ORIGINAL ARTICLE

The effect of age, BMI, and bone mineral density on the various lumbar vertebral measurements in females

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Abstract

Purpose Healthy spinal balance is dependent on spinal sagittal alignment. It is evaluated by several spinopelvic measures. The objective of this study is to investigate the effect of age and body mass index and the bone mineral density on the several vertebral measures and sagittal spinopelvic measurements.

Methods In this cross-sectional study, a total of 89 female patients were grouped according to age ($> 70, < 70$); to BMI (underweight (< 18.5 kg/m^2), normal weight (18.5–25 kg/m^2), overweight (25–30 kg/m^2); and to spine T scores (normal, osteopenia, and osteoporosis). On lateral lumbar X-ray, lumbar lordosis (LL) angle and pelvic incidence (PI) are measured. On sagittal T2 MRI images, anterior and posterior vertebral heights and foraminal height and area of the L1–L5 segments were measured.

Results The mean age of the participants was 70.54 ± 6.49. The distribution of the patients in BMI groups and BMD groups were even. Mean lumber lordosis (LL) was 48.27 ± 18.06, and the mean pelvic incidence (PI) was 60.20 ± 15.74. In the younger age group, LL was found to be higher than the older age group. The vertebral and spinopelvic angle measures within the different BMI and BMD groups revealed no difference in between. There were no statistically significant difference in correlation analysis.

Conclusion In this cross-sectional study, the results revealed that younger patients have higher lordosis angle, and normal BMD patients have higher foraminal height and area measures than osteoporotic and osteopenic patients. Obesity seemed not to have any influence on vertebral measures. Spinopelvic parameters seem not to be effected by BMD and BMI.

Keywords Age · Body mass index · Foraminal height · Foraminal area · Bone mineral density · Vertebral measures · Vertebral angle · Spinopelvic angle

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Introduction

Spinal sagittal alignment is the major element for normal spinal function and spinal balance. It is evaluated by several spinopelvic measures [9]. The most important sagittal spinopelvic measurement modifiers are sagittal vertical axis (SVA), pelvic tilt (PT), and pelvic incidence (PI) [9, 15]. Adult spinal deformity (ASD), which is mostly associated with low back pain, is defined as the disturbed spinal sagittal alignment that causes severe functional disability [12]. It is present in population over 50 years of age and effects mostly lumbar segment of the spine [6, 12]. Female population is known to be more prone to suffer from ASD [12]. The degree of severity of the symptoms in ASD is correlated to the alterations in spinopelvic parameters [1, 6]. However, recent studies have challenged this impact of

sagittal spinopelvic measurements on health status and demonstrated weak correlations with clinical outcome [3, 11].

Spinal sagittal alignment is shown to be affected by many variables such as age, sex, weight, pelvic morphology, and bone mineral density [5]. Although it is presented that decreased bone mineral density (BMD) is one of the suspected causes of sagittal imbalance [7], there is a study documenting no relations between BMD and thoracic kyphosis in elderly [18]. This information points out that normal spinal function depends not only on BMD but also several other factors [27]. The objective of this study is to investigate the effect of age and body mass index and the bone mineral density of the vertebral body on the sagittal spinopelvic measurements and foramen height, foramen area, and vertebral anterior and posterior height of the vertebrae.

Materials and methods

In this cross-sectional study, a total of 89 female patients who were examined in Department of Orthopedics Mugla Sitki Kocman University Hospital between January 2017 and January 2018 were included. The inclusion criteria were to be female patients who were suffering from low back pain over 50 years of age. Also, the candidates who have anterior–posterior lumbar X-ray radiographies and a lumbar MRI within the year of the examination were included to the study. Patients who has had spine surgery were excluded from the study. Diabetes, malignancies, or any treatment which may influence bone metabolism, such as estrogen receptor modulators or calcium treatment, were also excluded from the study.

To ease the statistical analysis, we have grouped the patients as over and equal to 70 years of age, and lower 70 years of age. Similarly, the BMI ranges were used to classify the underweight (< 18.5 kg/m^2), normal weight (18.5–25 kg/m^2), overweight (25–30 kg/m^2), and obese (> 30 kg/m^2). The BMD measurements of anteroposterior lumbar spine were performed using a dual-energy X-ray absorptiometry (DXA) machine (Stratos DR 2D Fan Beam DEXA, DMS™, 2009). In accordance with the World Health Organization criteria, normal BMD was defined as a value less than 1 standard deviation (SD) below the young adult peak BMD (T score), osteopenia was defined as a value ranging from 1.0 to 2.5 SD below the young adult peak BMD, and osteoporosis was defined as a value equal to or greater than 2.5 SD below that of the young adult peak BMD [16]. Standard reference data of country where the study was performed were used for the T score calculations (Table 1).

MRI image tracing and measurement of the lumbosacral spine was performed by Sigma HDx 1.5™ Viewer, UK with the subject in the routine supine position with the hips and knees flexed. The sagittal T2-weighted images of

Table 1 Group classifications of the patients are presented

|		n	%
Age	70 <	44	49.4
	70 ≥	45	50.6
BMI	Normal	30	33.7
	Overweight	30	33.7
	Obese	29	32.6
Spine T scores	Osteoporotic ($< - 2.5$)	25	28.1
	Osteopenic ($- 2.5$ to 1.0)	41	46.1
	Normal ($> - 1.0$)	23	25.8

the lumbosacral MRI were used for the measurements. The anterior and posterior vertebral height measures were performed on the midline sagittal section in which the spinous processes are visible and the dural sac is widest [23]. The foraminal heights were measured where the foramen is in largest dimension for each segment individually from L1–2 to L5–S1 (Fig. 1) [25]. It was documented as the longest distance between the border of superior and inferior pedicle. The foraminal area was calculated manually by this equation as follows:

Foraminal area = (anteroposterior [AP] diameter/2) × (foraminal height/2) × Π [2].

Lumbar lordosis angle (LL) and pelvic incidence (PI) were measured from a series of complete standing anteroposterior and lateral full-length spine radiographs [1, 22]. LL and PI are measured on the lateral spine graphs. LL is measured as the angle between straight lines from upper end plates of the L1 vertebrae and S1 vertebrae [1]. Pelvic Incidence (PI) is measured as the angle between the perpendicular to the sacral plate at its midpoint and the line connecting this point to the middle axis of the femoral heads (Fig. 2) [1]. All measurements were performed by a single physician (DBHR) blinded to the clinical data.

Statistical analysis

Statistical analysis between age and vertebra measurements was done by Student's t test. Statistical analysis between BMI and vertebral measurements were done by F test, and to identify the statistical significance within the BMI groups, Bonferroni analysis was performed. Similarly, F test was used to identify the statistical significance in between Spine T scores and vertebrae measurements. Bonferroni analysis was performed to seek the statistical significance within the Spine T scores. A p value of < 0.05 was considered statistically significant. Additionally, the Pearson correlation analysis for the vertebrae and foraminal measurements with the variables of age, spine T score values and BMI of the
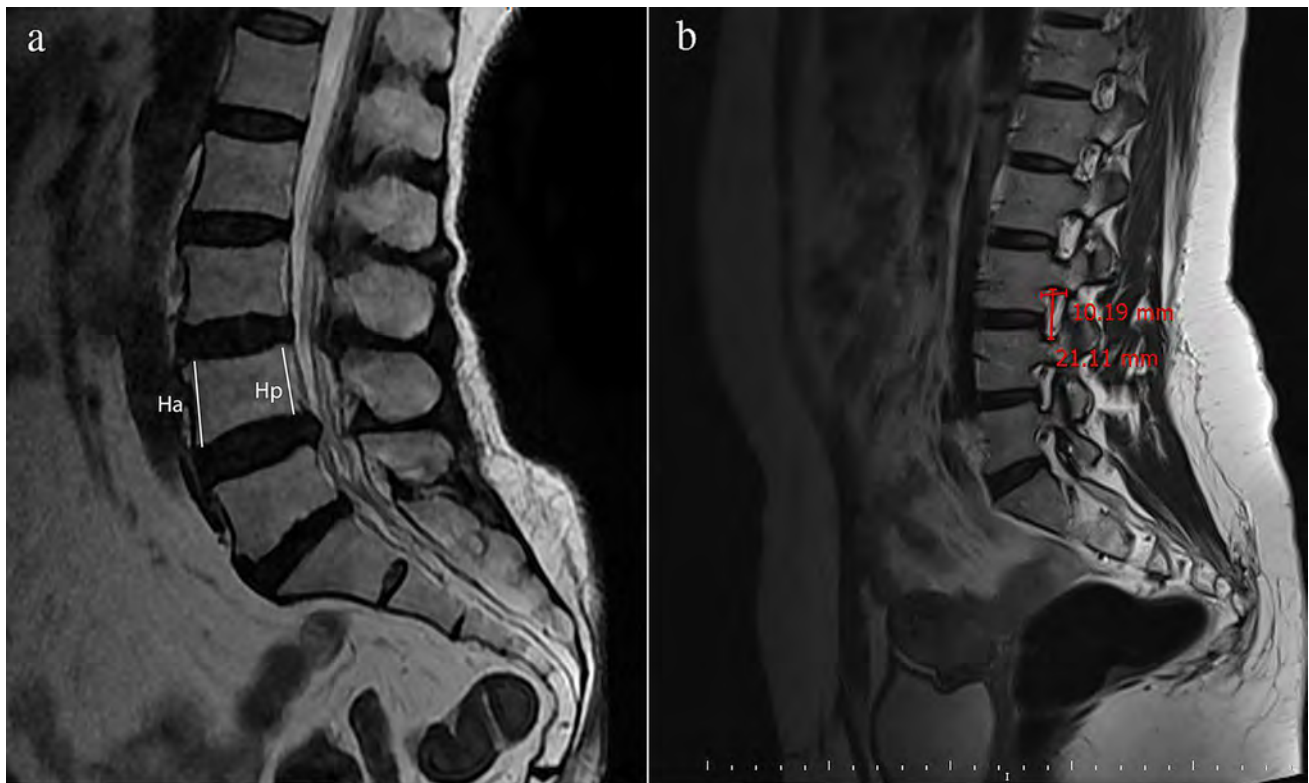
Fig. 1 Anterior and posterior height measurements of the vertebral body (**a**) and the foraminal measurements (**b**) are demonstrated

patients were evaluated. A p value less than 0.05 was considered significant.

Results

The mean age of the participants was 70.54 ± 6.49, %49.4 of the patients were under 70, and %50.6 were 70 and over. The mean BMI value was 29.12 ± 4.86, with %33.7 of the patients was within normal BMI values, %33.7 was overweight and %32.6 was obese. Mean Spine T score of the patients was found to be -1.74 ± 1.3, with %28.1 of the patients were osteoporotic, %46.1 were osteopenic and %25.8 had normal spine T scores. Mean lumber lordosis (LL) was 48.27 ± 18.06, and the mean pelvic incidence (PI) was 60.20 ± 15.74. The detailed measurement data of the other vertebra measurements are presented in Table 2. The foraminal measurements, foraminal height, and area did not differ in between patients who are over 70 years of age and lower. Similarly, the anterior and posterior vertebral height and the PI did not differ in between different age groups. LL angle in the younger patient group was significantly higher than older patients (Table 3). The anterior vertebral height measures did not differ for BMI values of the patients. However, normal weighted patients had significantly higher L4 posterior vertebral height compared to overweighed group.

Also, obese patients had significantly higher L3 posterior vertebral height compared to overweighed group. The LL and PI angles did not differ for BMI values of the patients.

The anterior and posterior vertebral heights did not differ for the Spine T score values of the patients. Similarly, LL and PI angles did not differ for the Spine T scores. Patients with normal bone mineral density values had significantly higher foraminal height values in L4–5 level than osteopenic patients (13.97 vs 11.26, $p = 0.03$). Additionally, osteoporotic and normal bone mineral density bearing patients have higher foraminal area values of L5–S1 compared to osteopenic patients (102.03 vs 78.51 vs 98.24; $p = 0.004$). Also, patients with normal bone mineral density has higher foraminal area of L4–5 compared to osteopenic patients (112.16 vs 79.33, $p = 0.011$).

We have also performed correlation analysis in between the variables. The correlation between BMI, Spine T score and incidence height and area revealed a very weak negative correlation in between BMI and L3–4 foraminal height ($r = -0.232$; $p < 0.05$). There was no significant correlation in between spine T scores and other variables. The correlation analysis within the foraminal heights and foraminal height and area values revealed weak positive correlation in between (Table 4).

The correlation between BMI, spine T scores, and vertebral height measurements revealed a weak negative
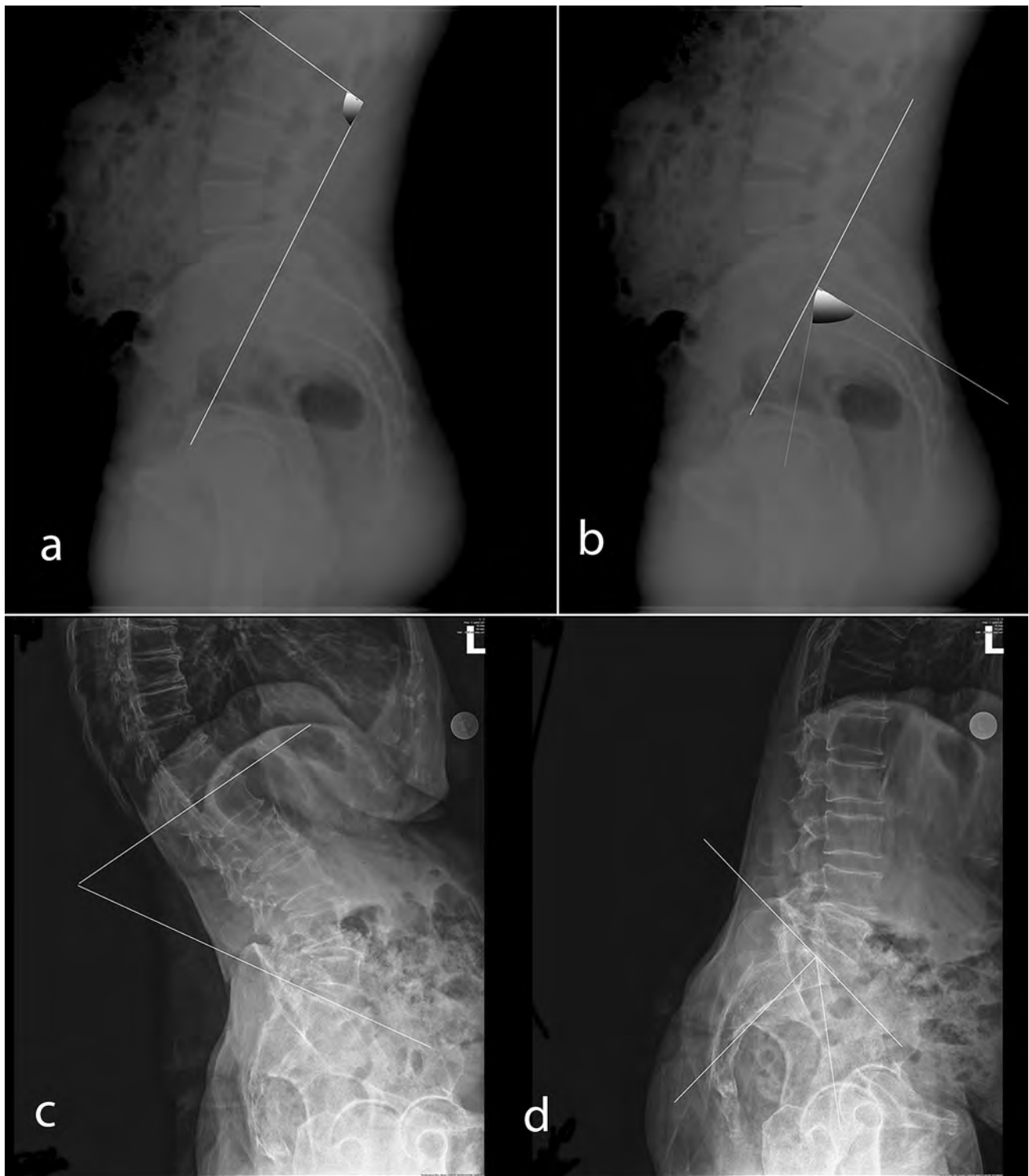
Fig. 2 Lumbar lordosis (LL) angle (**a**, **c**) and pelvic incidence (PI) (**b**, **d**) measurements are shown

correlation in between BMI and L4 Hp ($r = -0.215$; $p < 0.05$). There was no significant correlation in between spine T scores and other variables. The correlation analysis within the anterior and posterior vertebral heights revealed a very weak positive correlation also (Table 4). The correlation analysis in between LL vs spine T score and PI vs spine T score revealed no statistical significance. There was no correlation in between LL and foraminal

Table 2 Demographic characteristics of the participants are presented as mean values with standard deviations

		Minimum	Maximum	$\overline{X}$	S
Age		53.00	85.00	70.54	6.49
BMI		20.03	44.40	29.12	4.86
Spine T score		− 4.20	1.70	− 1.74	1.30
Lumber lordosis (LL)		6.02	82.07	48.27	18.06
Pelvic incidence (PI)		8.02	90.00	60.20	15.74
Foraminal height (FH)	L5 S1	3.71	19.08	12.82	3.16
	L4 L5	3.15	21.33	12.49	4.23
	L3 L4	3.80	23.43	14.79	4.28
	L2 L3	5.12	26.90	15.30	4.49
	L1 L2	6.34	35.78	15.82	3.53
Foraminal area (FA)	L5 S1	0.58	175.41	90.22	31.52
	L4 L5	0.59	194.47	90.58	42.69
	L3 L4	0.54	191.44	105.22	42.75
	L2 L3	0.69	250.86	107.04	43.93
	L1 L2	0.66	183.91	96.10	30.75
Anterior vertebral height (Ha)	L5 Ha	5.89	28.35	21.25	3.21
	L4 Ha	16.06	29.96	21.82	2.79
	L3 Ha	5.88	26.46	21.94	3.27
	L2 Ha	14.82	265.22	24.47	25.91
	L1 Ha	12.23	26.75	20.48	2.82
Posterior vertebral height (Hp)	L5 Hp	10.48	26.50	18.54	3.54
	L4 Hp	13.36	26.94	20.58	3.07
	L3 Hp	13.31	27.68	21.96	2.82
	L2 Hp	15.28	28.82	22.30	2.46
	L1 Hp	14.43	26.94	21.25	2.45

measurements; however, we have detected a very weak negative correlation in between PI and foraminal height of L1–L2 vertebrae level ($r = − 0.219$; $p < 0.05$) (Table 5). The correlation analysis in between LL and PI revealed very weak positive correlation ($r = 0.233$; $p < 0.05$). We have also detected a weak positive correlation in between LL and L5 Ha ($r = 0.371$; $p < 0.01$), and again a weak positive correlation in between LL and L3 Ha ($r = 0.287$; $p < 0.01$). PI revealed no correlation with anterior and posterior heights of the vertebral measures (Table 6).

Discussion

This study investigated the effect of age, BMI, and bone mineral density on the vertebral measures in female patients. In this cross-sectional study, we have achieved an almost even distribution of patients among different groups. The distribution of age was even, almost half of the patients were under 70 years of age, and the remaining were over 70. Similarly, the number of patients within the BMI groups and BMD groups was similar. In this study, MRI was used for vertebral measurements. Even though the X-ray examination and CT scanning are gold standard for evaluation of bone pathologies, they have some limitations. In addition to the radiation damage caused by these techniques, it is also difficult to clarify disc structure and soft tissue, especially the orientation of the nerve tissue relative to the bone [26]. In clinical point of view, recent literature points out the importance of evaluation of both bone and soft tissue in vertebral pathologies [17, 29] Therefore, MRI has become an important imaging tool for diagnosing spinal pathologies. More and more studies in the literature investigate the accuracy of MRI and have proven the reliability of MRI in vertebral measurements, identifying the details of its anatomy [10, 14, 20, 21, 24]

The degree of severity of the symptoms in spinal disease is correlated to the alterations in spinopelvic parameters [1, 6]. Spinal sagittal alignment is shown to be affected by many variables such as age, sex, weight, pelvic morphology, and bone mineral density [5]. The results revealed that younger patients have higher lordosis angle, and normal BMD patients have higher foraminal height and area measures than osteoporotic and osteopenic patients. Obesity seemed not to have any influence on vertebral measures.

Among different age groups, no difference was detected with the vertebral measurements and the spinopelvic angles, except for LL. In the younger age group, LL was found to be higher than the older age group. This finding is comparable with the recent literature [8]. It is stated that a decrease in LL itself triggers spinal sagittal imbalance in elderly, and the rest of the spinopelvic measurements have almost no effect. In this study, although there is a slight decrease in the anterior height of the vertebra in the elderly group, it revealed no statistical difference [10]. In

Table 3 The comparison of LL and PI angles for different age groups

	Age	n	$\overline{X}$	S	t	p
Lumber lordosis	70 <	44	52.93	17.06	2.477	0.015*
	70 ≥	45	43.71	18.03		
Pelvic incidence	70 <	44	58.53	16.19	0.656	0.327
	70 ≥	45	61.83	15.29		

*$p < 0.05$

Table 4 The correlation analysis in between foraminal measurements, BMI, and spine *T* scores

				Foraminal height					Foraminal area				
BMI			Spine *t* skor	L5 S1	L4 L5	L3 L4	L2 L3	L1 L2	L5 S1	L4 L5	L3 L4	L2 L3	L1 L2
BMI		1	0.170	− 0.087	− 0.174	− 0.232*	− 0.153	− 0.160	0.031	− 0.072	− 0.030	0.004	0.049
Spine *T* score			1	− 0.049	0.036	− 0.096	0.034	0.100	− 0.030	0.170	− 0.012	0.024	0.148
Foraminal height	L5 S1			1	0.301**	0.347**	0.361**	0.087	0.590**	0.173	0.146	0.269*	0.042
	L4 L5				1	0.626**	0.359**	0.105	0.205	0.790**	0.550**	0.317**	0.225*
	L3 L4					1	0.620**	0.149	0.227*	0.519**	0.765**	0.511**	0.264*
	L2 L3						1	0.310**	0.285**	0.239*	0.445**	0.750**	0.453**
	L1 L2							1	0.058	0.138	0.039	0.198	0.424**
Foraminal area	L5 S1								1	0.291**	0.247*	0.399**	0.197
	L4 L5									1	0.678**	0.302**	0.403**
	L3 L4										1	0.535**	0.327**
	L2 L3											1	0.520**
	L1 L2												1

*$p < 0.05$, **$p < 0.01$

Table 5 The correlation analysis in between vertebral height measurements and LL, PI angle measurements

				Anterior height					Posterior height				
LL			PI	L5 Ha	L4 Ha	L3 Ha	L4 Ha	L1 Ha	L5 Hp	L4 Hp	L3 Hp	L4 Hp	L1 Hp
	LL	1	0.233*	0.371**	0.182	0.287**	− 0.072	0.194	− 0.048	0.066	0.026	0.072	− 0.004
	PI		1	− 0.027	− 0.207	− 0.094	− 0.117	0.031	− 0.133	− 0.156	− 0.126	− 0.108	− 0.066
Anterior height	L5 Ha			1	0.494**	0.339**	0.001	0.058	− 0.056	0.280**	0.365**	0.261*	0.178
	L4 Ha				1	0.511**	0.019	0.327**	0.278**	0.424**	0.445**	0.398**	0.344**
	L3 Ha					1	0.126	0.542**	0.194	0.240*	0.448**	0.304**	0.300**
	L4 Ha						1	0.238*	0.179	0.186	0.199	0.214*	0.254*
	L1 Ha							1	0.425**	0.314**	0.423**	0.507**	0.549**
Posterior height	L5 Hp								1	0.553**	0.515**	0.493**	0.411**
	L4 Hp									1	0.644**	0.575**	0.500**
	L3 Hp										1	0.712**	0.647**
	L4 Hp											1	0.662**
	L1 Hp												1

*$p < 0.05$, **$p < 0.01$

the literature, especially anterior height of the vertebra was found to be lower in elderly to younger age group [28]. However, the foraminal measures seems to be divergent within the age groups.

The distribution of different vertebral and spinopelvic angle measures within the different BMI groups revealed no difference in between groups, except for the posterior height of the L4 and L5 vertebrae. In the literature, there are studies confirming the effect of BMI on the vertebral and spinopelvic measures [19, 28]. It is stated that in obese patients with higher BMI values, spinal inclination angle increases with an increase in lumbar and thoracic kyphosis angles [13]. Similarly, in another study, it is stated that the risk of spondylolisthesis increases in obese patients with increase in PI measures [4].

The spinopelvic measures and vertebral height measures in our study did not differ among different BMD values. In this study, it was detected higher foraminal height and foraminal area values in normal Spine *t* value patients compared to osteopenic and osteoporotic patients in L4–5 and L5–S1 levels. This finding supports the hypothesis that normal BMD bearing patients have higher foraminal measures in the transitional spine segment end up with less possible nerve root decompression and adult spinal deformity, therefore, with less low back pain[2]. Within our knowledge, there is no specific study documenting the foraminal measure changes among patients with different BMD values.

However, in aspect of spinopelvic angles, there are different studies documenting different results [7]. It is presented that there is significant difference in terms of

Table 6 The correlation analysis in between vertebral measurements vs LL and PI

			PI	L5 Ha	L4 Ha	L3 Ha	L4 Ha	L1 Ha	L5 Hp	L4 Hp	L3 Hp	L4 Hp	L1 Hp
Anterior height													
LL	LL	1	0.233*	0.371**	0.182	0.287**	− 0.072	0.194	− 0.048	0.066	0.026	0.072	− 0.004
	PI		1	− 0.027	− 0.207	− 0.094	− 0.117	0.031	− 0.133	− 0.156	− 0.126	− 0.108	− 0.066
Anterior height	L5 Ha			1	0.494**	0.339**	0.001	0.058	− 0.056	0.280**	0.365**	0.261*	0.178
	L4 Ha				1	0.511**	0.019	0.327**	0.278**	0.424**	0.445**	0.398**	0.344**
	L3 Ha					1	0.126	0.542**	0.194	0.240*	0.448**	0.304**	0.300**
	L4 Ha						1	0.238*	0.179	0.186	0.199	0.214*	0.254*
	L1 Ha							1	0.425**	0.314**	0.423**	0.507**	0.549**
Posterior height	L5 Hp								1	0.553**	0.515**	0.493**	0.411**
	L4 Hp									1	0.644**	0.575**	0.500**
	L3 Hp										1	0.712**	0.647**
	L4 Hp											1	0.662**
	L1 Hp												1

*$p < 0.05$, **$p < 0.01$

spinopelvic angles in osteoporotic patients and femur neck BMD and high PI were found to be the significant parameters in determination of sagittal balance in osteoporotic patients [7]. On the other hand, another study documented no difference in spinopelvic angle measures among different BMD value patients [7].

The correlation analysis in between variables did not reveal significant powerful correlation. However, there were some interesting weak correlations in between, such as a very weak negative correlation in between BMI and L3–4 foraminal height. In this study, the authors found out that as BMI increases, the foraminal height in L3–4 decreases; however, the rest of the segments do not differ statistically. Similarly, there is weak negative correlation in between BMI and L4 Hp ($r = − 0.215$; $p < 0.05$) and a weak positive correlation in between LL and L3 Ha ($r = 0.287$; $p < 0.01$). These results reveal no significant clinical outcome; however, they point out that L3–L4 vertebra level is the most effected vertebra level with other variables. The authors found out that bone mineral density changes do not affect other variables, such as vertebral measures or spinopelvic angles, so there is no correlation in between. This result is similar to the literature, presenting no correlation in between age and bone mineral density with spinopelvic parameters [7]. However, Lee et al. presented that although there was no significant difference in between osteoporosis and control group in terms of PI [5], there seems to be strong correlation between osteoporosis and spinopelvic angles and also the outcome of the patient [7]. The authors also detected no significant difference in terms of PI among groups; however, our correlation analysis revealed no clinically important result. The reason for that could be due to distribution of the patients and the low number of cases included in our cross-sectional study.

There were some limitations to this study. The number of patients was limited. For these patients included in the study, only MRI examination was indicated when they had their appointment. None of the patients have had CT examinations. CT scanning is good for the evaluation of some parameters of bone and can be good for previous studies. Recent literature investigates the accuracy of MRI using MRI measurements, and has proven the reliability of MRI in vertebral measurements identifying the details of its anatomy; therefore, all subject measurements were done on MRI. In addition, since the results were focused on a specific geographic region, regional and racial differences may have impacted the outcome.

Conclusions

In this cross-sectional study, the results revealed that younger patients have higher lordosis angle, and normal BMD patients have higher foraminal height and area measures than osteoporotic and osteopenic patients. Obesity seemed not to have any influence on vertebral measures. Spinopelvic parameters seem not to be effected by BMD and BMI.

Compliance with ethical standards

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