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Variation in lumbar regional kyphosis between supine and standing positions. Implications for spinal fracture management

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ABSTRACT

Purpose: The variation of lumbar lordosis between standing and supine position is poorly explored in literature. This study sought to analyze variation of lumbar regional angulations (RA) in healthy volunteers between standing and supine positions, according to pelvic incidence (PI).

Methods: This study included 171 patients who had an abdominal CT-scan in supine position and 879 healthy volunteers with full-body stereoradiographs. The two populations were matched using a propensity score including age, PI, and sex. PI and RAs for all vertebrae from T12 to L5 (measured between the overlying vertebra's upper endplate of and the underlying vertebra's lower endplate) were assessed. Studied parameters were compared between Supine and Standing groups in the whole cohort and in every PI group. Multivariate analysis was performed to ascertain the effect of position change.

Results: The analysis was performed on 314 subjects (157 matched in each group). In the overall cohort, all RAs from L1 to L4 were more lordotic in the Standing group, ranging from 3 to 8° difference (all $p < 0.001$), while T12 and L5 RAs were comparable in both groups ($p = 0.55$ and 0.49 , respectively). Multivariate analysis confirmed the significant associations between subject's position and all RAs except for L5 and T12. RA variation between positions occurred at more vertebral levels and tended to be greater in higher PI groups.

Conclusion: RA values in the lumbar spine are more lordotic in standing position than supine, except for T12 and L5. These results help estimate RA in Standing position in patients with lumbar fractures.

Level of evidence: IV.

1. Introduction

Thoraco-lumbar fractures are frequent, reaching up to 11 in 1000 persons per year, and can induce major disability [1,2]. Hence, they can be considered as a public health issue. Indications for surgery and surgery type vary among centers and have evolved with the improvement of surgical techniques [3]. Indeed, minimally invasive and percutaneous techniques have become preponderant in the treatment of non-neurological compression fractures [3–5]. In case of neurological impairment, urgent decompression and stabilization is required to improve neurological recovery [6]. However, for compression fractures

without neurological injury or mechanical instability, the main criterion to consider in order to indicate surgery is regional kyphosis. Indeed, post-traumatic malunion can be responsible for debilitating back pain, and might lead to a revision surgery, often requiring osteotomy procedure [7]. Several percutaneous techniques have been proven efficient to correct kyphosis, that can be used after assessment of post-traumatic deformity [8].

To assess post-traumatic kyphosis, several criteria are commonly used (Fig. 1). First, the vertebral wedge angle measures vertebral kyphosis. Second, regional kyphosis takes into account adjacent discs and vertebral bodies [9]. This parameter allows taking into account

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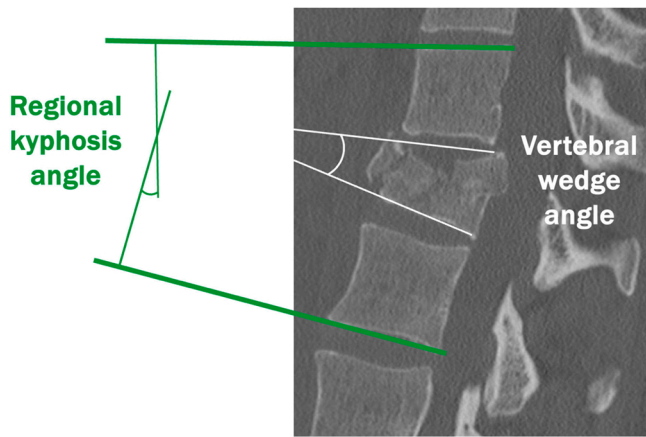


Fig. 1. Illustration of vertebral wedge angle and regional kyphosis angle measurement on CT-scan.

adjacent disc lesions, predominantly occurring at the cranial level at follow-up [10]. Last, traumatic regional angulations can be obtained by subtracting regional kyphosis angles from reference values [11]. These normative values have been provided by Vialle, Guigui et al. [12]. Nevertheless, these abacuses present two limitations: they were calculated regardless of subject's pelvic incidence (PI) and on standing radiographs. However, baseline radiological check-up for patients presenting thoracic or lumbar fracture consists of a CT-scan in supine position, and on the other hand, it has been demonstrated that lumbar lordosis is dependent on pelvic incidence value [13]. Last, Marie-Hardy et al. published regional angulations abacuses on CT-scans in a healthy population according to patients' PI [14].

However, the lumbar lordosis variation between standing and supine position is poorly explored in literature. The goal of this study was to analyze lumbar regional angulations variation in healthy volunteers between standing and supine positions, according to pelvic incidence. Our hypothesis was that regional angulations were lower in supine position, and that this variation was greater in patients with larger pelvic incidence.

2. Methods

2.1. Population

This was a multicentric retrospective study, including two groups of subjects. The first group, "Supine", included 171 patients from Marie-Hardy et al.'s study who had an abdominal CT-scan in supine position at an emergency department (120 kV, 65 mAs - Siemens Somatom Definition Edge®) [14]. All patients presented with abdominal pain and the CT-scans were realized after pain control by adequate medication to collect normal CT-scans in healthy control subjects regarding spinal pathology.

The second group, "Standing", included 879 healthy volunteers aged over 18 between 2011 and 2023, who had full-body biplanar radiograph (EOS™ system, Alphatec, CA, USA) in free-standing position (in upright position, fingers positioned on the cheeks or clavicles, and one foot slightly forward) [15].

Patients were not included if they reported pain in the spine, or presented any spinal condition, musculoskeletal deformity, scoliosis, isthmic or degenerative spondylolisthesis, lumbosacral transitional vertebra, and history of spinal surgery. This study was approved by regional ethics committees (APHP approval #20220630143858 and C. P.P. Ile-de France VI approval N° 6001 and 6061). All participants provided their informed written consent.

2.2. Parameters

Demographic parameters including age and sex were collected. Pelvic incidence (PI) was measured between the perpendicular to sacral plateau and the axis joining the center of femoral heads to the sacral plateau center [13]. On CT-scans, PI was measured on two dimensional orientated views at 300 mm-thickness images [16,17].

According to Cobb method, regional angulations (RA) were measured for each vertebra from T12 to L5, between the upper endplate of the overlying vertebra and the lower endplate of the underlying vertebra (Fig. 2) [9]. For L5 vertebra, RA was measured between the upper endplate of L4 and the sacral plateau.

2.3. Statistical analysis

The two populations were matched using a propensity score

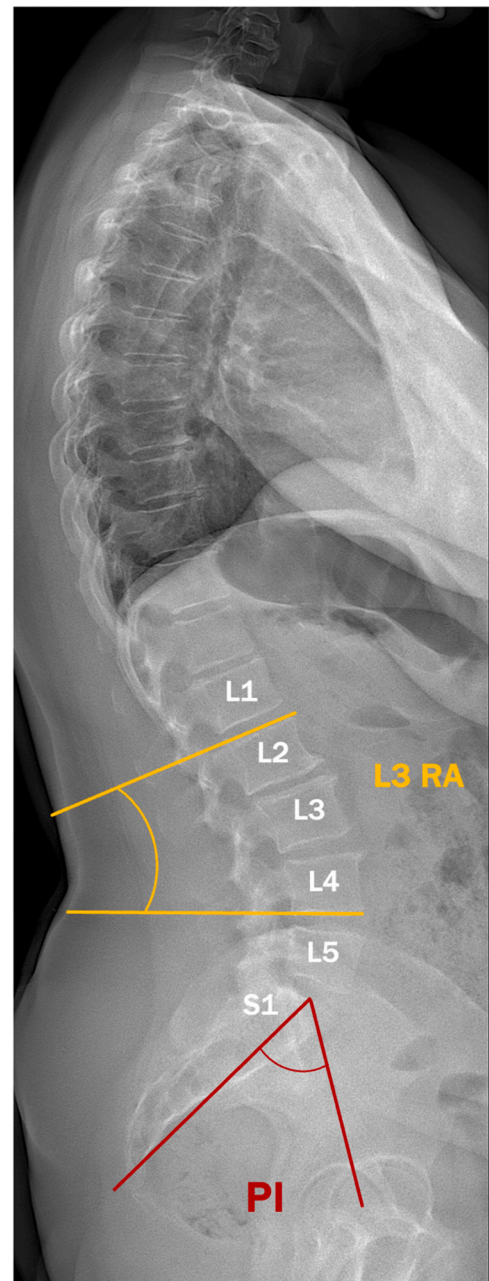


Fig. 2. Representation of pelvic incidence (PI) and L3 regional angulation (RA) measurements on a standing lateral X-ray.

including age, PI, and sex (caliper = 0.05). All variables were tested for normality using Shapiro-Wilk's test. First, a global description of the cohort was made, with parameters expressed by their means \pm standard deviation (SD). Studied parameters were compared between Supine and Standing groups using Student's *t* tests if applicable, or Wilcoxon's tests otherwise. Correlations were sought between RA at each level and PI and age.

The cohort was divided into four PI subsets according to Jenks discretization method: PI-1 (PI < 43°), PI-2 (43°; 53°), PI-3 (53°; 62°), PI-4 (>62°). Comparisons between supine and standing positions were further carried out in every subset of pelvic incidence. Last, multiple linear regressions were performed for each regional angulation, including age, PI, and group to ascertain the effect of position change.

By convention, lordosis is expressed by negative values whereas kyphosis is given with positive ones. All statistical analyses have been carried out using RStudio (version 2024.04.1 + 748), with *p*-values lower than 0.05 considered significant.

3. Results

3.1. Cohort description

This study included 314 subjects, 157 in each group (Supine and Standing). Both groups were comparable in terms of age, pelvic incidence, and sex ratio ($p = 0.25$, $p = 0.71$ and $p = 1$, respectively) There were 50.3% of women, mean age was 39.2 ± 14.5 years (range = 18 to 77 years). Mean pelvic incidence was $52.9 \pm 9.8^\circ$ (Table 1).

In the overall cohort, all regional angulations from L1 to L4 were more lordotic in the Standing group (all $p < 0.001$) (Fig. 3, Table 1). Conversely, the T12 and L5 regional angulations were comparable in the two groups ($p = 0.55$ and 0.49 , respectively) (Fig. 3, Table 1). There were low correlations of age with L4 and L5 regional angulations, only in Standing group (both $r = 0.2$, $p = 0.02$).

Multivariate analysis confirmed the significant associations between subject's position and all regional angulations except for L5 and T12 (Table 2). Pelvic incidence was an independent factor associated with increasing RA at each level, while age presented no significant relationships with any RA (Table 2).

3.2. PI subsets

In every PI subset, Standing and Supine subjects were comparable in terms of PI and age (Table 3). In PI-1 subset, there were no significant differences between Standing and Supine groups for L1, L2 and L5 RA ($p = 0.60$, $p = 0.05$, and $p = 0.24$, respectively) (Table 4). In PI-2 subset, L2, L3 and L4 RA were significantly more lordotic in Standing group with median differences of -6.0° , -8.0° , and -5.7° , respectively (Table 4). In PI-3 and PI-4 subsets, RA values from L1 to L4 were more lordotic in Standing group, with differences ranging from -4.0° to -9.3° (Table 4).

Table 1

Studied parameters comparison between Supine and Standing groups. Significant *p*-values are denoted with an asterisk.

Cohort	Supine	Standing	Difference	<i>p</i>
n	157	157	-	-
PI (°)	53.1 ± 9.7	52.7 ± 9.9	-	0.71
Age (years)	39.4 ± 11.7	39.0 ± 16.7	-	0.25
Sex (females)	50.3%	50.3%	-	1
L5 RA (°)	-37.7 ± 7.3	-37.2 ± 7.4	0.5 ± 10.0	0.55
L4 RA (°)	-29.7 ± 7.9	-35.0 ± 7.8	-5.4 ± 12.0	<0.001*
L3 RA (°)	-13.1 ± 7.4	-21.5 ± 7.8	-8.4 ± 11.4	<0.001*
L2 RA (°)	-4.3 ± 6.8	-10.7 ± 7.7	-6.3 ± 10.8	<0.001*
L1 RA (°)	2.0 ± 5.1	-1.1 ± 7.4	-3.2 ± 9.0	<0.001*
T12 RA (°)	5.7 ± 4.9	6.0 ± 6.7	0.3 ± 8.3	0.49

4. Discussion

Defining optimal alignment has become cornerstone in the treatment of spinal conditions, even in short fusions. It appears irrelevant not to do so for spinal traumatology patients (Fig. 4). In the setting of lumbar fractures, patients present with preoperative CT-scan in supine position, as they are asked to remain in recumbent position. However, the alignment goal must be determined according to standing position. How does segmental lordosis vary between supine and erect position? Does this variation change with patient's pelvic incidence? What correction target for which patient? To our knowledge, there were no data in literature regarding this matter. This study exhibited significant variation in lumbar regional angulations between standing and supine positions, except for L5 and T12. Here are provided reference values for supine and standing positions according to each PI group, and their corresponding difference. The magnitude of variation between positions tended to increase along with pelvic incidence value for L3 and L4 RA.

In this study, a significant increase in regional angulations was noted in standing position compared to supine. These findings are consistent with Wood et al.'s results in a study comparing standing and supine lumbar lordosis in 50 healthy volunteers and 50 low back pain patients [18]. Ohyama et al. studied preoperative lumbar lordosis variation between erect and supine positions before a transforaminal lumbar interbody fusion procedure [19]. They noted poorer post-operative clinical outcomes in patients with less than 4° variation in preoperative lumbar lordosis, claiming that this could be used as a tool to predict patients' post-operative residual symptoms.

The T12 and L5 regional angulations did not significantly vary between the two positions, in the cohort and in every PI subset. These findings indicate that supine RA values can reasonably be considered as reference when treating patients with a T12 or L5 fracture. This result is particularly useful given the important proportion of T12 location in thoraco-lumbar spine fractures [20]. This low variation in T12 RA may be explained by the lesser mobility of the thoracic spine due to the rib cage to which it presents close relationship [21,22]. Interestingly, Prost et al. described the T10-L1 segment as being invariant regardless of age and pelvic incidence in a whole-spine alignment study [23]. Regarding L5 RA, its low variation between Supine and Standing can be explained by the lower range of motion in flexion at the L5-S1 level [24]. The ilio-lumbar ligaments are likely responsible for this decreased range of motion as their posterior bands control forward flexion on L5 over S1 [25].

The normative values provided in the present study can help the surgeon determining what should the patient's regional angulation be at the fracture level according to his pelvic incidence, further indicating lumbar alignment in upright position. In this study, the change in regional angulations between standing and supine position varied according to pelvic incidence, with RA changes tending to be greater in subjects with larger PI. In PI-1 subset, L2 and L1 RA did not significantly differ between the two position groups, as well as L1 RA in PI-2 subjects. Conversely, in PI-3 and PI-4 subsets, L1 and L2 RA values were significantly more lordotic in Standing group. More, the variation in RA in the upper lumbar spine (L1 and L2) tended to be greater in the two higher PI groups. For instance, L1 RA difference between the two groups was -4.1° in PI-4 subset versus -1.1° in PI-1 subjects.

It is important to consider spino-pelvic alignment in standing position when treating patients with lumbar fractures [26]. Indeed, in addition to the preoperative variations previously detailed, post-operative kyphosis increases in instrumented spine when shifting from prone to standing position. Thus, Finoco et al. exhibited a 2.3° correction loss between intra-operative and post-operative X-rays a few days after surgery [11]. This correction further lost 4.1 more degrees on average at one-year follow-up. These results suggest that an over-correction may be useful to compensate for subsequent correction loss. This correction loss occurs mainly in the discs, as demonstrated by Wang et al. who exhibited significant regional kyphosis increase while

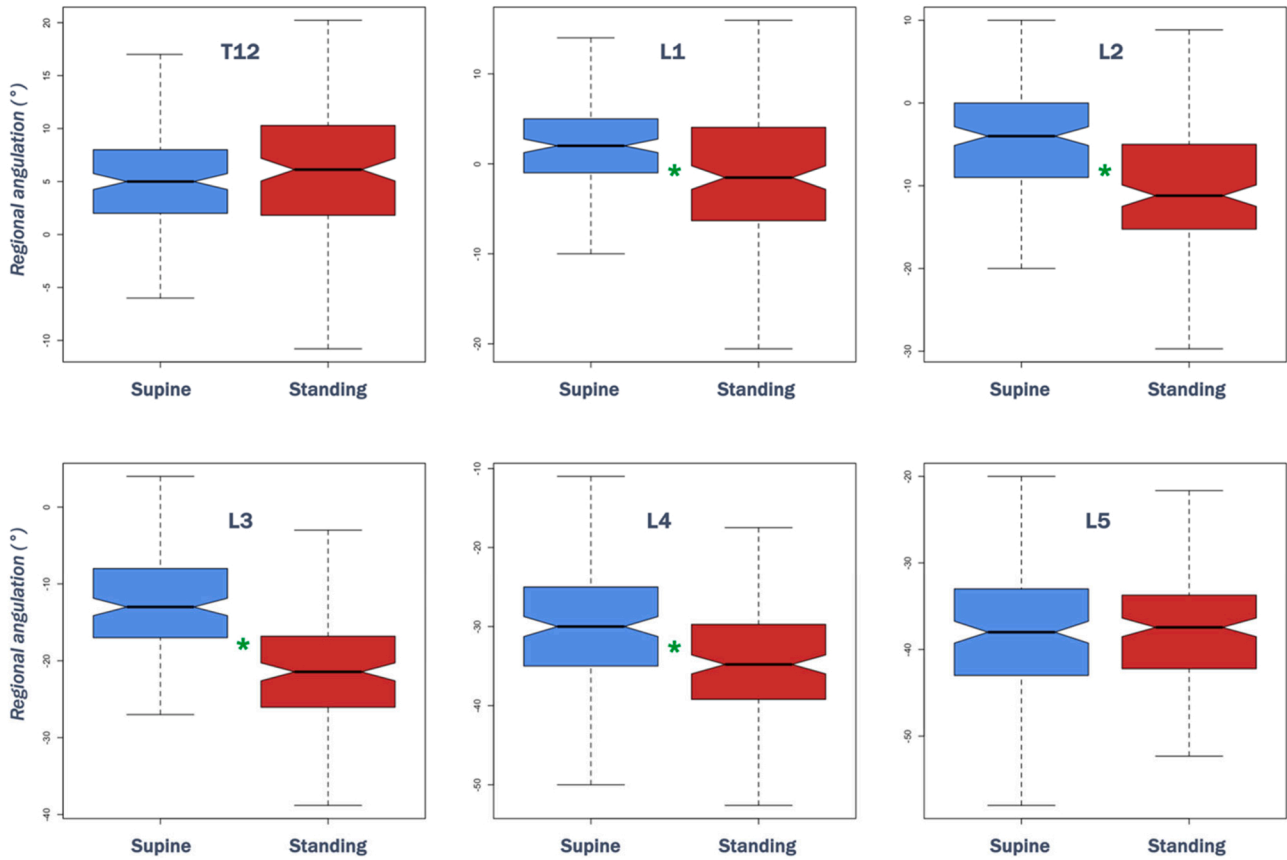


Fig. 3. Regional angulations from T12 to L5, in Supine and Standing groups. Significant differences between the two groups are denoted with a green asterisk.

Table 2

Multivariate β coefficients and respective p-values for each regional angle. Significant p-values are marked with an “***”.

	Position (Standing vs Supine)		PI		Age	
	β	<i>p</i>	β	<i>p</i>	β	<i>p</i>
L5 RA (°)	0.44	0.58	-0.26	<0.001*	0.05	0.07
L4 RA (°)	-5.50	<0.001*	-0.33	<0.001*	0.05	0.05
L3 RA (°)	-8.49	<0.001*	-0.31	<0.001*	-0.02	0.56
L2 RA (°)	-6.46	<0.001*	-0.30	<0.001*	0	0.87
L1 RA (°)	-3.24	<0.001*	-0.23	<0.001*	0.02	0.33
T12 RA (°)	0.30	0.65	-0.10	0.004*	0.04	0.12

Table 3

Sample size description and comparison of age and pelvic incidence between groups in each PI subset. Significant p-values are marked with an “***”.

	Supine	Standing	<i>p</i>
PI-1			
n	26	28	-
PI (°)	38.9 ± 4.0	38.5 ± 3.7	0.72
Age (years)	35.5 ± 11.8	36.7 ± 16.4	0.83
PI-2			
n	52	52	-
PI (°)	48.3 ± 3.0	48.0 ± 2.6	0.65
Age (years)	41.3 ± 10.7	40.4 ± 18.6	0.25
PI-3			
n	54	51	-
PI (°)	57.8 ± 2.7	57.8 ± 2.7	0.51
Age (years)	40.7 ± 12.6	40.1 ± 16.0	0.72
PI-4			
n	25	26	-
PI (°)	68.0 ± 3.8	67.5 ± 3.5	0.80
Age (years)	36.7 ± 11.0	37.1 ± 16.1	0.58

Table 4

Comparison of regional angulations between Supine and Standing in the four PI subsets. Significant p-values are denoted with an “***”.

	Supine	Standing	Difference	<i>p</i>
PI-1				
L5 RA (°)	-32.3 ± 6.5	-34.7 ± 5.9	-1.5 ± 10.3	0.24
L4 RA (°)	-24.5 ± 8.3	-30.7 ± 5.9	-6.2 ± 13.9	0.004*
L3 RA (°)	-8.9 ± 7.6	-15.4 ± 5.3	-6.2 ± 13.3	0.001*
L2 RA (°)	-0.9 ± 6.8	-3.7 ± 5.7	-2.8 ± 12.5	0.05
L1 RA (°)	3.9 ± 6.1	5.4 ± 6.0	1.5 ± 10.7	0.60
T12 RA (°)	6.1 ± 4.1	8.9 ± 5.1	2.8 ± 8.1	0.03*
PI-2				
L5 RA (°)	-37.5 ± 7.3	-35.3 ± 8.0	2.2 ± 9.6	0.18
L4 RA (°)	-29.1 ± 6.3	-33.3 ± 6.6	-4.2 ± 10.0	0.004*
L3 RA (°)	-13.0 ± 6.0	-20.2 ± 7.3	-7.2 ± 10.4	<0.001*
L2 RA (°)	-4.0 ± 6.0	-9.3 ± 6.6	-5.3 ± 9.3	<0.001*
L1 RA (°)	2.1 ± 4.9	0.3 ± 7.0	-1.8 ± 8.3	0.12
T12 RA (°)	5.4 ± 5.4	7.3 ± 6.4	1.9 ± 7.4	0.08
PI-3				
L5 RA (°)	-38.4 ± 6.5	-38.1 ± 5.6	0.3 ± 8.5	0.74
L4 RA (°)	-30.1 ± 7.4	-36.0 ± 6.6	-5.9 ± 11.3	<0.001*
L3 RA (°)	-13.6 ± 6.9	-23.2 ± 6.0	-9.6 ± 10.4	<0.001*
L2 RA (°)	-5.5 ± 6.5	-13.3 ± 6.3	-7.8 ± 10.1	<0.001*
L1 RA (°)	1.0 ± 4.8	-4.4 ± 6.3	-5.4 ± 8.3	<0.001*
T12 RA (°)	5.5 ± 4.8	3.8 ± 7.6	-1.7 ± 9.3	0.12
PI-4				
L5 RA (°)	-42.0 ± 6.7	-41.6 ± 8.5	0.4 ± 12.7	0.80
L4 RA (°)	-35.2 ± 8.4	-41.4 ± 9.5	-6.2 ± 14.9	0.01*
L3 RA (°)	-16.8 ± 8.9	-27.5 ± 8.8	-10.7 ± 13.1	<0.001*
L2 RA (°)	-5.9 ± 7.8	-15.7 ± 7.8	-9.8 ± 12.8	<0.001*
L1 RA (°)	2.0 ± 4.7	-4.7 ± 6.1	-6.7 ± 9.5	<0.001*
T12 RA (°)	6.1 ± 5.0	4.5 ± 5.2	-1.6 ± 8.4	0.36

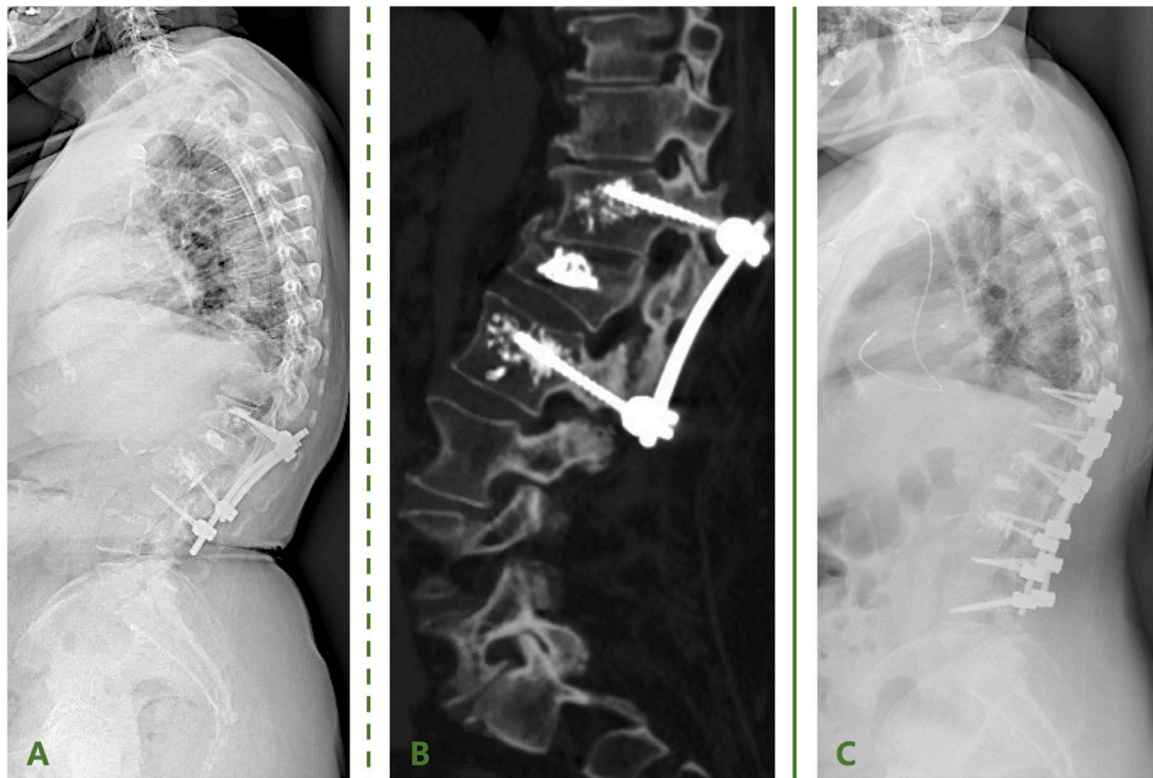


Fig. 4. Example of a 67-year-old patient, treated for an L1 compression fracture with percutaneous fixation from T12 to L3, with L1 kyphoplasty (A). CT-scan confirmed poor correction of vertebral wedge and regional kyphosis angle (B). Posterior fusion extension from T10 to L4 was performed with L1 pedicle subtraction osteotomy (C).

vertebral wedge angle remained stable after short fixations in thoraco-lumbar burst fractures [27]. Further, Lee et al. found a significant correlation between overlying disc injury and secondary correction loss [28]. These results underline the necessity to consider more than the fractured vertebral body only, but also to take regional kyphosis into account in order to obtain optimal alignment for patients.

4.1. Limitations

The main limitation of this study is that we were not able to compare supine and standing images in the same subjects, as we compared individuals from two distinct cohorts. However, subjects were propensity-score-matched so they were comparable in terms of age, sex, and pelvic incidence in the two groups. Moreover, it seems difficult from an ethical standpoint to ask a healthy volunteer to undergo both a standing X-ray and a CT-scanner, notably regarding irradiation. Another limitation is the absence of focal alignment for each lumbar disc and vertebral body as well as global alignment measurement.

5. Conclusion

Regional angulation values in the lumbar spine are more lordotic in standing position than supine, ranging from 3 to 8° difference. This difference was more important in high-PI patients for L1 and L2 levels. No significant difference between positions was observed for T12 and L5 regional angulation values.

These results indicate that for lumbar fractures, patient's PI and standing alignment must be considered in the setting of lumbar fracture surgery. All reference values are provided according to PI subsets, in standing and upright position to help surgeons indicating surgery and determining correction goals according to patient's PI and fracture level.

CRediT authorship contribution statement

MK: conception and design, data collection, statistical analysis, writing.

EF: supervision, reviewing.

WS: supervision, reviewing.

PG: supervision, reviewing.

CV: supervision, reviewing.

LMH: data collection, reviewing.

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

No AI-assisted technology was used in the writing process for this manuscript.

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Declaration of competing interest

None.

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