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The assessment of sagittal balance in scoliosis surgery

THESIS

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BY

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TO OBTAIN THE DEGREE OF DOCTOR OF MEDICINE

KEYWORDS

Sagittal balance, scoliosis, spinopelvic parameters, posterior spinal fusion, outcome, quality of life, SRS-22r.

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At the time of being admitted as a member of the medical profession:I solemnly pledge to dedicate my life to the service of humanity; the health and well-being of my patient will be my first consideration;I will respect the autonomy and dignity of my patient; I will maintain the utmost respect for human life; I will not permit considerations of age, disease or disability, greed, ethnic origin, gender, nationality, political affiliation, race, sexual orientation, social standing or any other factor to intervene between myduty and my patient;
I will respect the secrets that are confided in me, even after the patienthas died; I will practice my profession with conscience and dignity and inaccordance with good medical practices; I will foster the honor and noble traditions of the medical profession;I will give to my teachers, colleagues, and students the respect and gratitude that is their due I will share my medical knowledge for the benefit of the patient andthe advancement of healthcare; I will attend to my health, well-being, and abilities in order toprovide care of the highest standard; I will not use my medical knowledge to violate human rights and civilliberties, even under threat; I make these promises solemnly, freely and upon my honour.

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DEDICATIONS

In loving memory of my dear father,

I dedicate my degree to you, for you were my guiding light, my unwavering support, and my greatest inspiration. Though you are no longer here with me, the depths of my love for you transcend time and space. Your memory lives on in my heart, and my love for you remains eternal.

You were the embodiment of compassion, selflessness, and constant support. Your words of wisdom, love, and encouragement propelled me forward, pushing me to overcome obstacles and reach for the stars. Through your example, you instilled in me the values of empathy, perseverance, and the pursuit of knowledge.

As I embark on this new chapter, I carry your memory within me. This degree is not only a testament to my work and dedication but also a tribute to your unwavering belief in my abilities and the profound impact you had on my life. Though I deeply wish you were here to witness this achievement, I know that you are watching over me, filled with pride and joy, guiding my every step. I am forever grateful for the unconditional love, sacrifices, and guidance you provided, both in life and in memory.

Your memory will forever be intertwined with my academic journey, reminding me of the strength and determination you exemplified throughout your life.

Thank you for being my source of strength and my eternal inspiration. This achievement is dedicated to you with profound love and gratitude.

I love you, dad.

To my amazing mother,

Words cannot express the depth of my gratitude and admiration for you. Throughout my life, you have been my unwavering pillar of strength and my source of unconditional love and support.

In moments of uncertainty, you have been my rock, providing wisdom, guidance, and a shoulder to lean on. Your sacrifices and selflessness have been the foundation upon which I have built my dreams. You have always put my needs before your own, and for that, I am eternally grateful.

As I stand at the culmination of my degree, I dedicate it to you, my sweet mother. I carry your love, support, and encouragement in my heart as I pursue my dreams, knowing that you will always be by my side. This accomplishment is as much yours as it is mine, for without you, I would not be the person I am today.

Je t'aime ma petite maman.

To my extraordinary sister, my ride or die,

Throughout my journey, you have been my constant source of inspiration. Your presence in my life has brought immeasurable joy and strength.

You have consistently shown me the true meaning of love, compassion, and resilience. I am forever grateful for the countless ways you have uplifted me, encouraged me, and believed in me. You have not only been my sister but also my mentor, confidante, and my best friend.

Thank you for being my role model, greatest teacher and my guiding light. This degree is a testament to the love, guidance, and influence you have had on my life. With immense love and deep appreciation, I dedicate this achievement to you, may our bond continue to grow stronger, and may we continue to inspire and uplift each other on this remarkable journey called life.

I love you, sunshine.

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Thesis Chairperson
Head of the Neurosurgery Department

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This work serves as a testament to express our profound appreciation and deep admiration for your exceptional scientific and human qualities.

To my supervisor, Professor LAGHMARI Mehdi,
Professor of Neurosurgery

I would like to express my sincere and special regards for your invaluable guidance, support, and expertise throughout the research and writing process. Your dedication, encouragement, and insightful feedback have been instrumental in shaping the outcome of this thesis. I am truly grateful for your mentorship and for believing in my capabilities. Thank you for your unwavering commitment and for sharing your knowledge and expertise with me.

To Professor, GHANNANE Houssine,
Thesis jury member
Professor of Neurosurgery

Your gracious acceptance to serve as a distinguished member of this esteemed committee fills us with profound gratitude. We are deeply honored by your presence and your genuine interest in our thesis topic. Your vast knowledge and expertise will undoubtedly enrich our work. Please find here the expression of my utmost respect and admiration.

To Professor, SALAMA Tarik,
Thesis jury member
Professor of Pediatric Surgery

Thank you for the great honor you bestow upon us by accepting to be part of this esteemed committee. Your willingness to contribute your time, expertise, and valuable insights is truly appreciated. Please accept my sincerest expression of high esteem, utmost consideration, and deep respect.

TABLES AND FIGURES

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ABBREVIATIONS

List of abbreviations

AF	: Annulus fibrosis
AIS	: Adolescent Idiopathic Scoliosis
AP	: Antero-posterior imaging view of a radiograph
ASF	: Anterior spinal fusion
ATR	: Angle trunk rotation
C7PL	: C7 plumb line
CL	: Cervical lordosis
CR	: Correction ratio
CSVL	: Central sacral vertical line
CT	: Computed tomography
CVA	: Coronal vertical axis
EBL	: Estimated blood loss
ECHO	: Echocardiography
EKG	: Electrocardiogram
FH	: Femoral heads
FSU	: Functional spinal unit
GCB	: Global coronal balance
GSB	: Global sagittal balance
HRQoL	: Health-related quality of life
ICU	: Intensive care unit
IVD	: Intervertebral disc
LIV	: Lower instrumented vertebrae
LL	: Lumbar lordosis
MEP	: Motor evoke potential
MFS	: Marfan syndrome
MRI	: Magnetic resonance imaging
MT	: Main thoracic
ORT	: Operative time
PFT	: Pulmonary Function Testing
PI-LL	: Pelvic incidence minus lumbar lordosis
PI	: Pelvic incidence
PJK	: Proximal junctional kyphosis
PMT	: Posteromedial translation
PROMs	: Patient reported outcome measures
PS	: Pedicle screw
PSF	: Posterior spinal fusion
PT	: Pelvic tilt
PT	: Proximal thoracic
RBC	: Red blood cells
SB	: Sublaminar bands
SRS-22r	: Scoliosis Research Society Questionnaire version 22 revised.

SRS : Scoliosis Research Society
SS : Sacral slope
SSEP : Somatosensory evoked potential
SSI : Surgical site infection
SVA : Sagittal vertical axis
TK : Thoracic kyphosis
TL/L : Thoracolumbar/ lumbar
UIV : Upper instrumented vertebrae
2D, 3D : Two-dimensional, three-dimensional

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INTRODUCTION

Human bipedalism is exclusive, stable, and ergonomic. Unlike other vertebrates, the human spine comprises successive, opposing curves which allow the trunk to maintain an erect position (1). In order to maintain this balanced posture, an optimal combination of spinal, spinopelvic, and lower limb joint alignments is required. Certain conditions can compromise the natural curvature of the spine and lead to suboptimal sagittal alignment, one of such is scoliosis.

Scoliosis is a complex three-dimensional (3D) deformity of the spine, classically defined as a lateral curvature of the spine of more than 10° in the coronal plane, associated with vertebral rotation in the axial plane. It is also known that scoliosis is usually associated with a loss of thoracic kyphosis (2-4). The surgical management of scoliosis remains controversial, particularly regarding the optimal posterior fusion strategy (5,6). However, there appears to be a consensus on the necessity to stabilize the deformity and restore the coronal and sagittal balance of the trunk.

The importance of sagittal spinopelvic organization in spinal deformity and the necessity of its restoration after surgical treatment are now well recognized in the literature (7). Parameters that allow the assessment of sagittal balance are commonly used. Geometrical parameters, described by Duval-Beaupère (8,9), characterize pelvic shape and orientation, including pelvic incidence (PI), pelvis tilt (PT), and sacral slope (SS). These parameters are interrelated by the formula: PI = PT + SS. Several parameters, such as lumbar lordosis (LL) and thoracic kyphosis (TK), are used to describe the different curvatures of the spine. In terms of the global orientation of the spine, C7 positioning is generally accepted for its stability over the pelvis and femoral heads in the balanced asymptomatic population (10).

Sagittal malalignment has been shown to affect the clinical outcomes and health-related quality of life (HRQoL) of patients with all types of scoliosis, ranging from mild to severe. Therefore, identifying and maintaining correct sagittal alignment, establishing a normative range, and determining the necessary degree of correction in spinal deformity patients proves to be crucial for developing treatments that can achieve and sustain significant benefit.

This study was therefore conducted to analyze the impact of posterior instrumented fusion on sagittal balance and spinopelvic parameters in the setting of scoliosis and to evaluate the clinical-functional outcomes of surgical correction, validated by patient-reported outcome measures (PROMs), to determine utility in clinical decision-making.

MATERIALS AND METHODS

I. Aim

The purpose of our study was to assess pre- and post-operative spinopelvic sagittal alignment and evaluate the sagittal plane reciprocal changes following posterior spinal fusion in the setting of scoliosis. Furthermore, this study aimed to investigate the correlation between the restoration of spinal balance and improvement of functional outcomes using patient-reported outcome measures (PROMs).

II. Study Design

A retrospective single-center analysis of the spinopelvic and global sagittal parameters of patients who underwent posterior spinal instrumented fusion surgery for spinal deformity at the Neurosurgery department in Mohammed VI University Hospital of Marrakech within the period from January 2016 until December 2022 was carried out.

III. Study Population

As inclusion criteria, all patients affected by spinal deformity and who received anteroposterior (AP) and lateral standing radiographs as part of routine clinical assessment prior to scoliosis correction and with a minimum clinical and radiologic follow-up of 12 months following surgery at our department were selected (n=17).

Exclusion criteria were: (1) patients with incomplete medical records; (2) unsuitable examinations (low radiographic density, incomplete inclusion of the pelvis, and poor clarity of the spinopelvic parameters); or (3) inadequate follow-up.

A total of 10 patients (8 female and 2 male), treated by posterior arthrodesis, satisfied the inclusion criteria and were included in our study. Figure 1 shows the flowchart of patient selection.

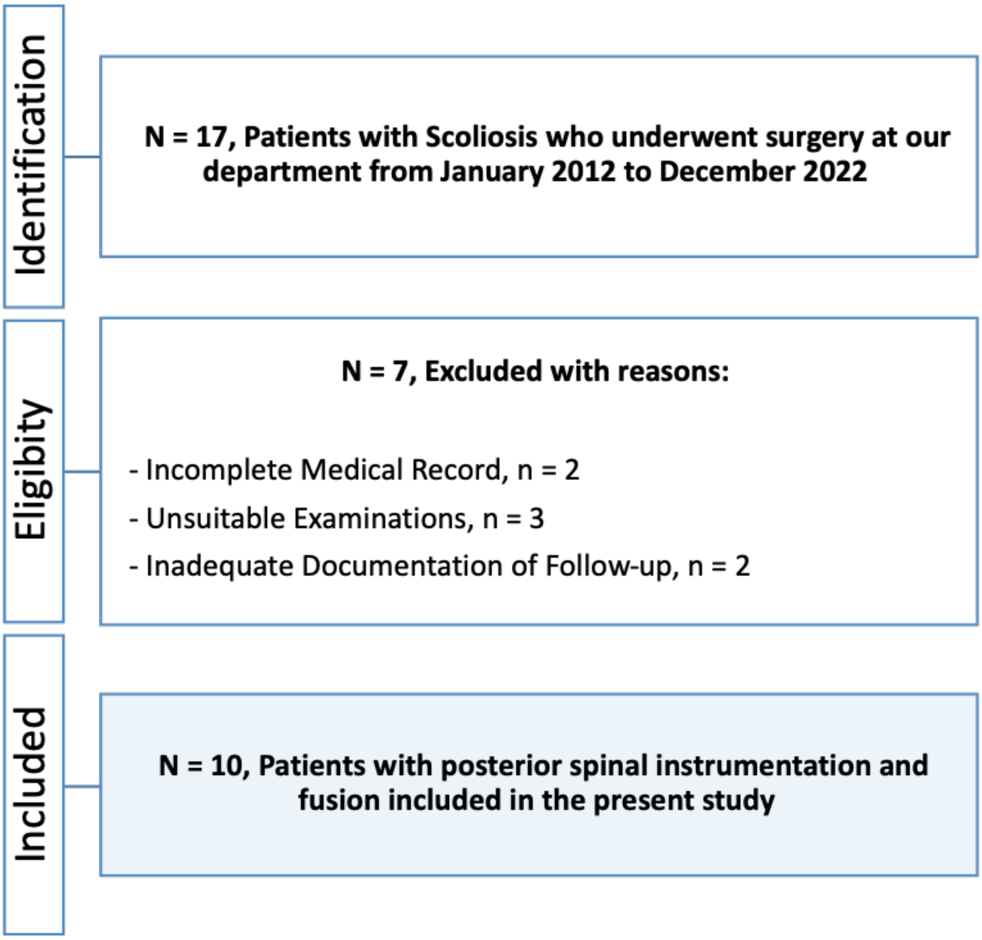


Figure 1: Flowchart of the selection process of the patients in the study

IV. Methods

1. Clinical Evaluation and Surgical Data

Prior to surgical correction, all patients underwent a comprehensive evaluation, which consisted of a patient health history, physical and neurological examinations. Specific attention was given to assessing any disturbances of motor strength in the upper and lower extremities, exploration of sensation of the extremities and trunk, including cold and warm sensation, tendon reflexes and pathological pyramidal signs (levels of cutaneous abdominal reflexes, Babinski phenomenon, or increased muscle tone). (please refer to Appendix 1 for the Patient Information Form)

Pulmonary Function Testing (PFT) and Echocardiography (ECHO) to assess cardiopulmonary function and the presence of congenital cardiac malformations, respectively, were performed on each patient.

The operative information and surgical results, including operative time (ORT), estimated blood loss (EBL), and fusion status were reviewed.

2. Surgical Procedure

All patients underwent posterior-only approach correction and instrumentation (Figure 2). The primary aim of the surgery was to obtain a solid fusion and a balanced spine in the coronal and sagittal planes in all patients.

Under general anesthesia, patients were placed prone on a Jackson table with intraoperative Neurophysiological monitoring (motor evoke potential [MEP] and somatosensory evoked potential [SSEP]. The posterior elements of the predecided fusion levels of the spine were exposed by subperiosteal paraspinal muscle stripping. Instrumentation using either all pedicle-screw (PS) or hybrid construct combining pedicle screws and sublaminar bands (SB) was implemented. The correction was performed using two 5.5-mm diameter titanium rods, contoured according to the desired sagittal alignment, and was attained through manipulation of the screws and derotation of the rod or by posteromedial translation. Additional correction was obtained by means of compression of the curve on its convexity, relaxation of the concavity, or modeling of the rod. The surgery was finished with a tight closure of the layers with placement of a subfascial drain.

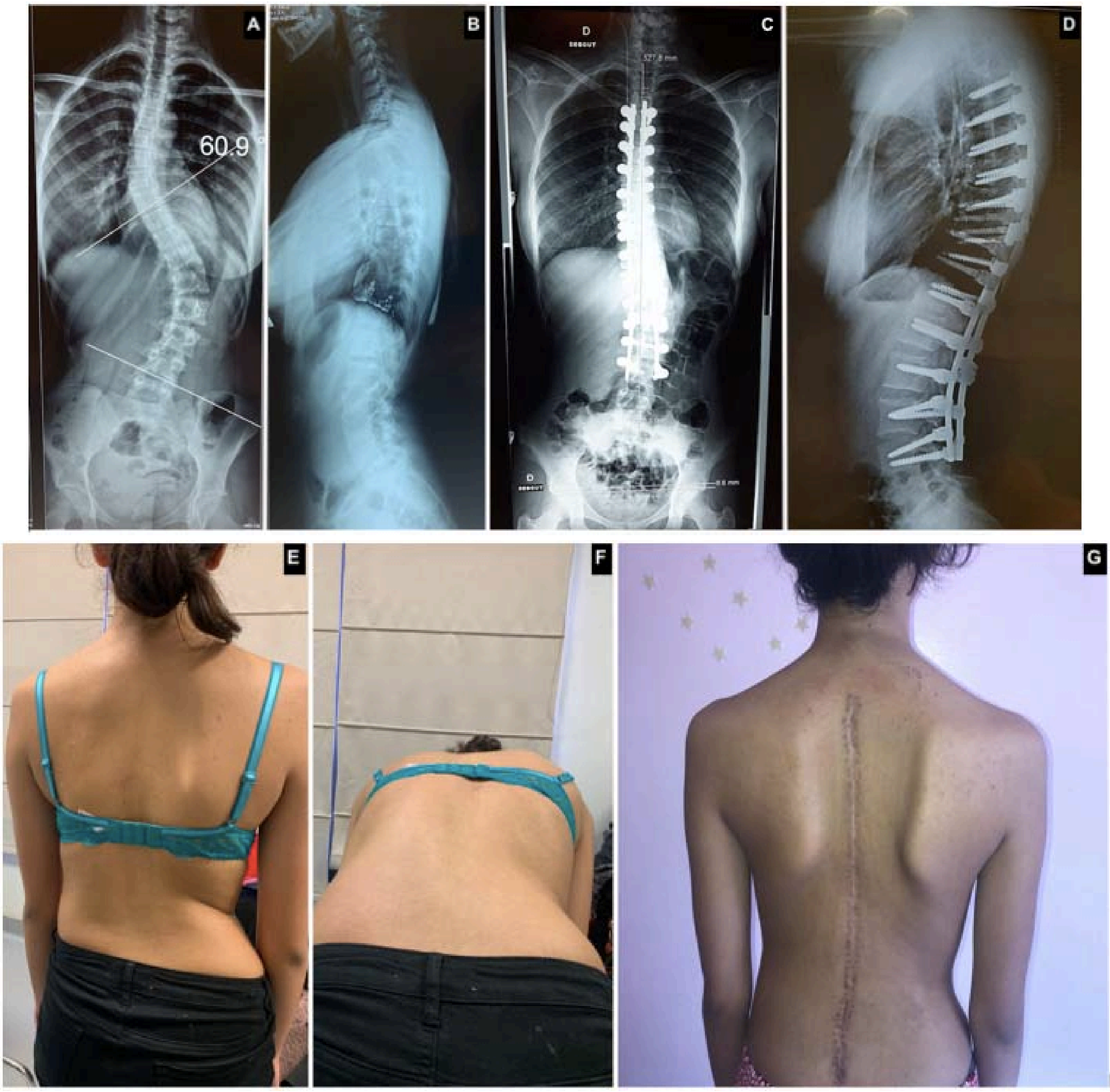


Figure 2: 17-year-old female patient with an adolescent idiopathic scoliosis (AIS) who underwent posterior spinal instrumentation and fusion. (A, B) Preoperative anteroposterior (AP) and lateral x-rays. (C, D) Post-operative AP and lateral x-rays. (E, F) Clinical photographs preoperatively. (G) Clinical photographs at follow-up. After surgical correction a satisfactory coronal and sagittal spinal balance were restored.

3. Radiological Measurements and Analysis

For each patient, Computed Tomography (CT) scans, as well as full spine standing anteroposterior (AP) and lateral x-rays were acquired with a standardized radiographic protocol. Acquisitions were performed pre-operatively, early post-operatively, and at most recent follow-up. The radiographic parameters were conducted using validated software (Surgimap® version 2.3.2.1) (11,12) (Figures 3 and 4).

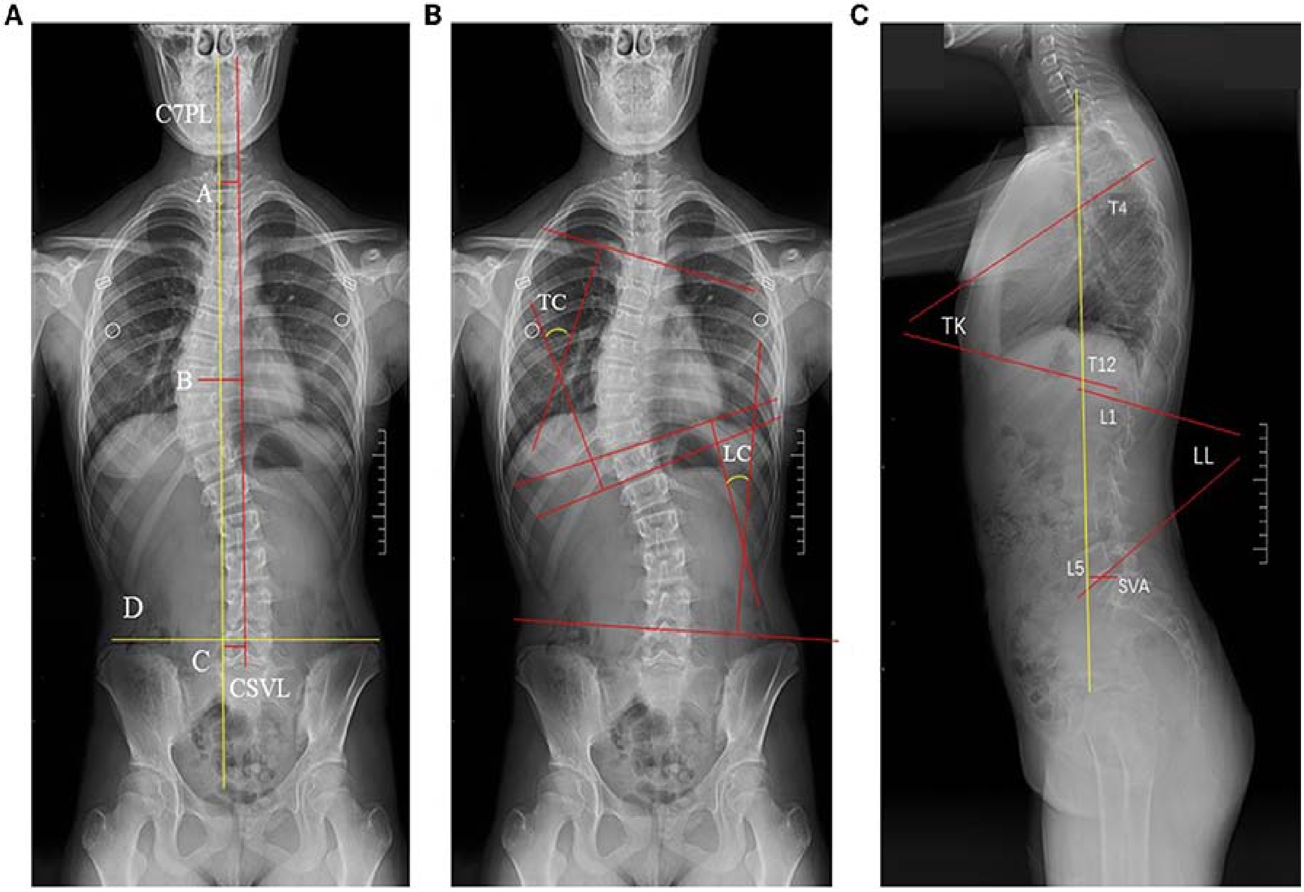


Figure 3: Radiographic representation of spinal parameter using whole spine AP and lateral x-rays: C7 plumb-line (C7PL); thoracic Cobb angle (TC); lumbar Cobb angle (LC); global coronal balance (GCB); central sacral vertical line (CSVL); thoracic kyphosis (TK); lumber lordosis (LL); sagittal vertical axis (SVA). In (A), the assessment of coronal balance. Line A (GCB) stood for the width between the central sacral vertical line (Line C, CSVL) and the mid-C7 vertebra plumb line. (B,C) Showed the parameters of TC, TC, LC, TK, LL, SVA.

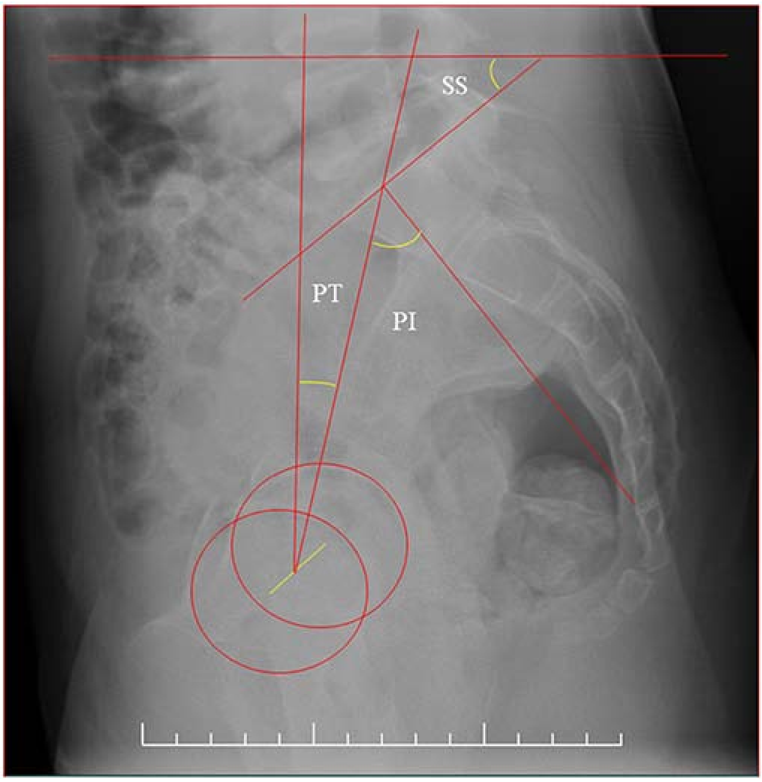


Figure 4: Sacro-pelvic parameters: sacral slope (SS); pelvic tilt (PT); pelvic incidence (PI).

The parameters recorded in the coronal plane included:

1. The Risser sign was used to denote the degree of skeletal maturity (Appendix 2).
2. Cobb angle of proximal thoracic (PT), main thoracic (MT), and thoracolumbar/lumbar (TL/L) curve.
3. Global coronal balance (GCB) was measured as the distance between the vertical line through the centre of C7 (C7 plumb line) and the midpoint of the S1 endplate (CSVL). A negative value indicated that the C7PL was right to the CSVL. Coronal imbalance is defined while this distance (CVA) exceeds 20mm.
4. Correction ratio: [(Preoperative Cobb angle- Postoperative Cobb angle)/Preoperative Cobb angle] x 100.

The main measurements evaluated on the lateral radiographs for the study of sagittal alignment include the following:

5. Thoracic kyphosis (TK): The angle between the upper endplate of T4 and the lower endplate of T12. Thoracic hypo-kyphosis was defined by a pre-operative sagittal T4-T12 Cobb angle of less than 20 degrees.
6. Lumbar lordosis (LL): The angle between the upper endplate of L1 and S1. Normal lumbar lordosis is defined by an average lumbosacral angle of 40° - 60°
7. Pelvic incidence (PI): The angle between the perpendicular to the sacral plate at its midpoint and the line connecting the point to the middle axis of the femoral heads.
8. Pelvic tilt (PT): The angle between the line connecting the midpoint of the sacral plate to the axis of the femoral heads, and the gravity line.
9. Sacral Slope (SS): The angle between the sacral plate and the horizontal plane.
10. Pelvic incidence minus lumbar lordosis (PI-LL): Sagittal alignment is considered optimum when spino-pelvic mismatch (PI-LL) is less than 10° (LL= PI ±10°).
11. Global sagittal balance (GSB) was measured as the horizontal distance between the C7 plumb line and the posterior superior corner of the sacrum. A negative value indicated that the C7 plumb line was posterior to the sacrum posterior corner. Sagittal imbalance is defined while this distance (SVA) *exceeds 40mm*.

4. Functional Outcomes and Complications Assessment

- Scoliosis Research Society-22 revised questionnaire, SRS-22r

Scoliosis-specific questionnaire was selected to evaluate the Health-Related Quality of Life (HRQoL) of patients after the spinal fusion surgery. The questionnaire was completed by patients through an in-person interview process. Patients were assessed preoperatively, before hospital discharge and at the latest follow-up. The translated Arabic version of the SRS-22 revised questionnaire developed by the Scoliosis Research Society was applied in our study (13). It consists of five domains covered by 22 questions. Function, pain, self- image and mental health all have five questions each. The last domain, overall satisfaction, has only two questions.

The scoring scale ranges from 5 as best to 1 as worst. Results are expressed as the mean (total sum of the domain divided by the number of items answered) for each domain (see Appendix 3 for the SRS-22r questionnaire).

- Perioperative and post-operative complications were also recorded during the follow-up period.

V. Statistical Analysis

The data regarding the patients' history, basic clinical examination, laboratory investigations, imaging results, and outcome measures were coded and entered using Microsoft Excel Software. Collected data was processed using SPSS version 19 (SPSS Inc., Chicago, IL, USA). The quantitative data was expressed as means, while the qualitative data was expressed as numbers and percentages (%). Correlations between the different parameters were assessed through Pearson's correlation coefficient. Significance level was set at p-value < 0.05. Results were presented in tables and graphs.

VI. Informed Consent

Written informed consent was obtained from all subjects, and their parents prior to participating in this study.

RESULTS

I. Demographic Data

1. Age at surgery

The mean age at the time of surgery for the entire cohort was 17.1 years, ranging from 15 to 23 years. The age group most affected was the 11-18 age range, with a frequency of 90%.

Table I: Characteristics of the study population by age.

	Age
Mean	17.1
Minimum	15
Maximum	23

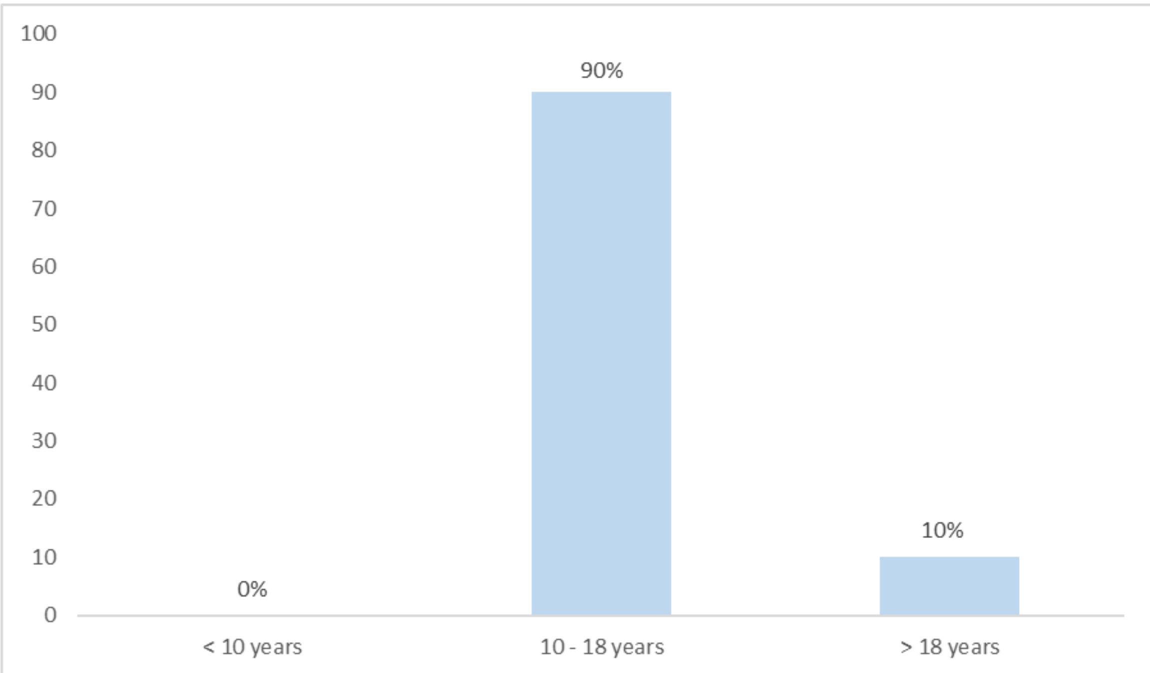


Figure 5: Distribution of studied population by age at the time of surgery.

2. Gender

Ten patients were identified of whom 2 were male (20%) and 8 female (80%).

Analysis of distribution based on age and gender shows female predominance. The female-to-male ratio is 4 :1.

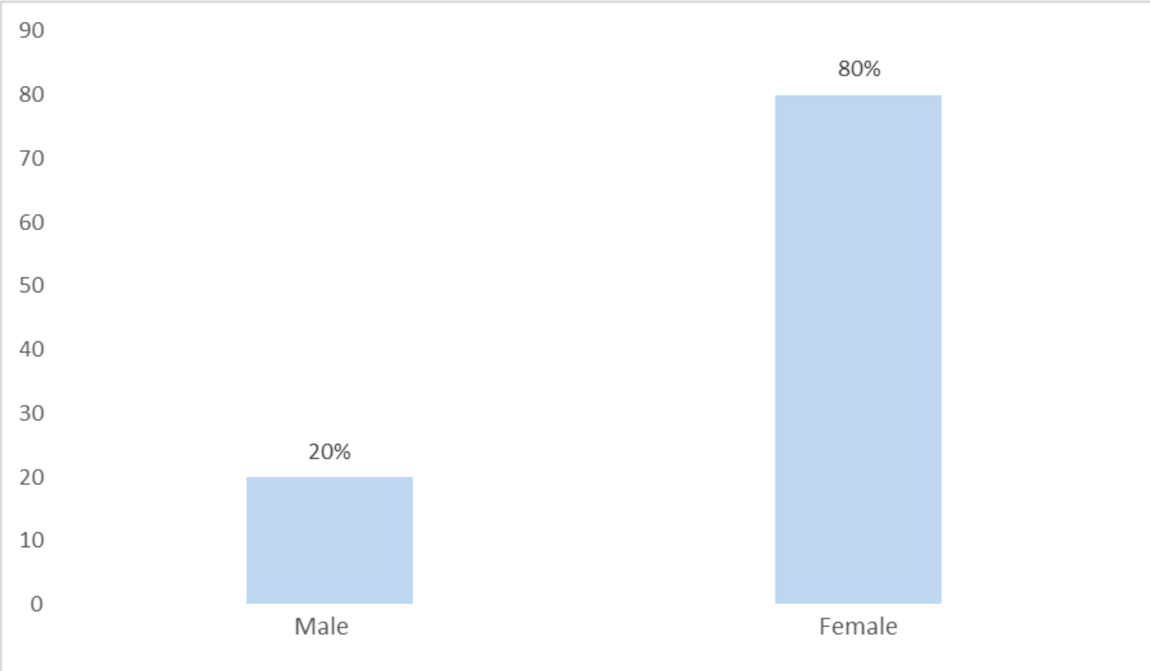
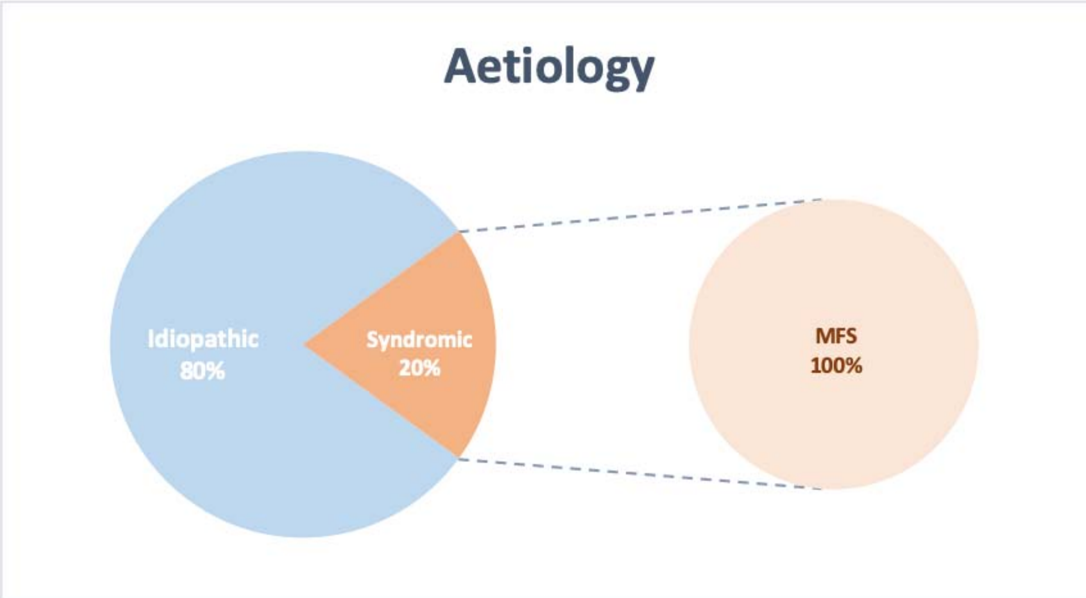


Figure 6: Distribution of studied population by gender.

3. Aetiology

The idiopathic form accounts for the majority of cases of scoliosis among our study population, comprising 80% (n=8), while syndromic scoliosis associated with Marfan syndrome represents 20% (n=2).



MFS, Marfan syndrome.

Figure 7: Aetiology distribution within the study population.

II. Clinical Data

1. Clinical Features

1.1. Chief Complaint

The main clinical manifestations for all patients were as follows:

- Cosmetic deformity (80%):
  - Rib prominence: This was the primary symptom observed in our series.
  - Shoulder asymmetry.
  - Rib gibbosity and waist asymmetry.
- Back pain and stiffness (20%).

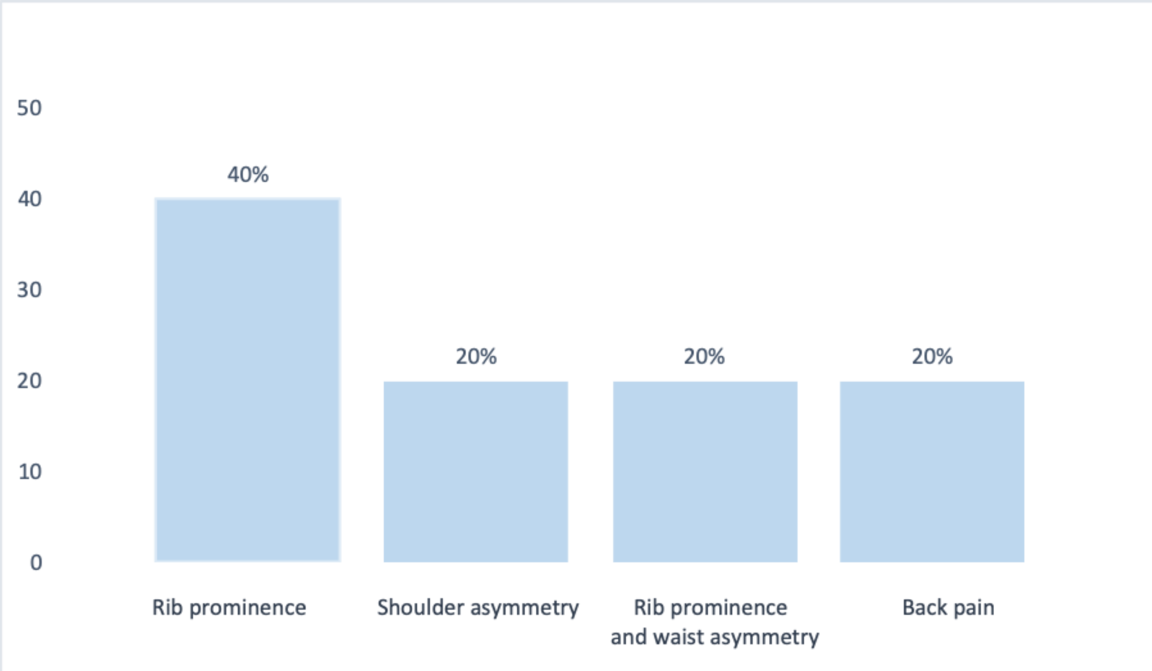


Figure 8: Distribution of the study population by chief complaints

1.2. Past Medical History

- Two cases have been diagnosed with Marfan's syndrome (MFS) and their scoliosis was attributed to the underlying disease.
- Overall, 80% of our patients had no relevant medical history.
- None of the patients had similar case of scoliosis in their family.

2. Physical Examination

All patients underwent a systematic physical examination in addition to a thorough neurologic evaluation, and all symptoms were recorded.

- None of the patients in our studied population had lower-limb length discrepancy.
- All cases were neurologically intact.
- All cases screened positive in the Adam's forward bending test, with an average trunk rotation angle of 12° (ranging from 8° to 18°) preoperatively.

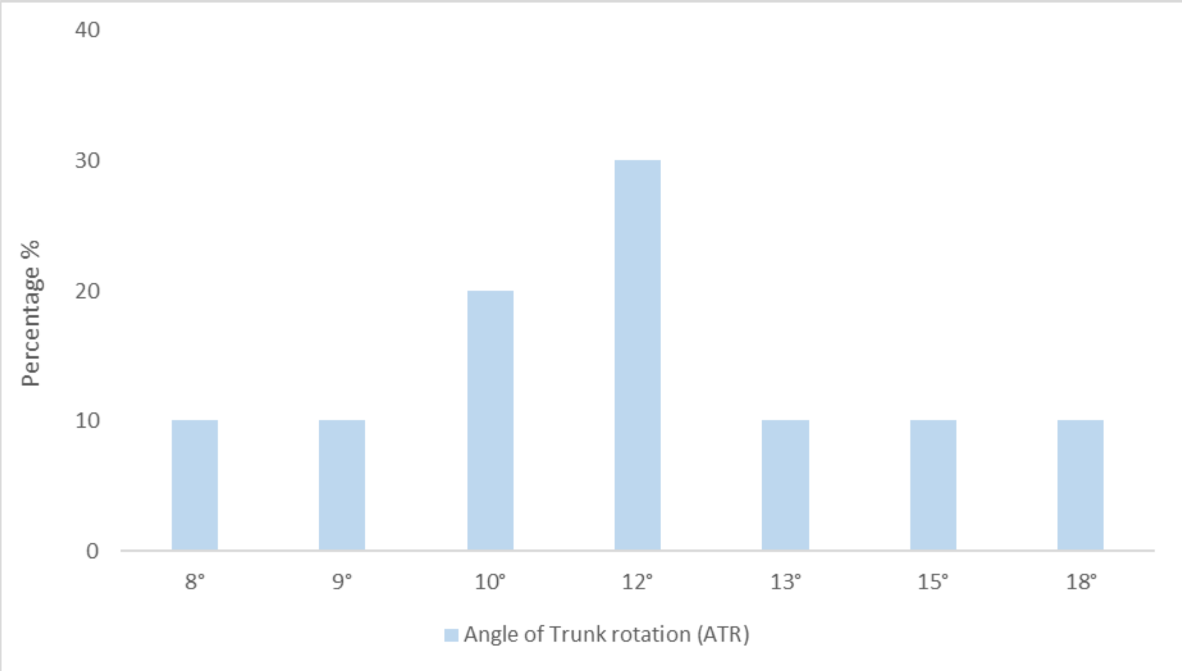


Figure 9: Percentage distribution of studied population by the angle of trunk rotation

III. Preoperative Radiographic Evaluation

1. Risser Classification

The distribution of skeletal maturity was as follows: four cases were classified as Risser IV, and six cases were classified as Risser V. The mean Risser stage for the entire cohort was 4.7.

Table II: Risser stage of the studied population.

Risser stage	Number
0, I, II, III	0
IV	4
V	6

2. Coronal Radiographic Parameters

2.1. Curve Magnitude (Coronal COBB)

Curves were classified into proximal thoracic (PT), main thoracic (MT), and thoracolumbar/lumbar (TL/L), depending on the location of the apex of the curve and their Cobb angles were measured according to the Cobb method.

The mean preoperative Cobb angle for the PT, MT, and TLL curves in the upright position were 28.1°, 53.7°, and 39.1°, respectively.

Table III: Coronal plane curve characteristics of the studied population.

Curve	Mean Cobb angle (°)
Proximal thoracic (PT)	28.1
Main thoracic (MT)	53.7
Thoracolumbar/ Lumbar (TL/L)	39.1

2.2. Curve Pattern

According to Lenke's classification, the most frequent patterns encountered were as follows: type I with 3 cases, followed by types II and V with 2 cases each. Types III, IV and VI each had 1 case. (Figures 10 and 11).

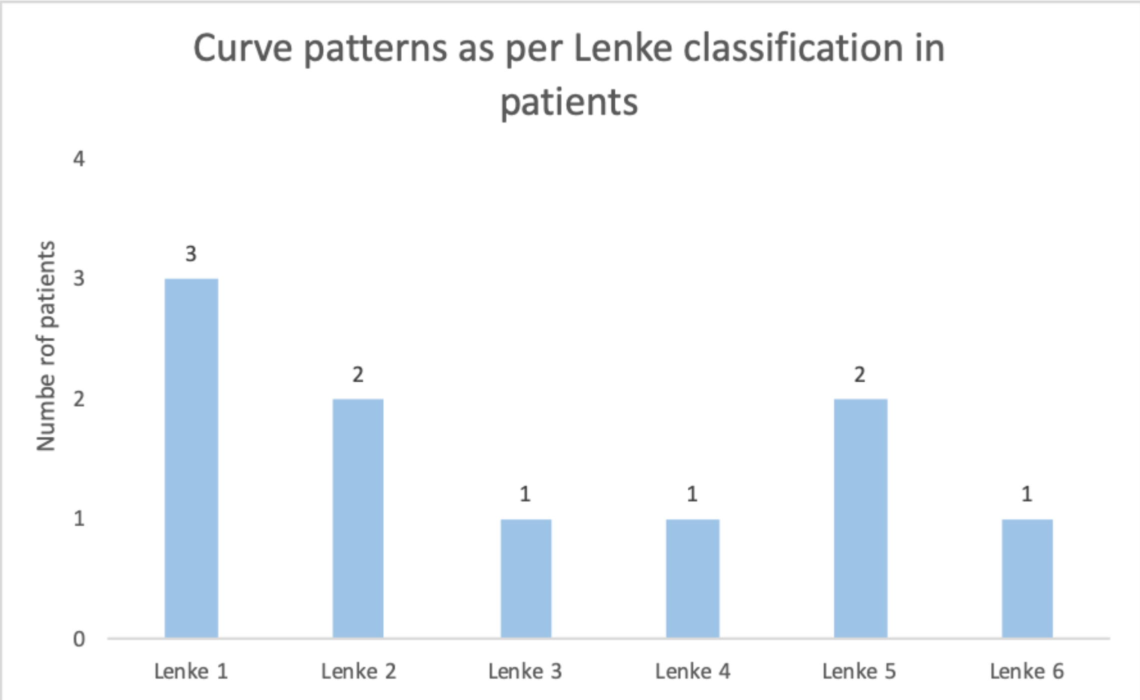


Figure 10: Distribution of curve patterns as per Lenke classification in patients.

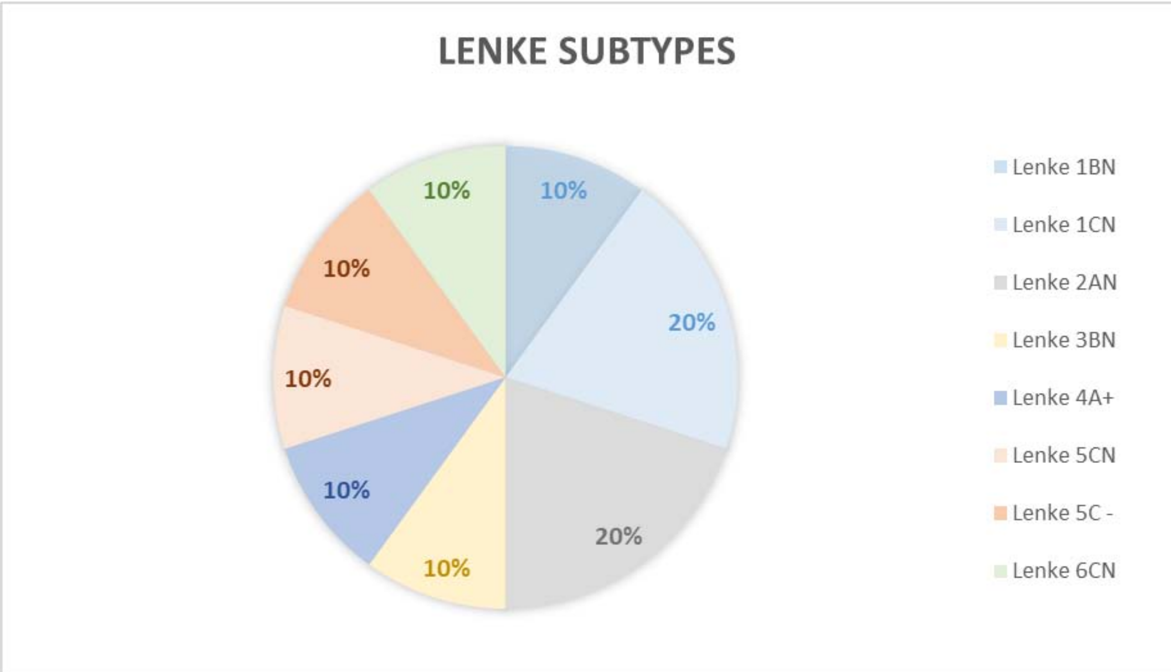


Figure 11: Distribution of Lenke classification subtypes in the studied patients.

2.3. Global Coronal Balance (GCB)

The mean preoperative CVA distance for the entire cohort was 9.4 mm ranging from -9 mm to 24 mm. In patients without imbalance, the mean CVA was 4.4 mm, while in patients with imbalance, it was 23.3 mm.

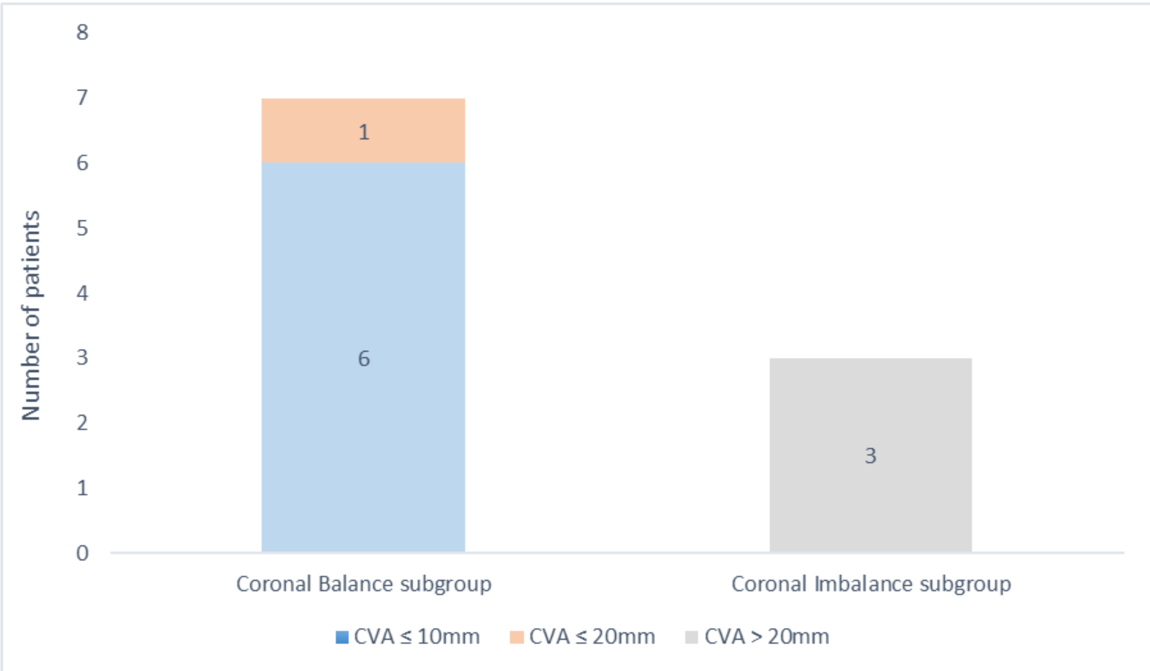
Of the 10 patients:

- 30% exhibited preoperative coronal decompensation.
- 10% had satisfactory coronal alignment ($\leq$ 20 mm away from midline).
- 60% had excellent coronal alignment ($\leq$ 10 mm away from midline).

Table IV: Mean values of the CVA in the subgroups.

Coronal Alignment Subgroups	Number	CVA; mean (mm)
Overall	10	9.4
Balanced subgroup	7	4.4
Imbalanced subgroup	3	23.3

CVA; Coronal vertical axis.



CVA; Coronal vertical axis.

Figure 12: Distribution of the global coronal balance in the studied population

3. Sagittal Radiographic Parameters

3.1. Spinopelvic Parameters

The mean preoperative values of the measured spinopelvic parameters for the entire cohort were as follows:

Table I: The mean preoperative spinopelvic parameters of all subjects.

Parameters	Mean (°)
Thoracic Kyphosis (TK)	19
Lumbar Lordosis (LL)	50
Pelvic Incidence (PI)	54.5
Pelvic tilt (PT)	14.5
Sacral Slope (SS)	40

a. Sagittal Curvatures

- Preoperatively, the mean value of thoracic kyphosis was 19°. Thoracic hypokyphosis was showed in 8 patients, 1 patient had normal thoracic kyphosis, and one patient was hyperkyphotic (Figure 13).
- Lumbar lordosis was averaging 50°. Four patients had preoperative normal lordosis, five were hypolordotic, and hyperlordosis was found in only one case (Figure 14).

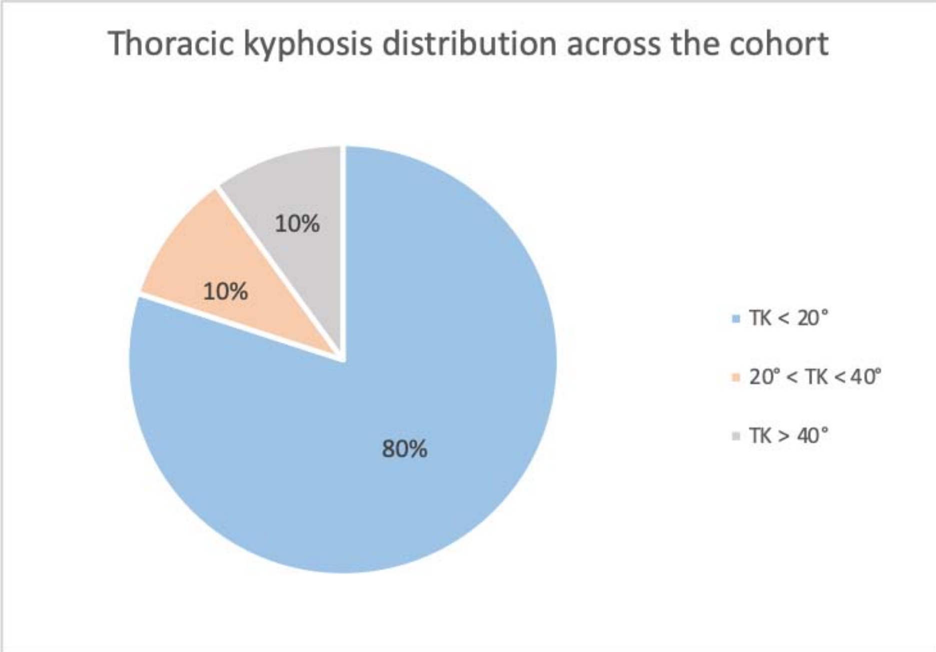


Figure 13:The pre-operative distribution of Thoracic Kyphosis (TK) in the studied population.

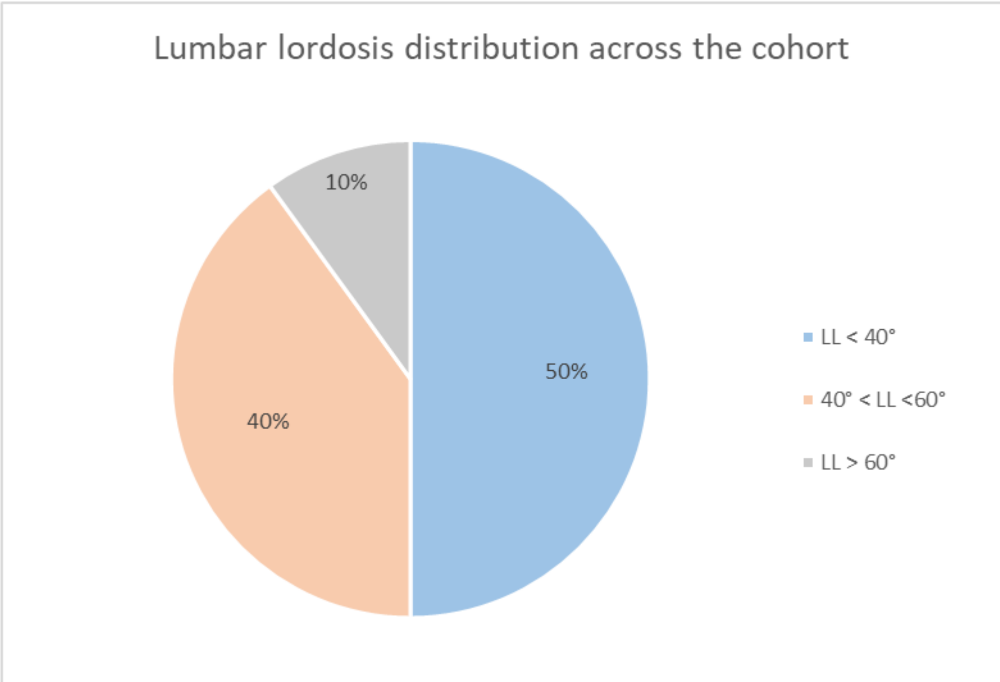


Figure 14: The pre-operative distribution of Lumbar Lordosis (LL) for the entire cohort.

b. Pelvic Parameters

Before surgery, mean PI was 54.5°, with corresponding mean SS and PT values of 40° and 14.5°, respectively.

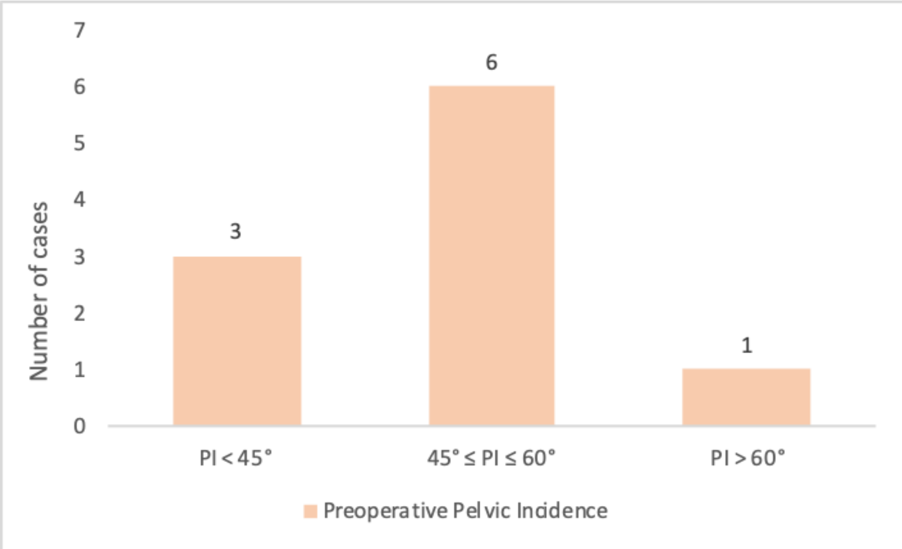


Figure 15: The preoperative distribution of Pelvic Incidence in the cohort.

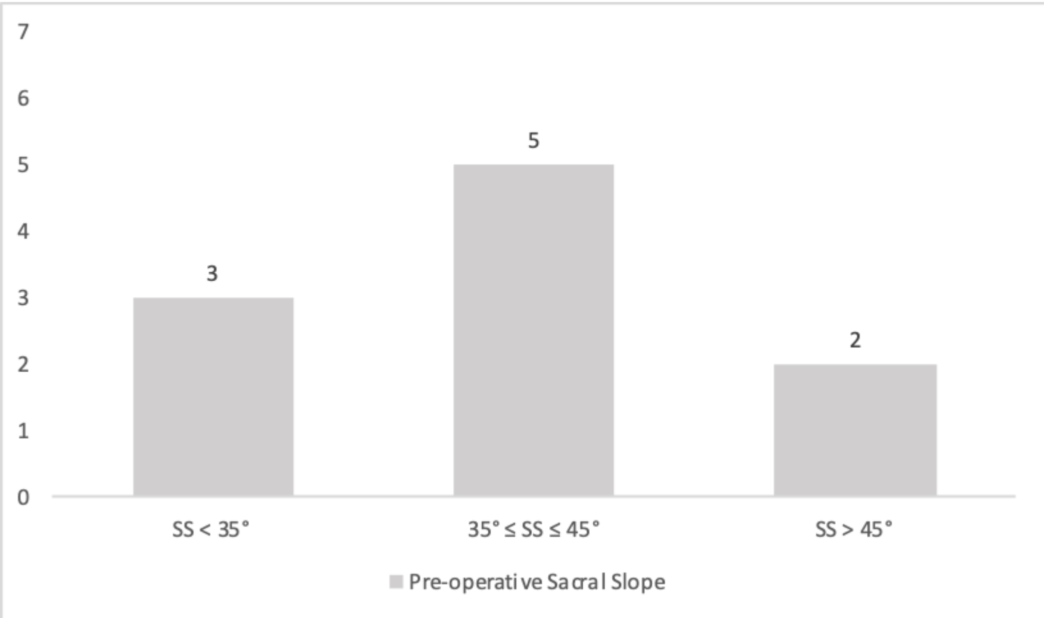


Figure 16: The preoperative distribution of Sacral Slope in the cohort.

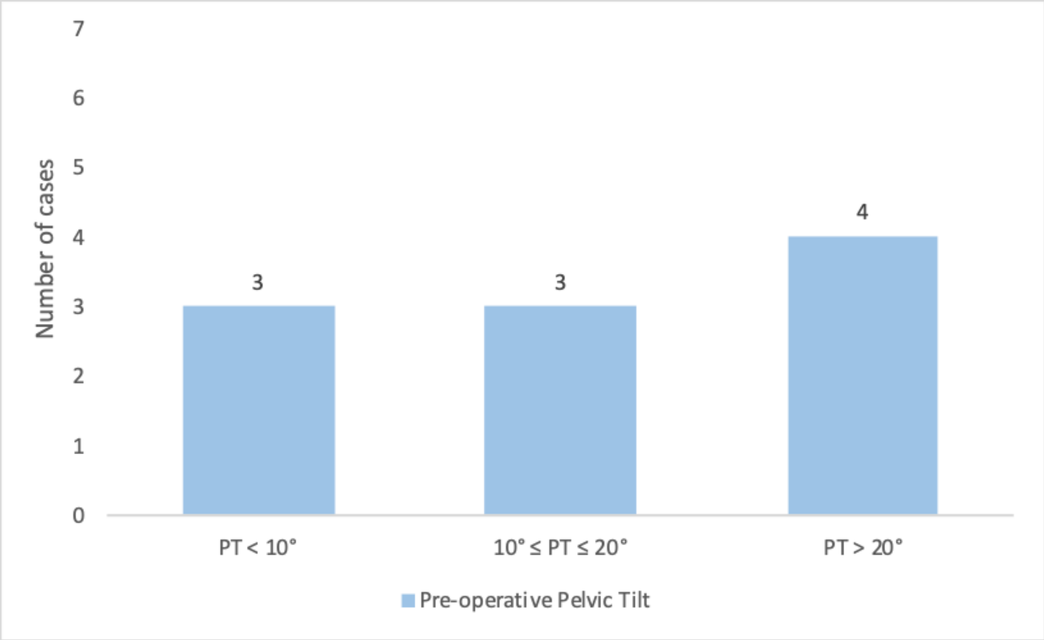


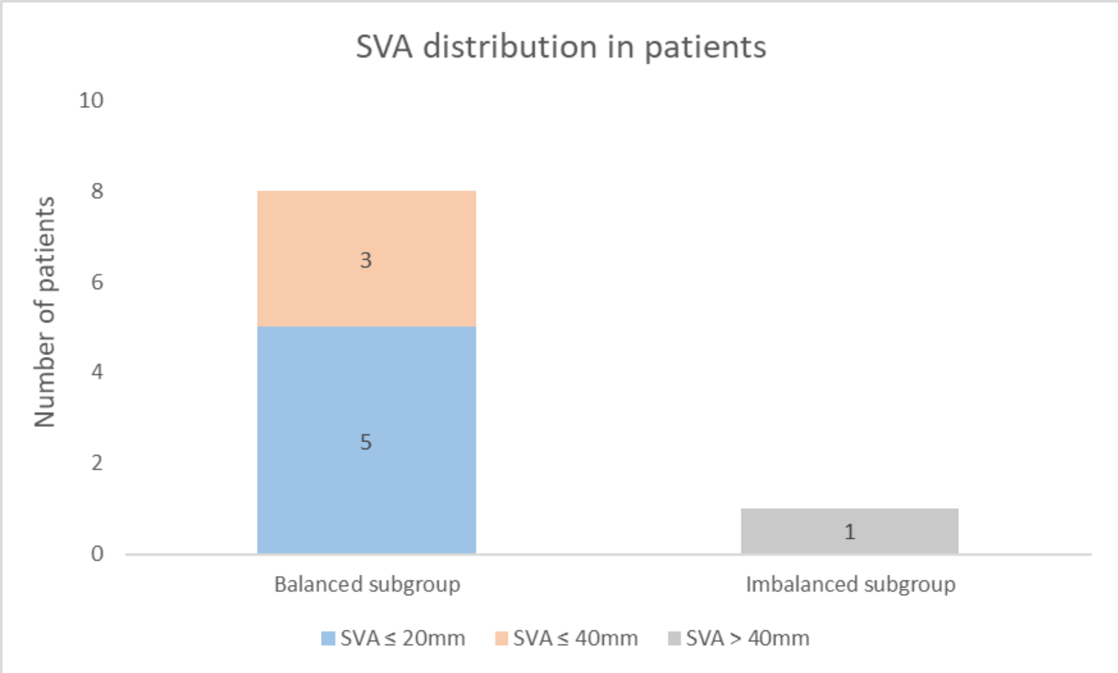
Figure 17: The preoperative distribution of Pelvic Tilt in patients.

3.2. Spinopelvic Alignment

a. Global Sagittal Balance (GSB)

The mean preoperative SVA across the study population was 13.8 mm, ranging from -29 mm to 60 mm.

Of all cases, positive sagittal imbalance has been found in only one case (10%), preoperatively.



SVA; Sagittal vertical axis.

Figure 18: Distribution of the global sagittal balance in the studied population.

b. Pelvic Incidence minus Lumbar lordosis (PI-LL)

To assess spinal alignment, the relationship between pelvic incidence and lumbar lordosis was evaluated by calculating PI-LL, the discrepancy between PI and LL.

The mean pre-operative PI-LL value was 8.3°. In all, three patients presented a PI-LL mismatch (PI-LL > 10°) and had a lumbar lordosis not correctly correlated to their pelvic incidence of which one patient suffered a severe mismatch (PI-LL > 20°).

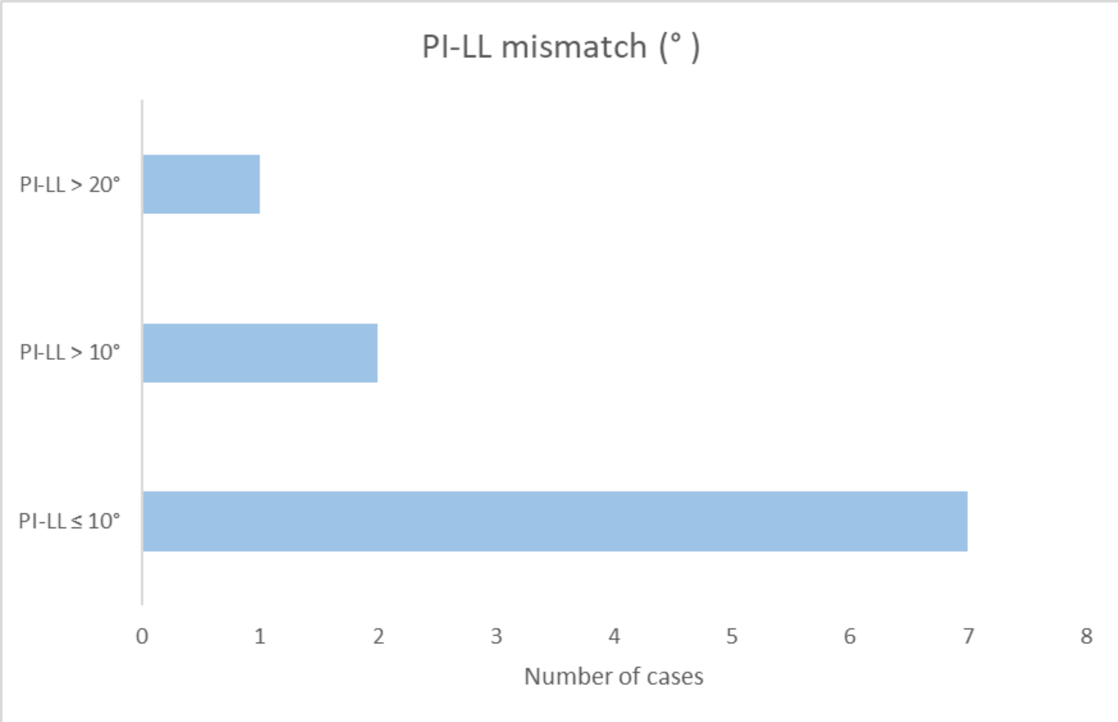


Figure 19: The distribution of patients by the PI-LL value.

IV. Operative Management

1. Preoperative Assessment

Due to the potential for significant pulmonary, cardiac, and neurologic comorbidities associated with advanced scoliosis, a thorough preoperative evaluation was performed to assess the patient's neurological status, and the extent of dysfunction in organ systems.

Based on the severity of the curve and the level of respiratory impairment and other organ involvement, the following preoperative laboratory studies were performed for our patients:

- Magnetic resonance imaging (MRI) was performed to assess the spinal canal and neural elements. All patients underwent preoperative whole spine MRI scans, which were found to be normal.

- Computed tomography (CT) with 3D reconstruction.
- Chest x-ray.
- Electrocardiogram (EKG).
- Echocardiogram.
- Pulmonary Function Testing (PFT).
- Arterial blood gases.
- Complete blood count.
- Coagulation studies: Platelet count, Prothrombin time and activity.
- Electrolyte panel.
- Liver and renal functions test.
- Urine analysis with bacteriological culture.

2. Perioperative Assessment

2.1. Surgical Procedure

Arthrodesis was performed by posterior approach only. Patients were placed in the prone position after general anesthesia was induced. After a standard midline incision, subperiosteal dissection of the posterior soft tissues was performed. Instrumentation with polyaxial screws or hybrid construct combining pedicle screws and sublaminar bands was implemented. Two titanium rods were then connected to the claws and pedicular screws to obtain a rigid frame. Reduction maneuvers were performed by rod derotation/ posteromedial translation and screws manipulation, with or without in situ bending of rods. Intraoperative monitoring of spinal cord function was conducted using MEPs and SSEP. Before completing the surgery, a subfascial drain was inserted.

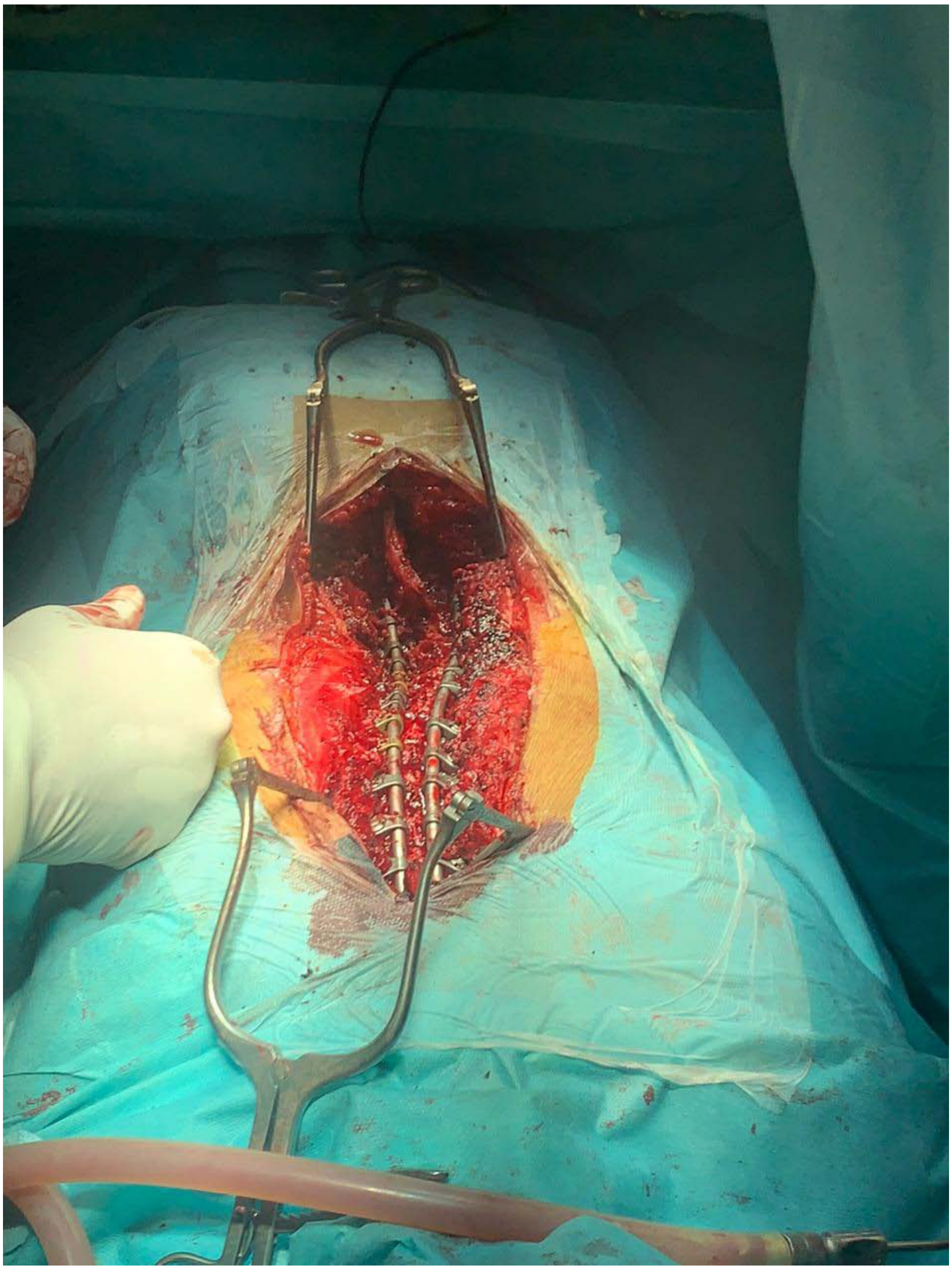


Figure 20: Intraoperative picture showing implant placement and deformity correction.

2.2. Surgical Data

- The operative time averaged 235 minutes. The mean ICU stay was 2.5 days. Total hospital stay averaged 11 days.

- Estimated blood loss (EBL) at surgery averaged 840.3 ml, and the volume of red blood cells (RBC) transfused was 663.7 ml.
- The number of instrumented vertebrae averaged 11.7

Table III: Surgical data of the studied population.

Parameters	Data of the entire cohort; mean
Surgical time (min)	235
Blood loss (mL)	840.3
Number of fused vertebra	11.7
ICU stay (days)	2.5
Hospital stay (days)	11

ICU, Intensive Care Unit.

2.3. Fusion Levels

- The averaged fusion length was 11.7 segments.
- The upper instrumented vertebrae (UIV) ranged from T1 to T10, including T1 and T2 in one case each, T3 in three cases, T4 and T5 in two cases each, and T10 in one case.
- The lower instrumented vertebrae (LIV) ranged from T12 to L4, including T12 in two cases, L1 in one case, L3 in two cases, and L4 in five patients.

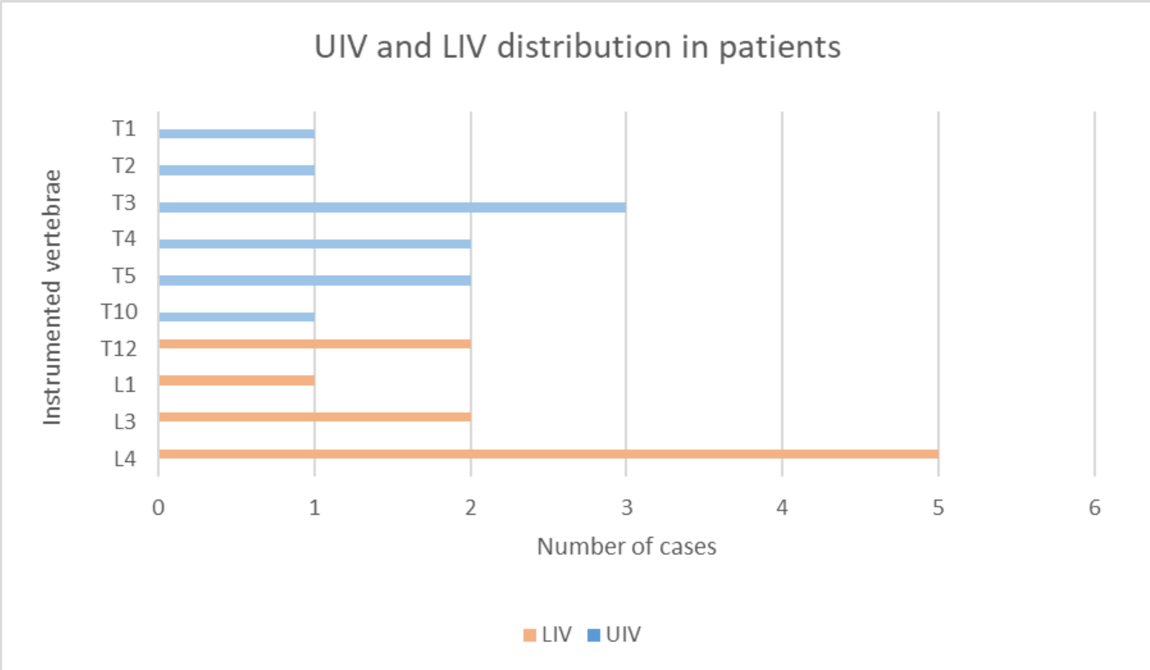


Figure 21:Upper instrumented vertebra (UIV) and lower instrumented vertebra (LIV) distribution in patients.

3. Post-operative Assessment

3.1. Follow-up

The length of the postoperative follow-up ranged from 12 months to three years and seven months. The average duration of the follow-up period was 38.5 months.

Tableau III: Average Follow-up period of the cohort.

	Follow-up periods (months)
Mean	38.5
Minimum	12
Maximum	43

3.2. Complications

Complications were evaluated regarding their time of onset and devided into: intraoperative, perioperative (< 4 weeks), and post-operative (> 4 weeks).

- A perioperative complication was identified in one case of syndromic scoliosis (Marfan's syndrome) where the patient developed deep surgical site infection (SSI) on day 20 post-operative and was treated successfully with early debridement within 32 hours of presentation and administration of parenteral antibiotics according to bacteriological culture and antimicrobial sensitivity tests until complete clearing up of the infection with clinical and laboratory parameters. The implant was successfully retained
- Throughout the post-operative period and during the final follow-up, there were no cases of neurological deficit, pseudoarthrosis, proximal junctional kyphosis (PJK), or implant failure. No revision surgery has been performed to date.

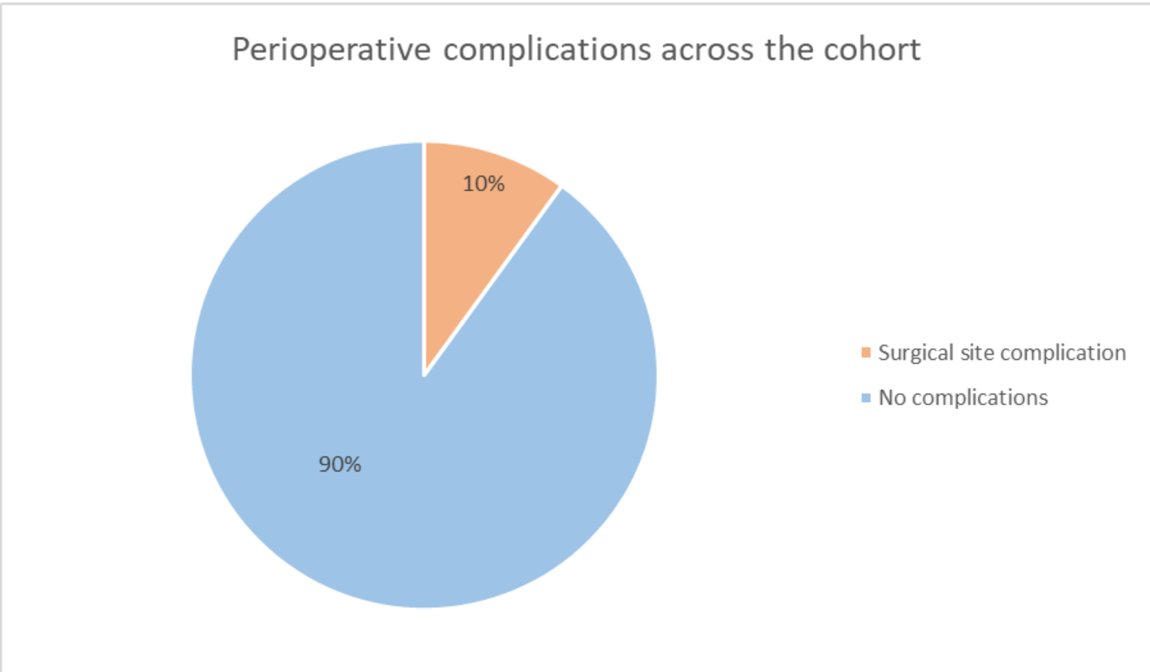


Figure 22: Pie chart demonstrating perioperative complications following the operative procedure.

V. Surgery Outcomes:

1. Radiographic Outcome

Table VIII summarizes the preoperative, early post-operative, and final follow-up results for the entire cohort.

Table IV: Pre-operative, immediate post-operative and last follow-up values.

	Preoperative ; mean	Early post-operative ; mean	Final follow-up ; mean	p-value
Coronal plane				
PT curve (°)	28.1	13	13.4	**<0.01*,****
MT curve (°)	53.7	17.2	19	**<0.01*,****
TLL curve (°)	39.1	14.5	16.4	**<0.01*,****
CVA (mm)	9.4	6.5	3.3	0.85* / **0.02****
Sagittal plane				
TK (°)	19	24.5	26.3	**<0.01*,****
LL (°)	50	50.7	55.6	0.53* /**0.09****
PI (°)	54.5	54.4	54.2	0.62*,**
PT (°)	14.5	15.9	14	**0.02*** /0.81**
SS (°)	40	38.3	40.2	**0.03***/ 0.47**
SVA (mm)	13.8	12	5	0.74*/ **0.02****
PI-LL (°)	8.3	6	3.2	0.66*/ **0.03****

Bold indicates statistical significance at p < 0.05; *, Before surgery vs Early postoperative; **, Before surgery vs Last follow-up.

1.1. Coronal Parameters

a. Curve Correction

In the early post-operative period, in the entire cohort:

- The mean coronal Cobb angles of the PT, MT, and TLL curves were decreased from 28.1°, 53.7°, and 39.1° to 13°, 17.2°, and 14.5°, respectively, representing an average correction rates of 53.7%, 68%, and 63%, respectively, with a significant correction of the deformity ($p < 0.001$).

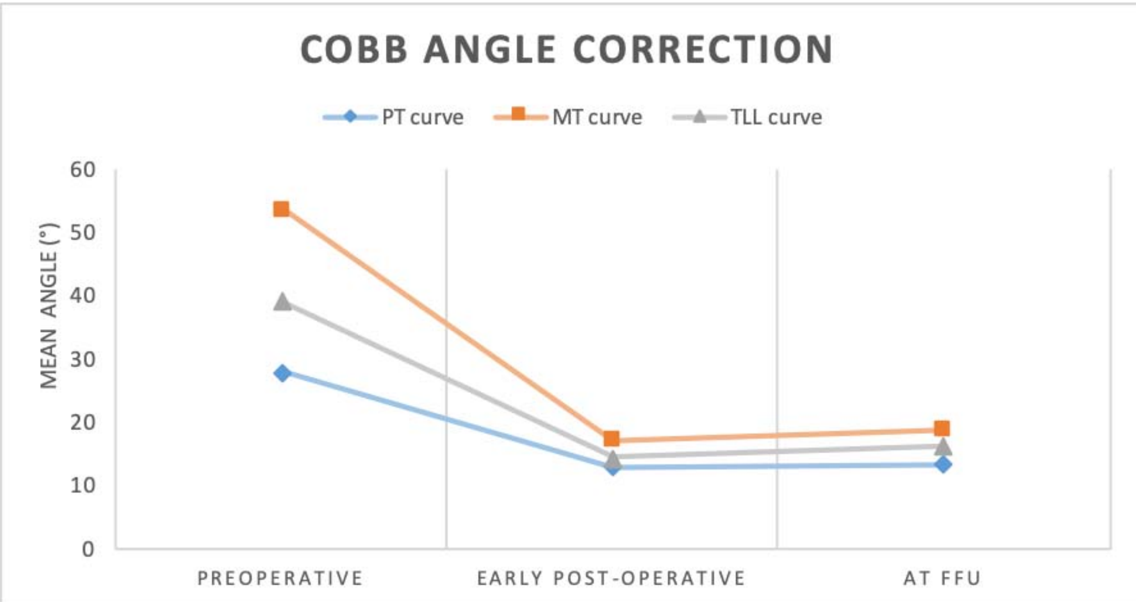
At the final follow-up:

- The Cobb angle of the PT, MT, and TLL curves was significantly conserved compared to the post-operative measurements, with achieved correction of 52.3%, 64.6%, and 58%, respectively. Complete data is reported in Table IX and in Figure 23.

Table IX: Cobb angle assessment for the total patient sample.

Coronal plane	Preoperative	Early post-operative		Final follow-up	
	Mean (°)	Mean (°)	Correction rate (%)	Mean (°)	Correction rate (%)
PT curve	28.1	13	53.7	13.4	52.3
MT curve	53.7	17.2	68	19	64.6
TLL curve	39.1	14.5	63	16.4	58

PT, proximal thoracic; MT, main thoracic; TLL, thoracolumbar/lumbar.



PT, proximal thoracic; MT, main thoracic; TLL, thoracolumbar/lumbar; FFU, final follow-up

Figure 23: Primary Cobb angle correction for the entire patient cohort.

To comprehensively evaluate the degree of correction achieved in our cohort, a sub-analysis was performed according to the reduction technique used. Patients were divided into 2 groups: The PS group consisted of patients in whom an all-pedicle screw construct was utilized, whereas the SB group included patients treated with hybrid instrumentation using sublaminar bands (Table X).

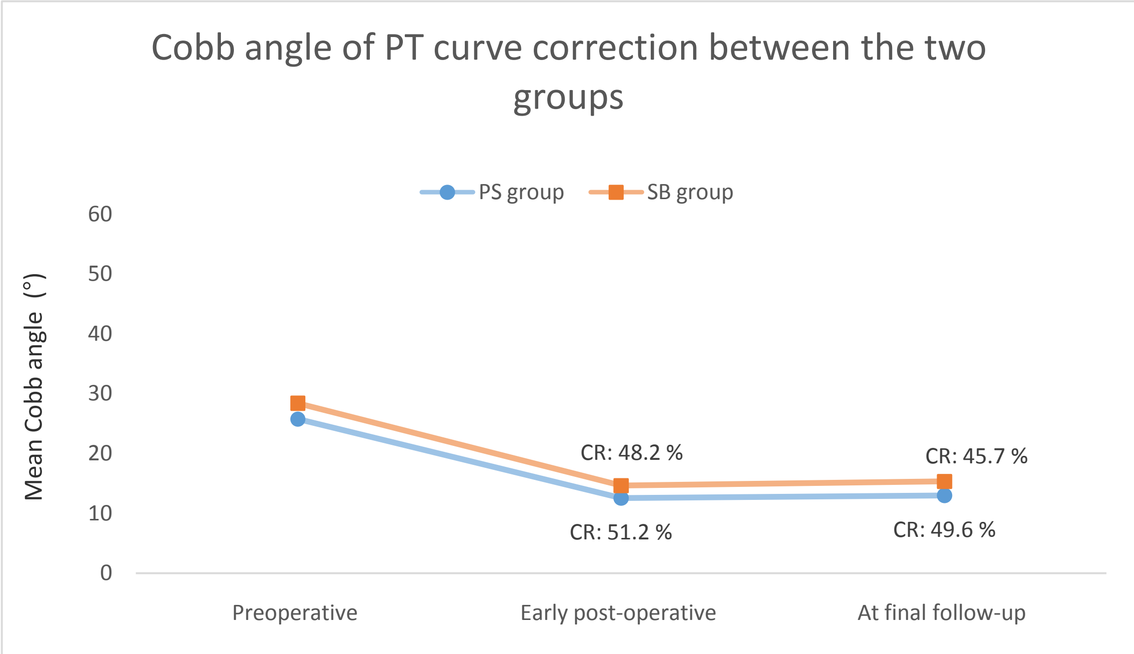
Table X: Comparison of coronal parameters change between the two treatment groups at early postoperative and final follow-up.

Variables	PS group (n=7)	SB group (n=3)	p-value
PT curve			
Preoperative (°)	25.8	28.4	0.26
Early post-operative (°)	12.6	14.7	0.37
Correction rate (%)	**51.2**	**48.2**	0.08
Final follow-up (°)	13	15.4	0.42
Correction rate (%)	**49.6**	**45.7**	0.63
MT curve			
Preoperative (°)	52.3	54	0.58
Early post-operative (°)	13.4	18.3	**0.04**
Correction rate (%)	**74.4**	**66.1**	**0.02**
Final follow-up (°)	15.6	22	**0.02**
Correction rate (%)	**70.2**	**59.2**	**<0.01**
TLL curve			
Preoperative (°)	38.6	39.5	0.70
Early post-operative (°)	11.2	15.4	**0.02**
Correction rate (%)	**71**	**61**	**0.02**
Final follow-up (°)	12.5	17.8	**0.04**
Correction rate (%)	**67.6**	**55**	**<0.01**

Bold indicates significance level: $p < 0.05$. PT, proximal thoracic; MT, main thoracic; TLL, thoracolumbar/lumbar; n, number of patients.

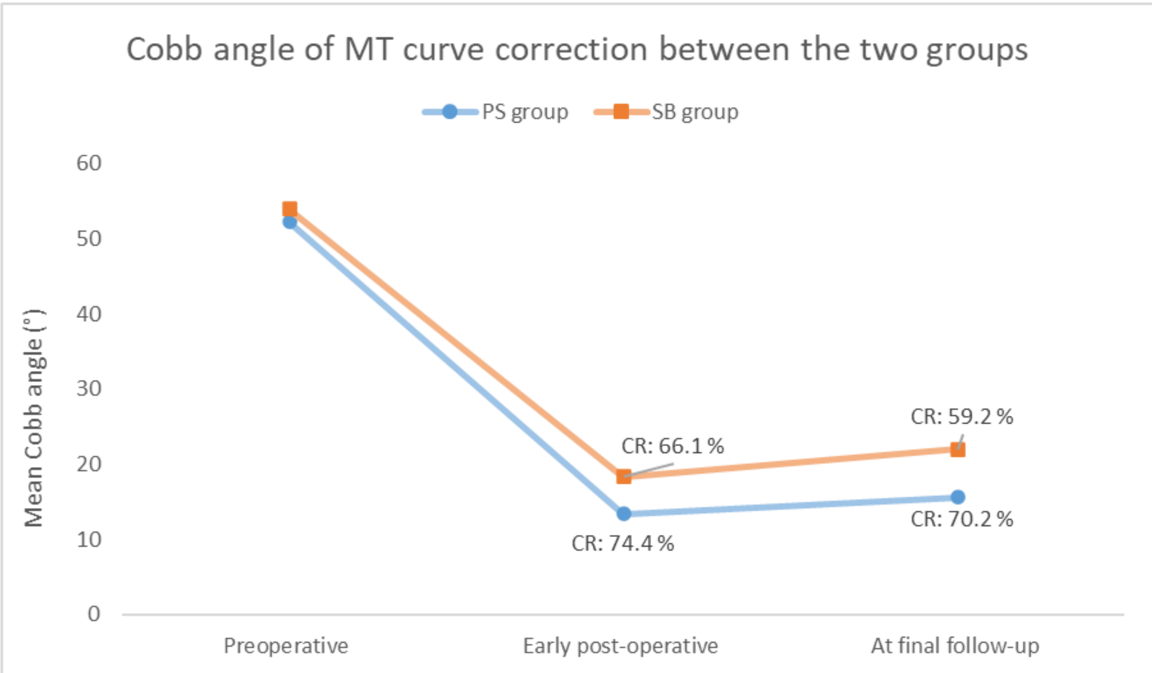
At the time of their first erect radiographs, patients in the PS group had better correction of the Cobb angle of the MT, and TLL curves compared to the SB group (mean 74.4% and 71%, respectively versus mean 66.1% and 61%, respectively) (Table X).

At the final follow-up, loss of correction was greater in the SB patients compared to the PS patients (mean -3.7° and -2.4°, respectively versus mean -2.2° and -1.3°, respectively) (Figures 24-26).



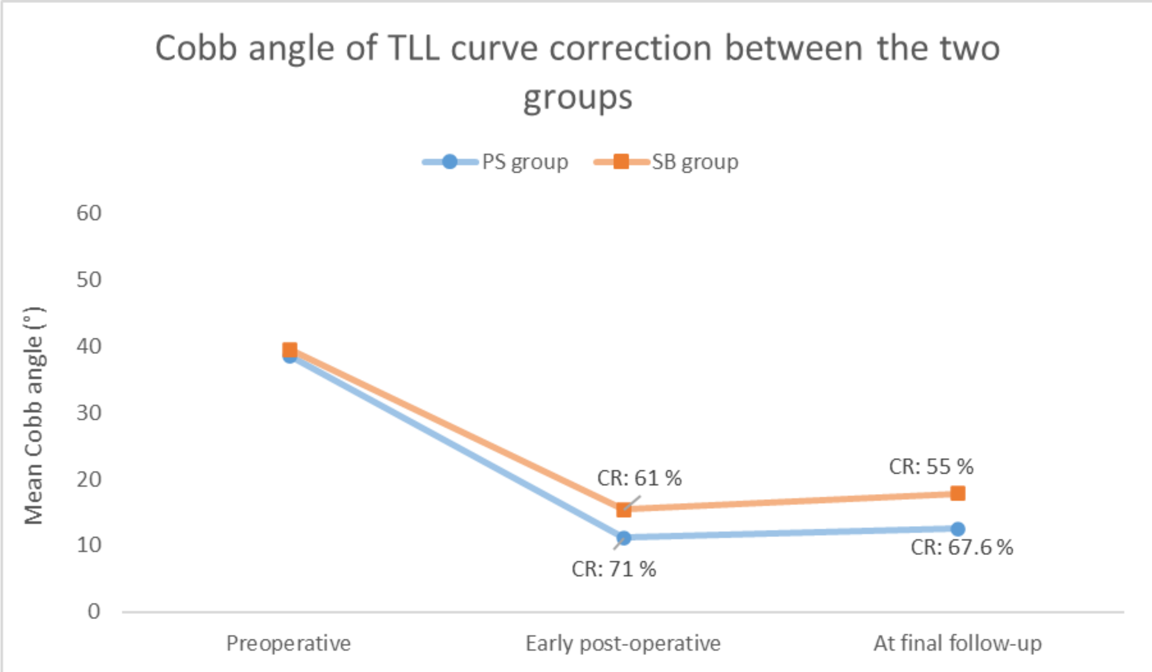
PT, proximal thoracic; CR: correction rate

Figure 24: Postoperative coronal correction of the cobb angle at the PT curve between the two groups.



MT, main thoracic; CR: correction rate

Figure 25: Postoperative coronal correction of the cobb angle at the MT curve between the two groups.



TLL, thoracolumbar/ lumbar; CR: correction rate

Figure 26: Postoperative coronal correction of the cobb angle at the TLL curve between the two groups.

b. Global Coronal Balance (GCB)

Regarding CVA, the preoperative mean displacement of 9.4 mm observed in the entire cohort improved to 3.3 mm at the final follow-up.

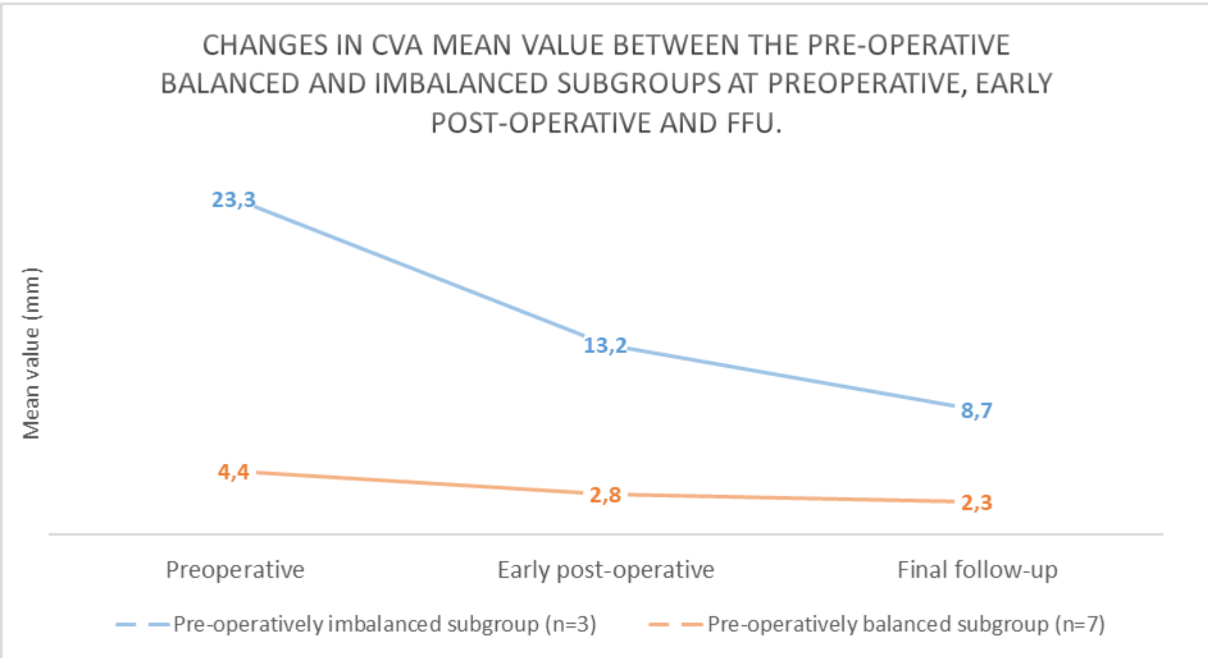
To further study the restoration of coronal balance, subgroup analysis was performed according to whether the preoperative CVA exceeded 20mm. As shown in Table XI, both groups showed improvements in coronal balance following surgery, with the CVA being larger in the imbalanced subgroup than that in the balanced one.

Post-operatively, the coronal alignment was maintained in the patients with preoperative coronal balance and was restored to normal in all the patients in the imbalanced subgroup with further improvement in the subsequent follow-up visits (Figure 27).

Table VI: Comparisons of Coronal Balance Between the balanced and imbalanced groups.

CVA (mm)	Preoperative	Early post-operative		Final follow-up	
	Mean	Mean	p-value (pre- post)	Mean	p-value (post- FFU)
Total cohort (n=10)	9.4	6.5	0.85	3.3	0.21
Pre-operative imbalanced subgroup (n=3)	23.3	13.2	**<0.01**	8.7	**<0.01**
Pre-operative balanced subgroup (n=7)	4.4	2.8	0.14	2.3	0.26

p-value was calculated between preoperative measurement and follow-up evaluations. Statistical significance at p-value<0.05.



FFU, final follow-up.

Figure 27: Coronal balance variation between the Preoperative balanced and imbalanced groups.

1.2. Sagittal Parameters

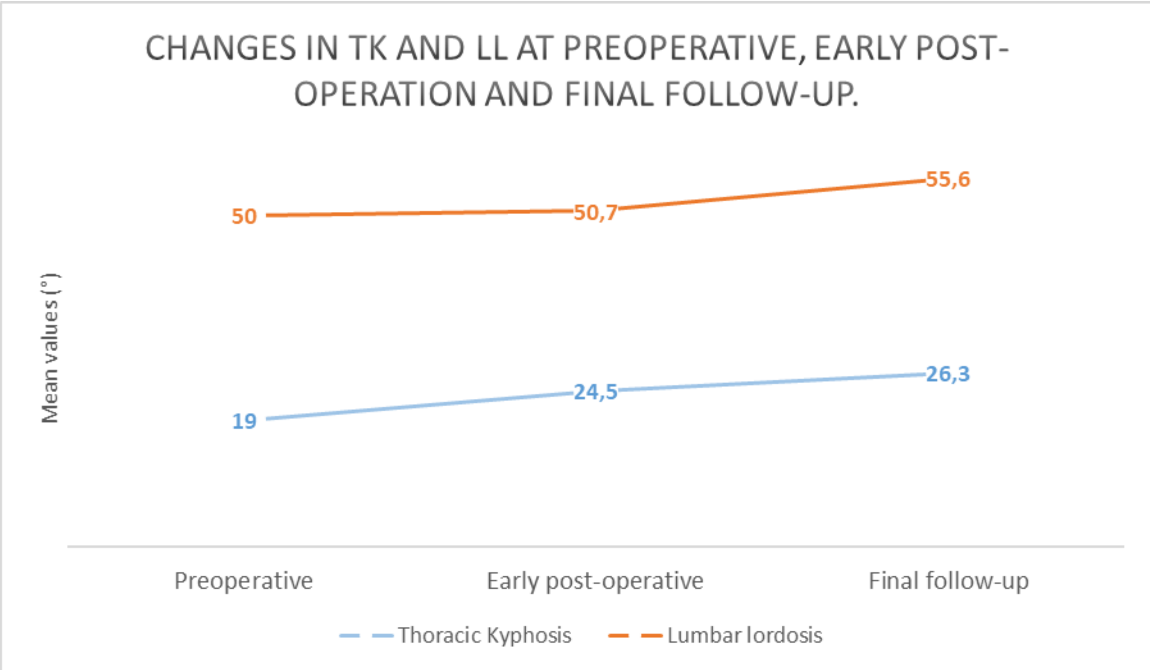
a. Sagittal Curvatures

After surgery, in the entire cohort:

- The degree of thoracic kyphosis had a tendency to increase during the follow-up period. The mean preoperative TK was 19°, which increased to 24.5° postoperatively. The difference between preoperative and early post-operative thoracic kyphosis was significant (p-value <0.01). The measurements at the final follow-up did not show further significant differences (26.3° versus 24.5°, p-value = 0.15).

- Concerning lumbar lordosis, there was no significant difference between the pre- and early post-operative measurements (50° versus 50.7°, p-value = 0.53), but further significant modifications were observed during the following visits. At the final follow-up, LL increased significantly from early post-operative measurements (average delta value of 5°, p-value = 0.04).

Results on the entire population are summarized in Figure 28 and Table XII.



TK, thoracic kyphosis; LL, lumbar lordosis.

<u>**Figure 28:** Variations in sagittal parameters in the entire cohort.</u>

To further evaluate the variations of TK and LL before and after surgery, a sub-group analysis was performed based on the preoperative TK (Table XII):

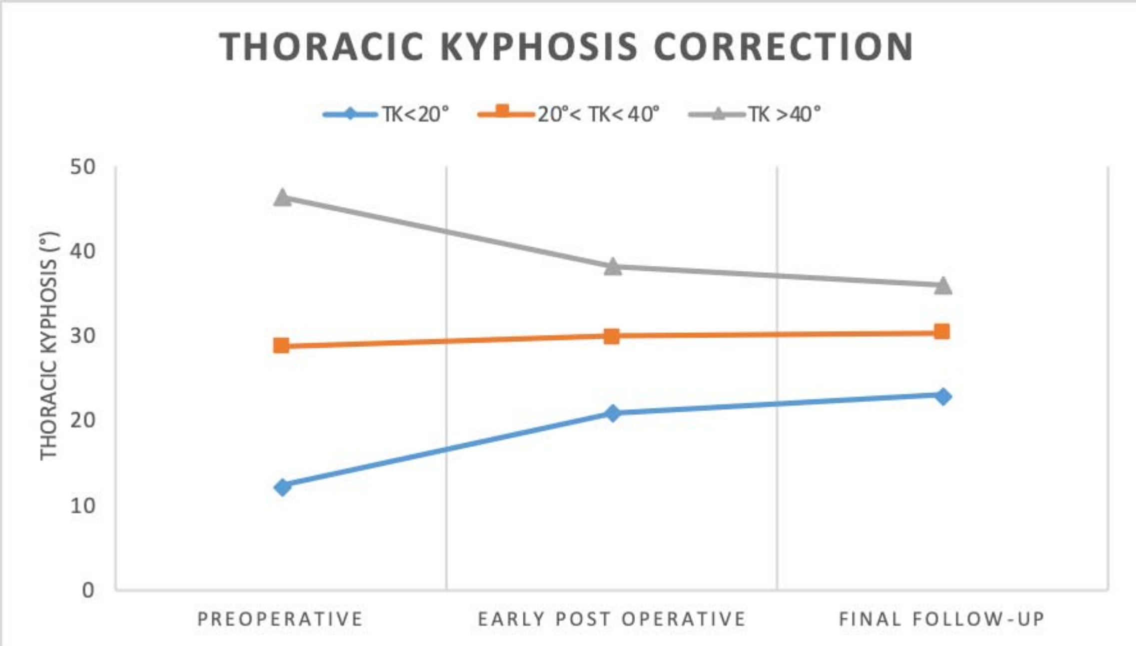
- At final follow-up, patients with a preoperative hypokyphosis, exhibited, on average, a significant increase in TK of 10.7°, with a reciprocal increase in LL of 4.3°. For patients with a preoperative hyperkyphosis, both TK and LL were significantly decreased from 46.5° to 36° and from 54.4° to 51°, respectively. Conversely, patients with normal preoperative kyphosis, the instrumentation has maintained a normal TK and secondary a normal LL.

Table VIII: Summary of changes in sagittal parameters by subgroups.

Study Subjects	Parameters (°)	Preoperative	Post-operative		FFU	
		Mean	Mean	p-value (Pre- post)	Mean	p-value (Post-FFU)
Total cohort (n=10)	TK	19	24.5	**<0.01**	26.3	0.15
	LL	50	50.7	0.83	55.6	**0.04**
Hypokyphosis (TK < 20°) (n=8)	TK	12.3	21	**<0.01**	23	0.06
	LL	43.4	44.5	0.39	47.7	**0.02**
Normokyphosis (20° < TK < 40°) (n=1)	TK	28.8	30	0.27	30.4	0.65
	LL	50.8	51.4	0.12	52.3	0.27
Hyperkyphosis (TK > 40°) (n=1)	TK	46.5	38.2	**<0.01**	36	0.14
	LL	54.4	50.2	0.37	51	0.52

TK, thoracic kyphosis; LL, lumbar lordosis; p-value was calculated between preoperative measurement and follow-up evaluations. Statistical significance at p-value<0.05.

At the final follow up, 8 patients achieved an optimal outcome with thoracic kyphosis within the physiological range while 2 were under-corrected (Figure 29).



Data expressed as mean; TK, thoracic kyphosis.

Figure 29: Thoracic kyphosis improvement in patients.

To assess the influence of the type of instrumentation on the restoration of thoracic kyphosis, we performed a comparative analysis between the two groups of patients (Table XIII).

- Preoperatively, 8 patients had a hypokyphosis, with 5 in the PS group and 3 in the SB group.
- At final follow-up, there was a significantly greater improvement in TK in the SB patients compared to the PS patients (+13.2° versus +6.7°; $p < 0.01$) (Figure 30). No significant difference was observed in LL values between the two groups ($p = 0.36$).

Table VIIII: Comparison of thoracic kyphosis restoration between the two groups.

	Variables	PS group (n=7)	SB group (n=3)	p-value
Hypokyphosis subgroup TK < 20° (n=8)	Number of cases	5/7	3/3	-
	Thoracic kyphosis (°)			
	Preoperative	13.8	12	0.37
	Early post-operative	18.3	23.4	**0.02**
	Final follow-up	20.5	25.2	**0.01**
	Lumbar lordosis (°)			
	Preoperative	44	42.3	0.82
	Early post-operative	44.7	43.5	0.51
	Final follow-up	46.6	49	0.36

Data expressed as mean; Bold indicates significance level at $p < 0.05$.

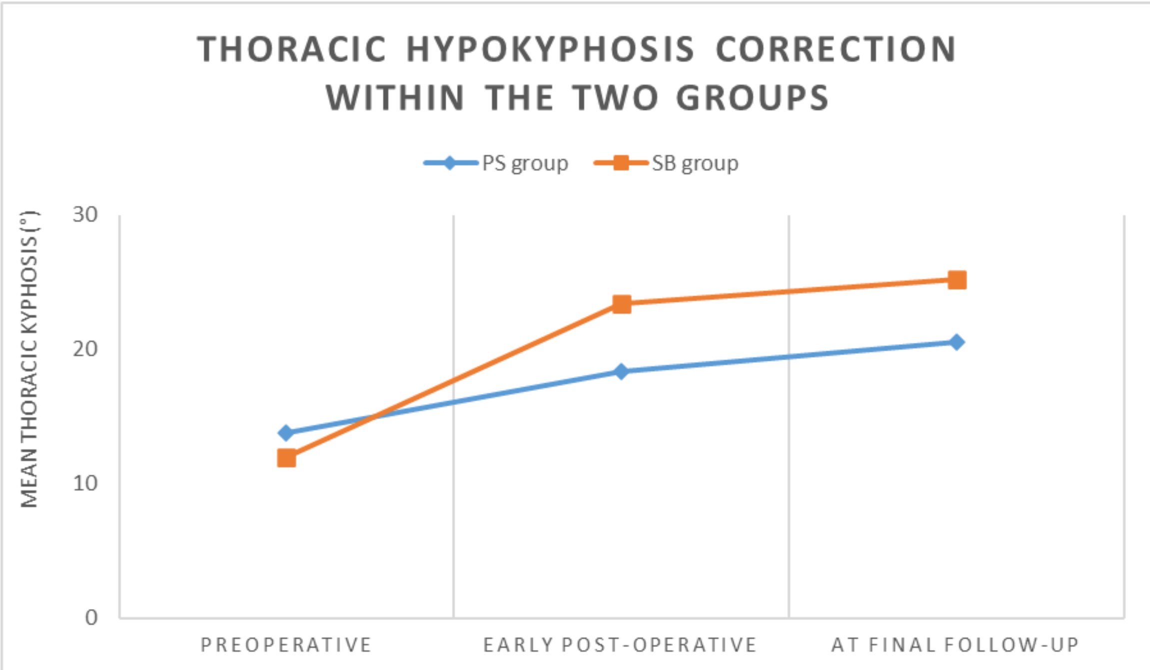


Figure 30: Chart showing comparison of Thoracic kyphosis change between pedicle screw (PS) and sublaminar band (SB) patients.

b. Pelvic Parameters

In the early post-operative:

- The mean preoperative PI was 54.5° and did not change post-operatively.
- There was a significant increase of PT coupled to a decrease of SS with a mean ΔPT and ΔSS of 1.4° and -1.7°, respectively. However, these changes were transitory and were normalized to pre-operative values at the last follow-up.

At the final follow-up:

- PI, PT, and SS remained unchanged between pre-operative and last follow-up.

Table XIV: Mean preoperative, early post-operative and at final follow-up values of the pelvic parameters.

Pelvic parameters	Preoperative	Early post-operative	Final follow-up
PI (°)	54.5	54.4	54.2
PT (°)	14.5	15.9	14
SS (°)	40	38.3	40.2

PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope

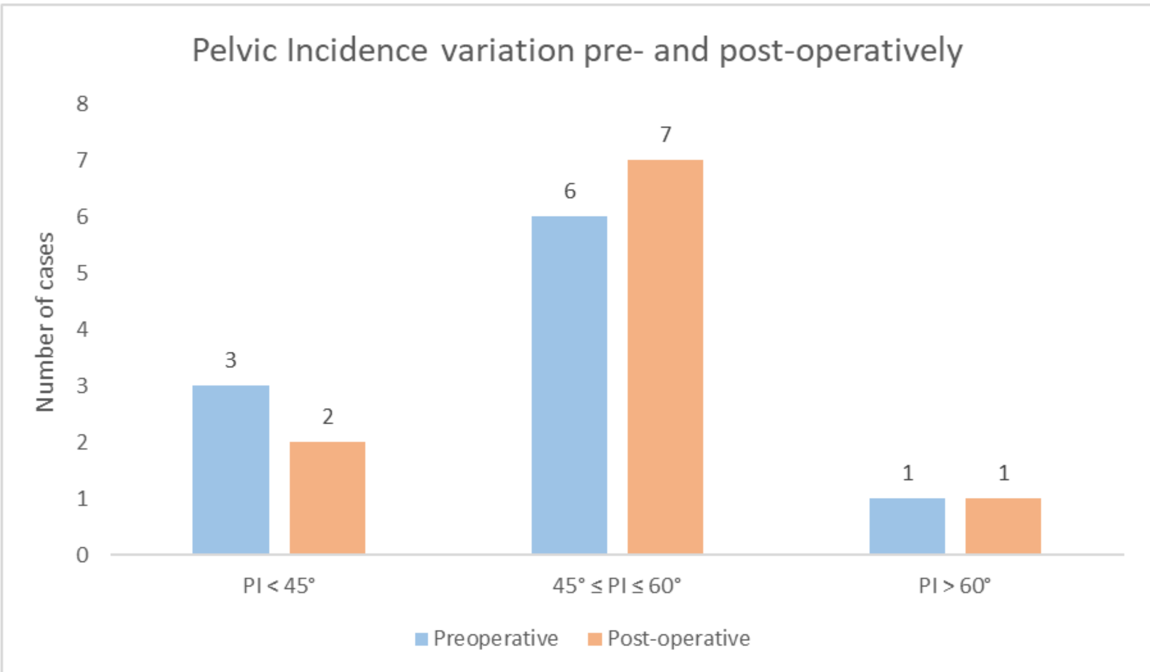


Figure 31: Pelvic Incidence distribution in the studied population before and after surgery.

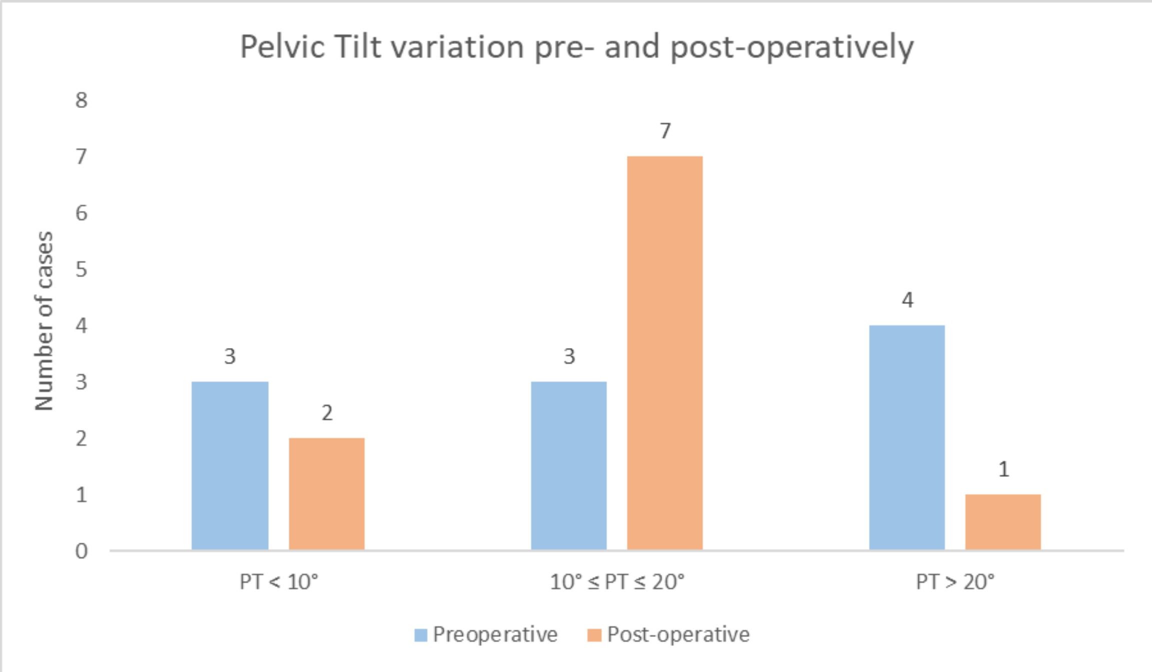


Figure 32: Pelvic Tilt distribution in the studied population before and after surgery.

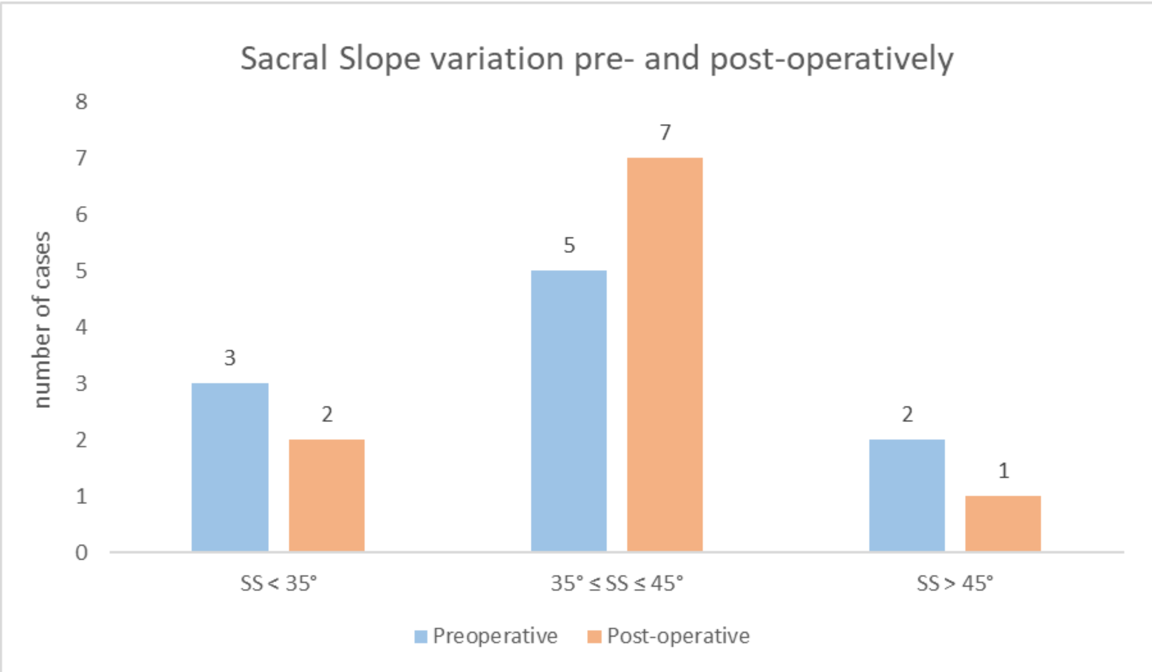


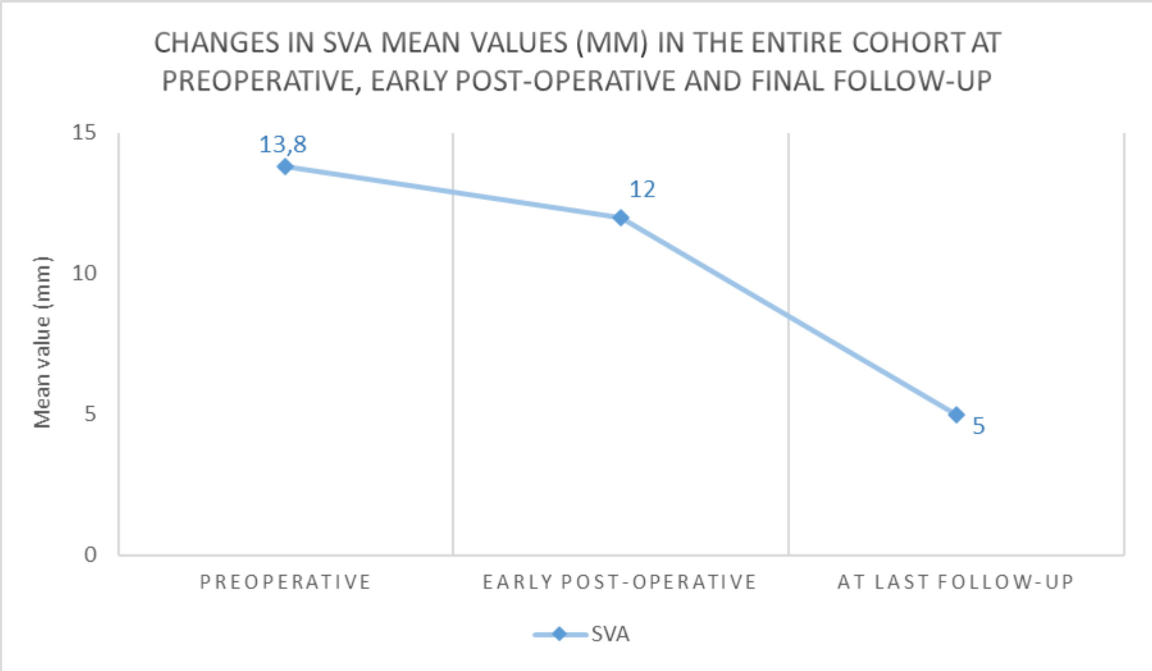
Figure 33: Sacral Slope distribution in the studied population before and after surgery.

1.3. Spinopelvic Alignment

a. Global Sagittal Balance (GSB)

The mean preoperative SVA was 13.8 mm for all patients, and post-operatively, the mean SVA was 12 mm, which did not show any statistical significance (p-value = 0.74). At the final follow-up, mean SVA has been improved and was shifted posteriorly to 5 mm. When compared to baseline measurements, this value was significantly lower (13.8 mm versus 5 mm, p-value = 0.02) (Figure 34).

Following surgery, the majority of patients (8 out of 10) had maintained their preoperative sagittal balance, and one patient showed improvement while sagittal decompensation was developed in only one patient. However, at the final follow-up, sagittal imbalance was normalized to an ideal range in all the patients (Figure 35).



SVA, sagittal vertical axis.

Figure 34: Sagittal vertical axis variation in patients before and after surgery.

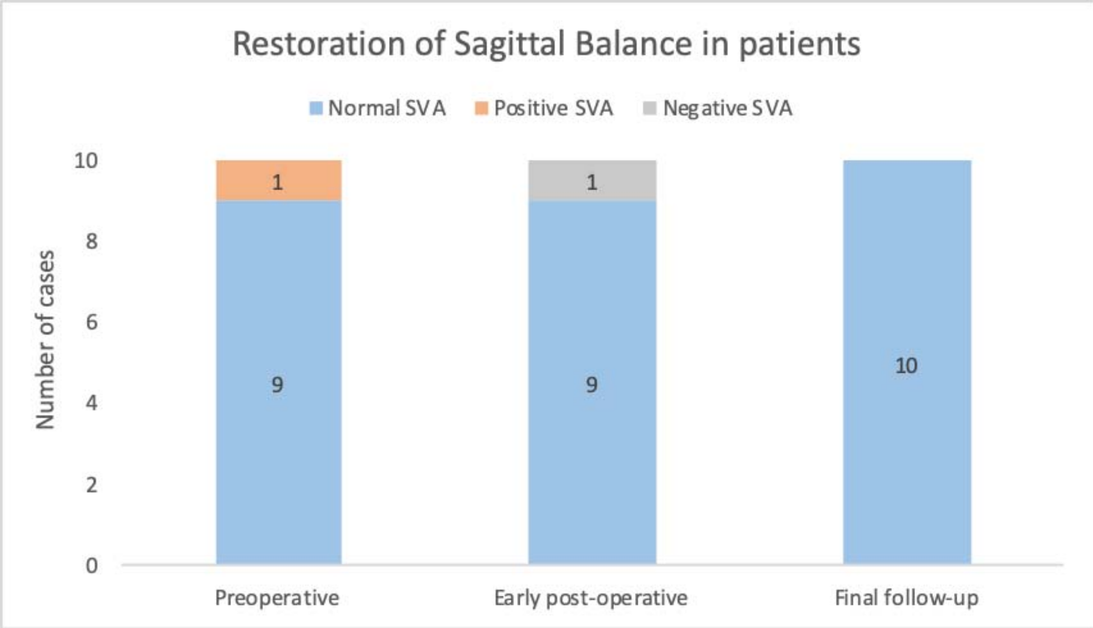


Figure 35: Sagittal Balance restoration of the entire cohort.

When comparing the effectiveness of PS and SB instrumentations in terms of sagittal balance restoration, no significant difference is SVA was found between the two groups at the early post-operative assessment (mean 10.4 mm versus mean 9.3 mm; p = 0.56) and at the final follow-up (mean 4.7 mm versus mean 6 mm; p = 0.72) (Table XV).

Table XV: Comparison of sagittal vertical axis change between pedicle screw (PS) and sublaminar band (SB) patients.

Sagittal vertical axis (SVA)	PS group (n=7)	SB group (n=3)	p-value
Preoperative (mm)	12.8	10.6	0.47
Early post-operative (mm)	10.4	9.3	0.56
Final follow-up (mm)	4.7	6	0.72

Data expressed as mean; Statistical significance at p-value<0.05.

b. PI-LL

In the early post-operative, the mean PI-LL was 6°. Two patients were still presenting mismatch with a lumbar lordosis not correctly correlated to their pelvic incidence (Figure 36).

At the final follow-up, there was a significant improvement in the mean PI-LL, which decreased to 3.2°, and the number of patients with LL in accordance with their PI was significantly higher (90%) (Figure 37).

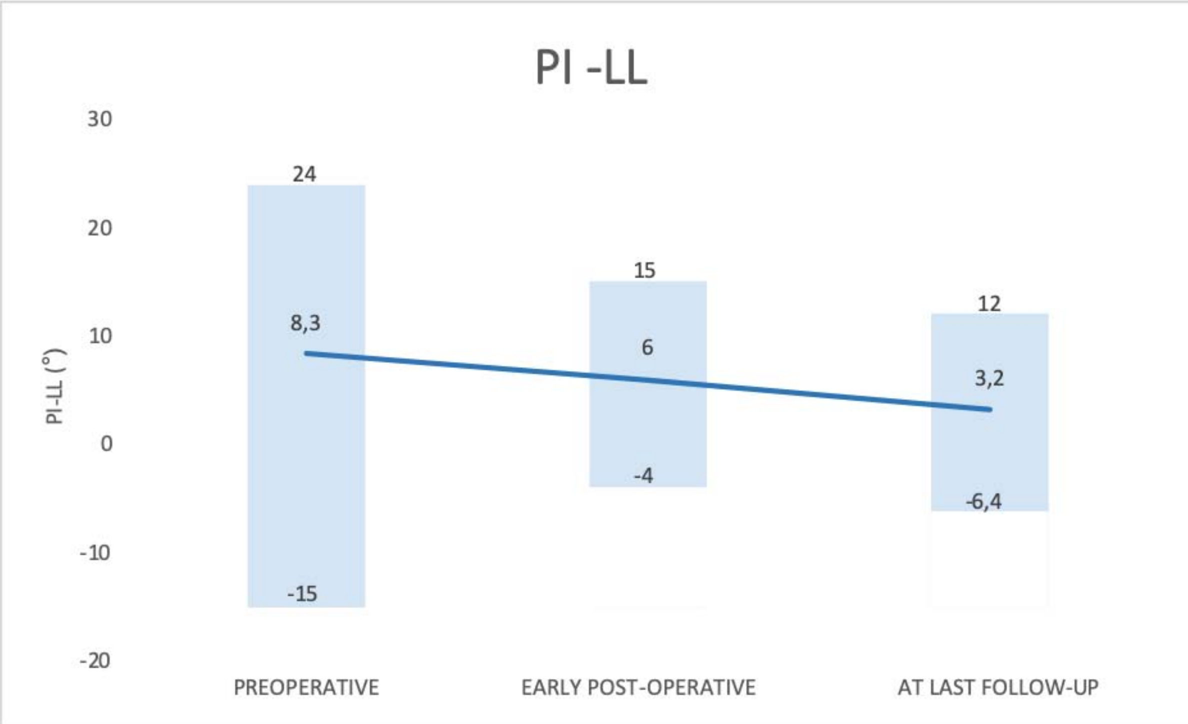


Figure 36: Post-operative improvement of the PI-LL mismatch in studied population.

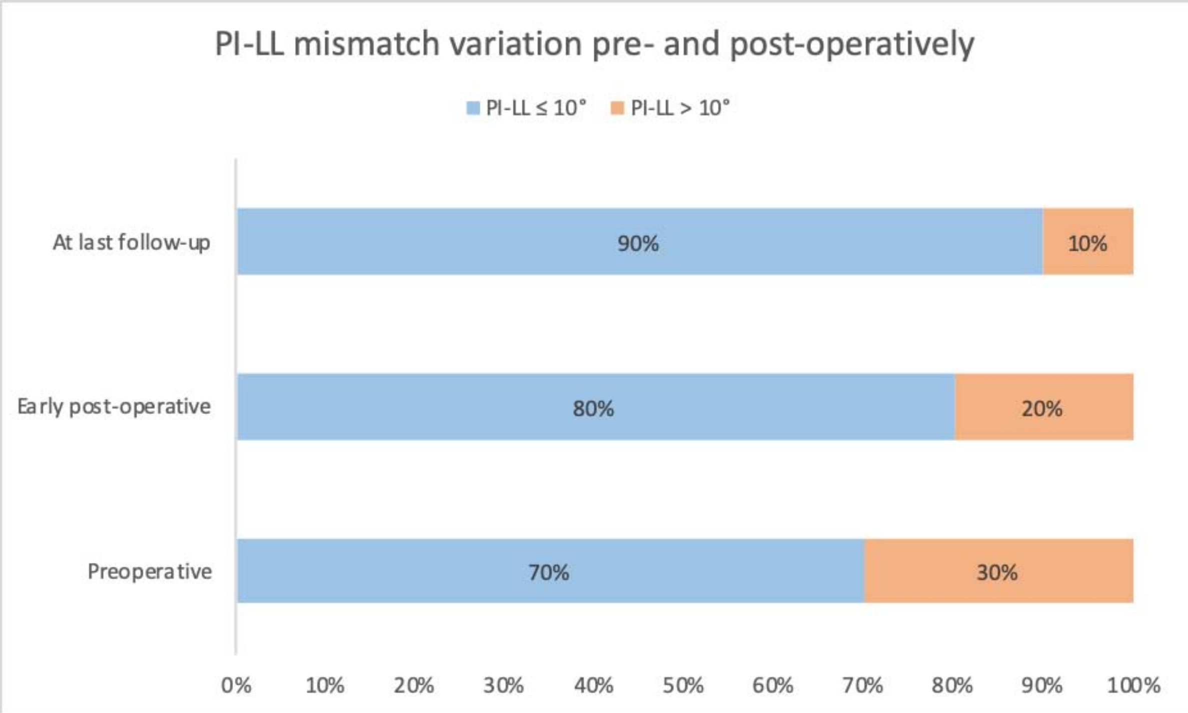


Figure 37: PI-LL mismatch distribution across the entire cohort before and after surgery.

Although PI-LL values were significantly improved at the last follow-up in the PS and SB groups, the results showed no significant differences between the two groups (Table XVI).

Table XVI: Comparison of pelvic incidence minus lumbar lordosis change between pedicle screw (PS) and sublaminar band (SB) patients.

PI – LL (mm)	PS group (n=7)	SB group (n=3)	p-value
Preoperative	8	9.2	0.43
Early post-operative	7.3	8	0.96
Final follow-up	5.4	2.5	0.11

Data expressed as mean; Statistical significance at p-value<0.05.

2. Patient-Reported Outcome Measures (PROM)

After surgery, all patients showed a significant improvement in both the global score and the five domains of the Scoliosis Research Society-22 revised questionnaire (SRS-22r). These improvements were maintained in subsequent evaluations ($p < 0.001$) (Figure 38).

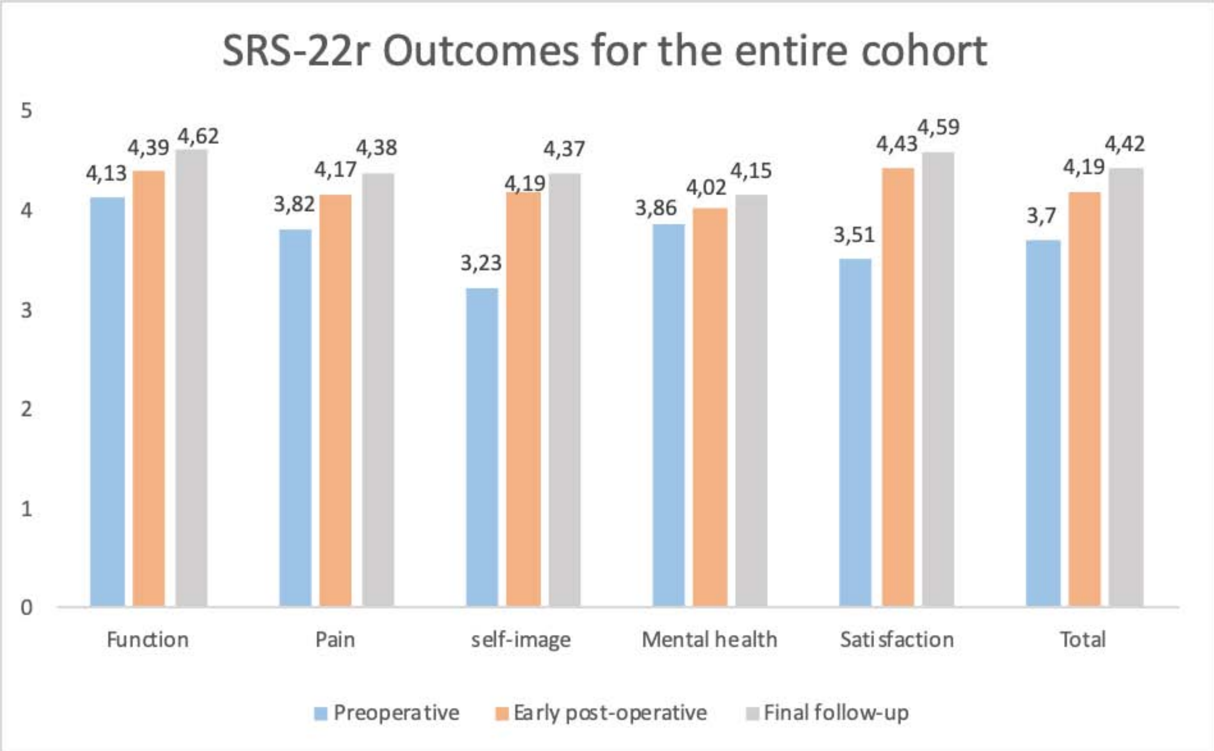


Figure 38: Clinical outcomes of Scoliosis Research Society-22r score after surgery.

The total SRS score, satisfaction, and self-image, exhibited a meaningful dimension from preoperative at all post-operative intervals, becoming more relevant with the most significant variation (Table XVII).

Table XVII: SRS-22 Questionnaire scores before and after surgical correction.

SRS-22 Domains	Preoperative ;mean	Final follow-up ;mean	Mean difference	p-value
Function / activity	4.13	4.62	0.49	<0.01
Pain	3.82	4.38	0.56	<0.01
Self-image	3.23	4.37	1.14	<0.01
Mental health	3.86	4.15	0.29	<0.01
Management satisfaction	3.51	4.59	1.08	<0.01
Total score	3.7	4.42	0.72	<0.01

SRS-22, Scoliosis Research Society. Statistical significance at $p < 0.05$.

The correlation analysis of different subdomains of the SRS-22r questionnaire after surgery revealed the following findings (Table XVIII):

- Function and self-image scores showed a positive correlation with the mental health domain ($r = 0.69$, $p < 0.01$ and $r = 0.54$, $p < 0.01$, respectively).
- Satisfaction with management was highly correlated with self-image ($r = 0.71$, $p = 0.02$) and pain ($r = 0.51$, $p = 0.01$).
- The global SRS-22r score revealed a positive and significant correlation with all subdomains: function ($r = 0.77$, $p = 0.04$), pain ($r = 0.49$, $p = 0.03$), self-image ($r = 0.61$, $p = 0.02$), mental health ($r = 0.52$, $p = 0.05$), and management satisfaction ($r = 0.54$, $p = 0.01$).

Table XVIII: Correlation between different domains of SRS-22 questionnaire after surgical correction.

Parameters	Postoperative SRS-22 questionnaire domains				
	Function/activity	Pain	Self-image	Mental health	Satisfaction
Pain					
r	0.02	-	-	-	-
p-value	0.83	-	-	-	-
Self-image					
r	0.19	-0.05	-	-	-
p-value	0.27	0.75	-	-	-
Mental health					
r	0.69	-0.02	0.54	-	-
p-value	**<0.01**	0.93	**<0.01**	-	-
Satisfaction					
r	0.38	0.51	0.71	0.28	-
p-value	0.07	**0.01**	**0.02**	0.17	-
total score					
r	0.77	0.49	0.61	0.52	0.54
p-value	**0.04**	**0.03**	**0.02**	**0.05**	**0.01**

r: correlation coefficient. Statistical significance at $p<0.05$.

The post-operative Cobb angle showed a significant correlation with the mean total SRS-22r score (p = 0.04). Among the five domains of SRS-22r, self-image/appearance (p = 0.02), and satisfaction with management (p = 0.01), were significantly correlated with residual deformity after posterior spinal surgery. There was no significant correlation between the amount of deformity correction after posterior spinal surgery and the mean total SRS-22r score (p = 0.16). However, self-image/appearance (p = 0.03) and satisfaction with management (p = 0.01) showed significant correlations with the amount of deformity correction (Table XIX).

There were no statistically significant differences in SRS-22r scores (all p-value > 0.45) when comparing patients with and without post-operative complications.

Table XIX: Correlation between the last follow up radiographic measurements and patient-reported outcomes after surgery.

SRS-22r and its domains	Radiographic Parameters								
	post-op Cobb's angle (p-value)	Cobb correction (p-value)	TK (p-value)	LL (p-value)	PI (p-value)	PT (p-value)	SS (p-value)	SVA (p-value)	CVA (p-value)
Total score	**0.04**	0.16	0.29	0.32	0.48	0.37	0.74	0.37	0.26
Function	0.96	0.68	0.59	0.58	0.72	0.59	0.35	0.49	0.33
Pain	0.66	0.45	0.70	0.19	0.38	0.24	0.47	0.35	0.24
Self-image/ appearance	**0.02**	**0.03**	0.57	0.70	0.81	0.59	0.32	0.76	0.93
Mental health	0.07	0.92	0.81	0.92	0.77	0.60	0.81	0.53	0.61
Satisfaction with management	**0.01**	**0.01**	0.35	0.53	0.98	0.52	0.42	0.89	0.75

TK, thoracic kyphosis; LL, lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; Statistical significance at P-value<0.05.

DISCUSSION

Part I: Review

I. The Normal Spine

1. Spinal Alignment

Spinal alignment is the integration of anatomical regions that provide shape, position, form and function between the spine, pelvis and hips (14,15). The ability to maintain a vertical posture in humans is a result of bipedal locomotion that involves simultaneous extension of the vertebral column, pelvis, hips and lower extremities. The vertebral column viewed from the side, is comprised of a number of curvatures, the cranial cervical and caudal lumbar lordotic curves that are separated by the kyphotic thoracic curve (16). These curvatures are intrinsically related and assist with maintenance of spinal sagittal alignment (14,15).

The degrees of curvatures vary between individuals and have been shown to influence the form and function of the pelvis and hip joints (14). Spinal alignment may not be a static entity but rather the result of a dynamic evolution to mechanical loads. Spinal curvatures have also been categorized by morphological and positional measurements that help to determine the pelvic parameters (17).

A well-balanced spino-pelvic-hip complex assists humans to maintain an upright posture, forward gaze and to minimize energy expenditure (8,15,16,18). In order to achieve a well-balanced spino-pelvic sagittal alignment, the pelvic girdle must facilitate the lumbar lordosis curvature with hip joint extension (8,15,16,18-21). Therefore, the pelvic girdle becomes a mobile platform through which the spinal column communicates with the lower extremity.

2. Spinal Column: Anatomy and Structure

The vertebral column (Figure 39) has several curvatures in the sagittal plane, cranial and caudal lordotic curves that are separated by the thoracic kyphotic curve (16). The curvatures must be capable of ensuring two mechanical requirements, rigidity and plasticity (22). Extending from the base of the skull to the pelvis, the column consists of a series of vertebral bodies that increase in size from the cervical to the lumbar region. Seven vertebrae (labelled C1 – C7) are found in the cervical region, compared with twelve vertebrae in the thoracic region (T1 – T12), and five vertebrae in the lumbar region (from L1 – L5). The sacral region has five vertebrae (S1 – S5) and is fused. Intervertebral discs form the anterior pillar of the vertebral column whilst paired facet joints, and a vertebral arch form the posterior pillar and separate the vertebral bodies (23)

The vertebral motion segment (vertebra-disc-vertebra) (Figure 40) or functional spinal unit (FSU) consists of a superior and adjacent inferior vertebra with their intervening disc, facet joints and ligamentous attachments. The intervertebral disc (IVD) is comprised of the central nucleus pulposus (NP), the circumferential annulus fibrosis (AF) and two hyaline cartilage endplates (EP) that connect to the superior and inferior vertebral bodies (24,25). The different tensile properties of the IVD enable it to withstand and transfer heavy spinal loads and to accommodate spinal motion (26). The shape and orientation of the facet joints, largely determines the range and type of movement possible between two vertebrae (23). Moreover, the vertebral column is capable of flexion, extension, lateral flexion and rotation however; movement within the column varies between regions. The anterior pillar has a static role whilst the posterior pillar has a dynamic role. There appears to be a functional link between the anterior and posterior pillars aiding in the absorption of compression from both passive and active stresses. Plasticity of the spinal column is achieved through the multiple components of the anterior and posterior pillars that are interlinked by the complex attachments of ligaments and muscles (22).

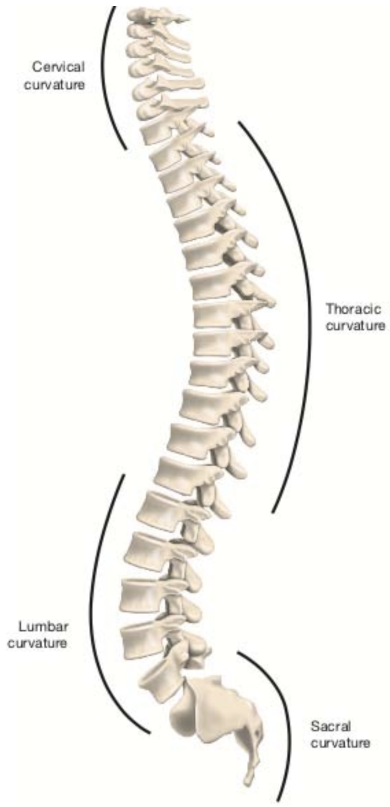


Figure 39: Vertebral column with spinal curvatures.

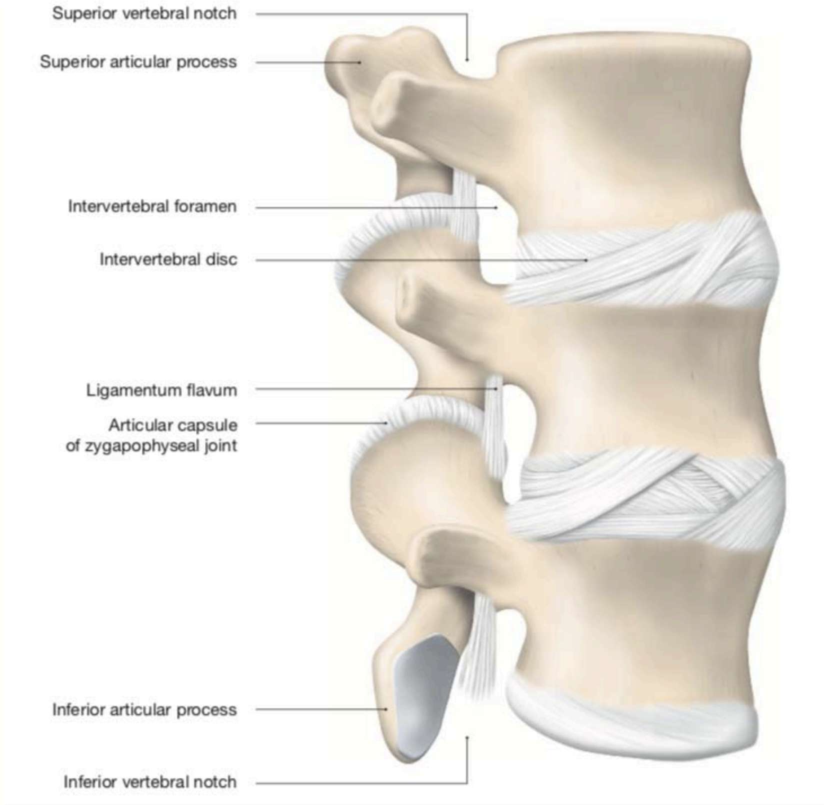


Figure 40: Vertebral motion segment.

3. Development of Spinal Morphology

From embryology, it is known that the normal human spine possesses one primary (thoracic curvature) and two secondary (cervical and lumbar) curves. The thoracic kyphosis (TK) curve is termed primary because it is initially developed while still in an embryo as the secondary curves are not present at birth and develop during infancy (27) ; with normal neuromuscular development, CL develops by 3 months and LL by 1 year. Development of the cervical lordotic curve occurs as a result of an infant beginning to hold the head upright, whilst the lumbar lordosis (LL) curvature develops as a result of an infant being able to sit upright and walk (Figures 41 & 42). Therefore, the ability to maintain a vertical posture and bipedal locomotion in humans involves simultaneous extension of the vertebral column, hips, thighs and legs (20).

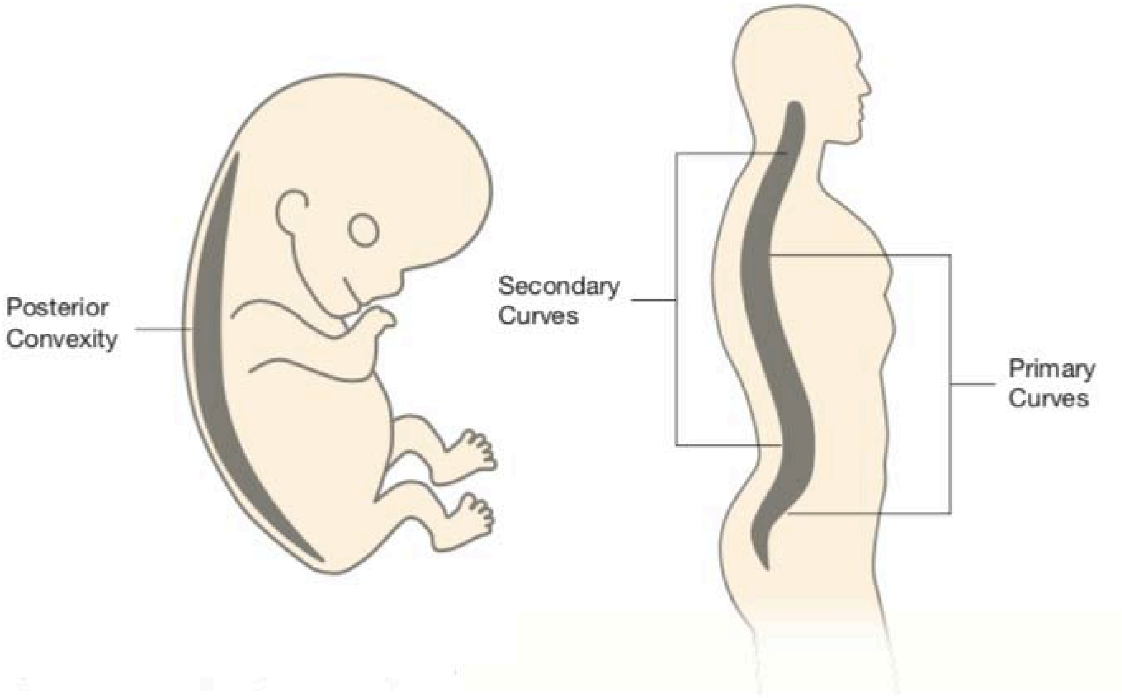


Figure 41: Development of primary and secondary curves.

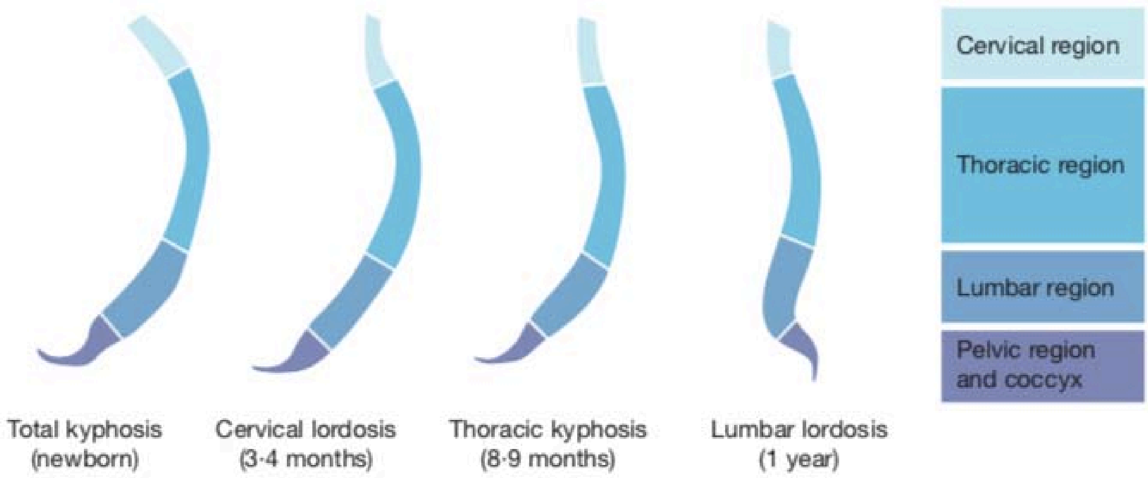


Figure 392: Development of spinal curvatures.

II. Scoliosis

1. Definitions

Scoliosis, a term derived from the Greek word meaning “crooked or curved", was first used regarding spinal deformities by Hippocrates (28,29), and used by one of his successors, Galen of Pergamon to describe an abnormal lateral deviation of the spine causing a curve in the coronal plane of ten degrees or greater as defined by the Scoliosis Research Society (SRS) (30-34). However, the deformity of scoliosis is much more complex affecting the spine in all three planes. In the frontal plane, there are lateral curves with vertebrae deviating from the midline. A relative anterior overgrowth of the vertebral bodies changes the sagittal alignment of the spine, resulting in a hypokyphosis and/or hyper-lordosis (35-37). Each vertebra within the deformity is not just laterally deviated and tilted, it is also rotated in the axial plane. This means that the scoliotic spine is deformed in all three planes.

Scoliosis is categorized regarding the underlying cause of the deformity and can be categorized into three major types: congenital, syndromic, and idiopathic. Congenital scoliosis represents a spinal malformation caused by a distorted formation and segmentation of the vertebrae (38), while syndromic scoliosis is associated with a disorder of the neuromuscular, skeletal, or connective tissue systems (e.g. Neurofibromatosis and Marfan syndrome) or other important medical condition (39). Idiopathic scoliosis, however, as the name implies, has no known cause, but it is most certainly multi-factorial, including genetics, heritage, biomechanical aspects, as well as hormonal factors (40-46). The clinical symptoms of patients with scoliosis are typically characterized by disfigurement of the torso with waist or shoulder asymmetry, rib rotation, and trunk imbalance yet sometimes back pain may be reported (47,48). Although scoliosis mostly manifests as a solitary deformity, further investigations might reveal other significant subclinical signs and exclude possible underlying pathology (49-51).

As scoliosis is a three-dimensional (3D) rotational deformity of the spine and trunk, the coronal and sagittal plane deformities are coupled (52). Thus, variations in the coronal plane may translate into sagittal plane changes (53-55). Due to the complex anatomical structure and movement mode of the human body, the sagittal profile changes in each segment of the spine are different. Mac-Thiong et al. evaluated sagittal alignment in patients with scoliosis and reported that thoracic scoliosis is usually associated with thoracic hypokyphosis, whereas thoracolumbar and lumbar curves most often preserve TK and tend to increase LL, confirming the impact of the curve type on sagittal parameters (56). Thus, the management of spinal pathologies is indissociable from understanding and maintaining or restoring individual sagittal alignment so as to ensure physiological distribution of stresses and limit onset of complications or decompensation in adulthood which negatively affects the quality of life (57-59).

2. Radiographic Evaluation

Despite widespread recognition that scoliosis is a 3D deformity, the evaluation of scoliosis has, historically, been based on frontal and sagittal examinations from standing radiographs using Cobb's angle, the gold standard for assessing the severity of scoliosis (Figure 43) (60). The images are two-dimensional (2D) and provide a good overview of the deformity as well as an opportunity to follow curve progression over time. However, because of the limited information regarding the complexity of the deformation as obtained by 2D images, the need for 3D assessment and diagnostics has been highlighted (61,62) .

Three-dimensional images and reconstructions have been made available through the development of new technologies such as biplanar radiographs (EOS), computed tomography (CT), and magnetic resonance imaging (MRI) (63,64).

Computed Tomography (CT) imaging produces true three dimensional (3D) representations of the spine and can thus better appreciate the vertebral rotation and sagittal deformity as it provides excellent spatial resolution of the bone structures, but for routine application the radiation exposure is too high (Figure 44). However, Recent advances have substantially reduced radiation exposure relative to standard technique which is particularly appealing in the peadiatric population (65). Low-dose biplanar stereoradiography (EOS Imaging) has appeared in the last decade. With the help of 3D reconstructions (Figure 45) , EOS 2D/3D imaging can also obtain relatively accurate information about the axial plane of spinal deformity with minimal vertical distortion (66), low doses of radiation, and no magnification, providing revolutionary novel possibilities in spine surgery (67-69). Nevertheless, if a scoliosis has been identified and 'red flags' such as back pain, signs of neurological abnormalities, or abnormal curve types are present then Magnetic Resonance Imaging (MRI) may be required to assess for any underlying pathology (70-72).

Figure 43: Standard imaging of a patient with scoliosis: 2D AP (frontal) and lateral x-ray views.

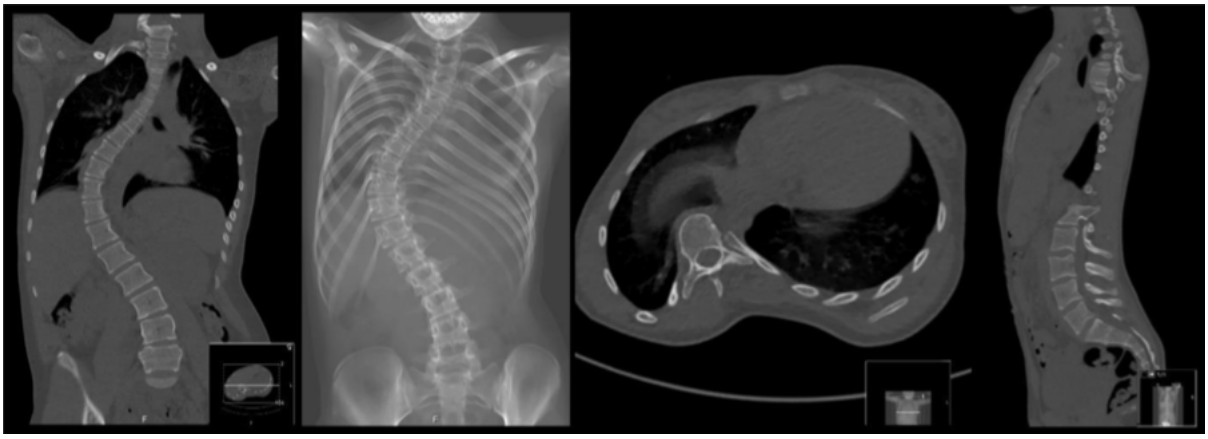


Figure 44: Images from a CT examination for detailed skeletal assessment. Frontal plane (left), 3D reconstruction (middle left), axial plane (middle right) and sagittal plane (right).

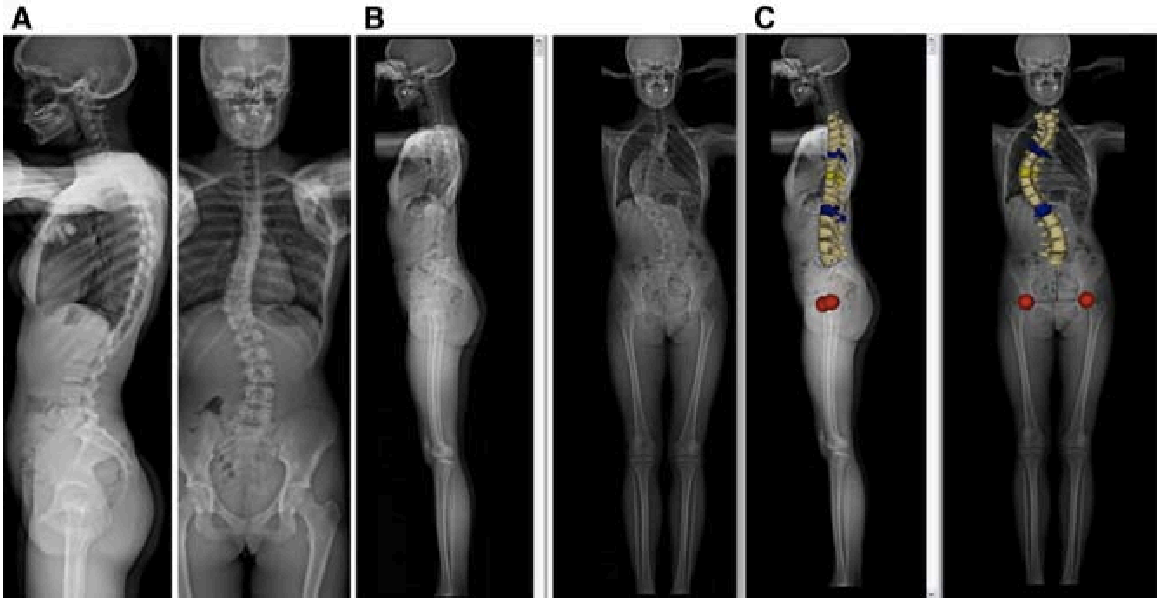


Figure 45: Simultaneous lateral and frontal EOS radiographs. (A) of the spine. (B) of the whole body. (C) 3D bone construction of the spine in frontal and lateral views.

3. Classifications

3.1. Chronological: Time of Onset

Based on the age of onset of the deformity, it can be subdivided into : *infantile (IIS)* (0 – 2 years), *juvenile (JIS)* (3 – 9 years), *adolescent (AIS)* (10 – 18 years) and a*dult* (>18 years) (73,74). This classification is most widely used by clinicians. Today the terms early onset and late onset, with early onset higher end range and late onset lower end range being at the age of 10, are commonly used (75).

Table XX: Chronological classification of AIS.

	Age of onset (years)
Infantile	0-2
Juvenile	3-9
Adolescent	10-18
Adult	18+

3.2. Curve Location:

This is defined on the basis of the location of the apical vertebra and is classified as *cervical* (apex between C2 and C6), *cervicothoracic* (C7-T1), *thoracic* (T2-T11), *thoracolumbar* (T12-L1), *lumbar* (L2-L4), or *lumbosacral* (L5 and below) (76).

Table XXI: Location of apex of the curve.

Curve	Apex
Occipitocervical	Occiput to C2
Cervical Coronal	C2-C3 disc to C6-C7 disc
Cervicothoracic junction	C7-T1
Proximal thoracic	T1-T2 disc to T5 disc
Main thoracic	T5-T6 disc to T11-T12 disc
Thoracolumbar	T12-L1
Lumbar	L1-L2 disc through L4-L5 disc
Lumbosacral	L5-S1

3.3. Angular: Curve Magnitude

The Cobb angle of a scoliotic curve (the angle between the most cranially and caudally tilted vertebrae) is one of the decisive factors in managing scoliosis, and it is directly correlated to all follow-up and treatment decisions (Figure 46) (60,77). Various classifications have been proposed according to these angular measurements. Although none has widespread validity, there is an agreement on some thresholds (33,77-81) :

- Curvature under 10° is considered a normal variation, the diagnosis of scoliosis should not be made.
- Mild scoliosis: Cobb angle in the range of 10 to 20 degrees.
- Moderate scoliosis: Cobb angle ranges from 21 to 35 degrees.
- Moderete to severe scoliosis: Cobb angle measurment of between 36 and 40 degrees.
- Severe scoliosis: Cobb angle in the range of 41 to 50 degrees.
- Severe to very severe scoliosis: Cobb angle ranges from 51 to 55 degrees.
- Very severe scoliosis: Cobb angle greater than 56 degrees.

From these thresholds , and considering the measurement error of this measuring method is approximately 5° when measured manually (82-87), but somewhat less with computer assisted measurement (88), clinical decisions are made (79).

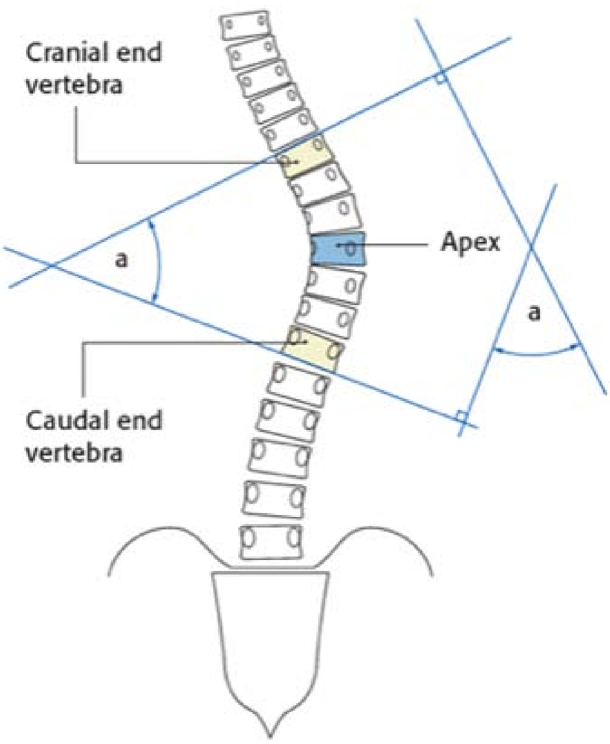


Figure 46: The Cobb angle measurement method.

3.4. Topographic: Curve Type

Most frequently used classifications of scoliosis are based on the anatomical location of the curves in the frontal plane, and is generally used to describe the patient sample and plan a therapy. *Ponseti* (89) was the first to describe scoliosis according to the location of the deformity. According to him, there are four major patterns; thoracic, lumbar, thoraco-lumbar and double (Figure 47). However, this classification system could not capture the true complexity of the deformity with curve type and location alone. Until, *King et al.* (90) developed a classification system in 1983 based on the experience of the surgical treatment, where five types of thoracic curves were defined, and while this classification system was heavily used to guide treatment options for many years, it could not be used to describe scoliosis as a three-dimentional deformity (91) (Figure 48 & Table XXII). With the aim to help predict treatment when planning surgery a new classification system was proposed by *Lenke et al.* in 2001 (92) including six types of curves (numbered 1 through 6), three lumbar modifiers (A, B, or C) that are based on deviation of the apical lumbar vertebra and, for the first time in any classification system for scoliosis, the sagittal profile was also included with three sagittal plane modifiers (-, N, or +) to classify the curve type (93,94) (Figure 49). Since its presentation, it has been endorsed by the SRS and widely used by surgeons to guide the surgical spinal fusion procedures.

Most recently, Abelin-Genevois et al. described a new sagittal classification system complementary to the Lenke classification. This classification describes four specific patterns of the presentation of the sagittal spinal profile on lateral radiographs: normal kyphosis (pattern 1), hypokyphosis (pattern 2a), hypokyphosis in combination with thoracolumbar kyphosis (pattern 2b), cervicothoracic kyphosis (pattern 3) (Figure 50) (95).

Furthermore, Researchers have recently provided simple and clinically oriented three-dimensional morphological (3D) classifications of scoliosis (96-100) However the most useful one in clinical practice, is far from being defined (101).

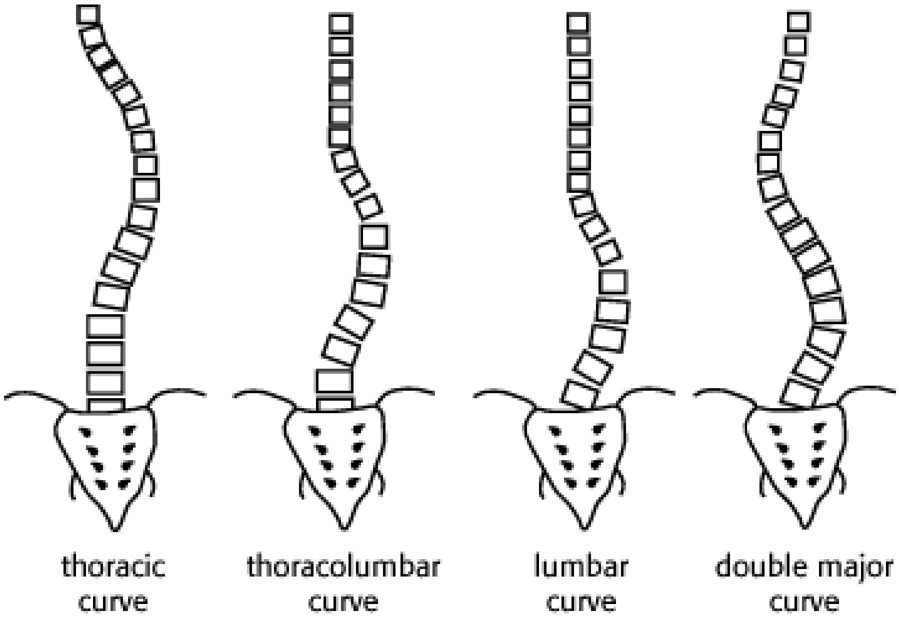


Figure 47: The Ponseti-Friedman classification of scoliosis.

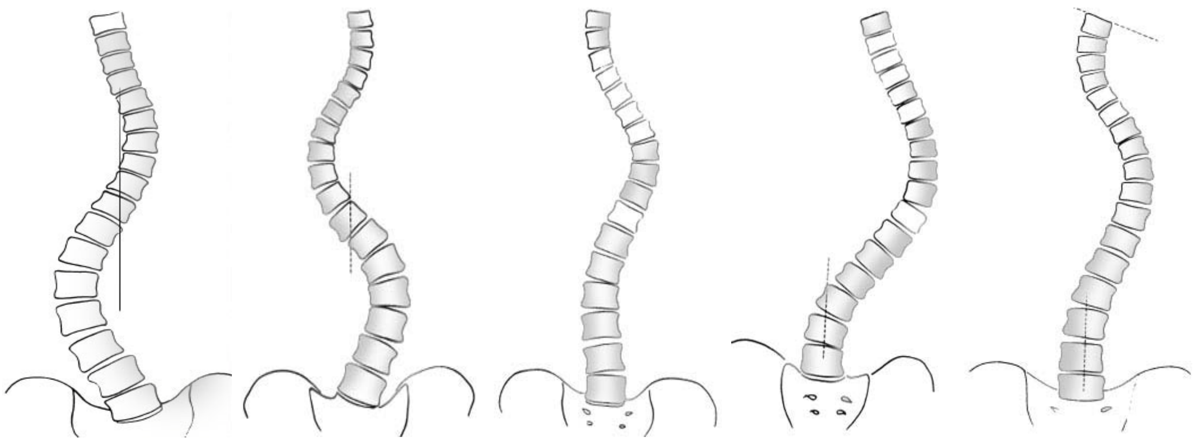


Figure 48: King's classification of scoliosis, based on a single coronal X-ray image. In type 1, one thoracic and one lumbar curve are present, with the latter being larger and less flexible; both curves cross the midline. In type 2, the thoracic curve is equal or larger than the lumbar curve. In type3, there is only a thoracic curve in which the lowest level does not cross the midline. In type 4, a single long thoracolumbar curve starting at L4 is present. Type 5 shows a double thoracic curve; T1 is involved in the upper curve.

Table XXII: King Classification: 5 Sub-Groups According to the Primary Curve and Compensatory Curve.

King Classification			
Type	**Primary Curve**	**Secondary Curve**	**Lateral Bending**
I	Lumbar, crossing the midline	Thoracic, crossing the midline	Lumbar curve is larger
II	Thoracic, crossing the midline	Lumbar, crossing the midline	Thoracic curve is larger
III	Thoracic	Lumbar, not crossing the midline	-
IV	Long Thoracic	Where L5 is centered over the sacrum	-
V	Double Thoracic T1 is tilted to the upper thoracic Curve	-	-

Type	Proximal thoracic	Main thoracic	Thoracolumbar/ lumbar	Curve type
1	Nonstructural	Structural (major*)	Nonstructural	Main thoracic (MT)
2	Structural	Structural (major*)	Nonstructural	Double thoracic (DT)
3	Nonstructural	Structural (major*)	Structural	Double major (DM)
4	Structural	Structural (major*)	Structural	Triple major (TM)
5	Nonstructural	Nonstructural	Structural (major*)	Thoracolumbar/Lumbar (TL/L)
6	Nonstructural	Structural	Structural (major*)	Thoracolumbar/Lumbar-main Thoracic (TL/L–MT)

*Major = largest cobb measurement (always structural)

Structural criteria (Minor curves)

Proximal thoracic	• Side-bending Cobb ≥25° • T2–T5 kyphosis ≥ +20°
Main thoracic	• Side-bending Cobb ≥25° • T12–L2 kyphosis ≥ + 20°
Thoracolumbar/ lumbar	• Side-bending Cobb ≥25° • T12–L2 kyphosis ≥ + 20°

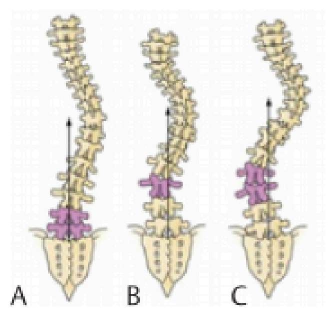
Minor = all other curves with structural criteria applied.

Location of Apex (SRS definition)

Curve	Apex
Thoracic	T2 body–T11/12 disc
thoracolumbar	T12 body–L1 body
lumbar	L1/2 disc–L4 body

Modifiers

Lumbar spine modifier	CSVL to lumbar apex
A	CSVL between Pedicles
B	CSVL touches Apical body(ies)
C	CSVL completely medial



Thoracic sagittal profile (T5–T12)		CSVL to lumbar apex
–	Hypo	<10°
N	Normal	10°–40°
+	Hyper	>40°

Classification: Curve type (1–6) + Lumbar modifier (A, B, C) + Thoracic sagittal modifier (–, N, +) (i.e., 2A+)
SRS = Scoliosis Research Society; CSVL = Center Saeral Vertical Line

Figure 49: Lenke classification system of curve type.

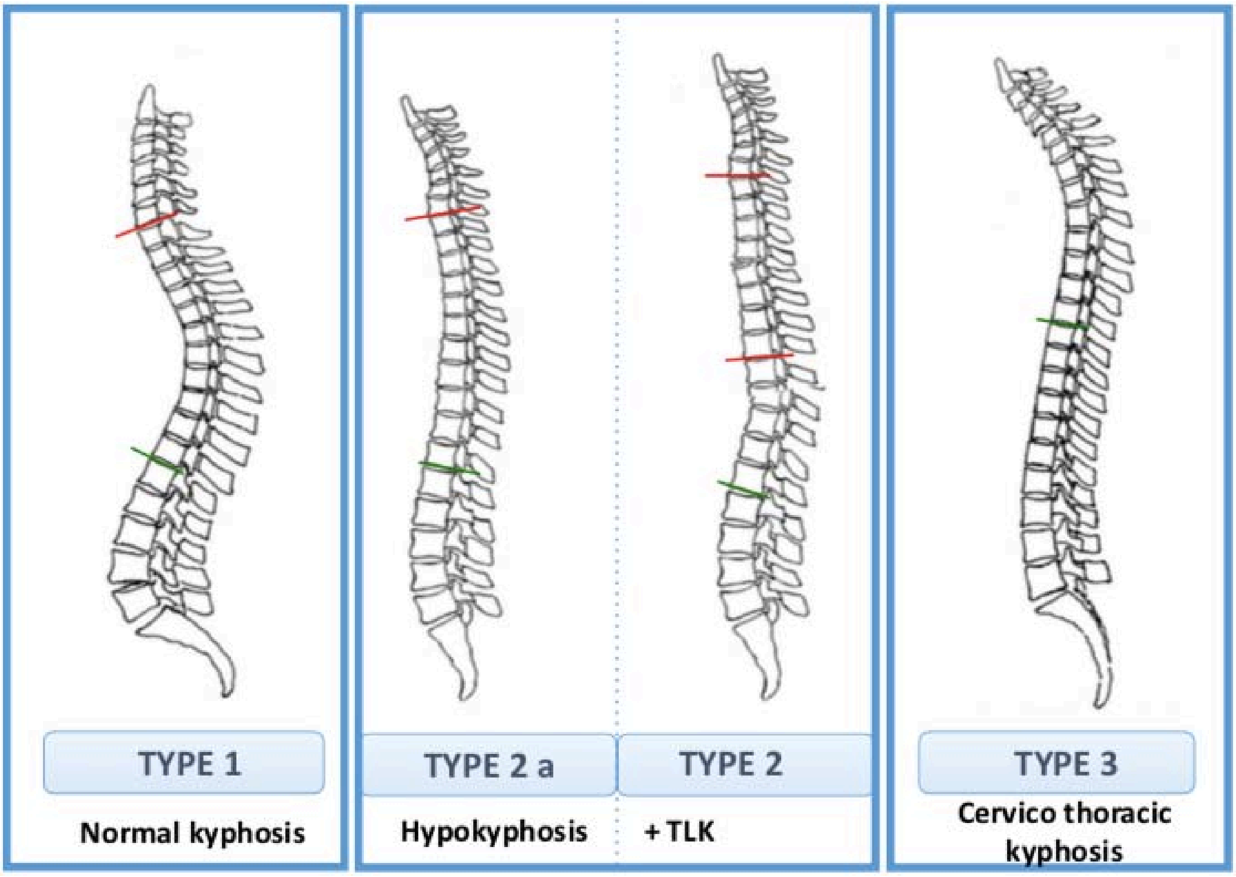


Figure 50: Abelin-Genevois classification.

4. Management of Scoliosis

Scoliosis is a complex three-dimensional deformity that can progress if untreated, causing chronic back pain and significant pulmonary impairment (102-108).

Surgery is typically indicated if the Cobb angle exceeds a threshold of 45°-50° at completion of growth and even more when a risk of progression remains; however, additional factors including age, curve progression, and symptoms such as pulmonary compromise are further indications for operative treatment (33,46,109-111). Although the indications and strategies vary, depending on the age of the patient and the deformity encountered, the ultimate goal of surgical intervention is to maximize deformity correction, retain spinal flexibility, and minimise complications, while achieving global coronal and sagittal spinal balance (112-114). As

40-46% of all AIS patients are hypokyphotic, special attention should be paid to restoring sagittal balance in these patients, with studies supporting that failure to restore thoracic kyphosis (TK) may predispose to proximal or distal junctional kyphosis, as well as late complications predisposing to future decompensation (3,95,115-117).

The current most commonly used surgical techniques aim at achieving a correction of the deformity in all three planes, creating a balanced spine, and maintaining this correction by arthrodesis. To do so, patients can undergo anterior spinal fusion (ASF), posterior spinal fusion (PSF), or a combined anterior and posterior approach. Instrumented correction techniques in scoliosis surgery have been reported with numerous systems, from Harrington's distraction principles to segmental realignment using a variety of techniques including translation with apical sublaminar wires or a rod rotation maneuver with Cotrel-Dubousset instrumentation, segmental approximation by cantilever maneuvers, and direct vertebral body derotation using pedicle screws (118-123).

Posterior instrumentation has proven effective and is the most commonly used method of correction for most patients (124). While a number of implants are available to achieve these goals (125-129), all-pedicle screw instrumentation (Figure 51) is the gold standard as it provides excellent coronal and axial correction with reliable vertebral derotation. However, some authors have raised concerns about the changes in the sagittal plane of the spine, as they allege that derotation has a lordogenic effect on the curves, especially in the thoracic region (130-134), this latter not observed with hybrid instrumentation using sublaminar bands in matched patients (6,135). Moreover, several recent studies have demonstrated that the use of hybrid instrumentation (Figure 52) provides a good correction of the curvature in the frontal plane but also a better restoration of sagittal balance of the spine while being associated with lower risk of complications (136-138).

Although the optimal posterior fusion strategy is still controversial (5,6,139,140), the necessity to restore an overall satisfactory spinal balance in the sagittal plane while correcting the preoperative hypokyphosis, is more widely recognised and appears to be crucial goal in the management of scoliosis, whatever the surgical strategy or implant system applied to obtain a solid arthrodesis (92,130,141-143).

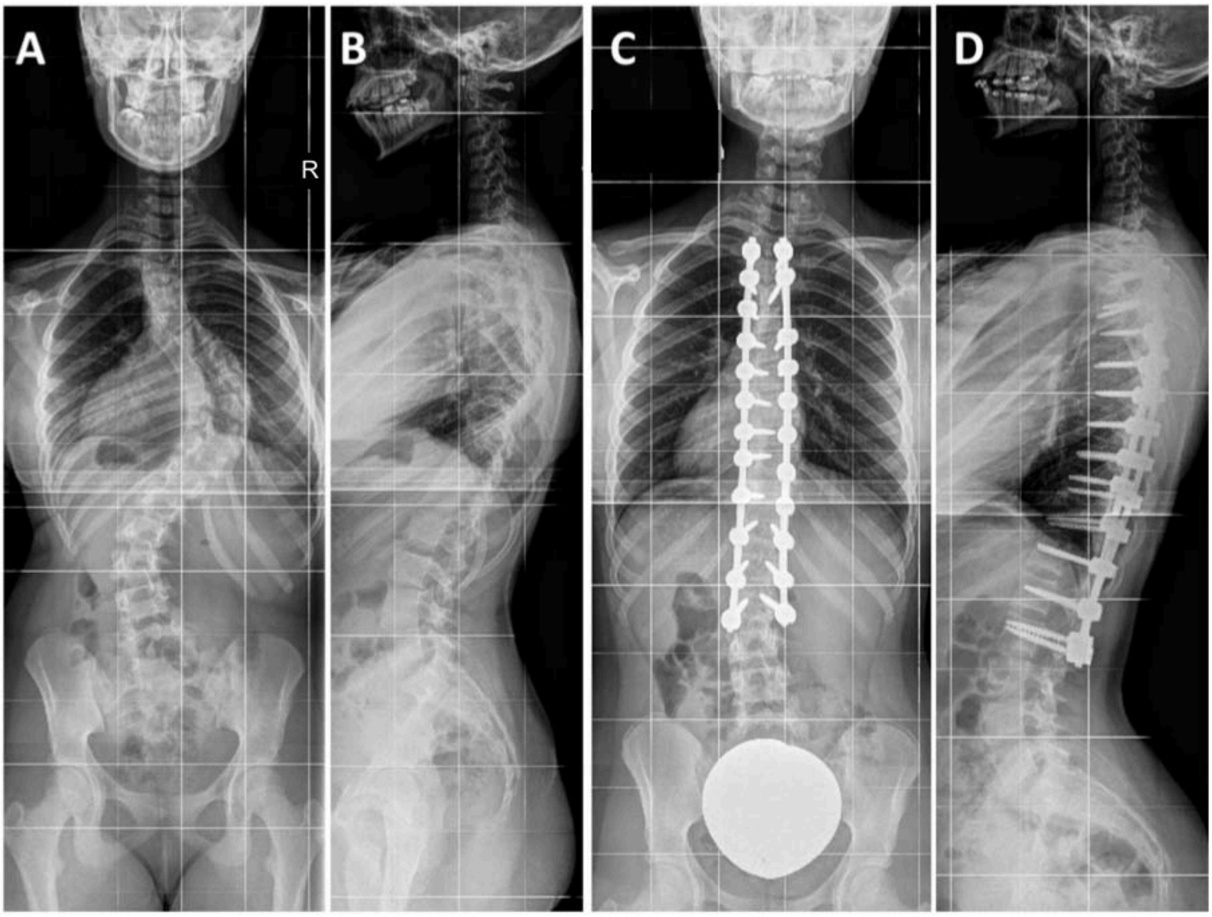


Figure 51: Surgical treatment of scoliosis using all-pedicle screw instrumentation. (A and B) Preoperative posteroanterior (PA) and lateral standing radiographs of a girl with right idiopathic scoliosis Lenke type 2. (C and D) Postoperative standing radiograph of the patient after posterior instrumentation. Satisfactory correction and a well-balanced spine are seen in both the sagittal and coronal planes.

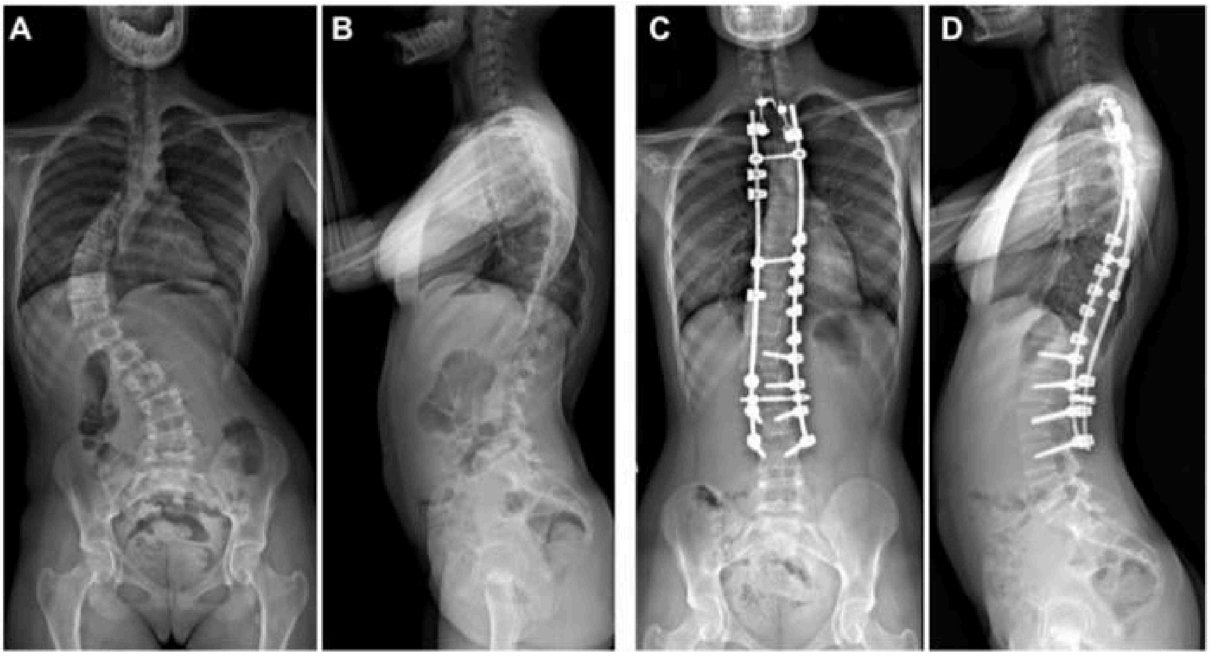


Figure 52: Surgical treatment of scoliosis with posteromedial translation using sublaminar bands. (A and B) Preoperative PA and lateral standing radiographs. (C and D) Postoperative standing radiograph of the patient after posterior instrumentation.

III. Sagittal Balance of the Spine

The spine and the body function within a cone of equilibrium with the focus of maintaining sagittal and coronal alignment with minimum energy expenditure (144). This happens with a harmonious relationship involving cervical lordosis, thoracic kyphosis, lumbar lordosis, and pelvic anatomy. These curvatures work in collaboration with the pelvis to allow equal distribution of forces across the spinal column. It is the disruption of this equilibrium by certain pathological processes or, as in most instances, ageing that results in spinal malalignment. To maintain sagittal balance against changes in the spine, the body reacts through various compensatory changes. Lordosis diminishes as the pelvis tilts backward; conversely, when lordosis increases, the pelvis tilts forward and seeks to maintain balance curvatures in the spine work together to adjust the orientation of the pelvis (Figure 53). However, the compensatory mechanisms may become insufficient (decompensated) and sagittal imbalance may become evident (145). These changes in the spine are evaluated through spinopelvic parameters (146,147).

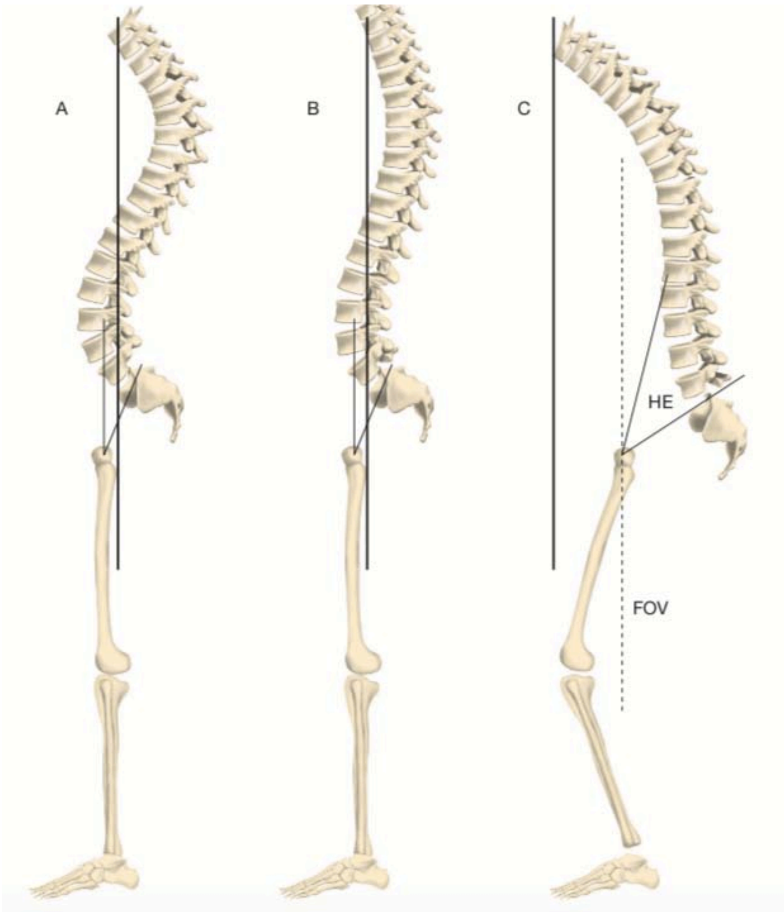


Figure 53: Spinal curvatures compensatory patterns. A. Balanced spine with slight pelvic retroversion and C7 plumb line (C7PL) over the sacral endplate behind femoral heads. B. Reduced lumbar lordosis, pelvic retroversion maintains C7 PL behind femoral heads. C. Thoracic kyphosis, hip extension (HE) limits pelvic retroversion. Compensations occur with knee flexion, as C7 PL passes forward to femoral heads.

1. Pelvic Parameters

Pelvic parameters have been shown to place significant emphasis on maintaining spinal sagittal balance (8,9,20).The anatomical relationship between the spine and the pelvis helps with modulating an erect posture through the pelvic girdle balancing lumbar lordosis with hip joint extension (20). Moreover, it has been suggested that the angle of Pelvic Incidence (PI) is an essential anatomical pelvic parameter that can be used as a means to classify both the morphology and functionality of the pelvis (8,148).

Three pelvic parameters have been defined and compared through pelvic geometry (Figure 54): Pelvic Incidence (PI), Pelvic Tilt (PT), and Sacral Slope (SS). PI is a morphological parameter, constant for each individual, and relates to the angle measured from a perpendicular line to the mid-point of the sacral plate and extended to the center of the femoral head as described by Legaye and Duval-beaupère (8). PT is the angle measured from a perpendicular line starting at the center of the femoral head and extending to the mid-point of the sacral plate and is a positional (functional) parameter. SS is a positional parameter measured from the superior endplate of S1 and a horizontal axis (17,149), and completes the geometric relationship resulting in the equation “PI = PT + SS” (9,150) (Figure 55).

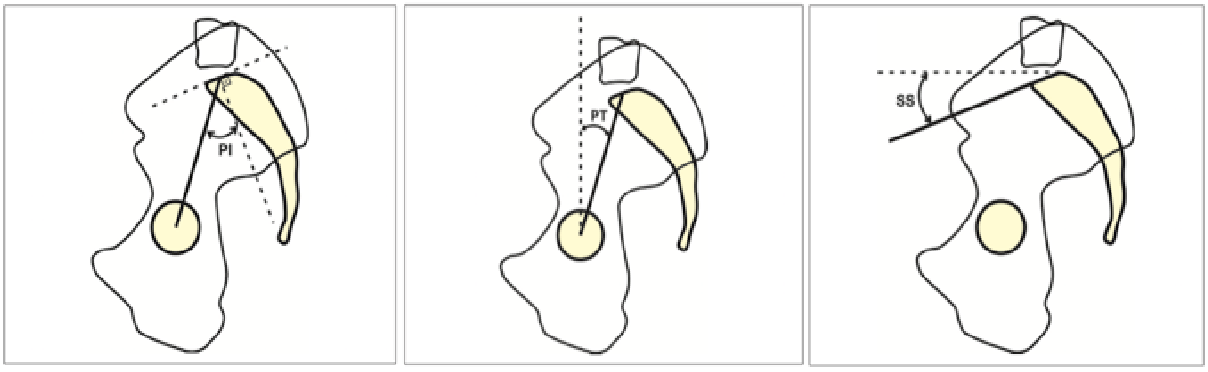


Figure 54: Pelvic parameters. PI, pelvic incidence; PT, pelvic tilt; SS sacral slope.

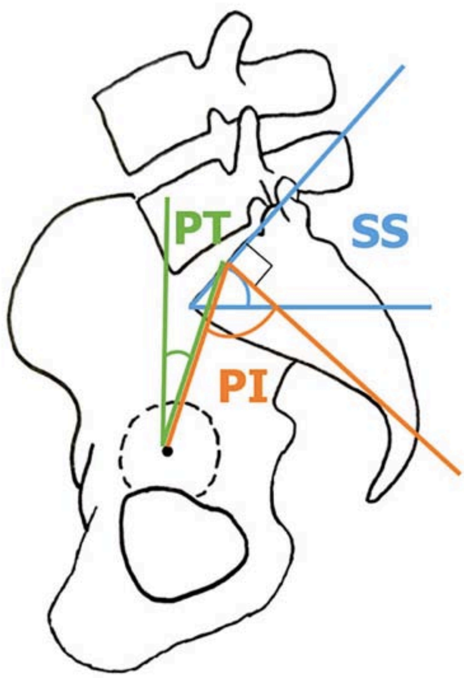


Figure 55: Geometrical construction of the pelvic parameters described by Dubal-Beaupère. PI=PT+SS.

1.1. Pelvic Incidence (PI)

The first pelvic parameter to be considered as the key factor for sagittal spinal balance is pelvic incidence (PI). This angle remains relatively constant during childhood. Thereafter, it increases significantly during adolescence, reaching its maximum value at adulthood (151). Moreover, the PI angle provides information pertaining to pelvic compensation such as an individual's ability to perform pelvic retroversion in relation to the femoral heads (20). The amplitude of retroversion is correlated to the pelvic incidence (PI) value: the greater the PI, the greater the ability for pelvic retroversion (Figure 56) (152,153). This parameter is closely related to lumbar lordosis in normal adolescents and adults (149,154,155). Legaye et al. (9) and Duval-Beaupère et al. (8) postulated that a high pelvic incidence is associated with a high sacral slope and pronounced lumbar lordosis, while a low pelvic incidence is associated with a lower sacral slope and a reduced lumbar lordosis, leading to the basic concept of an "economic standing position" (156).

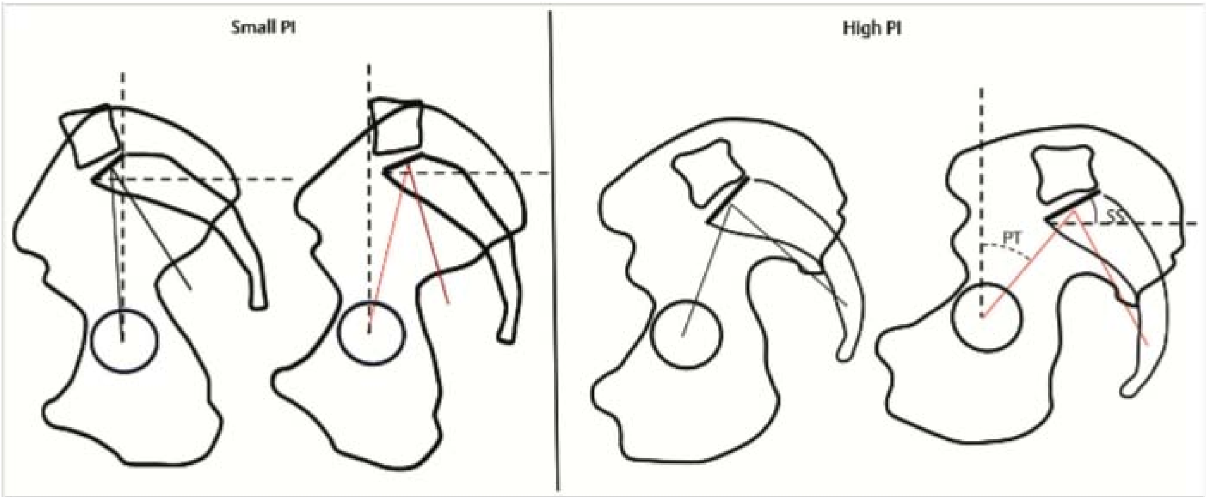


Figure 56: Difference in Pelvic tilt range regarding the value of pelvic incidence (PI). Note that in smaller PI, the sacral plateau is higher over the femoral heads (FH) close to the projection of the iliac crest. With higher PI, the sacrum looks smaller; the sacral plateau is in the lower position compared to the iliac crest level and posterior to FH.

1.2. Pelvic Tilt (PT)

PT indicates the rotational positioning of the pelvis around the femoral heads (FH). The mean value of the PT angle is approximately 12° ranging from 5° to 30° (9,157,158). Moreover, this is a compensatory angle and changes with posture. If the pelvis rotates backward (retroversion), PT increases. If the pelvis rotates forward (anteversion), PT decreases.

1.3. Sacral Slope (SS)

SS is a positional angle and may change throughout life, according to sagittal balance requirements. The mean value for the SS angle is approximately 40° ranging from 20° to 65° (159,160). The orientation of SS directly guides the orientation of L5 and the whole spine above. This parameter is the direct link between the pelvis and the lumbar lordosis (LL). In normal situations, SS is always tilted forward with positive increasing values. In pathological situations, SS may even reach the horizontal line (SS = 0°). Negative SS values, always indicating pathology, are exceptional.

2. Spinal Parameters

Historically, the human spine was divided into a LL, a TK, and a CL. This segmentation first described by Hippocrates, assigned for each anatomical segment of the spine a particular orientation: convex forward from L5-S1 to T12-L1, convex backward from T1 to T12-L1, and convex forward in the cervical spine. This anatomical segmentation remained even when using full length standing radiographs into more modern times (8).

2.1. Thoracic kyphosis

In the thoracic spine, global kyphosis is measured between the upper endplate of T1 and the lower endplate of T12 (20). The theoretical value in asymptomatic subjects is estimated to be equal to 0.75 times the global lumbar lordosis angle: TK (T1-T12) =0.75xLL (L1-S1) (161). However, because of the difficulty in visualizing the upper thoracic vertebrae, the classical measurement of TK has been the angle between T4 and T12 (Figure 57.A) (21).

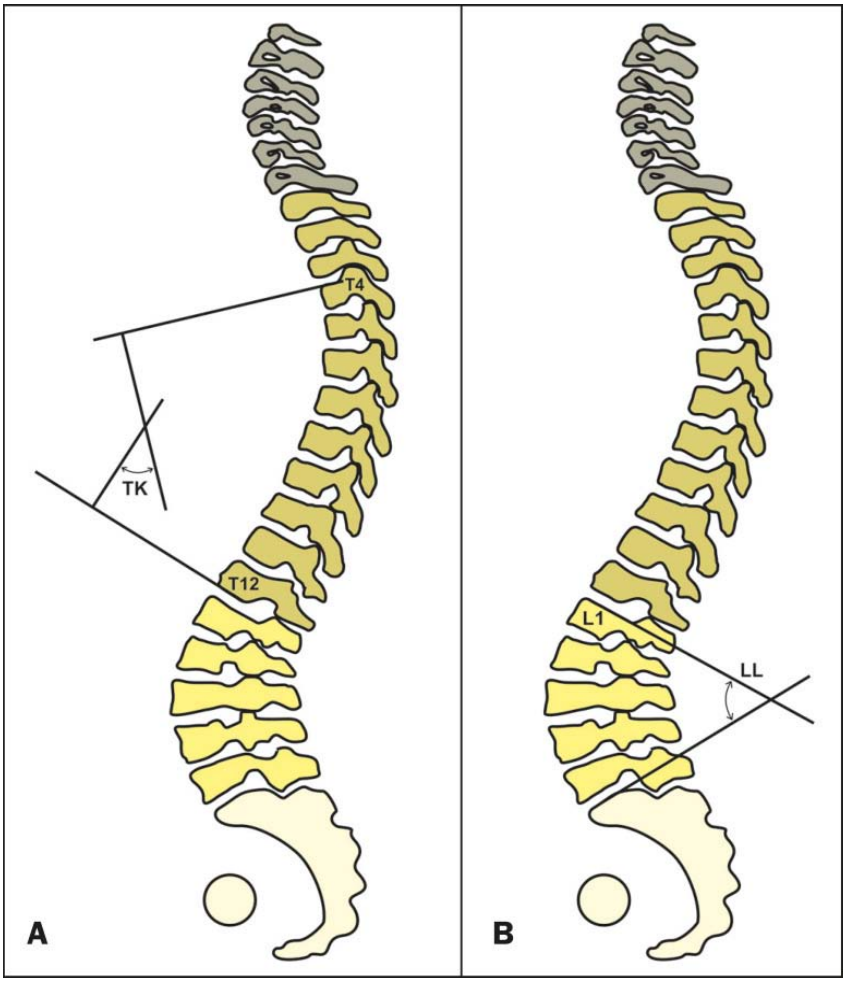


Figure 57: A: Schematic representation of the thoracic kyphosis (TK) angle, which is the measurement of the Cobb angle between the lower endplate of T12 and the upper endplate of T4. B: Schematic representation of the lumbar lordosis (LL) angle, which is the measurement of the Cobb angle between the upper endplate of S1 and the upper endplate of L1.

2.2. Lumbar Lordosis

At first, most authors described LL as the angle between the L1 superior endplate and L5 inferior endplate. Little while ago, there has been consensus to extend LL to the S1 plate as depicted in Figure 57.B. However, because the purely anatomical description of the spinal curves is not sufficient in the treatment of biomechanical pathologies, various proposals for a functional segmentation have been conducted, arguing that it is the orientation of the successive vertebrae that defines the curvatures: lordosis represents the area where the successive vertebrae are in extension and kyphosis in flexion. This concept has brought Berthonnaud et al. (15) to describe a segmentation model of the spine, suggesting the inflection point where lordosis turns into kyphosis, without reference to a specific anatomical landmark (Figure 58). Accordingly, lumbar lordosis is measured between the upper S1 endplate and the inflection point (17). Using this functional segmentation, it is shown that approximately two-thirds of the total lumbar lordosis are located at the ultimate two lumbar levels as previously reported by Jackson (162) and confirmed by Roussouly (163) : L4-S1=0.66×L1-S1.

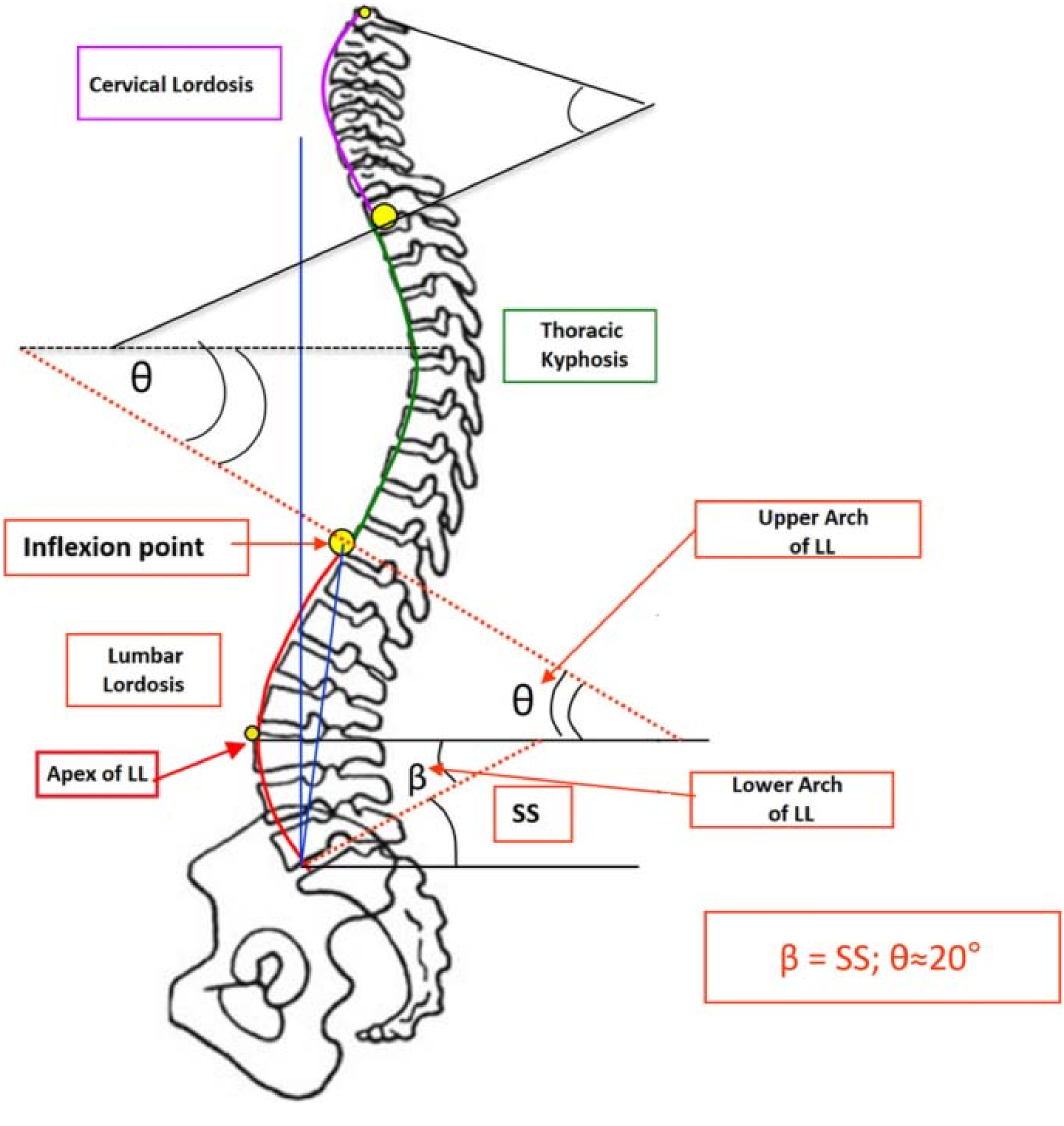


Figure 58: "Geometric" sagittal construction of the spine according to Berthonnaud in upright stance. SS, sacral slope; LL, lumbar lordosis.

There is a close relationship between the pelvic parameters and lumbar lordosis. Roussouly et al. have shown that lordosis varies according to sacral slope and pelvic incidence, and a high statistical correlation ($R=0.86$, $p<00.1$) was found between sacral slope and global lumbar lordosis (164). This indicates that the orientation of the sacral endplate dictates the amount of lumbar lordosis: a flat sacral endplate implies a small angle of lordosis, a more vertical sacral endplate implies a greater angle of lumbar lordosis.

Several predictive formulas for calculating lordosis have been proposed (165,166), but a simplified method of estimation has been more frequently used in the literature and clinical practice: LL=PI+10° was proposed by Schwab et al. in their description of the SRS spinal deformity classification (164,167,168). The concept of pelvic incidence to lumbar lordosis mismatch (PI-LL mismatch) derives from this latter classification system: PI-LL ≥ 10° (167).

3. Global Sagittal Balance:

LL and TK are not the only parameters that are needed to understand the shape of the normal spine in standing posture. Global alignment and balance need to be assessed as well. It is noteworthy to explain the difference between alignment and balance of the spine, because both notions are very often confused in the medical literature.

Both terms refer to full spine radiographs in standing position. Alignment refers to matching of the different spino-pelvic parameters to their normal theoretical values, whereas balance refers to the ability of the patient to adapt adjacent mobile segments' curves to keep the gravity line as close as possible within in the "polygon of support" ("polygone de sustentation" in French, described by Jean Dubousset) (169,170). This ability is called compensatory adaptation. The balance of a patient is the result of an interplay of spinal column architecture, muscular actions and neurological control. The balance can be normal, compensated or decompensated as shown by C. Barrey and other authors (152,153,171).

Various sagittal balance assessment parameters have been described (144) :

3.1. Sagittal Vertical Axis (SVA)

This is the simplest and most frequently used measurement for evaluating global spinal balance (159) (Figure 59). It is the distance between the posterior edge of the sacral plateau and the C7 plumb line projection (172) and is optimum when less than 5 cm (SVA < 5 cm) (162,173). SVA assesses if an individual is in neutral, positive or negative alignment by comparing the head position relative to the sacral promontory (174). Glassman et al. (175) showed that, among 352 patients with positive sagittal alignment, a high sagittal vertical axis correlated with pain and worse scores for health and quality of life.

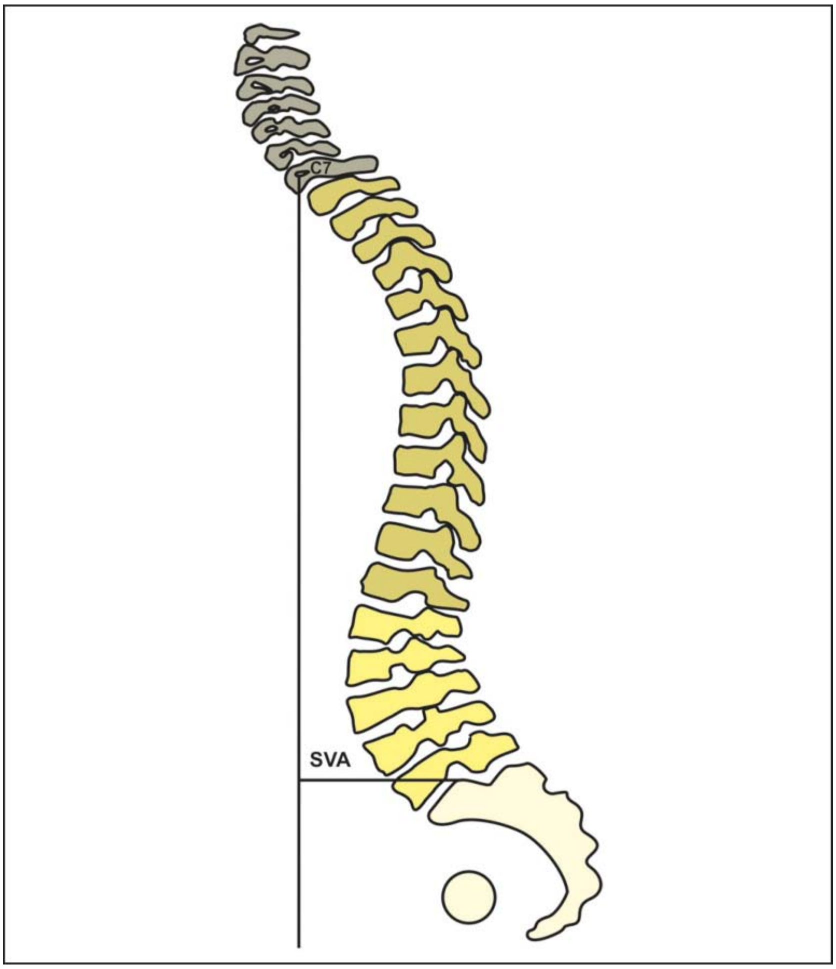


Figure 59: Schematic representation of the sagittal vertical axis (SVA), which is the horizontal distance between the C7 plumb line and the postero-superior corner of S1.

3.2. Pelvic Incidence minus Lumbar Lordosis (PI−LL)

The PI−LL is often used as a descriptive parameter for the spine alignment (148,168). Schwab et al. (176) found that the PI-LL correlated significantly with the pelvic tilt and the sagittal vertical axis. It has been suggested that a–PL be low 10° indicates a malalignment. Because the lumbar lordosis value must adapt to the pelvic morphology (evaluated by the pelvic incidence), a lack of correspondence between the two values would represent a condition in which the patient could not find a spinopelvic organization in accordance with their pelvic anatomy. The PI−LL showed a correlation with questionnaires related to health and quality of life (HQoL), simultaneously proving to be a valuable tool for the intraoperative planning of correction of flatback syndrome, being used as the basis for determining the target correction in surgical treatment of sagittal malalignment (177-179).

4. Spino-pelvic morphotypes and Sagittal Balance of the Spine in Normal Asymptomatic Subjects: The Roussouly Classification (164)

Based on the concept that the morphology and spatial orientation of the pelvis determine the organization of the spine and its curvatures, Roussouly et al. developed a classification of spinopelvic morphotypes translated by four types of lumbar lordosis according to the angle of SS and PI (Figure 60). **Types 1** and **type 2** are characterized by small pelvic incidence angles (<45°) but especially a small sacral slope, less than 35°. **Type 3** is the most commonly found in this study population and is characterized by a pelvic incidence angle of 50° in average, but mainly by a sacral slope angle value between 35° and 45°. Finally, **type 4** is characterized by an average pelvic incidence angle of 55° or more, but mainly a sacral slope greater than 45°.

In terms of statistical distribution, the most frequent type seen in the normal (non degenerative) asymptomatic population is **type 3** (38% of the total population in Roussouly's study), followed by **type 4** (30%), **type 1** (21%) and finally **type 2** (11%) (164). **Type 3** is also considered as the most well balanced spino-pelvic type, meaning that the amplitude of lumbar lordosis and thoracic kyphosis are similar and the inflection point (change from lumbar lordosis to thoracic kyphosis) is located at the thoraco-lumbar junction (T12 or L1). **Type 4** is characterized by a sacral slope of 45° or more, a great lordosis and great thoracic kyphosis, a lumbar apex (most prominent vertebra of the lumbar spine on a lateral x-ray) at L3 or higher.

From a biomechanical point of view, in **type 4** the gravity line runs in the area of the posterior elements. **Type 1** and **type 2** have similar pelvic incidence and sacral slope values, but a different spinal curve distribution: **type 1** is characterized by a long thoracolumbar kyphosis, a very short lumbar lordosis limited to 2 or 3 segments with an inflection point in the lower lumbar area and a lumbar apex at L5; **type 2** on the other hand has a more harmonious curve distribution with small angles of lumbar lordosis and thoracic kyphosis, an inflection point in the thoraco- lumbar area and an apex around L4. In **type 2**, the gravity line runs anteriorly in the lumbar spine (disc level), and in **type 1** it runs posteriorly in the lumbar spine (posterior facet joints) (180).

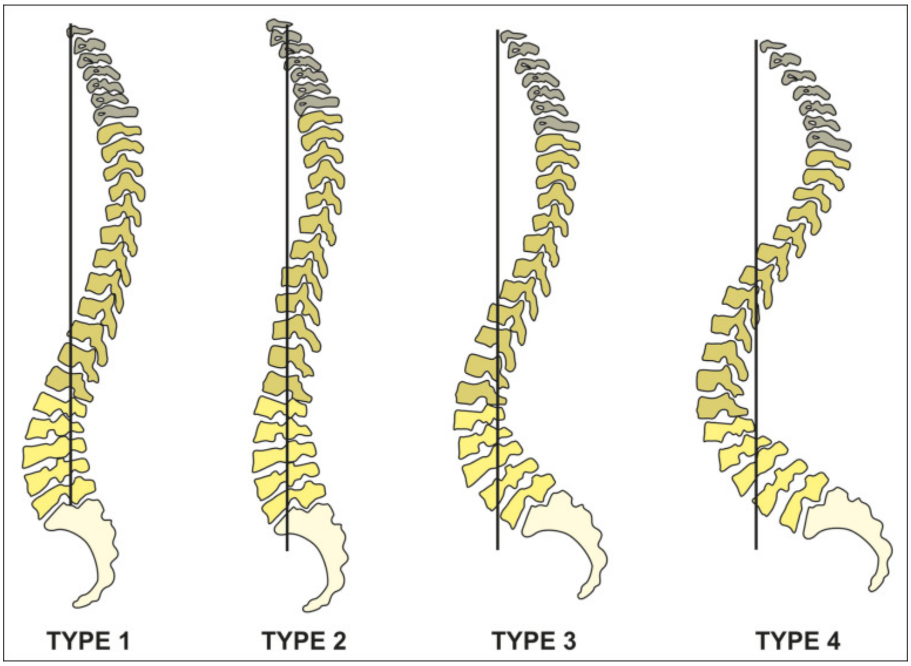


Figure 60: Sagittal classification of back type in healthy subjects according to Roussouly et al.

This classification has been recently updated to include a fifth type added to **type 3** curvature, as depicted in Figure 61, the anteverted **type 3**. This new type is characterized by low-grade PI, SS > 35°, and is associated with anteverted pelvis (181).

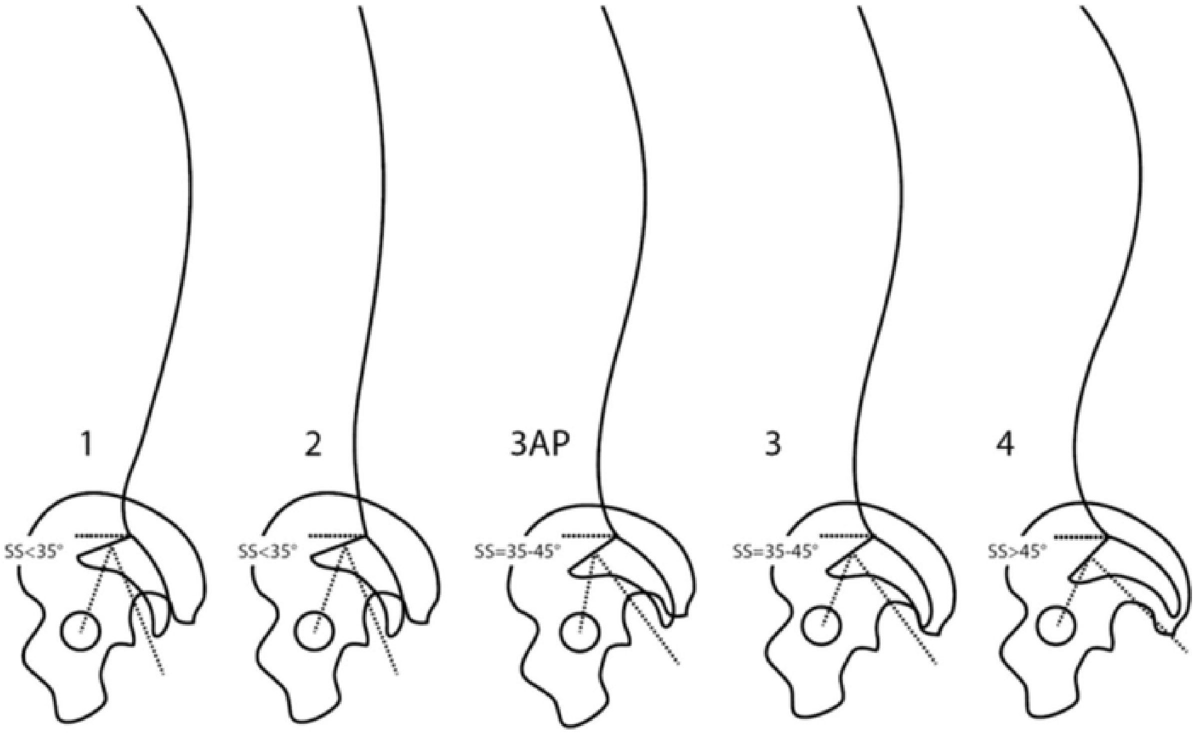


Figure 61: The modified Roussouly classification. Normal human spines could be divided into five different shapes according to sacral slope (SS) and pelvic incidence (PI).

Part II: General Discussion and Conclusions

Proper alignment of the spine and pelvis, including appropriate physiologic sagittal curves, is essential for efficient and painless maintenance of an erect posture and sagittal balance.

Over the past decade, much emphasis has been placed on the importance of sagittal balance of the spine with prolific evidence highlighting the impact of sagittal malalignment on balance and long-term clinical outcomes as if not properly addressed it can lead to poor functional outcome, and progressive degenerative disk disease in adulthood (21,53,168,175,182-185). Thus, several radiographic parameters have been established for an understanding of the sagittal alignment of both the spine and pelvis (168,176,186). Thoracic kyphosis and lumbar lordosis measurements are used to analyze trunk alignment. More recently, with the introduction of the concepts of pelvic incidence (PI), pelvic version (PV), and sacral slope (SS) and their relationship (PI = PT + SS) by Duval Beaupère (8,9), the role of the pelvis has been widely recognized in the assessment of spinal balance and alignment (187).

Previous studies have reported differences in sagittal alignment and spinopelvic parameters between scoliosis patients before spinal surgery and healthy populations. Thus, restoring normal spinopelvic alignment is of crucial importance in the surgical management of spinal deformity (7).

The primary purpose of the current study was to investigate the change in sagittal alignment and spinopelvic parameters following posterior spinal fusion in patients affected by scoliosis from the preoperative state to different time points after arthrodesis to determine whether the sagittal balance was maintained. Additionally, we aimed to assess the impact of surgery on the clinical outcomes and determine whether an improvement of sagittal balance had an alleviated effect on the health-related quality of life (HRQoL) for these patients.

I. Analysis of changes on spinal parameters

1. In the coronal plane

With respect to pre- and postoperative change in coronal alignment in these patients, it was shown that posterior spinal instrumentation and fusion surgery significantly improved all coronal parameters.

The correction rate of the primary and secondary curves in the study cohort at the final follow-up were 67 % (59% - 71.5%) and 60% (55.2% - 63.4%), respectively, which implied success in surgical correction. These results are comparable with the range of correction rates (60% to 70%) as described in literature for similar instrumentation (119,188-192).

Considering coronal imbalance, a shift of the plumb line toward the central sacral vertical line (CSVL) was observed postoperatively with a further slight improvement noted at the final follow-up of 3.3 mm. Importantly, 100% of the patients with preoperative coronal imbalance achieved restoration of coronal balance after surgery. This indicates an improvement in the coronal alignment of the spine over the pelvis. This result is in agreement with those reported in previous studies (193).

2. In the sagittal plane

Preserving or restoring proper sagittal alignment has been demonstrated as essential for achieving good long-term outcomes when performing instrumented fusion surgery to correct spinal deformity (194-197). Due to the relative anterior spinal overgrowth, thoracic alignment is generally characterized as being hypo-kyphotic or even lordotic in many cases of AIS (37,198-200). Mac-Thiong et al. (56) conducted a study comparing spinopelvic sagittal alignment between patients with AIS and normal individuals and found that AIS patients tend to have higher pelvic incidence (PI) and smaller thoracic kyphosis (TK). Thereafter, Upasani et al. (2) reported that the results of their study were similar to those of Mac-Thiong et al. (56).

Consistent with previous published studies, this cohort exhibited lower thoracic kyphosis (TK) values compared to age-matched controls (19° vs 45.8°), while lumbar lordosis (LL) was relatively similar (50° vs 57°) (166). These results are in line with earlier research and provide further evidence supporting the hypothesis that hypo-kyphosis is involved in the development of thoracic AIS (36,201).

A contemporary LL and TK increase during posterior fusion has been reported (202,203). However, recent studies have shown conflicting findings regarding the perioperative changes in thoracic kyphosis (TK) during posterior fusion. Roussouly et al. (184) not only found a prevalence of lower TK values than average but also a significant decrease in TK coupled to a decrease of LL in the normo-kyphotic group after corrective surgery, while TK was improved in the hypo-kyphotic group. Our findings, however, differ with regards to change in the TK and LL after posterior spinal fusion. Post-operatively, Greater mean changes in TK were observed in the hypo-kyphosis group than those in the total cohort group or the normo-kyphotic group. Our study demonstrated the statistically significant decrease in TK and reciprocal decrease in the LL reported by Roussouly et al. (184) was only seen in patients that were hyper-kyphotic at baseline. Hyper-kyphotic patients had a correction of their hyper-kyphosis from 46.5° to 36° whereas patients who were hypo-kyphotic at baseline showed a 87% and 10% increase of their TK and LL, respectively, while the normo-kyphotic ones at baseline did not have any statistically significant changes in these parameters. A few studies have reported results similar to this study (204,205). Although absolute values are different from our results, Dumpa et al. (204) reported that TK was significantly increased (7°-16.7°) in the hypo-kyphosis group and was decreased (48.7° to 25.7°) in the hyper-kyphosis group while TK did not change significantly (24.4° - 23.3°) in the normo-kyphosis group when the posterior approach was used. However, contrary to our findings in which LL significantly increased in the hypo-kyphosis group, Dumpa et al. did not find significant changes in the LL in either groups.

Several research have demonstrated a clear correlation between TK and LL in achieving sagittal alignment (151,206,207). In the present study, the restoration of a normal thoracic kyphosis has resulted in changes on adjacent sagittal curvatures. Immediate postoperative measurements showed no alteration in lumbar lordosis, but a significant increase was observed in the following months. This change had remained consistent at most recent follow-up. These findings are in agreement with those obtained by Blondel et al. (203), who also showed that improvement of lumbar lordosis secondary to thoracic kyphosis correction occurred during the following months. It portrays that lumbar lordosis is a parameter that secondarily adjusts to the new sagittal balance induced by the restoration of the thoracic kyphosis.

At final follow-up, the mean TK and LL were 30.4° and 52.3 degrees, respectively, in the normo-kyphosis group, while the mean TK and LL were 23° and 47.7°, respectively, in the hypo-kyphosis group, showing a persistent statistically significant difference between the 2 groups. This falls within the normal range of TK and LL, and indicates that surgical correction in our patients led to a satisfactory restoration of the sagittal profile.

3. Influence of instrumentation on initial coronal and sagittal radiological correction: Posteromedial translation using sublaminar bands versus rod-derotation with pedicle screws

Many authors have reported excellent frontal and axial correction of scoliosis using all-pedicle screw constructs, but their ability to improve hypokyphosis is less satisfactory (130,133,140,208). Surgeons applying posteromedial translation (PMT) with hybrid constructs have consistently achieved good results in terms of both coronal Cobb angle correction and final kyphosis (6,141,209,210).

Our results suggest that these two techniques had different advantages: while pedicle screw instrumentation results in a better coronal correction and maintenance of correction at final follow-up, sublaminar bands achieve a better restoration of sagittal alignment especially in patients with a preoperative hypokyphosis (+13.2° versus +6.7°). These results are matched in the literature, as many studies have shown that SB instrumentation is effective in restoring TK (136,211-214).

Restoring sagittal spinal balance continues to be one of the most challenging goals of scoliosis surgery. Our findings confirm the ability of hybrid constructs using sublaminar bands to restore a satisfactory thoracic kyphosis for hypokyphotic patients (Figure 62). Overall, the TK angle increased by 13.2°. This effect was not obtained at the expense of a noticeable decrease in coronal curve correction compared to other constructs (60% mean decrease). We ascribe this ability to restore thoracic kyphosis while correcting the coronal deformity to application by the dedicated reduction tool of a posteromedial translation force (215) that pulls the spine backwards to the pre-bend rods (209,216), while eliminating all risk of neurological compromise when inserting the screws into the concavity of the curve. Another advantage of this technique is the limited risk of overcorrection in the coronal plane, given the absence of rod-derotation manoeuvres as described with screw-only constructs (93,217). Ilharreborde et al. (218) reviewed patients with scoliosis treated by hybrid constructs with SB. They were able to restore thoracic kyphosis in 69% of patients; interestingly, 87.5% of patients with lordo-scoliosis showed a significant improvement of thoracic hypokyphosis, bringing values close to normal (16° increase of thoracic kyphosis, on average) (214,218). Similarly, Fletcher et al. (143) have demonstrated that all-pedicle screw constructs were less efficient than hybrid constructs with SB in the restoration of thoracic kyphosis in patients with scoliosis.

From these results, it appears that some guidelines can be proposed. For hypokyphotic patients with a preoperative TK below 20°, it may be better to use hybrid instrumentation with sublaminar bands to allow for proper restoration of the sagittal profile. Consequently, for patients with a preoperative hyperkyphosis, all-pedicle screw instrumentation should be preferred. However, further studies with a larger cohort are needed to confirm these findings.

Figure 62: A 17-year-old girl presented AIS with severe hypokyphosis. Hybrid instrumentation with sublaminar bands allowed correction of the deformity in frontal plane but also the restoration of the thoracic kyphosis. At the last follow-up, the correction in both frontal and sagittal planes is maintained and sagittal alignment is satisfactory.

II. Analysis of changes on sacro-pelvic parameters

Since the introduction of the important effect of pelvic morphology in the regulation of an adequate sagittal balance by Duval-Beaupère et al., many studies investigated the sagittal spinopelvic parameters in adults but little research has been devoted to examining this relationship on patients with AIS. Some authors have focused on the spinal balance in adolescents with scoliosis (56,142), but its relation to the pelvic configuration is poorly defined in the literature. Although, less is known about the distribution of these parameters in adolescent scoliosis, Mac-Thiong et al. (56) evaluated the spinopelvic sagittal alignment in AIS and found lumbar lordosis was strongly related to pelvic configuration. Likewise, Upasani et al. (2) also found that the sagittal contour of the lumbar spine was in strong association with the pelvic positioning. Moreover, compensatory mechanisms will attempt to maintain sagittal balance in the most energy-efficient way, and as such, a sagittal plane malalignment may be compensated by pelvic rotation or modulation of the sagittal profile of the spine.

In the literature, debate continues regarding deviations in the pelvic parameters between patients with scoliosis who underwent posterior instrumentation surgery and those of the healthy population. Although some authors stated no difference between the two populations (219-221), some authors (14,56) found the PI to be higher in patients with AIS compared to the normal population. Baseline values for sagittal alignment found in our study prior to surgery are consistent with previously published age-matched data and confirm that pelvic alignment is disturbed in scoliosis. When compared to measurements in a control cohort of healthy adolescents reported by Mac-Thiong et al. (14), we found higher values in pelvic incidence (52.5° vs. 46.9°), similar values in sacral slope (40° vs. 39.1°) and higher values in pelvic tilt (12.2° vs. 7.7°).

There are explicit data in the literature regarding variances relevant to some spinopelvic parameters in scoliosis patients following surgical management. For instance, Roussouly et al. (184) found no significant difference for PI (53° vs 53.5°) but reported a significant difference for SS (42° vs 41.1°) and PT (11.1° vs 12.7°) pre- and post-operatively. Similarly, La Maida et al. (222) reported a statistically significant increase in PT following spinal surgery, concluding that the increase in mean PT value after surgery to be a type of compensatory mechanism for sagittal balance of the spine. Furthermore, Tanguay et al. (220) obtained a significant relationship between lumbar lordosis (LL) and pelvic parameters in patients with scoliosis following posterior spinal instrumentation and fusion surgery, however they found no statistically significant difference in PT angles preoperatively or post-operatively. In accordance with the research reviewed above (220,222), significant decrease in SS (40° vs 38.3°) with a reciprocal increase in PT (14.5° vs 15.9°) indicating increased retroversion of the pelvis following surgery were found in our study, whereas no significant pre- or post-operative differences for PI (54.5° vs 54.2°). The retroversion of the pelvis post-operatively reflects an adaptation of the pelvis to the new sagittal balance. However, these changes are transitory and at final follow-up, pelvic parameters (SS and PT) returned to baseline. Similar results have been obtained by Pesenti et al. (212).

Considering the pre- and post-operative variances relevant to some sacro-pelvic parameters, the results obtained in our study has shown that arthrodesis did not alter pelvic alignment in the long term. However, it activates temporary series of compensatory mechanisms in the pelvis, the primary goal of which is to maintain the balance of the spine. This we believe that appropriate correction of TK and LL after surgery can improve pelvic morphology.

III. Reciprocal sagittal interactions

The sagittal curvature of the spine and the pelvic balance swing together to maintain a stable posture and horizontal gaze. Restoring an appropriate sagittal profile surgically is not only important to correct the thoracic segment but also has repercussions throughout the spine. In particular, changes in the thoracic spine may impact adjacent lumbar or cervical alignment. The relationship between pelvic parameters and lumbar lordosis, as well as their impact on health-related quality-of-life (HRQoL) measures, has been well established in the adult literature and to some extent in the pediatric population (176,223). However, the link between thoracic profile and lumbar lordosis in the pediatric population has been more variable, with publications both supporting and refuting a relationship (14,56,203,224). Sudo et al. (224) correlated thoracic kyphosis with lumbar lordosis and lordosis with pelvic parameters. Similarly, Newton et al. (134) found a correlation between thoracic kyphosis restoration and lumbar lordosis postoperatively that persisted at 2 years. However, others have not established a relationship between thoracic kyphosis and lumbar lordosis (14,56).

The findings in this study demonstrate that sagittal reciprocal changes occur after posterior fusion when TK is restored. Interestingly, improvement of lumbar lordosis occurred a few months postoperatively, whereas the increase in kyphosis was observed immediately after surgery. This chronological sequence illustrates that lumbar lordosis is a parameter that secondarily adapts to the new sagittal balance induced by the correction of thoracic kyphosis. These results are in line with those of previous studies (203,212). Moreover, LL is significantly better in accordance with the pelvic incidence PI at the final follow-up, which confirms the impact of adjacent curvatures correction on global sagittal alignment.

In the same way, changes have also been noticed on pelvic parameters. Postoperatively, there is a significant increase in PT and a decrease in SS, indicating a temporary retroversion of the pelvis, offsetting the TK increase. This is the consequence of the new postoperative balance. As the SVA remains substantially stable after surgery, the global sagittal balance is still maintained. The initial resistance of the lumbar muscles and ligaments probably forces the patient into pelvic retroversion to keep his balance. Furthermore, during the following months, lumbar lordosis increases with return of pelvic parameters (SS and PT) to baseline. Thus, patients appear to require a period of adjustment to adapt to their new TK (222).

IV. Complications

Reducing long-term sequelae resulting from spinal deformity surgery is a focus of spinal research by identifying risk factors of complications. However, complications arise in 1.5% to 5.7% of cases of corrective surgery for scoliosis. One of the currently most discussed problems is proximal junctional kyphosis (PJK) a common iatrogenic sagittal complication in scoliosis surgery, with a reported overall incidence as high as 46% (225,232) and a revision rate of about 10% (233). The high variability of PJK incidence rates can be partly explained by the use of different definitions and the poor visibility of the upper thoracic spine on lateral radiographs. The etiology of PJK seems to be multifactorial and has not yet been conclusively clarified.

Numerous aspects, including the surgical technique, different types of implants, and stiffness of rod material, preoperative thoracic hyperkyphosis, further parameters related to the sagittal profile, and certain types of scoliosis according to the Lenke classification, have been discussed to date as risk factors in the literature (227,234,235).

No PJK (236) was observed in our cohort with a mean follow-up of 38.5 months. Our results differ from those reported by Kim et al. (237), who found a PJK incidence of 26% after 5 years in a population of 193 patients and 27% after 2 years in a population of 410 patients (227). This difference can be explained by the fact that the majority of patients in our study, presented with preoperative hypokyphosis. Kim et al. (237) reported a lower rate of PJK for patients with hypokyphotic subpopulations: 10% (4 out of 40 patients) and 14% (10 out of 71 patients) (227). Although the small number of patients included in the study may limit our observations of PJK, it is proposed that restoring sufficient postoperative kyphosis and achieving proper global sagittal alignment following surgery decreases the risk to appear a PJK. These findings are supported by a similar study, conducted by Clement et al. (209).

V. Patient-reported outcome measures (PROM) following surgery

Historically, assessment of surgical treatment of scoliosis has always been on the basis of the lateral curvature of the spine and on the percent of curve correction obtained with treatment (238,239). Over the past few years, there has been a growing trend toward assessing scoliosis treatment success by focusing on patient-centered information, in addition to traditional radiographic measurements (240-242). However, consensus is lacking on the correlation between radiological outcomes and HRQoL. The SRS-22r questionnaire has gained acceptance as the most commonly used disease-specific outcome questionnaire for scoliosis patients (243-245). For scoliosis patients in Arabic-speaking population, the Arabic version of the SRS-22r questionnaire was developed and evaluated for reliability and validity using international standards. Results showed that the Arabic version of the SRS-22r is reliable and correlates well with a widely used generic health questionnaire (13,246,247).

Regarding the radiological parameters, it was revealed that surgical correction has elicited a significant decrease in Cobb's angle with significant restoration of sagittal spinal alignment without any significant change in the pelvic parameters reflecting the hopeful outcomes of the spinal surgery. In Mariconda et al.'s study (248), there was also a significant decrease in both thoracic and lumbar Cobb's angles with decrease in rib hump after 1-year follow-up from the surgical performance.

In our study, the mean total SRS-22 score was 4.42 which shows significant improvement in overall quality of life from preopratively to the final follow-up. Throughout the five domains of the questionnaire, the "satisfaction with management'' of patients after the surgical correction was considerably high reflecting the efficiency of the surgical outcomes and that was shown statistically through the present study results. Similar to our findings, Merola et al. (241) reported that the scores of the five domains demonstrated significant improvement after surgery in the follow-up analysis. These findings are consistent with those of Asher et al. (243) and Alsiddiky et al.'s (249) studies.

Hisam et al. (250), carried out a study on 44 patients with AIS and reported that the patients were highly satisfied with their quality of life after surgery as indicated by the mean value of total SRS score of 4.1 and with all domains except for "self-image'' after surgery. Conversely, in the present study regarding the "self-image'' domain, there was a significant increase from 3.23 score preoperatively reaching 4.37 score at the final follow-up, showing the highest increase among all the other domains. This outcome is also in agreement with the results of previous studies, which have found "self-image'' to be the main factor improved by surgical treatment (241,251-254).

There is literature showing a positive correlation between the radiological outcome and HRQoL (255,256) and those that show no correlation (250,257). D'Andrea et al. (238) found little correlation between radiological assessment and the SRS questionnaire scores in adolescents. In the present study, the postoperative Cobb's angle was significantly correlated with the mean total SRS-22r score which shows a significant overall improvement in quality of life despite residual deformity after posterior spinal surgery. Also, "self-image'' and "satisfaction with management'' were significantly correlated with post-operative Cobb's angle as well as the correction rate. Similar to our results, Ghandehari et al. (255) also found that the correction rate can significantly alter the overall score of SRS-30 and that it is positively correlated with patients' "Satisfaction with management''. These findings suggest that better radiological outcomes after posterior spinal surgery provide better self-image/appearance and satisfaction to the patient.

Regarding individual domains of the questionnaire, correlation of each of the domains revealed that "satisfaction with management'' was mainly attributed to improved "self-image'' and absence of "pain''. "Mental health'' had significant positive correlation with "self-image'' and "function''. This is also comparable to Ghandehari et al. (255) who showed that "self-image/appearance'' was positively correlated with "satisfaction''. Thus "self-image'' was found to be the most important factor for better satisfaction and improved mental health after surgery.

The results reported herein show that posterior spinal surgery for scoliosis, can not only provide adequate correction of spinal deformity, but also lead to significant improvements in health-related quality of life (HRQoL), as shown by improvement in all SRS-22r domain scores. Overall, 100% of the patients were satisfied.

VI. Strengths and limitations of the study

Several limitations should be acknowledged. Firstly, this is a single-center retrospective study of prospectively collected data with a small sample size and a relatively short follow-up period. Secondly, the study relies on radiographical outcomes, which are subject to inconsistencies in positioning, technician experience, and measurement reliability.

However, the major strength of this study is the detailed description of the relationship between sagittal balance and pelvic alignment before and after surgery. Moreover, considering the limited number of reports about the evaluation of SRS22r, this study represents a significant contribution in addressing the importance of evaluating the quality of life after surgical intervention to accurately assess our findings precisely.

CONCLUSIONS

Achieving proper alignment of the spine and pelvis is increasingly recognized as critical in the surgical management of spinal deformity. While the focus in the past has been on correction in the coronal plane, there has been a renewed interest in the sagittal alignment and its impact on functional balance and quality of life in scoliosis over the recent decades (258).

In this study, a comprehensive analysis of global sagittal alignment was conducted in patients with scoliosis, before and at different time-points after posterior spinal surgery. Several important findings were highlighted. Firstly, scoliosis patients were able to maintain their coronal and sagittal balance, but their sagittal balance can improve significantly postoperatively. Patients with thoracic hypokyphosis were able compensate for their particularly low kyphosis with a slightly lower lumbar lordosis, which allows them to keep the proper head-to-pelvis alignment. Secondly, spinopelvic parameters changed between the early post-operative and final follow-up. This confirms that sagittal alignment can continue to change for an extended period of time after surgery (259), and that the short-term follow-up radiographs capture the patient while he is still adapting his compensation mechanisms to keep balance after surgery. The third point of note is that the pelvis appeared to play an important role in these compensation strategies for maintaining a balanced spine. Fourthly, posteromedial translation (PMT) using sublaminar bands allows for a significantly better restoration of the sagittal profile, particularly in patients with hypokyphosis. Lastly, the surgery led to significant improvements in health-related quality of life (HRQoL), as shown by improvements in all SRS-22r domain scores of patients from preoperative to the final follow-up.

ABSTRACTS

Abstract

Title: THE ASSESSMENT OF SAGITTAL BALANCE IN SCOLIOSIS SURGERY

Study design: A retrospective correlation and comparative analysis of prospectively collected case series of patients at a single institution was undertaken.

Purpose: This study sought to investigate the impact of posterior arthrodesis on sagittal spinopelvic parameters and evaluate the clinical, radiological and functional outcomes of surgical correction in patients with scoliosis.

Background: Restoring three-dimensional (3D) alignment is critical in correcting patients with scoliosis using posterior spinal fusion (PSF).

Methods: Ten patients with scoliosis who underwent posterior spinal arthrodesis using either all-pedicle screw (PS) instrumentation or hybrid constructs with sublaminar bands (SB) between 2016 and 2022, with a minimum follow-up period of 12 months, were enrolled in the present study. Spinopelvic radiographic parameters were measured on pre- and post-operative full spine radiographs before surgery, early postoperatively, and at most recent follow-up. Clinical records, including demographic data, surgical data, and complications, were reviewed. Functional outcomes were assessed using the Scoliosis Research Society (SRS)-22r questionnaire. Clinical records—including demographic data; operating time; hospitalization time; blood loss; number of segments instrumented, fused, and osteotomized; functional improvement; follow-up duration; and complications—were recorded.

Results: In this study, 50% of the patients had a structural thoracic curve (type Lenke 1 or 2), and 50% had a structural thoracolumbar/lumbar curve (Lenke 3-6). The average correction of the primary curve in the coronal plane was 67%. The mean preoperative coronal balance (CVA) of 9.4 mm was improved to 3.3 mm at the final follow-up. Analysis of the sagittal contours between the preoperative and last follow-up evaluations demonstrated an improvement in thoracic kyphosis (TK) (19° vs. 26.3°), with 75% of hypokyphotic backs corrected to the physiological range. Additionally, there was an improvement in lumbar lordosis (LL) (50° vs. 55.6°), while no changes were observed in pelvic incidence (PI), pelvic tilt (PT), and sacral slope (SS). Sagittal balance showed statistically significant improvement, with the mean sagittal vertical axis (SVA) decreasing from 13.8 mm to 5 mm and the mean pelvic incidence minus lumbar lordosis (PI-LL) mismatch decreasing from 8.3° to 3.2°. All patients with preoperative sagittal imbalance recovered after surgery.

No significant preoperative differences were found between the all-pedicle screw (PS) group and the sublaminar band (SB) group. The restoration of thoracic kyphosis (TK) in hypokyphotic subgroups was significantly better in the sublaminar band group compared to the pedicle screw group (from 12° to 25.2° versus 13.8° to 20.5°). Comparison between the groups showed no significant differences regarding pre- and post-operative LL, SVA, and PI-LL. In the coronal plane, pedicle screws resulted in a significantly better correction than sublaminar bands at the final follow-up. The mean SRS-22r total and domain scores demonstrated significant improvements at the last follow-up ($p < 0.01$). No neurological deficits or proximal junctional kyphosis (PJK) were encountered during the follow-up period.

Conclusions: Posterior spinal fusion in scoliosis patients achieved good correction in the coronal plane and improved overall sagittal spinopelvic balance, which was maintained at the final follow-up. This outcome has been associated with high patient satisfaction and low complication rates. Furthermore, our findings indicate that posteromedial translation using sublaminar bands allows a significantly better restoration of the sagittal profile, particularly in patients with hypokyphosis.

Keywords: Sagittal balance, scoliosis, spinopelvic parameters, posterior spinal fusion, outcome, quality of life, SRS-22r.

RÉSUMÉ

Titre : ANALYSE DE L'ÉQUILIBRE SAGITTAL DANS LA CHIRURGIE DE LA SCOLIOSE.

Type d'étude : Il s'agit d'une étude rétrospective, descriptive, analytique, monocentrique avec recueil prospectif de données.

Objectif : Le but de notre étude était d'évaluer les résultats cliniques, fonctionnels et radiographiques de patients atteints de scoliose ayant bénéficié d'une prise en charge chirurgicale par arthrodèse.

Contexte : La restauration optimale de l'alignement rachidien dans sa tridimensionnalité (3D) est primordiale dans la correction chirurgicale des scolioses par instrumentation postérieure.

Méthode : Ont été inclus dans notre étude 10 patients atteints de scoliose ayant subi une arthrodèse vertébrale postérieure entre 2016 et 2022 avec un recul minimal de 12 mois. 7 patients été opérés en utilisant une instrumentation à vis pédiculaires (groupe vis pédiculaire), 3 patients été opérés en utilisant des montages hybrides avec des bandes sous-lamaires (groupe hybride). Les paramètres pelvi-rachidiens et de l'équilibre global ont été mesurés sur les radiographies de rachis entier face et profil effectués en préopératoire, en postopératoire immédiat et au dernier recul. Pour chaque patient ont été recueillis à partir de dossiers médicaux: les données démographiques, cliniques et évolutives dont les complications. Le questionnaire (SRS)-22r a été utilisé pour l'évaluation des résultats fonctionnels.

Résultats : Sur l'ensemble des 10 cas de notre étude, la courbure était classée Lenke 1-2 chez 50% des patients et était classée Lenke 3-6 chez le reste des patients. La correction coronale moyenne de la courbure principale était de 67%. Une amélioration progressive de l'alignement coronal global (CVA) de 9.4 mm en préopératoire à 3.3 mm au dernier recul avait été rapportée. Dans le plan sagittal, la cyphose thoracique avait été améliorée de façon significative au dernier recul (19° vs. 26.3°) et une normocyphose thoracique avait était restaurée chez 75% des patients présentant une hypocyphose en préopératoire. Au dernier recul, la lordose lombaire avait été augmentée de 50° à 55.6°. Aucune différence significative n'avait été retrouvée pour l'ensemble des paramètres pelviens (incidence pelvienne, version pelvienne, et pente sacrée). Une diminution significative de l'axe vertical sagittal (SVA) était retrouvée (13.8 mm vs. 5 mm) et l'adéquation entre LL et PI était significativement améliorée de 5.1° (8.3° vs. 3.2°). Au dernier recul, tous les patients étaient corrigés sur le plan sagittal et coronal (alignés).

Les deux groupes de patients (groupe vis pédiculaire et groupe hybride) étaient comparables concernant les données radiographiques préopératoires. Au dernier recul, la restauration de la cyphose thoracique dans le sous-groupe des patients hypocyphotiques était significativement plus importante dans le groupe hybride par rapport au groupe vis pédiculaire avec un gain moyen de 13.2° vs. 6.7°. Quant à la LL, SVA, et PI-LL aucune différence significative n'avait été observée entre les 2 groupes. Dans le plan coronal, la correction de la courbure principale au dernier recul était plus importante dans le groupe vis pédiculaire. Le score SRS-22r était significativement amélioré au dernier recul ainsi que l'ensemble de ses sous -score ($p < 0.01$). Aucun phénomène de cyphose jonctionnelle proximale (PJK) ou de complications neurologiques n'ont été retrouvés durant le suivi.

Conclusions : Le traitement chirurgical par arthrodèse postérieure chez les patients scoliotiques semblerait permettre une bonne correction de la déformation dans les deux plans coronal et sagittal, améliorerait la qualité de vie, et entrainerait peu de risques de complications. Ces résultats ont été maintenus au dernier suivi. La correction par translation postéro-médiale, reposant sur l'utilisation de bandes sous-lamaires, a montré un meilleur potentiel de correction dans le plan sagittal sans perte de correction dans le plan coronal.

Mots clés : Équilibre sagittal, scoliose, paramètres pelvi-rachidiens, arthrodèse postérieure, qualité de vie, SRS-22r.

ملخص

عنوان: التوازن السهمي للعمود الفقري في جراحة الجَنَف - الميلان الجانبي للعمود الفقري.

تصميم الدراسة: دراسة وصفية تحليلية بأثر رجعي لمرضى اعوجاج العمود الفقري.

الهدف: يهدف هذا البحث الى دراسة وتقييم النتائج الجراحية، الإشعاعية والوظيفية للمرضى ذوي اعوجاج العمود الفقري بعد التدخل الجراحي عن طريق تثبيت الفقرات.

البيانات الخلفية: يُمكِّن التدخل الجراحي لاعوجاج العمود الفقري (Scoliosis) عن طريق دمج الفقرات (Arthrodesis) من تقويم وتصحيح آمن ومثالي للعمود الفقري في المستويين الأمامي والسهمي وخلل التوتر المحوري.

المرضى والطرق: تم عمل الدراسة لعشرة مرضى يعانون من اعوجاج بالعمود الفقري وتم التدخل الجراحي لهم عن طريق تثبيت الفقرات الصدرية والقطنية باستخدام القضبان والمسامير (PS) من الخلف او باستخدام الشرائط (SB) وذلك في قسم جراحة الدماغ والاعصاب بالمستشفى الجامعي محمد السادس بمراكش من 2016 الى 2022. تم قياس زوايا الانحناء على الصورة الشعاعية الأمامية والخلفية، والجانبية للعمود الفقري بأكمله قبل وبعد الجراحة. تم استخدام استبيان رقم 22 لجمعية ابحاث اعوجاج العمود الفقري (SRS-22r) لتقييم النتائج الوظيفية للمرضى مع متابعة المرضى لمدة لا تقل عن 12 شهرًا من الجراحة.

النتائج: في هذه الدراسة، أظهر 50% من الحالات جنف صدري (نوع Lenke 1-2)، و50% جنف صدري - قطني (نوع Lenke 3-6). وقد حدث تحسن ملحوظ بعد التدخل الجراحي في متوسط القياسات التالي: تصحيح درجة الانحناء ب 67% والتوازن الاكليلي من 9.4 ملم إلى 3.3 ملم وزاوية انحناء الفقرات الصدرية (TK) من 19° الى26,3° و زاوية انحناء الفقرات القطنية (LL) من 50° الى55,6° و التوازن السهمي (SVA) من 13,8 ملم الى 5 ملم في حين لم يكن أي تغيير على مستوى زاوية انحراف الحوض (PI) وزاوية امالة الحوض (PT) وزاوية منحدر الحوض (SS).

قبل الجراحة، لم يُظهر تحليل الخصائص السريرية والإشعاعية للمرضى أي فرق كبير بين المجموعتين، مما سمح لنا بمقارنة فعالية كلاهما. بعد الجراحة، عند المرضى ذوي الجنف البزخي (Hypokyphosis)، حدث تحسن

كبير في متوسط زاويـة انحنـاء الفقرات الصدرية (TK) في مجموعة تثبيت الفقرات باستخدام الشرائط (SB) بالمقارنة مع مجموعة تثبيت الفقرات باستخدام القضبان والمسـامير (PS) (من °12 إلى °25,2 مقابل °13.8 إلـى°20,5). بينما لم تكن أي اختلافات مهمة فيما يتعلق بزاويـة انحنـاء الفقرات القطنيـة (LL) والتوازن السهمي (SVA) بين المجموعتين. على المستوى الأمامي، تصحيح درجة الانحناء كان أفضل عند مرضى مجموعة تثبيت الفقرات باستخدام القضبان والمسـامير. كما حدث تحسـن في جميـع مجـالات الاسـتبيان (SRS-22r) بعـد التدخـل الجراحي عند جميع المرضى. لم يظهر أي من المرضى في أي من المجموعتين اي حالات للعجز العصبي أو مضاعفات (PJK) أثناء المتابعة العلاجية.

الاستنتاج: تمكَّنَ التدخل الجراحي للعمود الفقري الجَنَفي من الحصول على تصحيح العمود الفقري في المستويين، الأمامي والسهمي، ومن استبقائه بعد استخدام تثبيت الفقرات. كما اوضحت الدراسة تحسن ملحوظ في جودة الحياة للمرضى ذوي اعوجاج العمود الفقري بعد التصحيح الجراحي.

الكلمات الرئيسية: التوازن السهمي، الجَنَف، الدمج الفقـري الخلفي، جودة الحياة، استبيان رقم 22 لجمعية ابحاث اعوجاج العمود الفقري .

APPENDICES

APPENDIX 1: PATIENT INFORMATION FORM

I. Identity of The Patient:

- Full Name: __________________________________
- Patient Identification: _________________________
- Date of admission: ____________________________
- Phone number: ______________________________
- Gender: □ M □ F
- Age: _______________________________________
- Profession/ occupation: _______________________

II. Past Medical History:

- Past or current medical conditions: □ NO □ YES _______
- Previous surgeries: □ NO □ YES _______
- Medications and allergies: □ NO □ YES _______

III. Reason for Hospital Admission: _______________

IV. Clinical Data

Clinical Presentation:

- Date of onset of symptoms: __________________________
- Neurologic symptoms: ______________________________
- Back pain and stiffness: □ NO □ YES
- Muscle fatigue from muscle strain and compensated posture:
  □ NO □ YES
- Shortness of breath: □ NO □ YES
- Family history of spinal disorders: □ NO □ YES _______

Physical Examination:

1. Vital signs:

Height: ______ cm Weight: ______ kg Heart rate: ____bpm
Resp. rate: ______ per min Blood pressure: _____ mm Hg

2. **Inspection**:

- Symmetry:
  - Shoulders asymmetry: ☐ Left ☐ Right
  - Trunk shift: ☐ Left ☐ Right
  - Waist fold difference: ☐ Left ☐ Right
  - Pelvic obliquity: ☐ Left ☐ Right
- Limbs:
  - Leg-length discrepancy: ☐ NO ☐ YES
- Café au lait spots: ☐ NO ☐ YES
- Axillary freckling: ☐ NO ☐ YES

3. **Examination of the spine:**

- Spinal alignment / the contour of the spine:
- Adam’s forward bend test:
  - Rib prominence: ☐ Left ☐ Right
  - Lumbar promincence: ☐ Left ☐ Right
- Palpation of the spine and paraspinal muscles:
  - Tenderness: ☐ NO ☐ YES____
  - muscle spasms: ☐ NO ☐ YES____
  - masses: ☐ NO ☐ YES____
  - swelling: ☐ NO ☐ YES____

4. **Neurologic Examination:**

- Motor strength:
- Reflexes:
- Sensory exam:
- Peripheral Nerve Examination:
- Coordination/gait:

V. Radiographic Data

1. **X-rays:** Full spine standing anteroposterior (AP) and lateral views:

- Risser sign:

  ☐ stage 0 ☐ stage 1 ☐ stage 2
  ☐ stage 3 ☐ stage 4 ☐ stage 5

- Lenke type: __________________

- Radiographic parameters:

PREOPERATIVE	
Coronal Cobb angle	Sagittal plane
Proximal thoracic: ______ Main thoracic: _________ Thoracolumbar curve: ____	TK: _________ LL: _________ SS: _________ PT: _________ PI: _________ SVA: ________ PI-LL: ________

2. **CT scan:** ____________________
3. **MRI:** _______________________

VI. Operative Data

- Surgical procedure: ______________
- Surgical time: ___________ min
- Estimated blood loss (EBL): _________ ml
- Fusion levels: ___________
- Length of hospital stay: ________ days
- Complications:
  - Intraoperative: ___________
  - Perioperative: ____________

VII. Surgical Outcomes

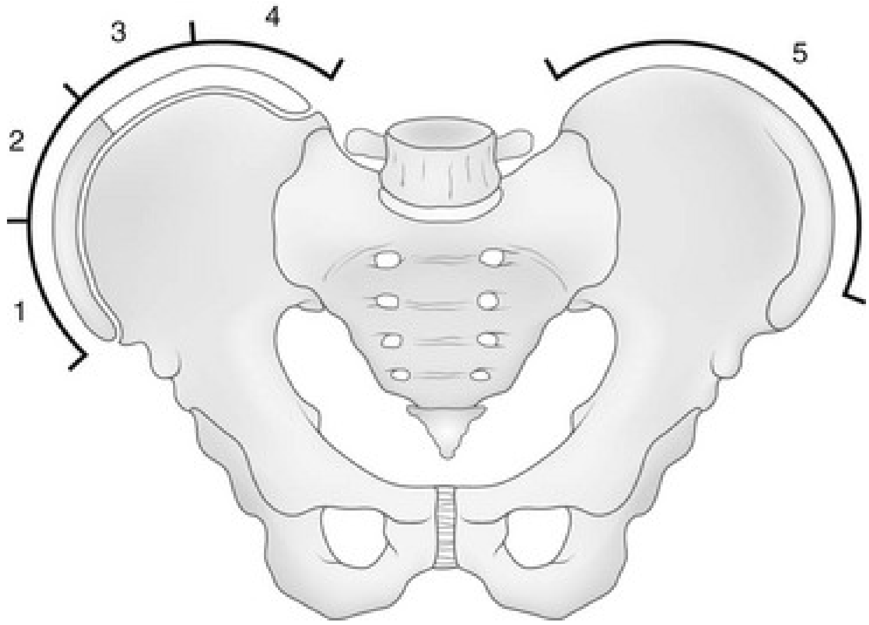
- Radiographic outcomes:

Early post-operative	At final follow-up
Coronal Cobb angle	Coronal Cobb angle
Proximal thoracic: ______	Proximal thoracic: ______
Main thoracic: _________	Main thoracic: _________
Thoracolumbar curve: ____	Thoracolumbar curve: ____
Sagittal plane	Sagittal plane
TK: _________	TK: _________
LL: _________	LL: _________
SS: _________	SS: _________
PT: _________	PT: _________
PI: _________	PI: _________
SVA: ________	SVA: ________
PI-LL: ________	PI-LL: ________

- Post-operative complications: ______
- Functional outcomes: _______________

APPENDIX 2 : RISSER GRAGING SYSTEM

- Stage 0 : Bonny iliac apophysis not yet visible on radiographs.
- Stage 1 : Initial < 25% ossification of the iliac apophysis.
- Stage 2 : From 25% to 50% of the ossification of the iliac apophysis.
- Stage 3 : From 50% to 75% ossification of the iliac apophysis.
- Stage 4 : More than 75% ossification of the iliac apophysis.
- Stage 5 : Iliac apophysis is 1005 ossified and fuses to the iliac crest.



APPENDIX 3 : SCOLIOSIS RESEARCH SOCIETY (SRS)-22r PATIENT QUESTIONNAIRE

Patient Name: _______________
Today's Date: ________________
Medical Record #: _______________
Date of Birth: _____/ ______/_______ (DD/MM/YYYY)
Age: ___________________

INSTRUCTIONS: We are carefully evaluating the condition of your back and it is **IMPORTANT THAT YOU ANSWER EACH OF THESE QUESTIONS YOURSELF.** Please **CIRCLE THE ONE BEST ANSWER TO EACH QUESTION.**

1. Which one of the following best describes the amount of pain you have experiencedduring the past 6 months?
   None
   Mild
   Moderate
   Moderate to severe
   Severe

2. Which one of the following best describes the amount of pain you have experienced overthe last month?
   None
   Mild
   Moderate
   Moderate to severe
   Severe

3. During the past 6 months have you been a very nervous person?
   None of the time
   A little of the time
   Some of the time
   Most of the time
   All of the time

4. If you had to spend the rest of your life with your back shape as it is right now, how would you feel about it?
   Very happy
   Somewhat happy

Neither happy nor unhappy
Somewhat unhappy
Very unhappy

5. What is your current level of activity?
    Bedridden
    Primarily no activity
    Light labor and light sports
    Moderate labor and moderate sports
    Full activities without restriction

6. How do you look in clothes?
    Very good
    Good
    Fair
    Bad
    Very bad

7. In the past 6 months have you felt so down in the dumps that nothing could cheer you up?
    Very often
    Often
    Sometimes
    Rarely
    Never

8. Do you experience back pain when at rest?
    Very often
    Often
    Sometimes
    Rarely
    Never

9. What is your current level of work/school activity?
    100% normal
    75% normal
    50% normal
    25% normal
    0% normal

10. Which of the following best describes the appearance of your trunk; defined as the humanbody except for the head and extremities?
    Very good
    Good
    Fair
    Poor
    Very Poor

11. Which one of the following best describes your pain medication use for back pain?
    None
    Non-narcotics weekly or less (e.g., aspirin, Tylenol, Ibuprofen)
    Non-narcotics daily
    Narcotics weekly or less (e.g. Tylenol III, Lorcet, Percocet)
    Narcotics daily

12. Does your back limit your ability to do things around the house?
    Never
    Rarely
    Sometimes
    Often
    Very
    Often

13. Have you felt calm and peaceful during the past 6 months?
    All of the time
    Most of the time
    Some of the time
    A little of the time
    None of the time

14. Do you feel that your back condition affects your personal relationships?
    None
    Slightly
    Mildly
    Moderately
    Severely

15. Are you and/or your family experiencing financial difficulties because of your back?
    Severely
    Moderately

Mildly
Slightly
None

16. In the past 6 months have you felt down hearted and blue?
    Never
    Rarely
    Sometimes
    Often
    Very often

17. In the last 3 months have you taken any days off of work, including household work, or schoolbecause of back pain?
    O days
    1 day
    2 days
    3 days
    4 or more days

18. Does your back condition limit your going out with friends/family?
    Never
    Rarely
    Sometimes
    Often
    Very often

19. Do you feel attractive with your current back condition?
    Yes, very
    Yes, somewhat
    Neither attractive nor unattractive
    No, not very much
    No, not at all

20. Have you been a happy person during the past 6 months?
    None of the time
    A little of the time
    Some of the time
    Most of the time
    All of the time

21. Are you satisfied with the results of your back management?
    - Very satisfied
    - Satisfied
    - Neither satisfied nor unsatisfied
    - Unsatisfied
    - Very unsatisfied

22. Would you have the same management again if you had the same condition?
    - Definitely yes
    - Probably yes
    - Not sure
    - Probably not
    - Definitely not

Thank you for completing this questionnaire. Please comment if you wish.

END

THE ARABIC VERSION OF SRS-22r

استبيان مريض الميلان الجانبي في العمود الفقري /ال َجنَف:
إصدار رقم 22 **المعّدل في 11/12 /03**

اسم المريض/ المريضة: ________________ **العمر:** __________
التاريخ: ______________
السجل الطبي#: ____________
الفحص: ما قبل العلاج 3 أشهر 6 أشهر سنة ____سنة

يقوم أطبائك بتقييم دقيق لحالة ظَّهرك قبل وبعد العلاج. الرجاء إختيار الجواب الأفضل لكل سؤال ما لم يُشر لخلاف ذلك.

جميع النتائج سوف تبقى سريّة

1- أي من الإحتمالات التالية تصف بشكل أفضل مدى الألم الذي شعرت به خلال الستة أشهر الماضية:

□ لم أشعر بالألم □ معتدل إلى حاد
□ خفيف □ حاد
□ معتدل

2- أي من الإحتمالات التالية تصف بشكل أفضل مدى الألم الذي شعرت به خلال الشهر الماضي؟
□ لم أشعر بالألم □ معتدل إلى حاد
□ خفيف □ حاد
□ معتدل

3- هل كنت خلال الأشهر الستة الماضية عصبيًا/عصبية جًدا؟
□ في معظم الأوقات □ في ولا وقت
□ في أوقات قليلة □ في كل الأوقات
□ في بعض الأوقات

4- إذا كان عليك أن تمضي بقية حياتك مع الشكل الحالي لظهرك، كيف يكون شعورك عندئذ ؟

□ غير سعيد إلى حد ما □ سعيد جدا
□ غير سعيد أبدا □ سعيد إلى حد ما
□ لا سعيد و لا حزين

5- ما هو مستوى نشاطك الحالي؟

□ طريح/ طريحة الفراش / كرسي متحرك
□ لا نشاط أساسا
□ العمل الخفيف كالأعمال المنزلية
□ أشغال يدوية معتدلة ورياضات معتدلة كالمشي وركوب الدراجات
□ النشاطات كافة بدون قيود

6- كيف يبدو مظهرك مرتديا/مرتدية ملابسك؟

□ جيد جدا
□ جيد
□ مقبول
□ غير جيد
□ غير جيد جدا

7- هل شعرت في الأشهر الستة الماضية بالإحباط إلى حد لا يمكن لشيئ أن يشرح صدرك؟

□ في كثير من الأحيان □ نادً را
□ غالبًا □ أبدا
□ أحيانًا

8- هل تشعر/ تشعرين بالألم في ظَّهرك عند الجلوس اوالإستلقاء ؟

□ غالبًا جدا □ نادً را
□ غالبًا □ ابدا
□ أحيانًا

9- ما هو المستوى الحالي لنشاطك في العمل/ المدرسة؟

□ طبيعي 100% □ طبيعي 25%
□ طبيعي 75% □ طبيعي 0%
□ طبيعي 50%

10- الظهر هو جسم الإنسان باستثناء الرأس والأطراف ;أي من الإحتمالات التالية تصف بطريقة أفضل شكل ظهرك؟

□ جيد جدا □ سيء
□ جيد □ سيء جدا
□ مقبول

11- أي من الإحتمالات التالية تصف بشكل أفضل استخدامك للدواء لأجل ظهرك؟

□ لا شيئ
□ أدوية غير مخدرة أسبوعيًا أو أقل (مثلا باراسيتامول كتايلانول ُو لإبروفان)
□ أدوية غير مخدرة يومياً
□ ادوية مخدرة أسبوعيًا أو أقل (مثلا كوداي، نيو-كوداي، ألغا-كودابن، دفالغان – كوداين، برِكوست)
□ أدوية مخٍّ درة يوميًا
□ مختلف (الرجاء التحديد أدناه)

الدواء :____

كيفية الإستعمال (أسبوعيًا أو أقل أو يوميًا):______________________________

12- هل يحّد ظهرك من قدرتك على القيام بأعمال منزلية؟
- □ أبدا □ غالبًا
- □ نادرا □ غالبًا جدا
- □ أحيانًا

13- هل شعرت بالهدوء والسكينة خلال الستة أشهر الماضية؟
- □ في كل الأوقات □ في أوقات قليلة
- □ في معظم الأوقات □ في ولا وقت
- □ في بعض الأوقات

14 - هل تشعر/ تشعرين أن حالة ظهرك تؤثر على علاقاتك الشخصية؟
- □ أبدا □ بشكل معتدل
- □ بشكل طفيف □ بشكل حاد
- □ قليلاً

15- هل تعاني /تعانين أنت او أحد افراد عائلتك من صعوبات مادية بسبب حالة ظهرك؟
- □ حادة □ طفيفة
- □ معتدلة □ لا صعوبات
- □ خفيفة

16- هل شعرت بالإحباط او بالإنقباض خلال الأشهر الستة الماضية؟
- □ أبدا □ غالبًا
- □ نادرا □ غالبًا جدا
- □ أحيانًا

17- هل أخذت خلال الأشهر الثلاثة الماضية إجازة مرضية من العمل /المدرسة بسبب ألم في ظهرك؟ إذا كان الأمر كذلك حدد/ حددى عدد الأيام:

□ 0 □ 1 □ 2 □ 3 □ 4 أو أكثر

18- هل تتنزه/ تتنزهين أكثر أو أقل من أصدقائك؟
- □ أكثر بكثير □ اقل
- □ أكثر □ أقل بكثير
- □ بالتساوي

19- هل تشعر/ تشعرين أنك جذاب/ جذابة في حالة ظهرك الحالية؟
- □ نعم، كثيرا □ لا، ليس كثيرا
- □ نعم، إلى حد ما □ لا، غير جذاب أبدا
- □ لا جذاب ولا غير جذاب

20- هل كنت سعيدا/سعيدة في الأشهر الستة الأخيرة؟
- □ في ولا وقت □ في معظم الأوقات

□ في أوقات قليلة □ في كل الأوقات

□ في بعض الأوقات

21- هل أنت راضي/ راضية عن نتائج علاج ظهرك؟

□ راض جدا □ غير راضٍ
□ راض □ غير راضٍ ابدا
□ لا راض ولا غير راضٍ

22- هل كنت ستتبع/ ستتبعين العلاج ذاته إذا مررت بنفس الحالة مجدًدا؟

□ بالتأكيد نعم □ على الأرجح لا
□ على الأرجح نعم □ بالتأكيد لا
□ ليس بالتأكيد

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قسم الطبيب

أقْسِم بِالله العَظِيم

أن أراقبَ الله في مِهْنَتِي.

وأن أصُونَ حياة الإنسان في كآفّةِ أطوَارهَا في كل الظروف والأحَوال باذلة وسْعِي في إنقاذها مِن الهَلاكِ والمرَضِ والألَم والقَلَق.

وأن أحفَظَ لِلنَاسِ كرَامَتهُم، وأسْتر عَوْرَتهم، وأكتمَ سِرَّهُمْ.

وأن أكونَ عَلى الدوَام من وسائِل رحمة الله، باذلة رِعَايَتي الطبية للقريب والبعيد، للصالح والطالح، والصديق والعدو.

وأن أثابر على طلب العلم، وأسَخِّرَه لِنَفْعِ الإنْسَان لا لأذَاه.

وأن أُوَقّرَ مَن عَلَّمَني، وأُعَلّمَ مَن يَصْغرَني، وأكون أختًا لِكُلِّ زَميلٍ في المِهنَةِ الطِّبِّيَة مُتعَاونِينَ عَلى البرِّ والتقوى.

وأن تكون حياتي مِصْدَاق إيمَاني في سِرّي وَعَلانيَتي، نَقِيَّة مِمّا يُشينهَا تجَاهَ الله وَرَسُولِهِ وَالمؤمِنين.

والله على ما أقول شهيدا

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التوازن السهمي للعمود الفقري في جراحة الجَنَف - الميلان الجانبي للعمود الفقري

الأطروحة

قدمت ونوقشت علانية يوم **2023/07/11**

من طرف

السيدة أبو المكارم محجوبة

المزدادة في 06 مارس 1996 ببني ملال

لنيل شهادة الدكتوراه في الطب

الكلمات الأساسية:

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