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Relation between sagittal pelvic and thoracolumbar parameters in supine position – Pelvic parameters and their predictive value for spinal Cobb angles

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ABSTRACT

Introduction: Predicting the pre-morbid sagittal profile of the spine or segmental angles could enhance the process of planning the extent of fracture reduction. There is evidence that spinopelvic parameters may be suitable for this purpose.

Research question: Is it possible to determine the inflection point and the mono- and bi-segmental endplate angles (EPA) in the thoracolumbar transition (from Th9 to L2) based on age, gender, spinopelvic parameters, and the adjacent EPA in the supine position?

Material and methods: Based on Polytrauma CT scans in the supine position, the following spinopelvic parameters were measured using non-fractured spines: pelvic incidence (PI), sacral slope (SS), lumbar lordosis (LL), and the apex of the LL.

Results: In this study, a total of 287 patients with a mean age of 42±16 years were included. Age-related changes were observed, where LL, thoracic kyphosis (TK), and PI increase with age. Gender-related comparisons showed that females had a more pronounced LL and reduced TK. Significant correlations between IP and spinopelvic parameters, with the apex of LL providing the best prediction, were found. However, the overall model quality remained low. Predicting mEPA and bEPA showed positive correlations. The prediction for mEPA L2/3 demonstrated the highest correlation. For bisegmental angles, the most caudal bEPA (L2) exhibited the highest correlation, albeit with some notable absolute differences in the values between measured and predicted values.

Discussion and conclusion: While this study highlights the complexity of the relationship between the pelvis and thoracolumbar parameters, finding a predictive tool for thoracolumbar reduction and stabilization was not possible.

1. Introduction

Spine surgeons are facing a growing incidence of spinal fractures. Approximately 80% of spinal fractures are located at the thoracolumbar region, wherein 50% occur at the thoracolumbar junction (Maier et al., 2010). Once the fracture heals in a kyphotic state, it can lead to kyphotic malformation, and thus, change the sagittal profile of the spine. As a result, the spine's static and dynamic can change, leading to constant pain and restriction of range of motion (Le Huec and Hasegawa, 2016)' (Glassman et al., 2005). Hence, a common surgical aim is to restore the patient's individual sagittal profiles. However, how the premorbid individual sagittal profile can be predicted regarding the reduction of spinal fractures remains to be elucidated.

This study focuses on the optimization of reduction planning for thoracolumbar spine injuries with the aim of restoring the sagittal profile. Currently, reduction planning primarily relies on the surgeon's clinical experience, lacking a well-defined method for estimating the individual premorbid sagittal profile in fractures observed in CT scans.

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While classification systems by Roussouly et al. and Laouissat et al. exist, they offer an assessment of the sagittal profile in the standing position only using spinopelvic parameters, but do not address segmental traumatic injuries (Roussouly et al., 2005)' (Laouissat et al., 2018) and an assessment in the supine position. Notably, planning segmental reductions becomes challenging when there is significant inflection point (IP) variance and when there is no knowledge of the pre-traumatic segmental position. The introduction of normal values in the supine position could significantly enhance the evaluation of thoracolumbar junction fractures, guiding therapy decisions more effectively.

Therefore, this study investigates key aspects of the spinal and pelvic dynamics, as described by Roussouly et al. (2005) and Laouissat et al. (2018) (Roussouly et al., 2005; Laouissat et al., 2018). Our aims include examining the relationship between spinal profile and pelvic parameters in the supine position, assessing the age- and sex-specific variations in spinopelvic parameters, and exploring the potential of spinopelvic parameters (including pelvic incidence (PI), sacral slope (SS), lumbar lordosis (LL), and the apex of the LL) to determine the localization of the inflection point.

Additionally, we examine the lumbar spine, focusing on mono-segmental endplate angle (mEPA) and bi-segmental endplate angle (bEPA) in the area of thoracolumbar transition, respectively von Th9 to L2. Specifically, we explore the correlation between the respective mono- and bi-segmental EPA and their predicted value, based on the adjacent segment angles. This study endeavours to identify indicators that can aid in deducing the individual premorbid sagittal profile of injured patients' spines.

2. Methods

To address the research question a retrospective study was conducted under the approval of the Ethics Committee of the Medical Association of Saxony-Anhalt (10/18). The study used patient data collected through the AGFA IMPAX 6 system and the ORBIS program of the hospital.

Access to CT images was provided by the radiology department. Only CT scans adhering to the polytrauma protocol were utilized, ensuring that patients were not exposed to additional radiation risk.

All Polytrauma CT Scans between 01/01/2015 and 03/06/2019 were examined. Scans were excluded if a spinal fracture occurred, the patient was younger than eighteen, complete visualization of the spine was not possible, fractures occurred in the pelvis or femoral region, scoliosis exceeded 15°, or spondylolisthesis exceeded Meyerding grade 1.

The study's exclusion criteria were developed with reference to previous studies (Roussouly et al., 2005; Laouissat et al., 2018; Anwar et al., 2015). These criteria were also influenced by considerations arising from the patients' supine positions to minimize potential information bias. Specific care was taken to ensure visibility of the entire spine without positioning pillows in the leg region. Additionally, patients with total hip arthroplasty were excluded from the study due to potential changes in spinopelvic parameters associated with this procedure (Kim et al., 2020). The ethnic origin of the patient was not recorded.

After identifying suitable CT scans for the study, all measurements of spinopelvic parameters were conducted by the lead author (AJ) to eliminate interrater bias. The lead author received guidance and practiced the measurement technique with an experienced clinician using practice cases.

Patient-related data were recorded pseudonymously, ensuring privacy and confidentiality. The CT images were accessed and evaluated in the coronal and sagittal planes, with specific attention to the spine's visibility and representation. The apex of the LL and pelvic parameters PI, PT, and SS, were measured following methods described by Roussouly et al. (2005) Mono- and bi-segmental Cobb angles of vertebral bodies were measured starting at the cranial endplate of Th8 up to the Endplate of S1. The predicted EPA (mEPA and bEPA) were calculated as the mean of the caudal and cranial adjacent corresponding mEPA or bEPA, respectively.

The comparison of metric, non-categorical, interval-scaled spinopelvic parameters (PI, PT, SS, global LL, upper and lower arc of LL) to the literature of Roussouly et al. (2005) was performed using summary values and *t*-test for independent samples, assuming no equality of variance. Age related correlation for lumbar lordosis (LL), thoracic kyphosis (TK), pelvic incidence (PI), and the apex of LL and the inflection point (IP) were analysed using Pearson and Spearman correlation, respectively. Differences between genders in LL, TK and the spinopelvic parameters PI, SS, and PT were checked using a *t*-test for independent samples.

The prediction of the inflection point (IP) was analysed using linear regression models for pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), and the apex of the lumbar lordosis. The Nagelkerke's pseudo r^2 was used to describe the quality of the regression model. The correlation of measured and predicted mEPA and bEPA were analysed using Pearson correlation, respectively.

Statistical analysis was conducted using SPSS V29 (SPSS Statistics for Windows, Armonk, NY: IBM Corp) with p = 0.05.

3. Results

3.1. Patients' demographics

A total of 1826 CT scans were screened checking inclusion and exclusion criteria. A total of 287 patients (16 %) could be included in the study, showing a male-to-female ratio of 72 %–28 %. The mean age of the patients was 42±16 years (range: 18–87), with a mean weight of 82 ± 15 kg, mean height of 176 ± 9 cm, and mean BMI of 26 ± 5 kg/m^2.

3.2. Spinopelvic parameters

An overview of the measured spinopelvic parameters in the supine position in comparison to Roussouly et al. and the results of the pairwise comparison of each spinopelvic parameter are given in Table 1.

Comparing our mean data with the literature (Roussouly et al., 2005) no significant differences can be found for the pelvic incidence. The angles of PT, SS, the global LL and the lower and upper arc of LL are different compared to Roussouly et al. (2005) While the SS is larger in our cohort, the PT, the global LL and the lower and upper arc of the LL are smaller.

The IP is localized in one vertebral body (VB) further cranially. The LL and the UA decreased in the study cohort in comparison (LL 10°, UA 6°). There is also an increase in the number of VB in the LL and UA Table 2.

Furthermore, the four LL types described by Roussouly et al. can be detected in the following distribution within the cohort: Type I: 29

Table 1

Comparison of the spinopelvic parameters (pelvic incidence: PI, pelvic tilt: PT, sacral slope: SS, the angle of the lumbar lordosis: LL and the angle of the upper and the lower arc lumbar lordosis: UA, LA) from N = 287 patients compared to the study collective of Roussouly et al. (2005) with N = 160. Data are presented as mean value and standard deviation, as well as the minimum and maximum (in brackets) in degrees, respectively.

Parameter	Our data (Supine position)	Roussouly et al. (2005) (Standing position)	p-value
PI, [°]	52 ± 11 (27–86)	52 ± 11 (34–84)	1.000
PT, [°]	9 ± 6 (-7–29)	12 ± 6 (-5–31)	<0.001
SS, [°]	42 ± 8 (18–73)	40 ± 8 (21–66)	0.012
Global LL, [°]	51 ± 11 (21–84)	61 ± 10 (41–82)	<0.001
UA, [°]	15 ± 7 (0–34)	21 ± 5 (7–35)	<0.001
LA, [°]	36 ± 9 (9–73)	40 ± 8 (21–66)	<0.001

Table 2
Comparison of the localization of the inflection point (IP), the apex of the lumbar lordosis (Apex LL) and the number of vertebral bodies (VB) of the lumbar lordosis of the study collective vs. Roussouly et al. (B: base plate, M: Middle).

Parameter	our data Supine position	Roussouly et al. (2005) Standing position
IP	Th12 M ± 1 VB (L4 M-Th8)	L1 M ± 1 VB (L4 M-Th10 M)
Apex LL	L4 M ± 0.5 VB (L5 B- L3M)	L4 M ± 1 VB (L5 B-L2 M)
No. VB LL	6 ± 1 (2–10)	4.5 ± 1 (1.5–7.5)
No. VB UA	4 ± 1 (2–9)	3 ± 1 (0.5-5)
No. VB LA	1.5 ± 0.5 (0–3)	1.5 ± 0.6 (0–3.5)

(10.1%), Type II: 27 (9.4%), Type III: 124 (43.2%), Type IV: 107 (37.3%). Type III is the most common identified in 124 patients and Type II is the least common, which was observed in 27 patients. However, Type I of the study cohort is underrepresented by 10.9% compared to the observations made by Roussouly et al., while Type III is overrepresented by 5.2% and Type IV by 7.3%.

The type III AP described by Laouissat et al. can also be identified with 12.9% ($N = 37$).

While investigating the influence of age on spinopelvic parameters, age-related changes were observed. The LL ($p = 0.001$, $r = 0.197$), TK ($p = <0.001$, $r = -0.325$) and PI ($p = 0.019$, $r = 0.139$) increase with age. In addition, the apex ($p = 0.001$, $r = -0.200$) and the IP ($p = 0.050$, $r = -0.116$) move further cranially with age.

In terms of gender, differences in LL and thoracal kyphosis (TK) were noted, with females having a more pronounced LL (+4°, $p = 0.014$) and less TK (−5°, $p < 0.001$). When analysing the variables, gender and pelvic parameters PI ($p = 0.968$), SS ($p = 0.983$) and PT ($p = 0.728$) revealed no gender-specific differences.

When it comes to the prediction of the IP by using the spinopelvic parameters, linear regression analysis showed significant correlations between the IP and the parameters PI ($p < 0.001$), SS ($p < 0.001$), LL ($p < 0.001$) and the apex of LL ($p < 0.001$). However, the model's quality varied between the used variables, with the apex of the LL providing the best prediction, but still with a low model quality Table 3. Using the spinopelvic parameters seems not sufficient for the prediction of the IP.

Regarding the aim to predict mEPA using the mean mEPA of the cranial and caudal adjacent mono-segmental segment angles, positive correlations were observed for each segment. The measures and predicted mEPA are given in Table 4. The prediction of the mono-segmental segment L2/3 showed the highest correlation with good variance clarification of 0.578.

Focusing on predicting the bEPA, using the mean of the cranial and caudal adjacent bEPA, significant correlations were found for each segment. Just like for the mEPA, the most caudal bEPA (bEPA of L2) showed the highest correlation Table 5. In general, the variance clarification was lower compared to the mEPA. However, the difference between the measured and predicted bEPA for L2 was with 7° quite large.

4. Discussion

This study aimed to analyse the potential of pelvic parameters, ascertain from whole-body CT scans in supine position, to estimate the physiological sagittal profile of the spine. This estimation could be an aid in fracture reduction planning.

Table 3
Linear regression model quality (R^2), according to Nagelkerke's pseudo r^2, predicting the inflection point for the parameters pelvic incidence (PI), sacral slope (SS), lumbar lordosis (LL) and the apex of the LL (Apex LL).

	PI	SS	LL	Apex LL
Nagelkerke R^2	0.064	0.110	0.098	0.144

The comparison of the results with data from the literature shows that PI is the only pelvic parameter that showed no difference, because it is an anatomical parameter and thus it is not dependent on body position. Despite the fact that SS and PT appear comparable to the literature and their values are in a comparable range, there are still significant differences. As expected, the transfer of the spinopelvic parameters from standing to supine position is limited. Notable differences were observed in spinal parameters, specifically lumbar lordosis and upper arc, which decreased significantly in the supine position (LL decreased by approximately 10°, UA by about 6°). Moreover, the Roussouly classification was applicable to data that were acquired from CT images in the supine position. Age- and sex-specific changes in spinopelvic parameters were identified. Although a correlation was observed between the IP and spinopelvic parameters, it was not precise enough to predict IP location. The estimation of mono- and bisegmental endplate angles based on mean values was possible, but the accuracy was limited. Due to this finding a clinical use for reduction planning cannot be recommended.

4.1. *Patient demographics and study size*

The study included a total of 287 patients who underwent polytrauma CT scans. The study size is considered appropriate within the context of relevant literature, with references to studies by Roussouly et al., Lyer et al., and Laouissat et al. (Roussouly et al., 2005)’ (Laouissat et al., 2018)’ (Iyer et al., 2016) These studies had varying patient caseloads, but the present study is deemed to have sufficient power based on similar variability. However, a larger study population could enhance external validity.

4.2. *Average age*

The average age of patients in this study was 42 years, which is notably higher compared to similar studies (Roussouly et al., 2005)’ (Iyer et al., 2016). The study aimed to ensure PI as a constant variable by including patients aged 18 years and older who were skeletally mature. We also sought to include patients of different ages to improve comparability with previously published data. The youngest patient in the study was 18, and the oldest was 87 years old. We demonstrated the age dependency of LL, TK, PI, the apex of lumbar lordosis, and IP. If there are age differences between the studies, these differences should also manifest in LL, TK, PI, apex, and IP. What we do not know, however, is how much this age influence differs between lying and standing positions.

4.3. *CT scan and angle measurement considerations*

Several critical points must be considered regarding the CT scans and angle measurements used in the study. Two different whole-body CT protocols, the "TIME protocol" and the "DOSE protocol," were utilized at the hospital, based on clinical patient conditions. Previous research by Reske et al. indicated that the "DOSE protocol" offered significantly better image quality compared to the "TIME protocol", which was also observed when measuring segmental angulation of the thoracolumbar spine (Reske et al., 2018). This resulted in reduced image quality for some patients, especially at the upper thoracal spine (Th1-5), potentially affecting the manual determination of corner points for endplate angle measurement.

Notably, the CT scans may have underestimated the severity of listhesis due to the exclusion criterion of spondylolisthesis exceeding Meyerding grade I. Previous research by Segebarth et al. found that one-third of spondylolisthesis cases were missed when assessing spinal positions using MRI in the supine position compared to lateral radiographs in standing, highlighting the potential for misclassification bias (Segebarth et al., 2015).

The study examined various parameters, including PI, PT, SS, apex of the LL, LA, and the number of vertebral bodies in the LA, and found,

Table 4
Presentation of the measured vs. the predicted mono-segmental EPA. Shown as mean value and standard deviation, as well as the respective minimum and maximum (in brackets) in degrees.

	measured mEPA		predicted mEPA				
	mean ± sd	(min - max)	mean ± sd	(min- max)	r	r^2	p
Th9/Th10	−3°±4°	(-18°–8°)	−4°±3°	(-17°–3°)	0.668	0.446	<0.001
Th10/11	−4°±4°	(-17°–7°)	−4°±3°	(-12°–3°)	0.587	0.345	<0.001
Th11/Th12	−5°±4°	(-17°–6°)	−4°±3°	(-13°–3°)	0.617	0.381	<0.001
Th12/L1	−4°±5°	(-16°–12°)	−3°±4°	(-14°–8°)	0.720	0.518	<0.001
L1/2	−1°±5°	(-16°–13°)	0° ± 4°	(-9°–12°)	0.727	0.529	<0.001
L2/3	5° ± 5°	(-8°–21°)	5° ± 4°	(-6°–19°)	0.760	0.578	<0.001

Table 5
Presentation of the measured and the predicted bi-segmental EPA. Shown as mean value and standard deviation, as well as the respective minimum and maximum (in brackets) in degrees.

	measured bEPA		predicted bEPA				
	mean ± sd	(min- max)	mean ± sd	(Min- Max)	r	r^2	p
Th9	−6°±5°	(-31°–6°)	−9°±4°	(-20°–1°)	0.446	0.199	<0.001
Th10	−6°±5°	(-21°–7°)	−8°±3°	(-19°–1°)	0.420	0.176	<0001
Th11	−7°±5°	(-23°–6°)	−4°±3°	(-12°–6°)	0.284	0.081	<0.001
Th12	−6°±6°	(-21°–11°)	−1°±3°	(-8°–10°)	0.383	0.147	<0.001
L1	−2°±6°	(-16°–18°)	4° ± 4°	(-6°–19°)	0.495	0.245	<0.001
L2	5° ± 7°	(-10°–27°)	12° ± 5°	(-2°–26°)	0.587	0.345	<0.001

despite significant differences between our date and these of Roussouly et al. and Laouissat et al., a relative consistent for the types of spine shape between the recumbent and standing positions (Roussouly et al., 2005; Laouissat et al., 2018). These results align not only with the works of Roussouly et al. and Laouissat et al. but also with various other studies, suggesting that these parameters are possibly position-independent and could contribute to the determination of the sagittal profile.

The findings that have been accumulated during this study, combined with previous research, indicate that two-thirds of the LL and the basis of the sagittal profile can be attributed to the L4-S1 vertebrae. Future efforts may focus on developing a method to determine the remaining third of the LL and the IP to aid in planning reductions, possibly by modifying the established formula and incorporating Roussouly's four LL types.

Differences in pelvic parameters due to the patient's position were confirmed. While there were minor alterations in parameters like SS and PT, these changes were considered negligible. The notable changes occurred in the spinal parameters, specifically LL and upper arc (UA), which flattened in the supine position. The IP shifted cranially, and the UA increased by one vertebral level. Position-dependent change in the LL was attributed to the influence of gravity, with standing relying on equilibrium and acting forces, while supine position depended on support, such as the CT stretcher.

The study successfully identified the four LL types described by Roussouly et al., with varying distributions in the cohort. Differences from Roussouly's data could be attributed to the supine position's effects on parameters like SS, potentially causing borderline cases to shift categories. The impact of UA changes on the localization of the LL apex and IP could lead to shifts between LL types. Comparing our Data with additional standing radiographs, within the same cohort, would have provided further insights into these effects. This was not possible due to ethical concerns for applying radiation only for research purposes.

4.4. *Age- and sex-specific changes*

This study investigated the impact of age and gender on spinopelvic parameters. We found that lumbar lordosis, thoracic kyphosis, and PI increased with age, while the apex of LL and IP moved cranially. The observed increase in LL and PI with age could be associated with sacroiliac osteoarthritis, as the sacroiliac joint is the only mobile part of the pelvis. This result aligned with prior research by Vrtovec et al. (2012).

Regarding LL, this study found less lordosis in a weight-bearing (standing) position compared to the supine position. The aging process of the whole spine, involving disc height reduction, extensor muscle atrophy, and degenerative bone changes, may influence these findings (Le Huec et al., 2019). Furthermore, the increase in hip flexion contractures with age can have significant implications for spinopelvic parameters and sagittal balance and may affect the results (Pinheiro et al., 2022). Older individuals may also experience segmental syndesmophytes in the thoracic spine, leading to some rigidity. These insights are pertinent for fracture reduction planning in elderly patients.

Gender also appeared to have an impact, with female patients displaying a more pronounced LL and decreased TK. While gender differences in spinopelvic parameters were confirmed for LL and TK, no significant differences were found in SS and PI, contrasting with some prior research findings (Iyer et al., 2016).

This study acknowledged certain limitations in analysing the data related to age and gender. Subgroup sizes based on age and gender were relatively small, with the need to merge some older age groups, possibly introducing bias due to outliers. The data was skewed towards males due to study selection criteria, which did not consider gender separately.

4.5. *Localization of the inflection point (IP)*

Results showed a positive correlation between the IP and several spinopelvic parameters, including PI, SS, LL, and the apex of the LL. The apex of the LL had the highest, but still moderate correlation with the IP. However, despite these correlations, the study concluded that spinopelvic parameters were not good enough to predict the exact localization of the IP.

The IP signifies the point at which the spinal curvature transitions from lordosis to kyphosis, and determines the number of vertebral bodies involved in this transition. Earlier research had limited studies exploring the correlation between spinopelvic parameters and the IP. A 2020 study by Pan et al. on asymptomatic patients found correlations between the IP and thoracic kyphosis, LL, apex of LL, and UA (Pan et al., 2020). Our findings confirm these correlations and further reveal a correlation with PI and SS.

This study's evaluation of radiomorphologically healthy patients determined that the average location of the IP was at Th12/L1 (Th12 30%; L1 33.4%). This aligns with existing literature (Pan et al., 2020)' (Berthonnaud et al., 2005). However, the study emphasized the wide range of IP localization from Th8 to L4 within the study population, highlighting the lack of a universal fixed IP location at Th12/L1 for all patients. This variability underscores the importance of careful consideration when applying guidelines for thoracolumbar spinal injuries, as inaccurate treatment based on a rigid IP location could lead to sagittal imbalance.

4.6. Segment determination via m- and bEPA

The study examined the hypothesis that the mean endplate angle value of adjacent segments can predict the segment endplate angle in between. This hypothesis was accepted; however, it needs to be viewed critically in terms of its accuracy. The predictability of segment position varies within the thoracolumbar region, with segment L2/3 being more accurately predicted than Th10/11, indicating substantial variability in predicting segment positions for both types of EPA. We found the strongest correlation between predicted and measured values in the caudal part. However, the correlation can be quite good, even with an existing offset. This is particularly evident for the bEPA. When using bi-segment angles, it is apparent that the segments used contain information from segments that are further away from the predicted segment. This implies that greater variability can be incorporated into the values. This would justify the statistically demonstrated better prediction of the mono-segmental angles. However, essentially, this suggests that EPA alone is not sufficient for fracture reduction planning. However, if they are used for prediction, we would clearly see the superiority of mEPA over bEPA.

4.7. Limitations

The study's retrospective, monocentric (single-center), non-randomized, and unblinded design limits the generalizability of the findings. The results may not necessarily apply to a broader population.

After selecting the CT images, that could be included in the study, all measurements of the spinopelvic parameters were carried out by the lead author herself. At the beginning of the study, an experienced clinician demonstrated the measurement technique to the lead author and practiced it with her. Despite the exercises and the increased experience gained during the study, we cannot rule out the possibility that interrater bias has occurred. It would have been desirable if the cases were cross-matched by a second clinician. This would have increased the interrater reliability.

Furthermore, the study's focus on the supine position restricted the scope of the findings to the sagittal profile of the whole spine and the regional alignment of the spine, rather than assessing sagittal balance, which is typically determined by methods involving the C7 plumb line and the sagittal-vertical axis.

Moreover, different ethnic groups are known to exhibit variations in whole spine profiles (Pan et al., 2020)' (Zhu et al., 2014)' (Hu et al., 2020). However, the study's dataset was obtained from an urban trauma center in eastern Germany, and the ethnicity of the patients was not recorded in a standardized manner. Considering the diverse ethnic backgrounds of patients in Germany, which has a significant immigrant population, potential ethnic differences may have influenced the study results. This lack of ethnic data and potential ethnic diversity among the patient population is a limitation. In conclusion, these limitations should be considered when interpreting and applying the findings of this study to other populations or clinical scenarios.

5. Conclusion

This study provides a comprehensive analysis of the sagittal profile in the supine position. It demonstrates that the spinopelvic parameters and the lumbar lordosis type described by Roussouly et al. can also be determined in the supine position. Nevertheless, there are position, age and gender-dependent changes that need to be considered.

Moreover, it shows that both types of endplate angles (EPA), mono- and bi-segmentally EPA, have a strong correlation between predicted and measured values in the caudal part of the spine. The more cranially the EPAs are, the more inexact the predicted values will be. Hence, essentially, this suggests that EPA alone is not sufficient for fracture reduction planning.

The findings highlight the complexity of the relationship between pelvis and thoracolumbar parameters and the limitations of using spinopelvic parameters alone for estimating the premorbid individual sagittal profile of the spine, despite some reliable correlations between pelvic parameters and lumbar EPA's.

Furthermore, it showcases the need for further research to develop a reliable algorithm to estimate the premorbid individual profile enabling surgeons to execute individual fracture reduction planning.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used DeepL in order to translate. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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