author's contributions

The author designed, conceptualized and conducted the study, prepared and revised the manuscript and performed all statistical analyses. The author (s) read and approved the final manuscript.

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Availability of data and materials

Not applicable.

Ethics approval and consent to participate

The study is observational and not clinical or experimental and did not involve medical records or human tissues. Data used were collected from hospitals and clinics. For these reasons, informed and explicit consent was not needed.

In China, under national laws and for this kind of data collection, no formal approval or authorisation is required or will be issued, neither by the national ethics committee nor by the cantonal commissioner for data protection. These are not even recommended by the medical-ethical guidelines for scientific integrity of the Central Ethics Committee.

Consent for publication

Not applicable.

Competing interests

The author declares that he has no competing interests.

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Figures

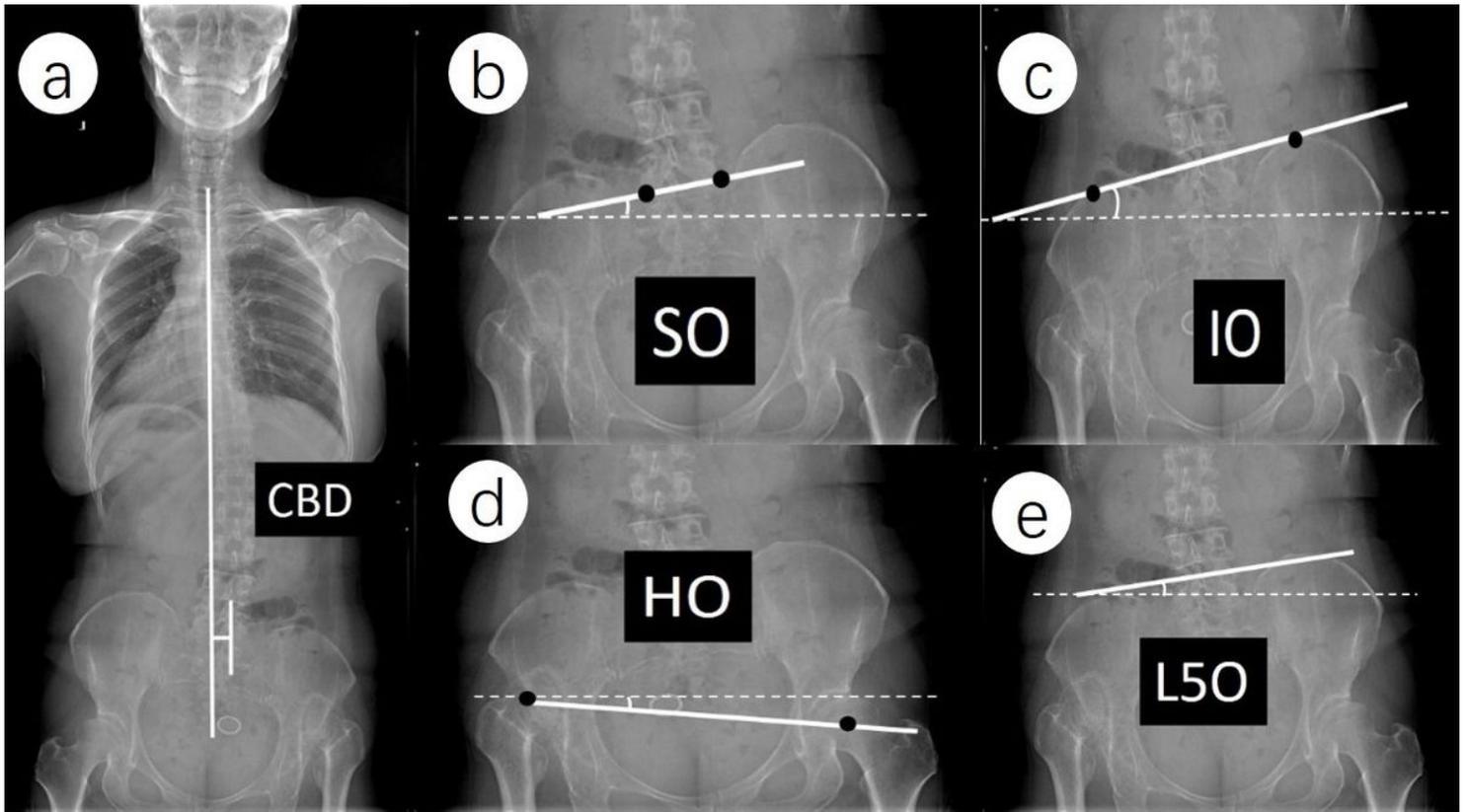


Figure 1

a. CBD: Horizontal distance from central sacral vertical line to C7 plumb line; b. SO: The angle between the line connecting the bilateral transition point of S1 superior articular process and the sacral wing and the horizontal line as sacral obliquity, which can reflect the obliquity of the sacrum; c. IO: The angle between the line connecting the highest point of bilateral iliac crest and the horizontal line is defined as iliac obliquity, which can reflect the obliquity of iliac; d. HO: The angle between midpoint line of femoral head and horizontal line; e. L5O: The angle between upper endplate of L5 vertebral body and horizontal line.

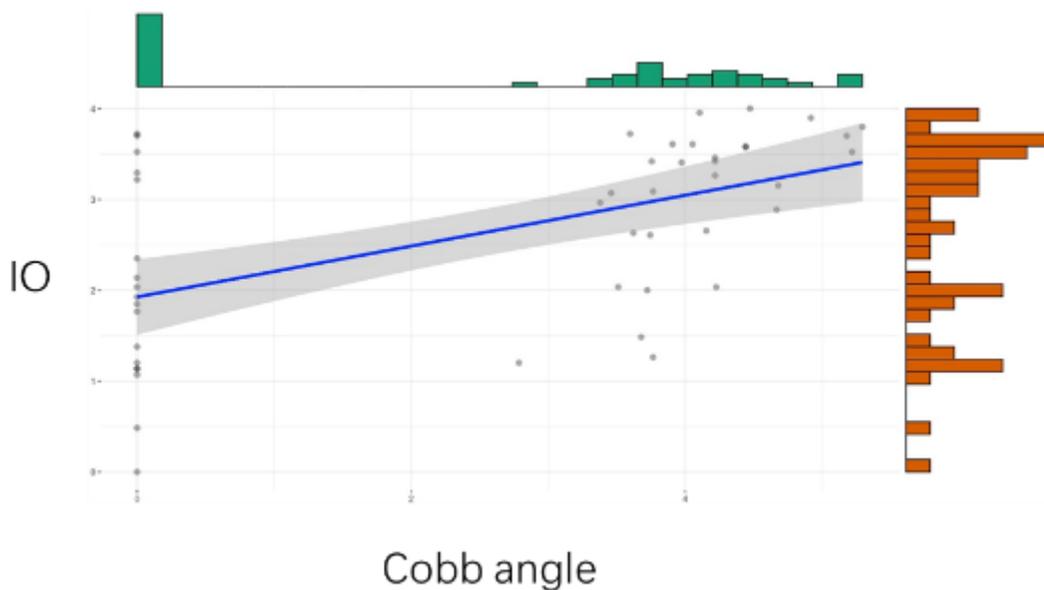


Figure 2

Correlation analysis between Cobb angle and IO

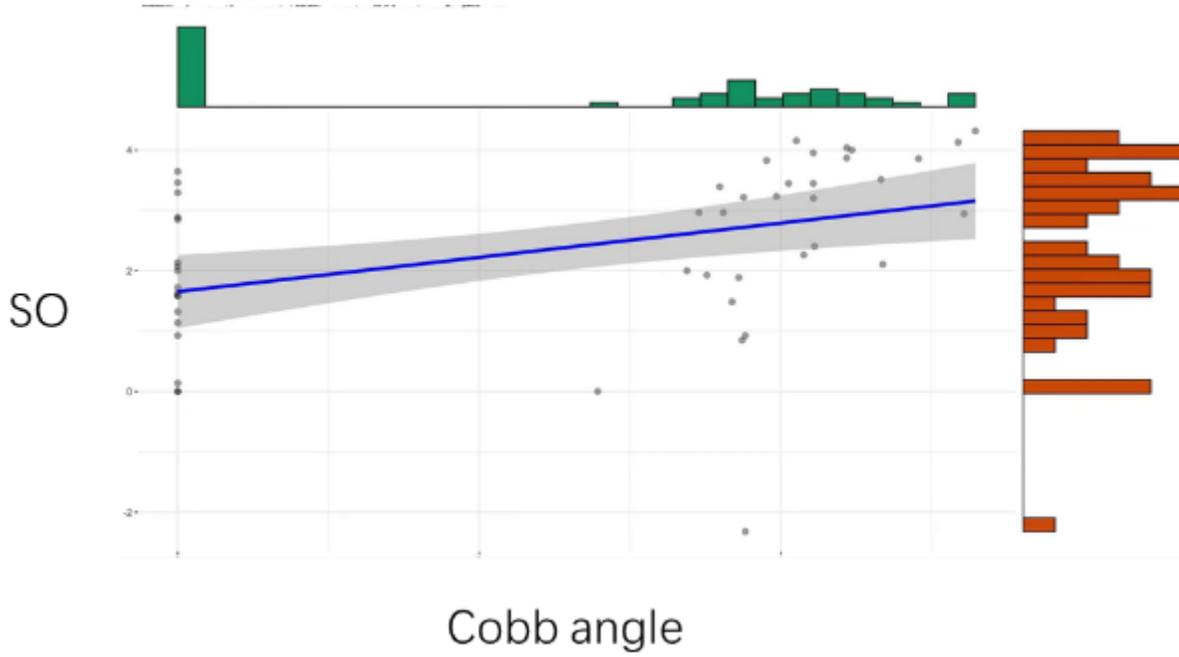


Figure 3

Correlation analysis between Cobb angle and SO

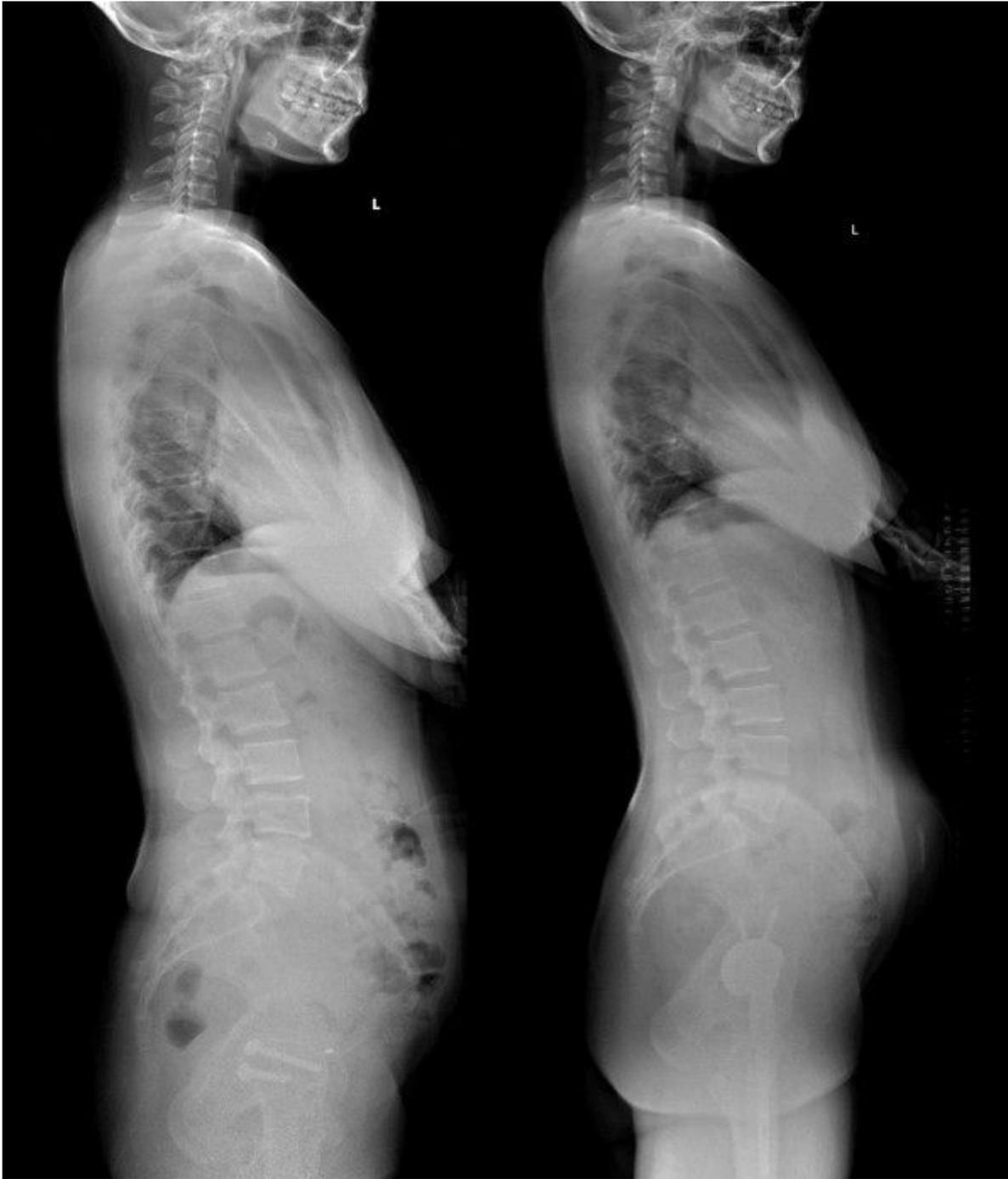


Figure 4

Full length sagittal standing X-ray film of patients with DDH before and after THA. Female, 38 years old, preoperative SVA = - 29.5 mm, PI = 51 °, PT= 8 °, SS = 43.3 °, LL = 55.2 °; Postoperative SVA = - 29 mm, PI = 31.9 °, PT = 2.8 °, SS = 29 °, LL= 52.7 °



Figure 5

Full length coronal standing X-ray film of patients with DDH before and after THA. Female, 48 years old, preoperative L50= 21.7°, IO = 12 °, SO= 16.5 °; postoperative L50= 18.9°, IO = 5.4 °, SO=12.9 °