CLINICAL ARTICLE

Clinical Application of the Roussouly Classification in the Sagittal Balance Reconstruction of 101 Adolescent Idiopathic Scoliosis Patients

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Purpose: Although Roussouly classification has been widely used in spinal surgery, it was mainly applied to degenerative scoliosis patients and correlational studies concerning adolescent idiopathic scoliosis (AIS) are still insufficient. This retrospective study explored the clinical application of Roussouly classification in surgeries and prognosis prediction for AIS.

Methods: This clinical research selected 101 AIS patients who received surgeries between August 2005 and November 2019. Whole spine standing radiographs were obtained for each patient preoperatively, postoperatively, and at the last follow-up (>24 months). All patients were classified into "theoretical types" and "current types." Patients were further divided into mismatch or match groups based on the consistency of their current type and theoretical type. The main parameters include: proximal junctional angle (PJA), pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), fixed thoracic kyphosis (TK), global TK, fixed lumbar lordosis (LL), global LL, thoracic tilt, proximal thoracic alignment (PTA), lumbar tilt, spino-sacral angle (SSA), and spinal tilt (ST).

Results: A total of 47.5% of AIS patients were subject to a preoperative mismatch of Roussouly classification. There was a significant difference in PI-LL between the preoperative mismatch and match groups ($p = 0.008$). There was a significant difference in the rate of PI-LL deformity between the match and mismatch groups with a preoperative mismatch ($p = 0.037$). A significant difference in thoracic tilt was observed between the postoperative mismatch and match groups ($p = 0.019$). The preoperative mismatch group has a higher risk of postoperative PI-LL malformation than match group (OR = 2.303, 95% CI: 1.026, 5.165). When mismatch occurred postoperatively, there were significant differences between groups in the rate of pelvic deformity ($p = 0.002$) and PI-LL deformity ($p = 0.025$) at the last follow-up. Compared with the postoperative match group, mismatch group had an increased risk of pelvic deformity (OR = 5.029, 95% CI: 1.618, 15.629) and PJK deformity (OR = 3.017, 95% CI: 1.709, 11.375) at the last follow-up. Short Form-36 and Scoliosis Research Society 22 score of the match group was significantly higher than that of the mismatch group at the last follow-up.

Conclusion: The Roussouly classification mismatch before or after operation leads to increased risks of PI-LL deformity and pelvis deformity postoperatively or at the follow-up, which seriously worsens the clinical symptoms and prognosis of patients. Therefore, recovering to the theoretical type in Roussouly classification may effectively improve patients' prognosis.

Key words: Adolescent idiopathic scoliosis; Roussouly classification; Pelvic deformity; PJK; Sagittal alignment mismatch

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Received 9 May 2022; accepted 23 August 2022

Orthopaedic Surgery 2023;15:141–151 • DOI: 10.1111/os.13503

Introduction

Adolescent idiopathic scoliosis (AIS) is a three-dimensional spinal deformity involving both coronal and sagittal planes.[1,2] Its characteristic clinical feature is trunk deformity with shoulder-waist asymmetries caused by vertebral body rotation without vertebral body dysplasia or neuromuscular diseases.[3] For AIS patients with a vertebral rotation more than 40°, a classic treatment is the posterior scoliosis correction and pedicle screw interbody fusion, which will correct scoliosis deformities and help patients obtain spinal balance with minimum energy consumption.[4] In the past, the correction effect of scoliosis was the major concern of surgeons, but now sagittal parameters have also received much attention as many studies suggest that they are more significantly connected to health-related quality of life.[5–7] Therefore, in recent years, more and more attention has been paid to sagittal parameters. In 2005, Roussouly[8] published the sagittal morphological classification of spine based on a normal population. Since then, this classification method has also been applied to populations with degenerative scoliosis.[9] It is suggested that PI, a constant parameter, can be used to classify patients with degenerative scoliosis more accurately and to guide the design of orthopedic program.[10] However, currently there is still a lack of relevant research on whether Roussouly classification can be used to guide the sagittal correction protocols for AIS patients. The goal of this study is to examine the influence of spinal deformity on sagittal morphology among AIS patients, and to explore the use of Roussouly classification in guiding orthopaedic surgeries and in predicting the prognosis of AIS patients, which could decrease complications as far as possible. Moreover, long-term follow-up research and large-scale, multi-center studies should be conducted to verify this conclusion in the future.

Material and Methods

This study was a single-center, retrospective study of AIS patients who received surgical treatment at the Peking University Third Hospital from August 2005 to November 2019. A total of 187 consecutive AIS patients were reviewed. Inclusion criteria were as follows: 1) diagnosed with AIS; 2) received posterior correction using all-pedicle-screw instrumentation; 3) surgery age younger than 22 years old; and 4) preoperative, postoperative, and follow-up full spine radiographs at posterior–anterior and lateral positions are completed. Exclusion criteria included: 1) diagnosed with additional scoliosis; 2) a follow-up period less than 24 months; 3) received other neuromuscular operations before; 4) poor radiograph image quality; and 5) lower extremity problem and surgery history. The study was approved by the hospital's Institutional Review Board and the requirement of informed consent was waived in consideration of the study's retrospective nature. The application number is M2019488. Following these criteria, the subjects included 25 males and 76 females with an average age of 16.6 ± 1.54 years.

Surgeries

All patients were treated with one-stage, posterior spinal fusion (PSF) and scoliosis correction by the same surgeon and at the same hospital.[11] The specific surgical techniques are described below: Based on the standard PSF, we first made an appropriate midline incision and exposed the spinous processes, laminae, facet joints, and transverse processes. We then inserted the pedicle screws with free-hand, anatomic technique at almost all levels navigated by fluoroscopy. Likewise, two rods of appropriate length are contoured on the normal sagittal plane to reproduce desired thoracic

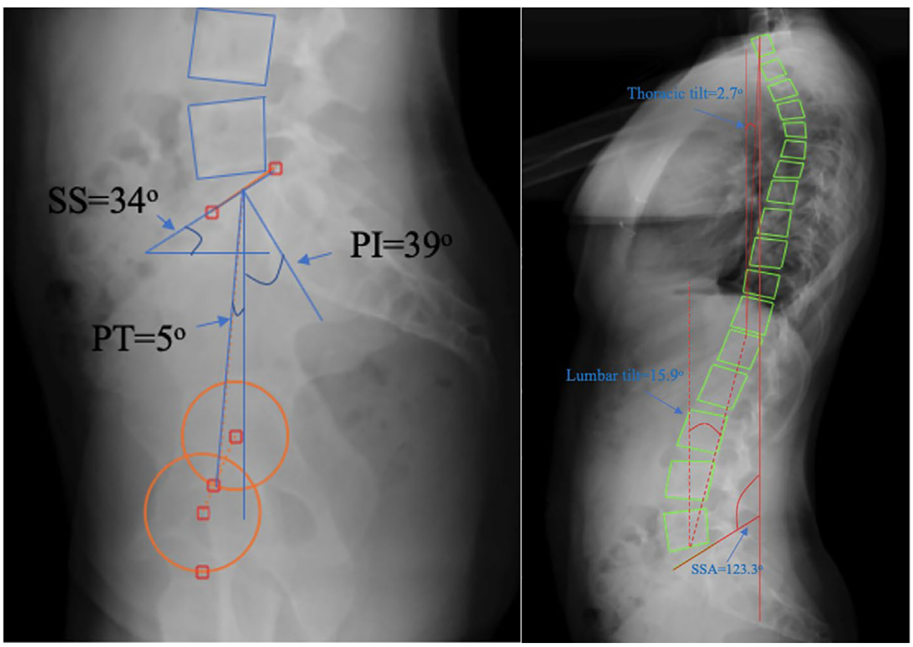

Fig 1 Illustration of the measurement of spinopelvic parameters.

kyphosis (TK) and lumbar lordosis (LL). Standard correction maneuvers were performed. Autograft composed of resected facets and allograft bone were used to facilitate fusion.

Image Analysis

All morphological data were archived with the picture archiving and communication system (PACS, GE, USA), from which we obtained the subjects' anteroposterior and lateral whole-spine radiographs on both coronal and sagittal planes before operation, 1 week after the operation, and at the last follow-up (>24 months). Then Surgimap (version v2.3.2.1) was used to measure the relevant parameters on the subjects' radiographs.

The parameters and their measurement methods were determined by authors. The measurement was carried out by two researchers, respectively. If there was no significant difference between the two measurements, their average result would be used. Otherwise, a third, senior author would be invited to adjudicate. By referencing previous studies, the following parameters were adopted for this study (Fig. 1): Cobb angle, fixed TK (T5–T12), global TK (T1–T12), fixed LL (L1–S1), global LL (L1–L5), thoracic tilt, proximal thoracic alignment (T2–T5), lumbar tilt, proximal junctional angle, PI, SS, PT, spino-sacral angle, and spinal tilt. PJA is defined as the angle between the lower endplate of the upper instrumented vertebrae (UIV) and the upper endplate of two vertebrae above the UIV.

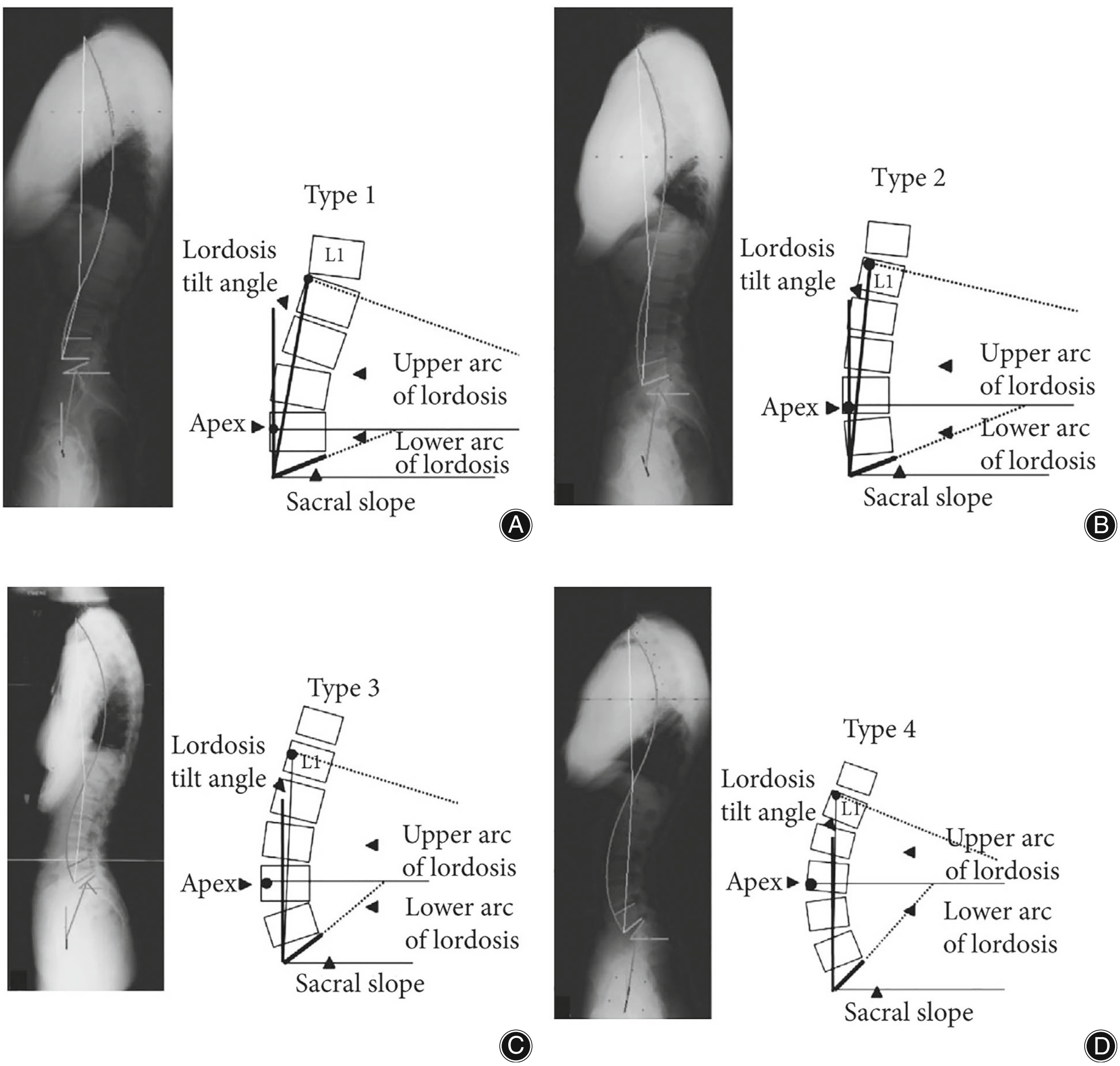

Fig 2 Roussouly classification. A four-part classification of morphology was used to classify each patient (a–d) (Taken from Roussouly *et al*.[8]).

In this study, a total of 101 AIS patients were recruited and divided into two groups based on the Roussouly classification, which involved two different classification criteria.[12] The first criterion, published in 2005, divided patients into different types according to the factors of SS, the number of vertebrae that formed lumbar protrusion, and the sagittal shape of the patient's spine on lateral radiographs[8] (we named it "current types"). It was determined based on the following criteria (Fig. 2): Type 1: SS ≤35° and LL involved less than four vertebrae; Type 2: SS ≤35° and LL involved more than three vertebrae; Type 3: 35° < SS < 45°; Type 4: SS ≥45°. The second criterion, published in 2018, was based on PI and determined the subject's "theoretical type".[10] Previous reports have demonstrated that theoretical Types 1 and 2 corresponded to PI <45°, Type 3 to PI between 45° and 60°, and Type 4 to PI >60°. The inflection point, the apical lumbar level, the number of levels included in the lordosis, and the sagittal shape with the original images drawn by Roussouly were especially important to differentiate Type 1 and Type 2 shapes, as PI values are "shared" by both sagittal shapes.

TABLE 1 Demographic data of the 62 patients

Items	Mean ± SD/Numbers
Age at surgery (years)	16.6 ± 1.54
Sex	
Male (N)	25
Female (N)	76
Height (cm)	159.21 ± 11.53
Weight (kg)	47.24 ± 13.44
BMI (kg/m^2)	17.89 ± 4.11
Follow-up period (mo)	39.12 ± 11.54
Hospital stay (d)	16.21 ± 22.03
Surgery duration (min)	311.52 ± 126.43
Total blood loss(mL)	781.19 ± 589.21
Comorbidities	
≥1 (N)	36
0 (N)	65
Complications	
≥1 (N)	5
0 (N)	97
Fused levels	11.87 ± 5.1

Considering that the same patient may be subject to distinct types according to the two criteria under Roussouly classification, we further divided the patients into the match group and mismatch group, based on the Pizones *et al.*[12,13] Each time the patient's current type was determined (preoperatively, postoperatively, or at the final follow-up), it would be compared with the corresponding theoretical type and classified into the match or mismatch group.

Based on previous literature, this study classified the sagittal deformities according to the following criteria[14]: PJK malformation: PJA >15° in the follow-up; PI-LL malformation: a difference between PI and fixed LL >10°; pelvic morphological malformation: anteversion (PT <0.2 × PI/2) and retroversion (PT >0.8 × PI/2).

Clinical outcome measurements of the patients were evaluated by using the Scoliosis Research Society (SRS) 22 questionnaire and the Short Form (SF)-36.

Statistical Analysis

All data were analyzed with SPSS 25.0 and displayed in percentage (%), mean ± SD, or histogram. Two-tailed paired sample *t*-test was used to identify changes before operation, after operation, and at the follow-up, and we used two-tailed independent sample *t* test to examine the relationship among the parameters at each measurement. Pearson correlation analysis was used to analyze the correlation between ordered variables, and chi square test was used to compare the categorical variables. Binary logistic regression analysis was employed to study independent risk factors. Statistical significance was set at p ≤ 0.05. The measurement was carried out by two researchers, respectively. Interobserver agreements were assessed using the intraclass correlation coefficient (ICC) method. All parameters showed excellent interobserver reliability (ICC >0.8).

Results

General Results

The demographic features of the patients are shown in Table 1. The mean age was 16.6 ± 1.54 years, the sex ratio

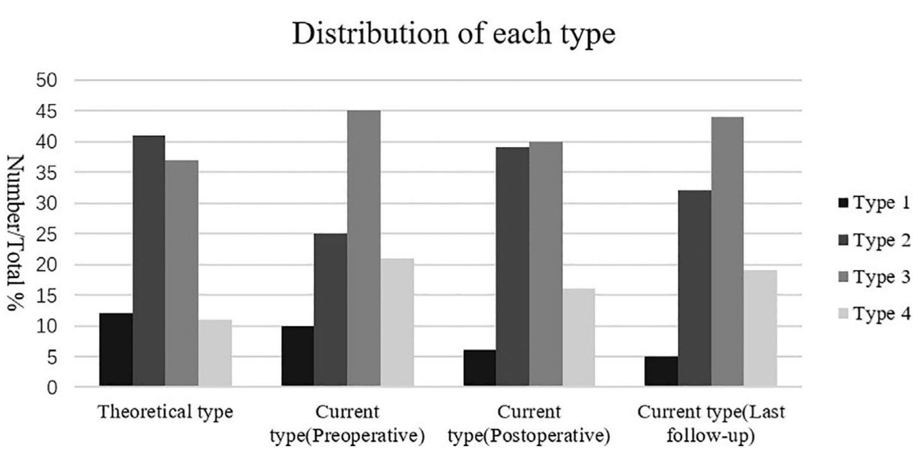

Fig 3 The distribution of each type.

was 25 females to 76 males. Fused levels were 11.87 ± 5.1. Minimum follow-up period was 24 months and mean follow-up period was 39.12 ± 11.54 months. Mean hospital stay was 16.21 ± 22.03 days and mean surgery duration was 311.52 ± 126.43 minutes. No intra-operative complication was reported (Table 1).

Effects of AIS on Sagittal Morphology

The distribution of patients' theoretical and current types in Roussouly classification in this study is shown in Fig. 3. In terms of theoretical types, the proportion of Type 1 and Type 4 was low, accounting for 11.9% and 10.9% respectively, whereas Type 2 had the highest proportion, accounting for 40.6%. As for current types, the proportion of Type 1 was the lowest at all three measurements. Before the operation, Type 1 accounted for 9.9% and the rest three types were relatively evenly distributed; after the operation, the proportion of Type 2 increased to 38.6%; at the last follow-up, the proportion of Type 2 decreased to 32%, and the proportion of Type 4 increased to 19%.

Various alterations in current type were observed in 49 patients after the operation. The highest proportion of these changes were from other types to Type 2, which happened to 24% of the patients and most of which were from Type 3 to Type 2. Compared to their preoperative types, there were 43 patients whose classification changed at the last follow-up, most of which were from Type 3 to Type 2 (23%). And compared to their postoperative types, changes were observed in 45 patients at the last follow-up, and more patients began to change to Types 3 or 4 (59%).

Our study further examined the mismatches between theoretical type and preoperative current type within each subgroup under Roussouly theoretical classification (Fig. 4). The results showed that, among different Roussouly theoretical types, mismatches were most common in Types 3 and 4, accounting for 53% and 57% respectively, and without any statistically significant differences ($\chi^2 = 4.993$, $p = 0.172$).

We then compared the sagittal parameters between the mismatch group and the match group (Table 2). The results showed that there was significant difference between the two groups in PI-LL before operation ($p = 0.008$) and in thoracic tilt after the operation ($p = 0.019$).

Relationship between Roussouly Type Mismatch and Postoperative Deformities

The distribution of deformities in this study is shown in Fig. 5. Before operation, there were 50 cases (50%) of PI-LL mismatch, and 37 cases (37%) of pelvic abnormality. After operation, 30 cases (30%) had PJK malformation, 50 cases (50%) had PI-LL mismatch, and 37 cases (37%) had pelvic abnormality. At the last follow-up, there were 35 cases of PJK malformation (35%), 40 cases of PI-LL mismatch (40%), and 27 cases of pelvic abnormality (27%).

This study found that when the preoperative current type did not match the theoretical type, there was a difference in the postoperative PI-LL deformity rate between the two groups ($p = 0.037$). When the postoperative current type did not match the theoretical type, there was also a intergroup difference in the rate of PI-LL deformity ($p = 0.025$) and the rate of pelvic deformity ($p = 0.002$) at the last follow-up, as detailed in Table 3.

Logistic regression analysis showed that the risk of postoperative PI-LL malformation was higher in the preoperative mismatch group than the match group (OR = 2.303,

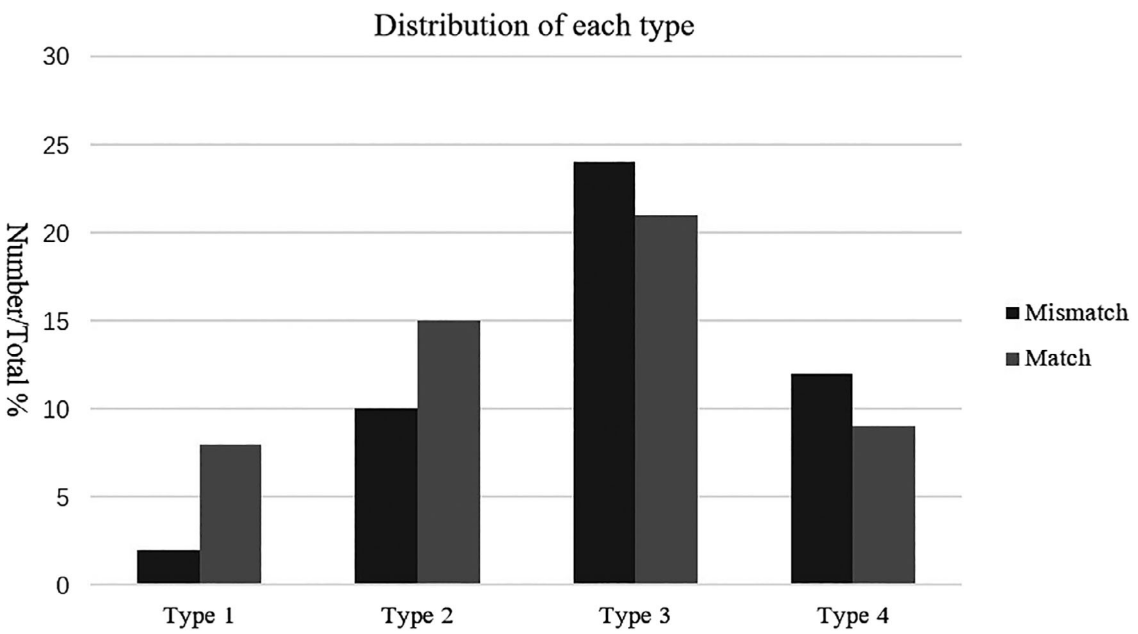

Fig 4 The distribution of mismatch between the theoretical type and the preoperative current type in Roussouly classifications.

TABLE 2 Univariate comparison of sagittal parameters between mismatch group and match group

	Preoperative				Postoperative				Last follow-up			
	Mismatch	Match	t value	p value	Mismatch	Match	t value	p value	Mismatch	Match	t value	p value
PJA	7.2 ± 5.9	7.7 ± 6.0	0.449	0.654	6.9 ± 6.6	6.7 ± 9.5	0.113	0.910	7.3 ± 7.7	7.5 ± 11.2	0.085	0.932
PI	43.4 ± 10.1	47.8 ± 14.0	1.832	0.070	42.9 ± 12.3	45.6 ± 16.5	0.908	0.367	43.0 ± 13.2	45.1 ± 15.2	0.611	0.541
PT	6.1 ± 13.5	9.8 ± 6.9	1.719	0.090	6.7 ± 10.8	9.1 ± 8.6	1.228	0.222	6.6 ± 11.0	10.8 ± 9.6	1.685	0.092
SS	38.9 ± 7.5	38.0 ± 11.3	0.514	0.608	36.2 ± 8.6	36.5 ± 11.2	0.105	0.917	37.2 ± 10.5	36.8 ± 10.5	0.159	0.874
Global LL	−54.4 ± 12.5	−51.0 ± 13.6	1.300	0.197	−45.2 ± 15.3	−48.1 ± 11.7	1.092	0.277	−51.8 ± 14.9	−53.1 ± 11.4	0.400	0.689
Fixed LL	−33.1 ± 13.5	−28.9 ± 16.1	1.429	0.156	−29.6 ± 14.5	−32.5 ± 10.6	1.154	0.251	−34.8 ± 10.8	−34.7 ± 10.4	0.031	0.975
Lumbar tilt	−6.0 ± 7.6	−6.9 ± 9.9	0.506	0.614	0.3 ± 7.3	0.7 ± 6.3	0.286	0.775	−3.5 ± 8.0	−6.3 ± 6.7	1.626	0.104
Global TK	28.2 ± 17.2	29.5 ± 16.3	0.391	0.697	25.2 ± 13.9	24.2 ± 8.6	0.436	0.664	28.5 ± 13.0	29.5 ± 10.5	0.369	0.712
Fixed TK	32.9 ± 16.2	30.9 ± 16.1	0.610	0.543	31.2 ± 13.8	30.1 ± 10.8	0.431	0.667	35.0 ± 11.9	37.9 ± 12.3	0.984	0.325
Thoracic tilt	−2.4 ± 8.9	−2.1 ± 7.4	0.227	0.821	0 ± 6.1	−2.8 ± 5.5	2.345	0.019	−2.8 ± 7.0	−3.0 ± 4.9	0.147	0.883
PTA	7.1 ± 9.9	8.0 ± 7.5	0.545	0.587	10.0 ± 9.5	9.6 ± 8.8	0.259	0.796	10.1 ± 8.1	12.4 ± 10.6	1.003	0.316
ST	92.7 ± 5.7	93.3 ± 5.5	0.516	0.607	89.6 ± 4.1	91.0 ± 3.9	1.795	0.076	92.6 ± 4.0	93.5 ± 3.7	0.994	0.320
SSA	134.2 ± 9.2	133.0 ± 10.6	0.611	0.542	127.4 ± 11.9	129.7 ± 9.4	1.073	0.286	132.7 ± 9.7	133.3 ± 9.9	0.247	0.805
PI-LL	−11.0 ± 15.5	−3.2 ± 13.2	2.700	0.008	−3.0 ± 15.1	−2.3 ± 10.9	0.249	0.804	−8.8 ± 16.8	−8.0 ± 11.9	0.252	0.801

95% CI: 1.026, 5.165, p = 0.043). The risk of pelvic deformity at the last follow-up was higher in the postoperative mismatch group than the match group (OR = 5.029, 95% CI: 1.618, 15.629, p = 0.005). The risk of PJK at the last follow-up was higher in the postoperative mismatch group than the match group (OR = 3.017, 95% CI: 1.709, 11.375, p = 0.037).

Physical component summary of SF–36 was better in the match group at last follow-up significantly (p = 0.043). Function (p = 0.037) and pain (p = 0.042) component of SRS-22 was better in the match group last follow-up. Self-image component of SRS-22 was better in the match group preoperatively (p = 0.034) and at last follow-up (p = 0.023). (Table 4).

Match group: Preoperative PI 45.2°, PT 5.8°, SS 39.4°, fixed LL 57.0°, fixed TK 25.0° (Fig. 6A). Current and theoretical types are both Type 3. Posterior T9-L3 fusion and scoliosis correction were performed. Postoperative PI 45.4°, PT 6.5°, SS 38.9°, fixed LL51.9°, fixed TK 27.1°, PJA 8.1° (Fig. 6B). Last follow-up PI 45.0°, PT 5.7°, SS 39.3°, fixed LL 55.6°, fixed TK 27.2°, PJA 5.4° (Fig. 6C). SF-36: PCS 41.5, MCS 45.5; SRS-22: F 4.4, P 4.2, S-I 4.8, MH 4.2, S 4.6. The follow-up period was 49 months. No related complications were observed. Mismatch group: Preoperative PI 45.0°, PT −0.2°, SS 45.2°, fixed LL 59.9°, fixed TK 21.8°(Fig. 6D). Current type is Type 4, and theoretical type is Type 3. Posterior T10-L4 fusion and scoliosis correction were performed. Postoperative PI 45.6°, PT −0.4°, SS 46.0°, fixed LL 67.1°, fixed TK 32.1°, PJA 11.1° (Fig. 6E). Current type is Type 4, and theoretical type is Type 3. Last follow-up PI 45.2°, PT −1.9°, SS 47.1°, fixed LL 70.1°, fixed TK 30.5°, PJA 19.2° (Fig. 6F). SF-36: PCS 39.2, MCS 44.6; SRS-22: F 4.4, P 4.2, S-I 3.5, MH 4.1, S 4.5. The follow-up period was 25 months. PJK, PI-LL malformation and pelvic morphological anteversion were observed.

Discussion

This study confirmed that the Roussouly classification mismatch before or after operation leads to increased risks of PI-LL deformity and pelvis deformity after operation or at the follow-up, which seriously worsens the clinical symptoms and prognosis of patients.

Sagittal spinal imbalance is an important manifestation of AIS disease progression and a predictor of poor prognosis.[15] In order to obtain good orthopaedic outcomes and reduce the incidence of postoperative and long-term follow-up complications in AIS patients, it has been a key concern for spinal surgeons to restore the sagittal spinal morphology in accordance with the patient's physiological state through surgery.[7,16,17] Based on Roussouly classification, Laouissat *et al.*[10] reanalyzed the sagittal spinal morphology of asymptomatic, healthy people aged from 18 to 48 years and proposed the importance of using PI as the basis for spinal alignment reconstruction. Some scholars have then applied this classification to guide the sagittal reconstruction of degenerative spinal diseases and achieved good clinical

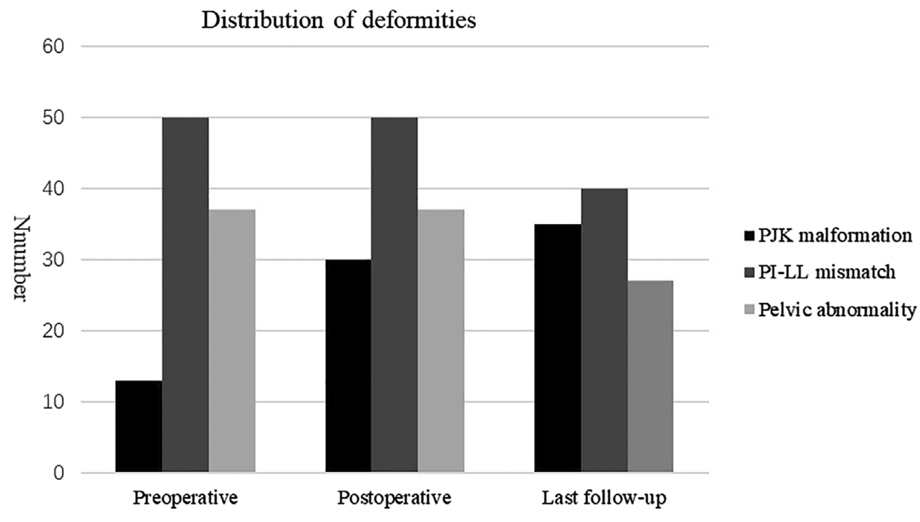

Fig 5 Preoperative, postoperative and final follow-up distribution of malformations.

TABLE 3 The distribution of mismatch between theoretical and current type in each deformity group

		Mismatch group	Match group	χ^2 value	p value
Preoperative			Postoperative PI-LL deformity		
	Yes	29	21	2.086	0.037
	No	19	32		
			Postoperative PJK deformity		
	Yes	12	18	0.984	0.325
	No	36	35		
			Postoperative pelvic deformity		
	Yes	20	17	0.999	0.318
	No	28	36		
Postoperative			Last follow-up PI-LL deformity		
	Yes	28	12	2.241	0.025
	No	14	18		
			Last follow-up PJK deformity		
	Yes	23	12	1.527	0.217
	No	19	18		
			Last follow-up pelvic deformity		
	Yes	22	5	3.090	0.002
	No	20	25		

TABLE 4 Univariate comparison of sf-36 and srs 22 between mismatch group and match group

	Preoperative				Last follow-up			
	Mismatch	Match	t value	p value	Mismatch	Match	t value	p value
SF-36								
PCS	35.6 ± 5.3	37.5 ± 4.8	1.825	0.068	39.6 ± 5.5	41.6 ± 4.4	2.024	0.043
MCS	41.5 ± 5.1	42.3 ± 4.9	1.499	0.134	44.5 ± 5.1	45.4 ± 5.1	0.494	0.612
SRS 22								
Function	4.2 ± 0.5	4.3 ± 0.3	1.141	0.254	4.4 ± 0.2	4.6 ± 0.4	2.086	0.037
Pain	4.1 ± 0.6	4.2 ± 0.5	0.452	0.651	4.3 ± 0.1	4.4 ± 0.3	2.034	0.042
Self-Image	3.2 ± 0.5	3.4 ± 0.3	2.120	0.034	4.5 ± 0.6	4.7 ± 0.5	2.273	0.023
Mental health	3.4 ± 0.5	3.3 ± 0.7	0.787	0.431	4.1 ± 0.7	4.2 ± 0.8	0.654	0.513
Satisfaction	4.0 ± 0.1	4.1 ± 0.2	1.585	0.113	4.6 ± 0.9	4.6 ± 0.2	1.711	0.087

PCS, physical component summary; MCS, mental component summary.

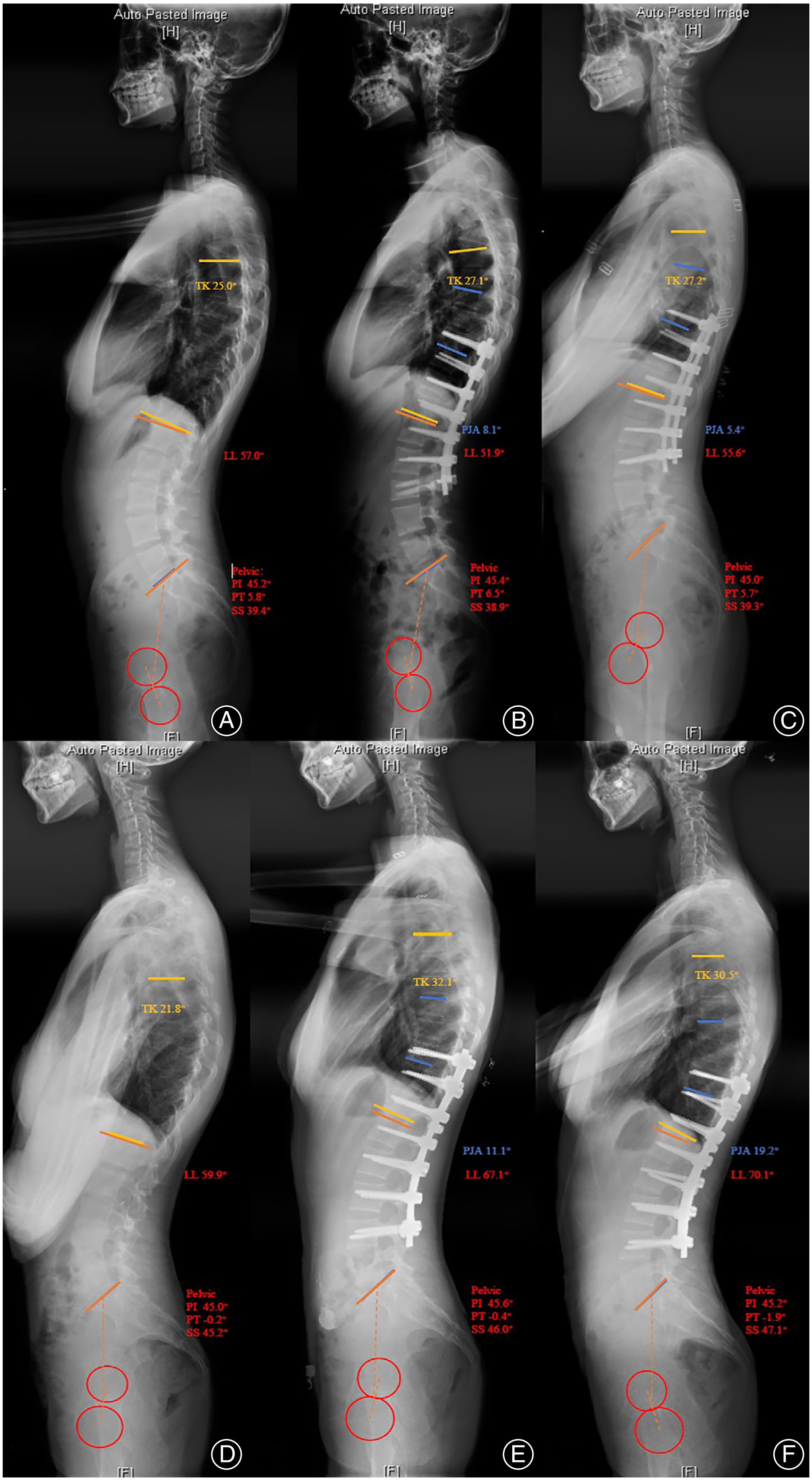

Fig 6 Prognosis comparison between match and mismatch group.

results.[12,18] In 2018, Pizones *et al.*[12] reported the notion of "theoretical type" and "current type" and applied this classification to adult spinal deformity patients for surgical planning. However, because AIS patients often have rotation deformities that involve multiple segments of vertebral bodies and have sagittal and coronal morphological changes, there are no conclusive findings on whether the spinal deformity will affect the patient's Roussouly classification outcome and on whether the classification can be used to guide the sagittal reconstruction after AIS. This study aims to address such gaps.

AIS Patients with Different Roussouly Classifications Showed Separate Sagittal Morphological Changes

As indicated in Fig. 3, the proportion of preoperative current Type 1 in AIS patients was relatively small whereas that of Type 3 was large. This result is in line with the distribution of Roussouly types among AIS patients reported by Ohrt-Nissen *et al.*,[14] but significantly diverges from that in the healthy population reported by Sun *et al.*[19] since in the latter Types 2 and 3 are the most prominent types, which is also related to the sagittal curvature characteristics of different species. Therefore, the spinal deformities caused by the AIS may affect patients' distribution under Roussouly classification. Since the current type of a significant number of patients changed to Type 2 after operation, it is suggested that patients with AIS tend to have a flat back appearance, which is also in line with the characteristics of pedicle screw fixation technique reported by Dalal *et al.*[20]

Pizones *et al.*[12] reported that mismatches between theoretical type and current type based on degenerative scoliosis were very common among ADS patients. This feature was also observed in the AIS patients in our study. The rate of mismatch between theoretical type and preoperative current type was 47.5% in this study, as contrasted by the 34.2% in ADS patients. This mismatch phenomenon also reflects the influence of spinal deformity on spinal morphologies. And the fact that AIS patients are subject to higher prevalence of mismatch than ADS patients may result from the younger age of the former, who have stronger spinal plasticity and larger rotation of vertebral body compared with the latter.

At the same time, the study found that the pathological process of AIS has different effects on patients of different types. As for Roussouly classification, Type 3 and Type 4 patients are subject to greater influence from AIS. The deformity of AIS is a three-dimensional morphological change that involves coronal plane, horizontal plane, and sagittal plane. The horizontal plane is characterized by the axial rotation of the vertebra.[15] According to Deacon *et al.*,[2] lordosis is closely related to the degree of axial rotation of the vertebra, which makes lordosis an important factor in the development of deformity. We think that it is because of their relatively larger LL as Type 3 and 4 patients are more likely to be affected by the axial vertebral rotation of AIS deformity and to change their normal morphology.

Therefore, the Roussouly classification scheme based on the SS, proposed by Roussouly *et al.*,[8] does not perfectly apply to AIS patients. Diebo *et al.*[21] have previously noted that most patients with degenerative scoliosis may often lose their LL. In addition, the reduction of LL can result in a compensatory reduction of SS,[22] which can also lead to mismatches in the sagittal classification of AIS patients. Thus, to classify AIS patients, we need a parameter that is free from the influence of age, pathology, or compensation, and we believe PI is the most appropriate option. As Roussouly[9] mentioned, "PI is the only index determining the original shape of the spine in the state of disease, and we can use it to restore the balance of the patient." This is the reason why we emphasized the notion of theoretical type.

In order to further reveal the influence of AIS on Roussouly classification, we compared relevant parameters between the mismatch group and the match group. The results showed that there was a significant difference in PI-LL ($p = 0.008$) between the two groups before operation as well as in thoracic tilt (0 ± 6.1, -2.8 ± 5.5) after operation ($p = 0.019$). The former indicates that PI-LL increases significantly as preoperative mismatch occurs. Since PI is a constant, AIS patients with preoperative mismatches may often have sagittal deformities with excessive loss of LL. According to Bari *et al.*,[23] restoring the apex of LL to the level corresponding to Roussouly classification can reduce the risk of PJK by 4.6 times. Therefore, for such patients, it is critical to correct their lumbar morphology, which cannot only restore their Roussouly classification but also help prevent postoperative complications. As postoperative mismatch occurs, the thoracic tilt will increase, and the thoracic lordosis will also significantly increase to compensate the sagittal balance of the body. Mak *et al.*[24] also reported that if PI-LL lost balance, the whole sagittal spine would be subject to a significant forward compensatory curvature, which is consistent with our results.

Guiding Significance of Roussouly Classification for Surgical Strategy and Prognosis of AIS Patients

To further explore the potential of Roussouly classification in guiding the surgeries for AIS, we compared the influence of preoperative and postoperative mismatches on postoperative spinal morphology. The results suggest that when preoperative mismatch occurs, patients will have an increased risk of postoperative PI-LL malformation, which is as high as 2.3 times of that in patients with preoperative match. The risk of PI-LL deformity, PJK deformity and pelvic deformity also increased at last follow-up in the postoperative mismatch group.

According to the Roussouly classification, the mismatch group had an imbalance in the curvature of the lumbar spine and pelvis, making it prone to have PI-LL deformity. Furthermore, PI-LL mismatch was correlated with postoperative PJK.[25] Matched PI-LL has a protective effect on postoperative PJK.[26] Besides, pelvic tilt depends on the relationship between PT and PI. When there were mismatches in Roussouly classification, the patients' sacrum and pelvis are out of the normal position leading to pelvic deformity. As for the sagittal correction of spinal deformities, Sebaaly *et al.*[27] propose that the goal for ADS patients is to change the current type to Type 1 or Type 2 for patients with low PI and to Type 3 or Type 4 for patients with high PI, so that the sagittal shape can restore to its theoretical type. Otherwise, it would be difficult for patients to achieve good clinical outcomes.[7,28] Similarly, among the AIS patients in our study, those with preoperative or postoperative mismatch have significant pelvic morphological abnormalities and sagittal imbalance aggravation, which compromise the patient's prognosis. Previous studies have demonstrated that sagittal position parameters of spine and pelvis are closely correlated with postoperative clinical symptoms.[28] As our study suggested, various subitems of SF-36 and SRS 22 score of the match group was significantly higher than that of the mismatch group at the last follow-up. Therefore, in order to prevent the above problems in the surgical treatment of AIS, we need to restore the patient's current type to its theoretical counterpart and correct the mismatch, which will help reduce clinical symptoms and improve prognosis.

Strengths and Limitations

Existing research concerning Roussouly Classification has only considered four types of classification itself. Therefore, we creatively applied the concept of "mismatch between the postoperative current type and the theoretical type" in AIS patients and made a prognosis comparison between mismatch and match group, which is meaningful for us to guide surgical correction of AIS patients. This study also has several limitations. First, throughout the study, we assumed that PI was a constant parameter. Although PI is almost fixed and static for adults, it is dynamic before adulthood.[24] Ilharreborde *et al.*[29] reported that PI was still subject to slight changes during growth. Therefore, there may be some errors in determining the theoretical type of AIS patients based on their PI. However, such errors can be very rare because the average age of AIS patients included in this study was 16.6 years old, and most of them were in grade 3 or above according to Risser classification, indicating that the possibility of growth was low. The second limitation concerns the retrospective nature of this study. Because the parameters were measured on sagittal radiographs that were taken at pre-given time slots, it was impossible to accurately determine the changes of deformity over time and the level of evidence was limited. We hope that prospective RCT research can be carried out in the future.

Conclusion

This study has confirmed that restoring patients to the theoretical type of Roussouly classification can effectively improve the prognosis of patients. However, the mismatch of Roussouly classification before and after surgery increases the risk of PI-LL deformity and pelvic deformity after surgery or at follow-up, which seriously deteriorates the clinical symptoms and prognosis of patients. Therefore, Roussouly classification matching must be paid attention to in AIS correction surgeries.

Authors' contributions

All the authors have made appropriate contributions to this review. Junyu Li: data measurements, study design, and manuscript revision; Miao Yu: study design, surgery, and manuscript revision; Yueyang Zhang: data measurements, manuscript preparation, and statistics; Yiqiao Zhang: manuscript preparation; Xinyi Li: data measurements and statistical analysis; Zexi Yang: data collection; Panpan Hu: study design; Others: surgery assistance and study design. We would like to acknowledge Wanheng Hu for his help in correcting the language content of the article.

Conflicts of interest

The authors declare no competing interests.

Acknowledgments

Consent to participate.
The present study was approved by the institutional review board of our institution before data collection and analysis. The requirement of informed consent was waived owing to the retrospective nature of the study.

Consent to publish

Subjects enrolled in the study provided written informed consent to publish the data.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Funding Information

This study was sponsored by the Natural Science Foundation of Beijing Municipality (No. 21L2308).

Ethical Statement

All methods were performed in accordance with the relevant guidelines and regulation. Approval was granted by the Peking University Third Hospital Medical Science Research Ethics Committee prior to the study. Formal consent was not required due to the retrospective design.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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