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Original article

Change in standing acetabular orientation 2 years postoperatively after surgical correction of adult spinal deformity

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Abstract

Introduction

Although sagittal alignment is known to influence pelvic position, few studies accurately identify the relationship between sagittal alignment and acetabular orientation. We hypothesized that postoperative PT should be correlated with acetabular change in native hips after surgical correction of adult spinal deformity.

The objective of this study was therefore to describe the correlation between the change in pelvic tilt and the change in acetabular orientation two years after surgical correction of adult spinal deformity.

Material and method

Based on a retrospective study of a prospective mono center database, 127 acetabuli out of sixty-nine patients were analyzed preoperatively and at two years postoperatively of surgical management of sagittal imbalance by posterior arthrodesis extended to the pelvis. The analysis was based on bi-planar EOS radiographs with 3D reconstructions of the pelvis and spine using SterEOS 3D software.

The following specific parameters were analyzed: sacral slope, pelvic tilt, lumbar lordosis, SVA, acetabulum tilt (AT) , anteversion (AA) (orientation of the acetabulum in the axial plane), abduction (AAbd) (orientation of the acetabulum in the frontal plane), inclination (AI) (orientation of the acetabulum in the sagittal plane), and anterior acetabulum coverage (ACA).

A Pearson correlation was performed between the pre-and postoperative change in acetabular parameters (right and left) and pelvic parameters. Linear regressions were performed to identify the most relevant pelvic and spinal parameters. A subgroup analysis was performed to identify a difference between distal sacral and distal ilium fixations.

Results

All measured acetabular parameters were significantly different two years after surgery. Changes in AT (p=0.03), AI (p=0.03) and ACA (p=0.05) were significantly greater in the ilium fixation group. Postoperative PT reduction was strongly correlated with the decrease of AT and AA (=0.61 and =0.57, p<0.001), it was also correlated with the increase of AI and ACA and the decrease of AAbd. The entire cohort linear regression analysis revealed that a 1° decrease in PT resulted in a 0.4° decrease in AA and a 0.6° decrease in AT (R2 =0.45 and =0.38).

Conclusion

Our study highlights the significant influence of the change in sagittal alignment on acetabular orientation in standing position. This correlation explains the increased risk of anterior hip impingement, the change in acetabular load distribution that might lead to early hip osteoarthritis, and the overall change in the subjects' gait pattern.

Level of evidence: IV.

Keywords: Acetabulum, 3D orientation, EOS, Sagittal balance, Hip, Spine.

Abbreviations:

LL: Lumbar Lordosis

PT: Pelvic Tilt

SS: Sacral Slope

PI: Pelvic Incidence

SVA: Sagittal Vertical Axis

AT: Acetabulum Tilt

AA: Acetabulum Anteversion

AAbd: Acetabulum Abduction

AI: Acetabulum Inclination

ACA: Anterior Coverage of the Acetabulum

Introduction

Correlation analyses between pelvic and spinal parameters are common in the literature, and different studies have documented these relationships during pre and postoperative course of various spinal pathologies [1–3]. Thus, the loss of lumbar lordosis and progressive increase of thoracic kyphosis related to aging or spinal deformity leads to a chain of compensatory mechanisms that aims to counterbalance the induced sagittal malalignment and maintain horizontal gaze [3–7]. Hip hyperextension, pelvic retroversion, and knee flessum are the main compensatory mechanisms that can indirectly be modified after sagittal correction surgery. Therefore, the change in pelvic tilt (defined as the angle between the vertical axis and a line running from the center of the bifemoral heads to the sacral endplate midpoint) has an impact on acetabular orientation during standing and walking [8–10].

This correlation can be responsible for a cross-symptomatology and is part of the definition of hip-spine syndrome [11,12]. It is therefore not uncommon to notice a decompensation of hip osteoarthritis after spine surgery or a postoperative low back pain decompensation after a total hip arthroplasty (THA) [13]. Concurrently, it has been reported that significant hip osteoarthritis leading to hip flessum can increase anterior sagittal imbalance and a THA surgery can therefore improve sagittal alignment and spinal symptomatology [14–16].

Spinal surgery has also been identified as a risk factor for THA instability [17,18] with an almost one-to-one ratio between angular changes in pelvic tilt and acetabular anteversion [10]. Such changes in acetabular orientation might also occur in native hips after spinal surgery. The analysis of the three-dimensional acetabular orientation in the standing position is therefore essential for the understanding and management of complex hip and spine pathologies. Recently, Masquefa et al. [19] have reported the reliability and reproducibility of 3D acetabular parameters measurements using full-spine biplanar radiographs and a dedicated software. This technique allows an analysis of the patient in the standing position, at the cost of much less radiation than a bone CT scan.

With regards to surgical management of adult spinal deformities (ASD), there is, to our best knowledge, no study that reported relationship between change in pelvic tilt and change in acetabular orientation of native hips in standing position. The objective of this study was therefore to describe the correlation between the change in pelvic tilt and the change in acetabular orientation two years after surgical correction of ASD. After formulating the hypothesis that postoperative PT should be correlated with acetabular change in native hips after surgical correction of ASD, we tried to answers the following questions:

- What are the changes in spinal and acetabular parameters 2-years after surgical management of ASD?
- What are the differences in acetabular parameters variations according to the lowest instrumented vertebra (sacrum vs. ilium)?
- Are there any differences in clinical outcomes according to the lowest instrumented vertebra (sacrum vs. ilium)?
- What are the correlations between postoperative changes in PT and acetabular parameters?

Methods

Study population

This is a retrospective analysis of a prospective, single-center database (IRB: 00009118). Patients over 18 years old who underwent extensive posterior arthrodesis including the lumbosacral junction for spinal deformity correction were analyzed. The exclusion criteria were neurological spinal deformity, non-walking patient, trauma or major surgery of the lower limbs, the existence of a THA or EOS radiographs whose quality did not allow specific analysis.

The cohort was further divided into two subgroups according to lowest instrumented vertebra: sacrum or ilium.

Study protocol

Preoperatively and two years postoperatively, each patient underwent a standing EOS full-spine radiograph (EOS Imaging®, Paris, France).

A 3D reconstruction of the pelvis and spine was performed by an orthopedic surgeon using a dedicated specific software (Arts et Métiers ParisTech, Paris, France). Based on the investigator's identification of key anatomical points on the AP and lateral views, a semi-automatic measurement of acetabular orientation and all spinal pelvic parameters according to the "functional" reference vertical was performed (Figure 1). The reliability and reproducibility of this reconstruction having already been previously established in the literature [19,20].

For each radiograph, the following spinopelvic parameters were analyzed: sacral slope (SS), pelvic tilt (PT), lumbar lordosis (LL, measured between the upper endplate of S1 and the thoracolumbar inflection point), C7-SVA (SVA).

The following measurements were performed on the acetabulum (Figure 2):

- Acetabulum tilt (AT) defined by Lazennec et al. [21] as the angle between the intersection of the plane of the acetabulum rim with the sagittal plane passing through the center of the acetabulum and the intersection of the horizontal plane passing through the center of the acetabulum.
- Acetabulum anteversion (AA) defined by the angle between the sagittal plane of the pelvis and the line passing through the outer point of the anterior border and the outer point of the posterior border of the acetabulum with the horizontal plane and the intersection of the sagittal plane.
- Acetabulum abduction (AAbd) defined by the normal of plane of the acetabular rim through the center of the acetabulum and the vertical.
- Acetabulum inclination (AI) defined by the angle between the plane of the acetabular rim with the frontal plane and the sagittal plane of the pelvis.
- Anterior coverage of the acetabulum (ACA) defined by the intersection of the horizontal plane passing through the center of the acetabulum with the anterior border of the acetabulum.

Aside radiographic parameters, for each patient, clinical scores that included Oswestry Disability Index (ODI), Lumbar visual analogic scale (Lumbar VAS) and Radicular visual analogic scale (Radicular VAS) were collected preoperatively and at last follow-up.

Statistical analysis

Postoperative changes in spinopelvic and acetabular parameters were calculated (mean, standard deviation, minimum and maximum). Statistical analysis was performed using SPSS® software. Paired bilateral Student's t-test were performed to compare pre-and postoperative data. Pearson correlation coefficients were determined between the postoperative change in acetabular and pelvic parameters. Linear regressions were performed to identify significant relationships between pelvic and spinal parameters. A subgroup analysis was performed between distal sacrum and ilium fixations in order to compare differences from pre to postoperative measurements (Figure 3). The significance level was set at 5% (i.e. $p<0.05$) for all statistical analyses.

Results

Study population

Between October 2016 and February 2019 we included 69 patients corresponding to 127 acetabulum (61 right and 66 left hip). The mean age was 67.2 years (SD=7.5 from 37 years to 80 years). The sex ratio was 3/1 in favor of women (54 women/15 men). All demographic and clinical data are presented in Table 1.

Postoperative changes

Mean preoperative PT was 30° (SD=9, min=4, max=47), mean preoperative PI-LL mismatch was 23° (SD=18) mean preoperative AT was 35° (SD=10, min=7 max=59), mean preoperative AA was 24° (SD=6, min=7, max=40) (Table 2, Figure 4).

At 2 years of follow-up, significant changes in spinopelvic parameters were found, with a significant decrease in PT and SVA and a significant increase in LL and TK (Table 2). All acetabular parameter values were significantly different postoperatively, without significant difference between right and left acetabular parameters.

While the average change in PI was not significant on the whole series, postoperative PI was increased by more than 5 degrees in 5 patients (4 distal sacral fixations, 1 distal iliac fixation). Among them, one patient had an increase of 15° following a sacral fracture.

Subgroup analysis (sacrum vs. ilium)

With regards to spinopelvic parameters changes from preoperative to postoperative measurements, no significant difference was found between the 2 subgroups (i.e. no significant changes in PT, LL, SVA and TK between subgroups). With regards to acetabular parameters, a significant decrease in acetabular anteversion and tilt associated with a significant increase of anterior coverage was found in the ilium fixation group. Other acetabular parameters did not differ significantly between the two subgroups (Table 3).

Clinical evaluation

On the whole series, all clinical scores were significantly improved, with an average decrease of 3.6 points in Lumbar-VAS (from 7.1 preoperatively to 3.5 postoperatively, $p<0.001$), 2.5 points in Radicular-VAS (from 5.1 preoperatively to 2.6 postoperatively, $p<0.001$) and 23.8% in ODI (from 60.4 preoperatively to 36.6 postoperatively, $p<0.001$). While no differences were found between the two subgroups for Radicular-Vas and ODI, a significantly greater decrease of the Lumbar-VAS was found in the subgroup of patients who had an iliac distal fixation (Table 3).

Correlation analysis

Postoperative PT reduction was significantly correlated with the decrease of AT and AA (rho=0.61 and rho=0.57, $p<0.001$, high correlation). It was also correlated with the increase of

AI and ACA and the decrease of AAbd. These correlations were stronger in the ilium fixation group (Table 4).

On the whole series, linear regression analysis revealed that a 1° decrease in PT resulted in a 0.4° decrease in AA and a 0.6° decrease in AT (R2 =0.45 and rho=0.38, medium correlation).

In the group of ilium fixation patients, a 1° decrease in PT resulted in a 0.47° decrease in AA and a 0.62° decrease in AT (R2 =0.3 and rho=0.38, medium correlation). In sacrum fixation patients, a 1° decrease in PT resulted in a 0.35° decrease in AA and a 0.6° decrease in AT (R2 =0.3 and rho=0.4, medium correlation) All relationships are presented in Table 4, linear regressions are presented in Figure 5.

Discussion

Postural adaptation to a spinal malalignment leads to different compensatory mechanisms [22]. Although full spine radiographs are now widely used in spine surgery, its use is still uncommon during preoperative assessments of hip surgery. It has been shown that the position of the pelvis in standing position, as reflected by the pelvic tilt angle, influences acetabular orientation [21,23–25]. Although this correlation has been previously analyzed after spine surgery on the orientation of a prosthetic acetabular implant, there is no study in the literature describing orientation changes of the native acetabulum.

Changes in spinopelvic and acetabular parameters

While the results from this study revealed significant changes in spinopelvic parameters after surgical management of spinal deformities, such results have been already reported in the literature. Results on native acetabular measurements have not, to date, been described and revealed that the correction of pelvic tilt was associated with a decrease of acetabular tilt and anteversion associated with an increase of acetabular inclination and anterior coverage. Previous studies [25,26] have highlighted the impact of lumbar or lumbosacral arthrodesis on hip biomechanics. A decrease in the adaptability of the lumbosacral junction may lead to episodes of subluxation or dislocation in patients with THA, but it may also lead to complications in a native hip. In addition to acute episodes of dislocation, a change in acetabular orientation when standing in a weight-bearing position and during walking can also have medium and long-term consequences [26]. Different studies have shown the reciprocal interactions of the lumbosacral junction and the hip ranges of motion during daily activities [26]. For most patients, during the transition from standing to sitting, the lumbar lordosis decreases, the pelvis retroverts and the acetabulum anteverts to avoid impingement, but when a lumbar arthrodesis fixes the pelvis, the dynamic retroversion capacity of the pelvis is blocked and the acetabulum cannot be anteverted, which may lead to anterior hip impingement [26,27]. Moreover, patients with anterior sagittal imbalance can have significant pelvic retroversion leading to an anterior superior uncovering of the acetabulum, which is explained by the functional and not anatomical hyper anteversion of the acetabulum in these patients. This loss of anterior coverage may be associated with a posterior bump effect due to compensatory hip hyper-extension (or by increased femoral anteversion in case of pelvic retroversion) when standing, which may cause destabilization of the native hip or the prosthetic implant [27].

Subgroup analysis

Despite the limited subgroup sizes in our study, we were able to identify significant differences between the two subgroups with a significant decrease of acetabular anteversion and tilt associated with an increase of anterior coverage in patients with a distal ilium fixation. These differences can be explained by the mobility of the sacroiliac joints in patients with sacrum fixation. Legaye et al. [28] demonstrated a significant increase in pelvic incidence in a low back pain population over 60 years of age, indicating rotatory mobility in the sacroiliac joints. This mobility, although it may be the cause of low back pain and truncated sciatica, may explain the differences between our subgroups with regards to clinical scores. Thus, ilium fixation leads to a greater constraint on the position of the pelvis with a greater modification of the acetabular tilt and anterior coverage (-5.3° Vs -3.1° p=0.03 and +4.7° Vs +2.5° p=0.05 Table 2). Distal sacrum fixation allows the patient to attenuate these acetabular changes at the cost of rotational stress applied to the sacroiliac joints, which may explain persistent pain in these patients. However, a study on larger cohorts is needed to confirm this result and it would be interesting to look for a difference in the progression of hip osteoarthritis in these two populations.

Correlations between Pelvic Tilt and acetabular measurements

Our study attempts to elucidate the correlations between postoperative changes in pelvic tilt and acetabular parameters after a posterior spinal fixation that included the lumbosacral junction. We were able to demonstrate significant changes in main acetabular parameters postoperatively with a significant correlation indicating that a 1° change in PT leads to a 0.6° change in acetabular tilt. This is consistent with different studies performed on patients with THA. This correlation relies directly on the specific anatomy of the acetabulum-bearing coxal bones with an internal rotation that depends on the pelvic incidence [27]. Mekhael et al. [20] have recently investigated the 3D orientation of the acetabulum in ASD and asymptomatic control subjects which is reported in figure 4. These results tend to reveal that all postoperative acetabular parameters tend to match the values of this normative group.

Femoral head coverage is a key consideration used as a diagnostic and prognostic factor in hip pathology, but it is also a positional factor that cannot be accurately assessed by a conventional CT scan obtained in lying position. The hypothesis that the change in femoral head coverage could be predicted from the change in PT was demonstrated by Uemura et al. [24] who found a linear correlation between changes in pelvic tilt and coverage of the anterior and posterior regions of the acetabulum. This change was particularly significant in the anterior part of the acetabulum. These results are consistent with our study, which reported an increase in anterior coverage during the postoperative decrease in pelvic tilt, although the linear regression performed does not allow us to determine a significant regression coefficient.

Limitations and perspectives

Although our cohort is large, it is important to highlight certain limitations of the study. The low degrees of variation in acetabular parameters raise questions about their clinical relevance, and suggest the need for a larger sample size to reduce potential measurement discrepancies. Enlarging the cohort would enhance the robustness of the study and provide a better understanding of the phenomenon.

The innovation of our study relies on the nature of the imaging used for the 3D reconstructions. Indeed, the use of EOS® radiography reduces the patient's radiation exposure and allows a study in the standing position. The significant follow-up after spinal surgery (more than 2 years) makes it possible to limit the impact of initial analgesic positions, which persist during the first year of rehabilitation after adult spinal deformity surgical correction. Further studies will be necessary to confirm these results and it is reasonable to believe that in a near future AI will help physicians to understand more accurately these phenomenon [29].

Conclusion

Our study highlights the significant influence of sagittal alignment modifications on acetabular's orientation in standing position. This correlation may influence various pathophysiological phenomena to be considered postoperatively after surgical correction of spinal deformity. These phenomena must be considered when planning deformity correction surgery and must be part of the information provided to the patient. It would also be advisable to perform an EOS radiograph in order to plan a THA.

Authors' contribution:

- Solène Prost, Romain Ambrosino: writing the manuscript.
- Stéphane Fuentes, Patrick Tropiano, Sébastien Pesenti, Benjamin Blondel and Wafa Skalli: coordinating the research, supervising the manuscript.

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Conflicts of interest:

In relation to this work: B. Blondel is an editor of OTSR.

Outside this work:

- B. Blondel : Consultant for Medicrea, Vexim-Stryker, Implanet, 3M, Centinel
- S. Prost : Compensation for travel expenses, Zimmer Biomet and Stryker
- S. Fuentes : Consultant for Medicrea, Medtronic, Stryker
- S. Pesenti: Consultant for Stryker et Implanet
- R. Ambrosino: No conflict
- W. Skalli : No conflict
- P. Tropiano: Consultant for Depuy Synthes, FH, Centinel, LDR Zimmer

Declaration of generative AI and AI-assisted technologies: no use of any generative AI or AI-assisted technologies to write this manuscript.

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Legend of the figures:

Figure 1: Example of 3D reconstruction from the AP and lateral EOS radiographs.

Figure 2: Acetabulum parameters measured

- Acetabulum tilt (AT) (Lazennec et al. [21]) was defined as the angles between the lines formed by the intersects of the sagittal plane with both the acetabular rim plane and the horizontal plane
- Acetabulum anteversion (AA) was defined as the angle between the lines resulting from the intersections of the horizontal plane with both the acetabular rim plane and the sagittal plane
- Acetabulum abduction (AAbd) abduction was defined as the angle between the line perpendicular to the acetabular rim plan and the vertical axis
- Acetabulum inclination (AI) was defined as the angle between the line resulting from the intersection of the acetabular rim plane with the frontal plane, and the vertical axis.
- Anterior coverage of the acetabulum (ACA) was defined as the angle between the line joining the two acetabular centers, and the line joining the acetabular center and the point at the intersection between the horizontal plane passing through the acetabular center and the frontal part of the acetabular edge.

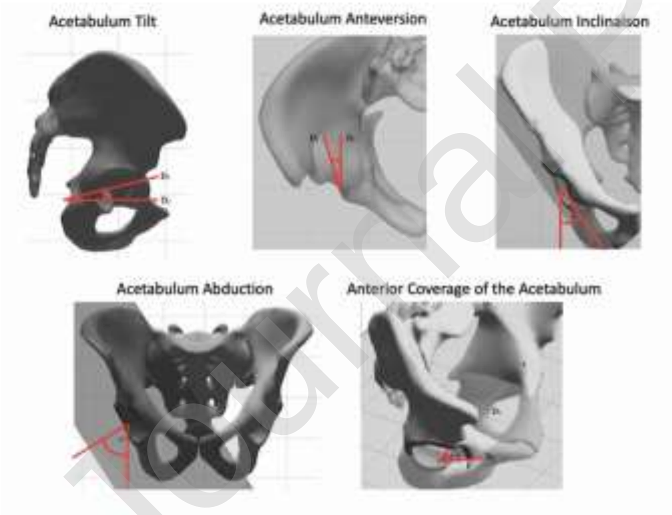

Figure 3: Example of EOS radiographs preoperatively and at 2 years postoperatively. A: Distal sacral fixation, B: Distal iliac fixation.

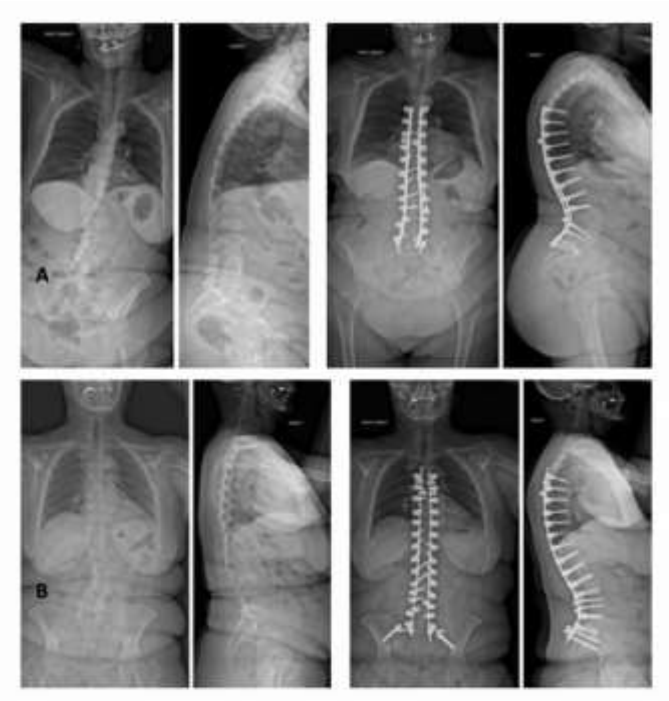

Figure 4: Postoperative radiographic results. * The results of the asymptomatic cohort from Mekhael et al. [20] has been added for reference.

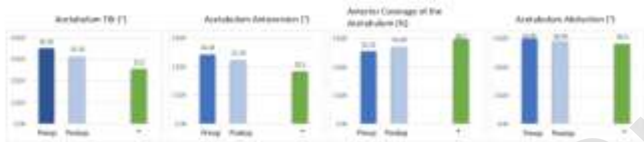

Figure 5: Linear regression of acetabular parameters based on pelvic tilt in the overall cohort. (PT: Pelvic Tilt, AT: Acetabulum Tilt, AA: Acetabulm Anteversion, AI: Acetabulum Inclinaison, AAbd: Acetabulum Abduction, ACA: Anterior Coverage of the Acetabulum, SD: Standard Deviation)

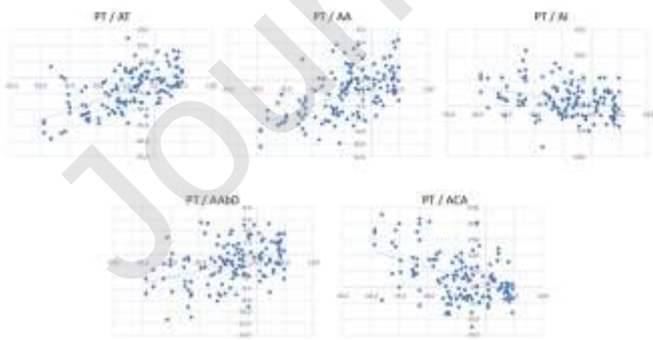

Table 1: Demographic and surgical data of the cohort.

		n	%
Acetabulum		127	100
Sex	Female	97	76
	Male	30	24
Age		67 SD=11 (From 37 to 80)	
Distal fixation	Ilium	46	36
	Sacrum	81	64
Proximal fixation	>T4	70	55
	T5-T8	28	22
	T9-T12	20	16
	L1-L2	9	7

Table 2: Changes of measured parameters from pre to postoperative radiographic evaluation.

Parameters	Preoperative		postoperative		*p*
	mean	SD	mean	SD	
Pelvic Incidence	52	11	54	4	0.056
Pelvic Tilt	30	9	25	7	<0.001
Lumbar Lordosis	32	19	49	13	
Sagittal Vertical Axis	75	61	47	37	
Thoracic Kyphosis	-48	20	-56	22	
Acetabulum Tilit	35	10	31	9	
Acetabulum Anteversion	24	6	22	6	
Acetabulum Inclination	32	4	34	4	
Acetabulum Abduction	60	5	58	4	
Anterior Coverage of the Acetabulum	51	9	54	8	

Table 3: Change in parameters at 2 years postoperatively, comparative subgroup analysis. (PT: Pelvic Tilt, LL: Lumbar Lordosis, SVA: Sagittal Vertical Axis, TK: Thoracic Kyphosis, AT: Acetabulum Tilt, AA: Acetabulm Anteversion, AI: Acetabulum Inclination, AAbd: Acetabulum Abduction, ACA: Anterior Coverage of the Acetabulum, SD: Standard Deviation.) Δ represents the change from pre to postoperative evaluation.

Parameters	**Global**		**Distal ilium fixation**		**Distal sacral fixation**		***p***
	Average	**SD**	**Average**	**SD**	**Average**	**SD**	
Δ ODI	-23.8	17	-26.7	13	-21.8	20	0.37
Δ Lumbar VAS	-3.6	1	-4.4	1	-3.1	1	**0.002**
Δ Radicular VAS	-2.5	3	-3.2	3	-2.1	3	0.21
Δ PI	3	7	2	6	3	5	0.34
Δ PT	-5	6	-6	7	-4	6	0.07
Δ LL	17	18	19	16	15	17	0.28
Δ SVA	-28	64	-40	80	-22	53	0.15
Δ TK	8	22	10	17	6	25	0.46
Δ AT	-4	6	-5	7	-3	6	**0.03**
Δ AA	-2	4	-3	4	-2	4	0.09
Δ AI	1	3	2	3	1	3	**0.03**
Δ AAbd	-2	4	-2	4	-1	3	0.09
Δ ACA	3	7	5	8	3	6	**0.05**

Table 4: Pelvic tilt/acetabular parameters correlation analysis. (PT: Pelvic Tilt, AA: Acetabulum Anteversion, AI: Acetabulum Inclinaison, AAbd: Acetabulum Abduction, ACA: Anterior Coverage of the Acetabulum). Δ represents the change from pre to postoperative evaluation.

Δ PT = 1°		**Pearson**		**Linear Regression**	
		ρ	***p***	**R2**	**Coefficient**
Global	Δ AA	0.57	<0.001	0.45	0.4
	Δ AT	0.61	<0.001	0.38	0.6
	Δ AI	-0.32	<0.001	0.12	-0.2
	Δ AAbd	0.41	<0.001	0.20	0.3
	Δ ACA	-0.47	<0.001	0.22	-0.5
Distal iliac fixation	Δ AA	0.59	<0.001	0.3	0.47
	Δ AT	0.57	<0.001	0.38	0.62
	Δ AI	-0.2	0.26	0.28	-0.3
	Δ AAbd	0.32	0.031	0.3	0.34
	Δ ACA	-0.37	0.012	0.2	-0.5
Distal sacral fixation	Δ AA	0.57	<0.001	0.3	0.35
	Δ AT	0.56	<0.001	0.4	0.6
	Δ AI	-0.11	0.33	0.13	-0.2
	Δ AAbd	0.25	0.02	0.2	0.25
	Δ ACA	-0.49	<0.001	0.25	-0.6