Original Article

Radiological analysis of the sagittal profile of the Indian population according to the theoretical Roussouly classification

ABSTRACT

Background: Pierre Roussouly *et al.* classified four distinct types of sagittal profiles in normal individuals based on their sacral slope (SS). It was modified by Laouissat *et al.*, (theoretical) including a fifth type.

Study Design: The study design was a cross‑sectional study.

Objective: The objective of this study was to identify and classify the types of sagittal alignment present in an asymptomatic Indian population using the parameters established by Roussouly *et al.* and modified by Laouissat *et al.*

Methods: The inclusion criteria were asymptomatic adults between 18 and 50 years old, without history of spinal surgery or significant musculoskeletal disorders. The sagittal profile was classified according to the Roussouly modified (theoretical) classification. The spinopelvic parameters were measured using Surgimap and the correlation analysis was performed using Pearson's correlation coefficient.

Results: A total of 104 participants (62 females and 42 males) were recruited and it was observed 26 (25%) participants with Type 1, 12 (11.5%) with the Type 2, 26 (25%) with Type 3, 30 (28.8%) Type 3AP, and 10 (9.6%) participants with the Type 4. Furthermore, the study showed that the Type 3 anteverted pelvic (AP) had similar characteristics compared with the Laouissat's study. The pelvic incidence shows a correlation with SS ($r = 0.602$, $P = 0.001$) and pelvic tilt ($r = 0.613$, $P = 0.001$). SS is also correlated with lumbar lordosis ($r = 0.734$, $P = 0.001$).

Conclusion: The analysis of the study showed that the Type 3 AP is the sagittal profile more frequency according to the theoretical Roussouly classification in the asymptomatic Indian population.

Keywords: Indian population, Roussouly classification, sagittal profile

INTRODUCTION

Various spinal shapes and positional parameters have been described by radiographic assessment of the asymptomatic population to understand how the spine and pelvis interact and adapt to maintain balance and functionality. The sagittal alignment of the spine is one of the cornerstones for understanding the biomechanical mechanisms that explain the sagittal morphology of both asymptomatic individuals and those with spinal pathologies through spinopelvic parameters.[1,2]

The study of the sagittal alignment of the spine began with the sacropelvic parameters described by Legaye *et al.*, such as pelvic incidence (PI), pelvic tilt (PT), and sacral slope (SS), which are crucial for defining different pelvic morphologies in the sagittal plane in healthy individuals.[3]

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Roussouly *et al*. to classify four different types of spinal shapes in normal individuals based on their SS[4] and it was modified and clarified later by Laouissat *et al*., in 2017, they used the PI to classify the individuals including a fifth type, since as we know, PI is a static morphological parameter and does not change in adulthood, which allowed to place theoretical Roussouly classification.[5] Roussouly *et al*. in their study identified 160 normal asymptomatic caucasian population, with 34 patients having an SS <35° associated with low PI, and 48 with an SS >45° associated with high PI. He also found a strong correlation between SS and PI (r = 0.080) and SS and LL (r = 0.86), finally PI and LL (r = 0.64).[4] The Type 3 Anteverted Pelvis (AP) variant, which was described by Laouissat *et al*., represented 16% of this asymptomatic population, with a PI with a range of 48° ± 6°, an SS of 44° ± 6°, and a PT of 4° ± 3°.[5]

In the literature review, the Roussouly classification was used to differentiate the sagittal profile in Caucasians,[4,5] Asians like Chinese,[6] Koreans,[7] and in multiethnic studies (MEANS).[8] There are few studies in India that have attempted to classify the sagittal profile of the population using the Roussouly classification, one of these studies is the one carried out by Pithwa *et al*.,[9] where they found 32 individuals (25.6%) Type 1, 41 (32.8%) Type 2, 45 (36%) Type 3, and 7 (5.6%) Type 4, but it used the classic Roussouly classification and the other study was carried out by Gururaj Sangondimath *et al*.,[10] where only the spinopelvic sagittal parameters were studied in 100 asymptomatic participants.[10]

Currently, there are studies have shown that restoring the sagittal reduces the complication rate in adult deformity surgery[11] but also predicts the long-term outcomes for patients and the occurrence of adjacent segment disease.[12]

This study will attempt to identify and classify the types of spinal sagittal alignment present in an asymptomatic Indian population using the parameters established by Roussouly *et al.*[4] and modified by Laouissat *et al.*[5] (theoretical), with the purpose it provides a basis for the normal sagittal profile in the Indian population.

METHODS

Study design and population

This cross-sectional study was conducted to analyze the sagittal alignment of the spine in an asymptomatic Indian population according to the modified Roussouly classification.[5] A total of 104 participants (62 females and 42 males) were recruited from Coimbatore, Tamil Nadu, India. The inclusion criteria were asymptomatic adults between 18 and 50 years old. The exclusion criteria included the presence of any spinal deformity, recent trauma, chronic pain conditions, or musculoskeletal pathology.

Radiographic evaluation and classification of types

Participants underwent standardized lateral and anteroposterior whole spine radiographs while standing with their arms crossed over their chest. The images were used to measure the following sagittal alignment parameters: PI, SS, PT, and lumbar lordosis (LL). All measurements were performed using digital software tool to ensure accuracy and consistency, Surgimap. Based on the modified (theoretical) Roussouly classification,[5] radiographs were categorized into five types according to PI: Type 1, Type 2, Type 3, Type 4, and Type 3 Anteverted Pelvis (3AP).

Statistical analysis

Descriptive statistics were calculated for all parameters using the Surgimap program for the standardized measurement of the sample, including measures of central tendency for quantitative variables and proportions for qualitative variables. Differences between males and females were assessed using independent t-tests for normally distributed variables and Mann–Whitney U tests for nonnormally distributed variables. The significance level was set at $P < 0.05$.

Correlation analysis was performed using Pearson's correlation coefficient to evaluate the relationships between the sagittal alignment parameters. The strength of the correlations was interpreted using the following categories: very weak (0.0–0.1), weak (0.1–0.3), moderate (0.3–0.5), strong (0.5–0.7), very strong (0.7–0.9), and perfect (0.9–1.0).

Ethical considerations

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Ethics Committee (IEC) of Ganga Hospital, Coimbatore, Tamil Nadu, India.

RESULTS

We included 100 asymptomatic adults from Coimbatore, Tamil Nadu, India, with a mean age of 41 years (range 18–50 years), most of them female (n = 62; 59.6%). All types of sagittal spinal alignment were identified, the most common being Roussouly Type 3AP (28.8%), followed by Type 3 and Type 1 (25%) [Table 1].

Each parameter, categorized by type and expressed as a mean, standard deviation, and minimum– maximum, it is presented comprehensively in Table 2: Type 3AP exhibited the lowest mean PI (38.63° ± 7.39°) and SS (35.5° ± 4.68°), whereas

Type 4 had the highest mean values PI (61.20° ±6.14°) and SS (48.1° ±1.97°). LL was also highest in Type 4 (-64.10° ± 7.37°) and lowest Type 2 (-38.25°± 16.5°). Notably, Type 3AP showed distinct characteristics with a mean PT of 3° ± 5.19°.

Table 3 illustrates the distribution of spinal sagittal alignment types between males and females. The most frequently observed type in female was Type 3, 19 (18.3%) participants and in male was Type 3AP, 14 (13.5%) participants. For males, the second-most common is Type 1 (10.6%), whereas for females, it is Type 3AP (15.4%). In addition, Type 3AP shows a higher prevalence in females compared to males.

Table 1: Distribution of frequencies by Roussouly, sex, and age

Variables	*n*=104, *n* (%)
Age (years), mean (IQR)	41 (17.3)
Sex	
Female	62 (59.6)
Male	42 (40.4)
Type*	
Type 1	26 (25)
Type 2	12 (11.5)
Type 3	26 (25)
Type 4	10 (9.6)
Type 3AP	30 (28.8)

*According to Roussouly *et al.*[4] and modifications from Laouissat *et al.*[5]
IQR - Interquartile range; AP - Anteverted pelvis

Table 2: Sagittal alignment measures according to type classification

Measure	Mean±SD	Minimum–maximum
	Type 1	
PI (°)	42.15±5.29	28–49
SS (°)	27.96±5.67	18–39
PT (°)	14.15±4.46	6–24
LL (°)	-49.04° ± 8.84°	−15–67
	Type 2	
PI (°)	39.83±7.81	26–49
SS (°)	26.33±8.3	11–40
PT (°)	13.33±4.33	4–21
LL (°)	-38.25° ± 16.5°	−11–45
	Type 3	
PI (°)	53.08±3.92	52–62
SS (°)	40.85±5.92	36–43
PT (°)	18.35±6.85	2–35
LL (°)	-50° ± 12.6°	−45–67
	Type 4	
PI (°)	61.20±6.14	51–75
SS (°)	48.1±1.97	46–52
PT (°)	14±6.54	2–29
LL (°)	-64.10° ± 7.37°	−45–72
	Type 3AP	
PI (°)	38.63±7.39	20–45
SS (°)	37.5±4.68	36–43
PT (°)	3±5.19	−13–8
LL (°)	-55° ± 8.74°	−45–72

PI - Pelvic incidence; SS - Sacral slope; PT - Pelvic tilt; LL - Lumbar lordosis; SD - Standard deviation; AP - Anteverted pelvis

The correlation matrix presented in Table 4, it shows the relationships between various sagittal alignment parameters, including PI, SS, PT, and LL. The PI shows a strong positive correlation with SS ($r = 0.602$, $P = 0.001$), a strong positive correlation with PT ($r = 0.613$, $P = 0.001$), and a moderate positive correlation with LL ($r = 0.34$, $P = 0.001$). The SS is also strong positive correlated with LL ($r = 0.734$, $P = 0.001$). Conversely, the PT shows a weak negative correlation with SS ($r = -0.259$, $P = 0.001$) and a weak correlation with LL ($r = 0.312$, $P = 0.001$).

DISCUSSION

Legaye *et al.*, through of their study, they said that the cornerstone of pelvic parameters is the PI, which is a fundamental for the regulation of sagittal balance and determining spinal sagittal alignment.[3] In this study, they found that the LL was closely related to the orientation of the pelvis expressed in the SS ($r = 0.85$), further in it had a relationship between the PI with SS ($r = 0.83$) and with the PT ($r = 0.54$), leading to the development of the formula known as PI = SS + PT.[3] Roussouly *et al.*, following this idea and also, they showed in their study the same strong correlation between PI with SS ($r = 0.80$) and PT ($r = 0.65$)[4] observed in the study previously described.[3]

Due to the great variability among humans in spinopelvic parameters and sagittal profiles from the evolution to bipedalism,[13] Roussouly *et al.* proposed a classification system in 2005 for the different spinal shapes.[4]

In the study conducted by Roussouly *et al.*, they analyzed a sample of 160 asymptomatic Caucasians volunteers and they found only 18 volunteers were Type 2, which was the least frequent and Type 3 was 60 volunteers, it was the most frequently found.[4] Others studies such as the Hu *et al.*, concerning 252 asymptomatics Koreans, where they found 58 (23%) participants were Type 1, 33 (13.1%) were Type 2 and Type 3 were 125 (49.6%).[6] Another example was the Asian study made by Cho,[7] in 272 automatic chineses, where were identified 63 (23.2%) volunteers were Type 1, 38 (14%) were Type 2, 130 (47.8%) were Type 3, and 41 (15.1%) were Type 4.

Furthermore, in India, the only study that tried to classify the spinal shapes from the population with the classic Roussouly classification was Pithwa *et al.*, in 2021, they studied 125 asyntomatic participants, when 32 (25.6%) participants were Type 1, 41 (32.8%) were Type 2, 45 (36%) were Type 3, and

Table 3: Frequencies of sex mixed with Roussouly classification

Roussouly	Female, *n* (percentage of the total)	Male, *n* (percentage of the total)	Total, *n* (percentage of the total)
Type 1	15 (14.4)	11 (10.6)	26 (25)
Type 2	5 (4.8)	7 (6.7)	12 (11.5)
Type 3	19 (18.3)	7 (6.7)	26 (25)
Type 4	7 (6.7)	3 (2.9)	10 (9.6)
Type 3AP	16 (15.4)	14 (13.5)	30 (28.8)

AP - Anteverted pelvis

Table 4: Correlation between pelvic and sacral parameters

	PI	SS	PT	P=0.05
SS	0.602			0.001
PT	0.613	−0.259		0.001
LL	0.344	0.734	0.312	0.001

PI - Pelvic incidence; SS - Sacral slope; PT - Pelvic tilt; LL - Lumbar lordosis

7 (5.6%) were Type 4, with some correlations of LL with PI was $r = 0.38$, ($P = 0.0001$) and LL with SS $r = 0.748$, ($P = 0.0001$);[9] compared to the current, the modified (theoretical) Roussouly classification was used in 100 asymptomatic volunteers, of which the most frequent was Type 3AP in 30 participants (28.8%) and the least frequent was Type 4 in 10 participants (9.6%), with some correlations of LL with PI was $r = 0.34$, ($P = 0.001$) and LL with SS $r = 0.734$, ($P = 0.001$), with which can be observed that there is a subpopulation in Type 3 with the theoretical classification, which must be taken into account, since its spinal shape is totally different and could change the surgical decision in these population.

When we analyzed the Laouissat *et al*. study,[5] they involved a population of approximately 296 Caucasians, of which the Type 3AP variant represented 16% of this asymptomatic population, with a PI with a range of 48° ± 6°, an SS of 44° ± 6°, and a PT of 4° ± 3°,[5] compared with the current study from 100 participants, 30 (28.8%) of asymptomatic people presented the Type 3AP variant, more frequent in men than women, with a PI: 38.63° (20°– 45°), SS with a mean of 37.5° (36°– 43°), and the PT with a mean of 3° (−13°– 8°), which showed a higher prevalence of this type of spinal shape in the Indian population.

A historical analysis of the most important references associated with the use of the classical and modified (theoretical) Roussouly classification was carried out, which was described in Table 5, which allows to see the behavior of the sagittal profile of the different populations and allows us to say that we cannot extrapolate parameters used for the Caucasian population, since differences are observed with respect to the Indian population.

An example of using the Roussouly classification to compare populations is the Means *et al*. study in 2024, where the current and theoretical Roussouly system was compared and assessed sagittal alignment in an asymptomatic cohort. It included the population from France, Japan, Singapore, Tunisia, and the United States. It was found that one in three patients exhibited a difference between the theoretical type and the current Roussouly classification and more so when they had a larger PI–LL mismatch, which led to the conclusion that if the Roussouly classification system will be applied in deformity surgery, it should be correlated with the current clinical-pathological state.[8]

The importance of this classification is that it allows spine surgeons to identify areas of stress in the spine and understand the different biomechanical principles that can lead more rapid degeneration of the spine compared to other population.[14] An example of this was found Roussouly *et al*. and Zhao *et al*., where individuals with sagittal profiles Types 1 and 2 have a tendency to present symptomatic disc herniations, unlike the individuals with sagittal profile Type 4 present more symptomatic spinal stenosis.[4,14,15]

In this moment, the Roussouly classification has been validated in numerous investigations as an indicator of surgical outcome and complications such as adjacent segment disease in short fusions[15,16] or in adult spinal deformities, where nonrestoration of the ideal spinal shape of the patient increases the risk of revision surgery.[17]

Limitations of the study were the limited by its cross-sectional nature, a small sample size and the use of a single classification and its modification to classify the population, another it was the failure to search for degenerative pathology exhaustively with spinal MRI, since it was only study patients with radiographs.

CONCLUSION

The modified (theoretical) Roussouly classification had a different behavior between the asymptomatic Indian population and other populations. However, a similar correlation was observed between PI, SS, PT, and LL compared to the study by Roussouly *et al.* and Laouissat *et al*.[4,5]

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Conflicts of interest

There are no conflicts of interest.

Table 5: Historical analysis of the standardization of Roussouly's classification and modification of Laouissat over time and the population groups studied

Spinal shape or sagittal profile	Roussouly *et al.*, 2005[4]	Laouissat *et al.*, 2018[5]	Hu *et al.*, 2016[6]	Cho, 2017[7]	Pithwa *et al.*, 2021[9]	Means study: Roussouly current versus theoretical 2024[8]	Muñoz Montoya *et al*, This study, 2024
Population	*n*=160 Caucasians	*n*=296 Caucasians	*n*=272 Chinese	*n*=252 Koreans	*n*=125 Indians	*n*=467 France: 98/467 Japan: 119/467 Singapore: 79/467 Tunisia: 80/467 United States: 91/467	*n*=104 Indians
Type 1	34 SS: <35 (21°–35°) PI: 41 (34–54) LL: 52° (41°–64°)	12% from the population SS: 29°±4° PI: 39°±5° LL: 51°±6° PT: 10°±5°	63 (23.2%) SS: 29.8°±4.2° PI: 40.3°±7.3° LL: 46°±6.3° PT: 10.5°±6.9°	58 (23%) SS: 22.8°±3.1° PI: 38.3°±2.6° LL: 47.8°±9.3° PT: 17.6°±3.9°	32 participants (25.6%)	35 (7.5%) SS: 27.2°±5.5° PI: 40.8°±9.2° LL: 43.7°±9.8° PT: 13.6°±8.9° (current)	26 (25%) SS: 27.96° (18°–39°) PI: 42.15° (28°–49°) LL: 49.04° (15°–67°) PT: 14.15° (6°–24°)
Type 2	18 SS: <35 (28°–35°) PI: 44 (38–57) LL: 52 (44°–58°)	22% from the population SS: 30°±4° PI: 41°±6° LL: 48°±5° PT: 10°±5°	38 (14%) SS: 31.4°±2.8° PI: 43.1°±8.6° LL: 38.8°±5.9° PT: 11.7°±6.7°	33 (13.1%) SS: 30.4°±2.4° PI: 46.1°±8.6° LL: 37.8°±5.5° PT: 18.6°±6.7°	41 participants (32.8%)	100 (21.4%) SS: 30.6°±3.7° PI: 43.6°±7.6° LL: 46.8°±8.5° PT: 13°±7.2° (current)	12 (11.5%) SS: 26.33° (11°–40°) PI: 39.83° (26°–49°) LL: 38.25° (11°–45°) PT: 13.33° (4°–21°)
Type 3	60 SS: 39° (35°–45°) PI: 51 (36–65) LL: 61 (43°–76°)	30% from the population SS: 39°±3° PI: 53°±7° LL: 58°±10° PT: 13°±7°	130 (47.8%) SS: 38.9°±2.8° PI: 47.6°±6.4° LL: 53.5°±6.7° PT: 8.6°±6.5°	125 (49.6%) SS: 38.9°±2.8° PI: 47.6°±6.4° LL: 53.5°±6.7° PT: 13.8°±2.1°	45 participants (36%)	222 (47.5%) SS: 40.1°±2.7° PI: 52.4°±7.6° LL: 58.9°±7.3° PT: 12.3°±7.1° (current)	26 (25%) SS: 40.85° (36°–43°) PI: 53.08° (52°–62°) LL: 50° (45°–67°) PT: 18.35° (2°–35°)
Type 4	48 SS: >45° (45°–66°) PI: 63 (43–83) LL: 71° (61°–82°)	20% from the population SS: 49°±4° PI: 62°±8° LL: 69°±6° PT: 12°±7°	41 (15.1%) SS: 51.3°±4.3° PI: 59.9°±9.8° LL: 65.1°±5.8° PT: 8.5°±9.6°	36 (14.3%) SS: 53.7°±5.1° PI: 60.4°±6.8° LL: 67.5°±5.6° PT: 17.08°±7.7°	7 participants (5.6%)	110 (23.6%) SS: 50.3°±4° PI: 62.4°±8.6° LL: 68.5°±7.1° PT: 12.2°±7.2° (current)	10 (9.6%) SS: 48.1° (46°–52°) PI: 61.2° (51°–75°) LL: 64.10° (45°–72°) PT: 14° (2°–29°)
Type 3AP	-	16% of the population SS: 44°±6° PI: 48°±6° LL: 64°±7° PT: 4°±3°	-	-	-	52 (11.1%) PI: 43.7°±5° (current)	30 (28.8%) SS: 37.5° (36°–43°) PI: 38.63° (20°–45°) LL: 55° (45°–72°) PT: 3° (−13°–8°)

PI - Pelvic incidence; SS - Sacral slope; PT - Pelvic tilt; LL - Lumbar lordosis

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