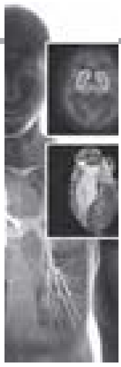
Research Article



Evaluation of lower lumbar morphometry in Asian population: A computed tomography scans study

Background: Morphometry of the lumbar vertebrae is necessary for the development of spine implants and instrumentations. Knowledge of surgically relevant anatomical parameters is essential for spine surgical interventions. However, results from previous studies varied among different ethnicities. This is the first cross-sectional study of lower lumbar morphometry (L3-L5) among the Indonesian population. This study also intends to show differences between genders, ages, and the lumbar levels.

Methods: The morphometric dimensions of total 900 vertebrae of L3-L5 on CT scan images were measured in 150 males and 150 females. The data were analyzed using Independent T-test or Mann Whitney to show gender differences. Correlation with ages were analyzed using Pearson or Spearman. Further, dimensions were subjected to One-way Anova and Tukey-b (Post Hoc) to show any significant differences between the means of the lumbar levels (L3-L5).

Results: In general, vertebral dimensions of L3-L5 were reported to be greater in males than in females. Besides, significant correlations (p-value <0.05) with age were found for L4-L5 cortical bone thickness, disc height, and L3 spinal canal width. The post hoc analysis showed significant mean differences between the lumbar levels (p-value<0.05), except for endplates width. There are significant gender and ethnic differences in various dimensions of the lumbar vertebrae.

Conclusions: This study may serve as anatomical reference in designing lumbar prosthesis and instrumentations in Asian people, especially Indonesian population, and thus critical for safe surgical interventions.

KEYWORDS: Morphometry ▪ Lower lumbar vertebrae ▪ Asian population ▪ Computed tomography scan

Introduction

Knowledge of lower lumbar morphometry is vital as the lumbar spine is a frequent site of implantation and fixation surgery due to degenerative diseases, trauma, infections, and malignancies. Reconstruction and fixation surgery using transpedicular screws and lumbar endoprosthesis have been widely used by many surgeons all over the world for various spinal disorders management [1-4]. The lumbar prosthesis should be able to substitute the pre-existing vertebra to restore the height, the sagittal alignment, and the biomechanical aspect to achieve structural stability. Besides, the prosthesis should be able to be embedded suitably on the implantation site to prevent adjacent neural, vascular, and visceral complications. Moreover, instrumentation failure and malposition or screw pullout, other anatomical complexity-related complications may occur, which may cause the need for revision surgery and serious clinical consequences [5-8]. It may lead to a demand for accurate anatomical mimic design and precise insertion technique to accommodate the fixation strength and stable implantation in the specific anatomical site. The anatomical configuration of the prosthesis is critical to attain this desirable outcome.

Several studies have been carried out to determine lumbar vertebrae morphometry using dry bones from anatomical banks or cadavers [9,10]. Currently, in this digital era which advances in computing, has led utilization of CT Scans for direct measurements as reported in previous studies [11-15]. Meanwhile, genetic, ethnic, and gender variations of vertebral dimensions among various populations have been documented. Unfortunately, this pertinent morphometry has never been carried out among the Indonesian population. This study aims to describe the morphometric characteristics of the Indonesian population of lumbar vertebral dimensions. This study also intends to show gender-related and level-dependent differences. Further, this study aims to show the correlation between age and lumbar dimensions. Thus, the database of the lower lumbar vertebral dimensions in the Indonesian population is vital for developing proper spinal implantable devices and spinal instrumentation, and therefore, safe application surgery can be achieved.

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Methods

Study population

This was a cross-sectional study on CT scan images of lower lumbar vertebrae (L3-L5) of 300 adults (150 males and 150 females). The data were collected from Cipto Manungkusumo, Universitas Indonesia Hospital, as the National Referral Hospital from all over Indonesia, which is presumed to represent all the ethnicities of the Indonesian population. The samples were collected retrospectively from January to June 2020. The age range of patients was 25 to 50 years old, where a complete fusion of vertebral epiphyseal plate has been achieved, meanwhile, the degenerative process has not begun. The patients had undergone the abdominal CT scan for various reasons, including trauma; abdominal, genitourinary, and gynecology malignant and benign tumors; liver and pancreatic diseases; intestinal obstruction and inflammatory bowel disease; other abdominal and genitourinary infections/diseases (abscess, peritonitis, stones). We exclude patients with vertebral pathologies such as fractures, congenital anomalies (for example, hemivertebrae), tumor, and other pathologies. This study has been approved by the Ethics Committee of Faculty of Medicine, Universitas Indonesia with protocol number registered 20-05-0528.

Measurements

The Digital Imaging and Communications in Medicine (DICOM) Viewer, INFINITT PACS tool, was used to measure the thin-cut (1 mm) CT scan images. DICOM Viewer is the leading standard for image data management in medical applications. The measurements were being done by a single observer to avoid inter-observer errors and were recorded in millimeters.

There were various anatomical parameters of planes and dimensions used in this study shown in **FIGURES 1 and 2**. The method of measurements was adopted from the study by Zhou which reported comprehensive vertebral and intervertebral dimensions [11]. In the lateral view of the CT scan, we measured the distance between both the upper and lower vertebral endplates at the anterior and posterior margin, termed as the Vertebral Body Height posterior (VBHp) and the Vertebral Body Height anterior (VBHa). We also measured the Disc Height (DH) in the midline of the vertebral body and the Pedicle Height (PH) by measuring the superior and inferior borders of the pedicles (**FIGURES 1A and 1B**).

Moreover, after adjusting the multiplanar line from the sagittal and the coronal view, other parameters were measured from the axial view. The distance between both lateral borders of the upper vertebral endplates termed Upper Vertebral Width (UVW), and the distance between the anterior-posterior borders of the vertebral body namely the Upper Vertebral Depth (UVD) was measured (**FIGURE 2A**). Similarly, the aforementioned measurements were also measured for the lower vertebral endplates, called the Lower Vertebral Width (LVW) and Lower Vertebral Depth (LVD) (**FIGURE 2B**). Besides, the distance between the pedicles was measured to obtain the Spinal Canal Width (SCW) and the distance from the posterior border of the vertebral body to the lamina at the midline was also measured, defined as Spinal Canal Depth (SCD). The cortical bone thickness (CTh) was measured as the distance between the inner and the outer borders of the lateral part of the vertebral body. The Pedicle Width (PDW), the distance between the medial and lateral borders of the pedicle was also measured (**FIGURE 2C**). Afterward, we changed the coronal section into 40 mm thickness to visualize the transverse process clearly and to redirect the multiplanar axis accordingly. Lastly, in the axial view, we measured the Transverse Process Length (TPL) which was the distance between the tip of the two processes (**FIGURE 2D**).

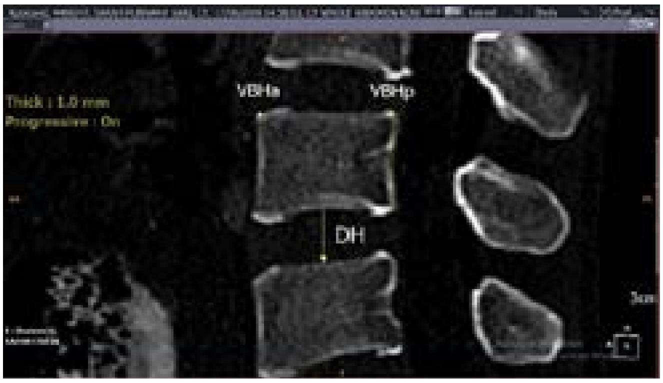

FIGURE 1A. Vertebral Body Height posterior (VBHp), Vertebral Body Height anterior (VBHa), Disc Height (DH).

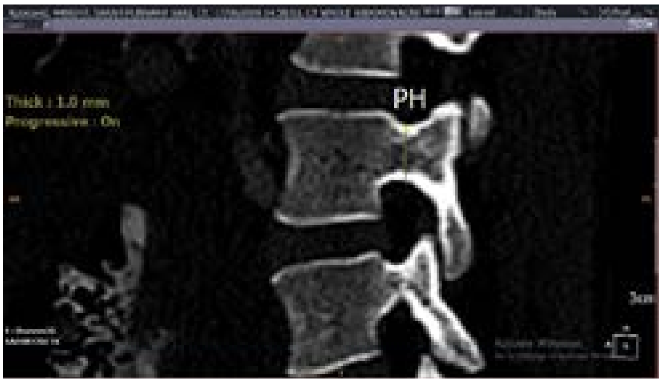

FIGURE 1B.Pedicle Height (PH) measured in the sagittal view of CT-Scan.

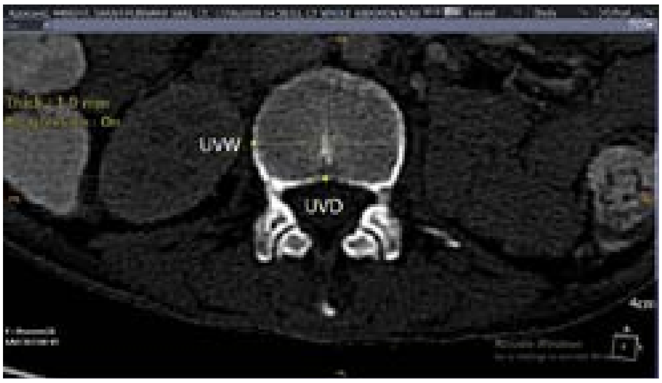

FIGURE 2A.Upper Vertebral Width (UVW), Upper Vertebral Depth (UVD).

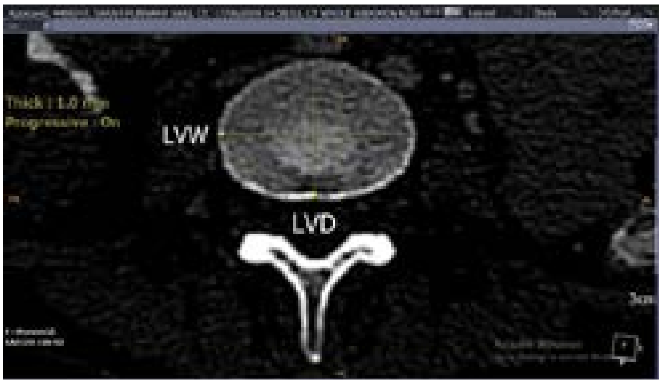

FIGURE 2B.Lower Vertebral Width (LVW), Lower Vertebral Depth (LVD).

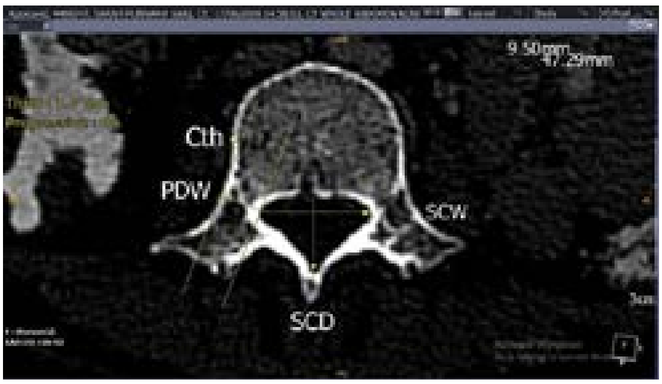

FIGURE 2C.Spinal Canal Width (SCW), Spinal Canal Depth (SCD), Cortical bone Thickness (CTh), Pedicle Width (PdW).

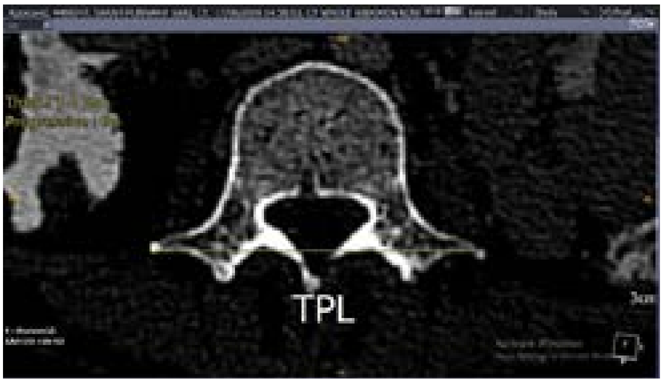

FIGURE 2D.Transverse Process Length (TPL) measured in the axial view of CT-Scan following the multiplanar line adjustment from the sagittal and coronal view.

The data were analyzed using SPSS IBM 20 software. The data were analyzed descriptively to obtain the mean and standard deviation, or the median (minimum-maximum). Further, the gender-associated statistical differences in the parameters were also analyzed using Independent T-test or Mann-Whitney. The correlation between age and all the parameters were also analyzed using Pearson or Spearman. Moreover, several dimensions were subjected to One-way Anova and Tukey-b (Post Hoc) to show any significant difference between the means of the lumbar levels (L3-L5). A p-value of ≤ 0.05 was considered to be significant.

Results

The results of all lumbar dimensions of L3-L5 in 300 patients (150 males and 150 females) with a median of age 35 (25-50) years old are provided in (**TABLE 1**). The correlation between each dimension and age is shown in **TABLE 2**. A post-hoc analysis on the vertebral body, vertebral endplate, and disc height of the three lumbar levels is shown in **TABLE 3**. Further, cortical bone thickness, spinal canal, and pedicle dimensions in **TABLE 4**.

TABLE 1.The gender-associated differences in the lumbar vertebrae dimensions.

Parameter	Parameter	The morphometry of Lumbar 3–Lumbar 5 (mean ± SD)/median (minimum–maximum)					
		L3	P-Value	L4	P-value	L5	P-value
UVW	Total	43.14 ± 3.61		45.74 ± 3.77		48.31 ± 3.99	
	Male (n=150)	45.59 ± 2.44	0.0001*	48.16 ± 2.75	0.0001*	50.43 ± 3.03	0.0001*a
	Female (n=150)	40.69 ± 2.85		43.32 ± 3.04		46.18 ± 3.72	
UVD	Total	33.32 ± 2.77		33.38 ± 2.72		33.22 ± 2.62	
	Male (n=150)	35.07 ± 2.09	0.0001*	35.12 ± 2.23	0.0001*	34.85 ± 2.26	0.0001*
	Female (n=150)	31.58 ± 2.22		31.65 ± 1.95		31.59 ± 1.82	
LVW	Total	45.96 ± 3.51		46.88 ± 3.58		47.84 ± 3.53	
	Male (n=150)	47.99 ± 2.91	0.0001*	49.12 ± 2.59	0.0001*	50.17 ± 2.67	0.0001*
	Female (n=150)	43.93 ± 2.83		44.63 ± 2.96		45.50 ± 2.62	
LVD	Total	33.03 ± 2.70		33.02 ± 2.78		32.42 ± 2.53	
	Male (n=150)	34.64 ± 2.42	0.0001*	34.66 ± 2.05	0.0001*	34.00 ± 2.10	0.0001*
	Female (n=150)	31.42 ± 1.89		31.37 ± 2.43		30.84 ± 1.83	

VBHa	**Total**	26.29 ± 1.80		25.87 ± 1.91		26.01 ± 2.01	
	Male (n=150)	26.19 ± 1.92	0.337	25.85 ± 1.99	0.806	25.94 ± 2.18	0.569
	Female (n=150)	26.39 ± 1.68		25.90 ± 1.84		26.08 ± 1.83	
VBHp	**Total**	26.58 ± 1.82		25.34 ± 1.91		23.71 ± 1.94	
	Male (n=150)	27.32 ± 1.77	0.0001*	26.06 ± 1.88	0.0001*	24.36 ± 2.02	0.0001*
	Female (n=150)	25.83 ± 1.55		24.63 ± 1.68		23.08 ± 1.63	
CTh	**Total**	1.80 ± 0.30		1.80 ± 0.31		1.88 ± 0.36	
	Male (n=150)	1.89 ± 0.25	0.0001*	1.89 ± 0.22	0.0001*	1.97 ± 0.25	0.0001*
	Female (n=150)	1.70 ± 0.32		1.71 ± 0.35		1.79 ± 0.43	
DH	**Total**	9.86 ± 1.32		10.54 ± 1.47		10.04 ± 1.43	
	Male (n=150)	10.00 ± 1.31	0.063	10.68 ± 1.48	0.107	10.19 ± 1.39	0.068
	Female (n=150)	9.72 ± 1.33		10.40 ± 1.44		9.89 ± 1.46	
SCW	**Total**	21.82 ± 1.69		23.85 ± 2.42		28.62 (20.94–43.65)	
	Male (n=150)	22.21 ± 1.77	0.0001*	24.47 ± 2.54	0.0001*	29.97 (21.99–43.65)	0.0001*a
	Female (n=150)	21.43 ± 1.52		23.24 ± 2.14		27.71 (20.94–39.06)	
SCD	**Total**	15.81 ± 2.07		16. 21 ± 2.27		15.61 (10.20–25.45)	
	Male (n=150)	14.76 ± 1.85	0.0001*	15.32 ± 2.38	0.0001*	14.91 (10.2–25.45)	0.0001*a
	Female (n=150)	16.85 ± 1.72		17.09 ± 1.76		15.97 (11.49–24.9)	
PDW	**Total**	8.49 ± 1.70		10.25 ± 1.82		13.46 ± 2.15	
	Male (n=150)	9.44 ± 1.44	0.0001*	11.17 ± 1.56	0.0001*	14.15 ± 2.00	0.0001*
	Female (n=150)	7.54 ± 1.39		9.33 ± 1.57		12.77 ± 2.08	
PH	**Total**	13.79 ± 1.43		12.75 ± 1.40		11.61 ± 1.49	
	Male (n=150)	14.28 ± 1.39	0.0001*	13.23 ± 1.32	0.0001*	11.81 ± 1.62	0.017*
	Female (n=150)	13.31 ± 1.30		12.27 ± 1.30		11.41 ± 1.33	
TPL	**Total**	82.98 ± 7.06		80.16 ± 7.01		86.23 (70.70–104.93)	
	Male (n=150)	86.39 ± 6.03	0.0001*	83.09 ± 6.49	0.0001*	88.15 (75.64–104.93)	0.0001*
	Female (n=150)	79.56 ± 6.34		77.24 ± 6.27		84.71 (70.70–101.86)	

*__Note:__ Values are recorded in millimeters (mm). *Asterisk indicates statistical significance at p-value ≤ 0.05. Data were analyzed using Independent T-test and Mann Whitneya (if data were not distributed evenly).

TABLE 2.The correlation between age and the lumbar vertebrae dimensions.						
Parameter	L3		L4		L5	
	Correlation Coefficient of Age	P-Value	Correlation Coefficient of Age	P-value	Correlation Coefficient of Age	P-value
UVW	-0.002	0.979	0.006	0.923	-0.024	0.673
UVD	-0.013	0.824	0.032	0.582	0.095	0.101
LVW	0.055	0.342	0.028	0.63	0.021	0.716
LVD	0.078	0.178	0.088	0.127	0.022	0.707
SCW	0.129	0.025*	0.065	0.259	0.001	0.988b
SCD	0.093	0.107	0.039	0.502	0.052	0.374b
PDW	-0.163	0.005*	-0.137	0.017*	0.001	0.983
CTh	0.005	0.928	0.114	0.048*	0.154	0.008*
TPL	-0.004	0.951	0.046	0.423	0.063	0.277b
VBHa	-0.057	0.323	-0.117	0.043*	-0.063	0.275
VBHp	-0.151	0.009*	-0.161	0.005*	-0.134	0.020*
DH	0.121	0.037*	0.056	0.337	0.084	0.147
PH	0.014	0.807	0.015	0.799	-0.031	0.595

Note: Correlation coefficient (r) is recorded as positive or negative (-), p-value ≤ 0.05 is statistically significant Data were analyzed using Pearson and Spearmanb (if data were not distributed evenly)

TABLE 3.The level-dependent (L3, L4, L5) differences of vertebral body and vertebral endplate dimensions.																		
Level	VBHa			VBHp			UWV			UVD			LVW			LVD		
	M+F	M	F	M+F	M	F	M+F	M	F	M+F	M	F	M+F	M	F	M+F	M	F
L3	26.29^{b}	26.19^{a}	26.39^{b}	26.58^{c}	27.32^{c}	26.83^{c}	43.14^{a}	45.59^{a}	40.69^{a}	33.38^{a}	35.07^{a}	31.58^{a}	45.96^{a}	47.99^{a}	43.93^{a}	33.03^{b}	34.64^{b}	31.42^{b}
L4	25.87^{a}	25.85^{a}	25.9^{a}	25.34^{b}	26.06^{b}	24.63^{b}	45.74^{b}	48.16^{b}	43.32^{b}	33.32^{a}	35.12^{a}	31.65^{a}	46.88^{b}	40.13^{b}	44.63^{b}	33.02^{b}	34.66^{b}	31.37^{b}
L5	26.01^{ab}	25.94^{a}	$26.08a^{b}$	23.71^{a}	24.35^{a}	23.08^{a}	48.31^{c}	50.43^{c}	46.18^{c}	33.22^{a}	34.85^{a}	31.59^{a}	47.84^{c}	50.17^{c}	45.50^{c}	32.42^{a}	34.00^{a}	30.85^{a}

*Note: Data were recorded in millimeters (mm) Data were analyzed using One Way Anova & Tukey-b test (Post Hoc). Different letters represent a significant difference in lumbar level measurements at p-value ≤0.05

TABLE 4.The level-dependent (L3,L4,L5) differences of cortical bone thickness, spinal canal, disc height, and pedicle dimensions.																		
Level	CTh			SCW			SCD			DH			PDW			PDH		
	M+F	M	F	M+F	M	F	M+F	M	F	M+F	M	F	M+F	M	F	M+F	M	F
L3	1.80^{a}	1.89^{a}	1.7^{a}	21.82^{a}	22.21^{a}	21.43^{a}	15.81^{a}	14.76^{a}	16.85^{ab}	9.86^{a}	10.00^{a}	9.72^{a}	8.49^{a}	9.44^{a}	7.54^{a}	13.79^{c}	14.28^{c}	13.31^{c}
L4	1.80^{a}	1.89^{a}	1.71^{a}	23.85^{b}	24.46^{b}	23.24^{b}	15.96^{a}	15.32^{ab}	17.09^{b}	10.54^{b}	10.68^{b}	10.40^{b}	10.25^{b}	11.17^{b}	9.33^{b}	12.75^{b}	13.23^{b}	12.27^{b}
L5	1.88^{b}	1.97^{b}	1.79^{a}	28.98^{c}	29.97^{c}	27.99^{c}	16.21^{a}	15.53^{b}	16.39^{a}	10.04^{a}	10.19^{a}	9.89^{a}	13.46^{c}	14.15^{c}	12.77^{c}	11.61^{a}	11.81^{a}	11.41^{a}

*Note: Data were recorded in millimeters (mm); Data were analyzed using One Way Anova & Tukey-b test (Post Hoc). Different letters represent a significant difference in lumbar level measurements at p-value ≤0.05

■ The vertebral endplate dimensions

All the width and depth of the upper and lower vertebral endplates of L3-L5 were noted to be greater in males than females (p-value<0.01). The width of both the upper and lower vertebral endplates increased gradually from L3 to the L5 and showed significant level-dependent differences (p-value<0.05) in both males and females. However, the depth of the vertebral endplates was not level-dependent. Only the lower vertebral depth of L5 was different compared to L3 and L4 in both males and females (p-value<0.05).

■ The vertebral body dimensions

The vertebral body height posterior in all the three levels of L3-L5 was greater in males than females (p-value<0.01). The posterior height decreased from L3 to L5 (p-value<0.05) in both males and females. However, analysis of anterior height only showed L4 to be significantly different from L3 and L5 in females (p-value<0.05). The vertebral body height posterior showed a weak negative significant correlation with age (r-0.151, p-value 0.009).

■ The cortical bone thickness dimensions

Gender-associated differences in vertebral cortical thickness were observed in all three levels (p-value<0.001). Moreover, the vertebral cortical thickness demonstrated a relatively homogenous measurement (1.80 ± 0.03; 1.80 ± 0.31; 1.88 ± 0.36) from L3 to L5, however, post hoc analysis showed L5 was significantly different between the other two levels (p-value<0.05). In addition, in L4-L5, a significant weak positive correlation with age could be observed (r=0.114, p-value=0.048; r=0.154, p-value=0.008 respectively).

■ The disc height dimensions

The disc height showed no significant differences between genders within all three levels (p-value>0.05). The disc height from L3-L5 showed similar results (9.86 ± 1.32; 10.54 ± 1.47; 10.04 ± 1.43). However, L4-L5 disc height showed to be greater compared to L3 to L4 and L5-S1 disc height (p-value<0.05). Besides, a weak significant positive correlation between the disc height and age was found only in L3 (r=0.121; p-value=0.037).

■ The spinal canal dimensions

Both the spinal canal width and depth were not distributed evenly in the L5, unlike other levels. Greater measurements of the spinal canal width were found in males. In contrast, in females, spinal canal depth was greater (p-value<0.01). In the L3, the spinal canal width showed a weak significant positive correlation with age (r=0.129; p-value=0.025). Besides, the spinal canal width increaseed craniocaudally from L3-L5 (p-value<0.05), while spinal canal width did not reveal level-dependent differences.

■ The pedicles and the transverse process dimensions

The pedicle width was increasing gradually from L3-L5 (p-value <0.05) and was significantly wider in males (p-value<0.01). Conversely, the pedicle height lowered through levels (p-value<0.05). The distance between the two transverse process tips was higher in males (p-value<0.01). Moreover, in L5, the transverse process length data were not normally distributed, with a wide range of standard deviation (7.06 mm).

Discussion

This study provides the data on several substantial lumbar vertebral dimensions, such as the vertebral endplate, the vertebral body, the spinal canal, the disc height, and the pedicle dimensions. Gender-related and level-dependent differences were found in various dimensions. Further, several dimensions demonstrated correlation with age.

The mean values were greater in males (p-value<0.01) in all dimensions, except for SCD which was greater in females (p-value<0.01) and VBHa which did not show significant gender-related differences (p-value 0.337). The results are consistent with other previous studies which also reported the observed significant sex differences [12]. The trends of the measurements in our study shared some similarities and differences with other populations. We found similar results with Pakistani and Singaporean populations [16]. However, the mean values in our studies were smaller compared to the Greek, English, and Turkish populations [5,11,12]. However, it is very interesting that the measurements varied comparably among ethnics, and thus failed to show a certain pattern (**TABLE 5**). As an example, in lower vertebral endplate width and depth dimensions, the Singaporean population had measurements closer to the other Western populations, than to our study and the Pakistani population. Another example, the Turkish had a very large width of upper and lower vertebral endplates up to 84.2 ± 6.8 mm, compared to other populations that fell within the range of less than 40 mm.

TABLE 5. Comparison of populations in the lumbar vertebral dimensions

Parameter	Vertebra Level	Author, population [Reference]											
		Present Study, Indonesia	Alam et al., Pakistan [15]		Tan, Singapore [17]	Zhou et al., United Kingdom [11]	Gulek B et al., Turkey [12]	Acharya et al., India [13]	Biscevic et al., Bosnia [14]	Nojiri et al., Japan [34]		Lotfinia et al., Iran [35]	
			Male	Female						Male	Female	Male	Female
UVW	L3 L4 L5	43.14 ± 3.61; 45.74 ± 3.77; 48.31 ± 3.99	45.45 47.08 48.95	40.88 43.43 46.24	46.96 ± 0.39 49.35 ± 0.22 48.89 ± 0.40	43.2 ± 4.3 48.5 ± 4.7 52.2 ± 5.1	51.5 ± 4.8 53.6 ± 5.0 56.6 ± 5.1	-	-	-	-	-	-
UVD	L3 L4 L5	33.32 ± 2.77 33.38 ± 2.72 33.38 ± 2.72	32.85 33.85 33.71	30.00 30.00 31.50	35.15 ± 0.30 36.26 ± 0.23 35.82 ± 0.57	32.3 ± 3.3 34.6 ± 3.6 35.7 ± 3.7	83.5 ± 6.5 84.2 ± 6.8 82.7 ± 6.9	-	-	-	-	-	-

LVW	L3 L4 L5	45.96 ± 3.51 46.88 ± 3.58 47.84 ± 3.53	45.39 46.91 47.04	42.35 43.51 44.90	51.19 ± 0.39 53.34 ± 0.57 51.42 ± 0.49	51.7 ± 4.8 52.5 ± 4.7 53.1 ± 6.0	54.1 ± 5.3 55.3 ± 5.2 55.3 ± 5.1	-	-	-	-	-	-
LVD	L3 L4 L5	33.03 ± 2.70 33.02 ± 2.78 32.42 ± 2.53	33.01 33.85 33.03	30.01 31.77 31.91	35.55 ± 0.47 35.62 ± 0.73 33.75 ± 0.51	35.3 ± 3.6 36.2 ± 3.7 36.0 ± 4.0	83.0 ± 6.8 81.0 ± 6.6 75.5 ± 7.1	-	-	-	-	-	-
VBHa	L3 L4 L5	26.29 ± 1.80 25.87 ± 1.91 26.01 ± 2.01	27.30 27.46 27.60	27.05 26.92 26.72	25.17 ± 0.33 25.36 ± 0.68 25.83 ± 0.66	30.2 ± 2.1 30.1 ± 2.4 30.8 ± 2.5	27.1 ± 2.0 27.0 ± 2.2 27.6 ± 2.3	-	-	-	-	-	-
VBHp	L3 L4 L5	26.58 ± 1.82 25.34 ± 1.91 23.71 ± 1.94	28.55 27.10 24.84	27.47 26.21 23.90	25.97 ± 0.46 25.42 ± 0.40 23.51 ± 0.71	29.6 ± 2.4 28.7 ± 2.3 25.9 ± 2.0	27.9 ± 2.1 26.9 ± 2.2 25.1 ± 2.0	-	-	-	-	-	-
DH	L3 L4 L5	9.86 ± 1.32 10.54 ± 1.47 10.04 ± 1.43	-	-	-	11.6 ± 1.8 11.3 ± 2.1 10.7 ± 2.1	11.1 ± 2 11.1 ± 2 9.9 ± 1.8	-	-	-	-	-	-
CTh	L3 L4 L5	1.80 ± 0.30 1.80 ± 0.31 1.88 ± 0.36	-	-	-	2.7 ± 0.4 2.7 ± 0.4 2.9 ± 0.52	1.5 ± 0.3 1.5 ± 0.2 1.5 ± 0.3	-	-	-	-	-	-
SCW	L3 L4 L5	21.82 ± 1.69 23.85 ± 2.42 28.62 (20.94 – 43.65	24.13 24.48 28.43	22.36 23.81 25.96	22.82 ± 0.51 23.82 ± 0.61 27.49 ± 0.72	24.2 ± 3.1 23.6 ± 2.9 28.0 ± 3.9	25.7 ± 2.5 26.1 ± 2.7 30.1 ± 3.5	-	-	-	-	21.88 ± 2.97 22.88 ± 4.07 55.32 ± 3.54	20.76 ± 2.79 22.24 ± 3.52 26.08 ± 4.93
SCD	L3 L4 L5	15.81 ± 2.07 16.21 ± 2.27 15.61 (10.20 – 25.45)	15.48 14.77 15.25	15.31 14.28 13.76	13.23 ± 0.30 13.22 ± 0.44 13.38 ± 0.43	16.1 ± 2.0 16.7 ± 2.7 17.1 ± 3.4	16.5 ± 2.7 17.3 ± 2.7 18.9 ± 2.9	-	-	-	-	14.36 ± 2.71 14.32 ± 2.13 13.36 ± 3.42	13.92 ± 1.38 13.72 ± 1.82 13.76 ± 2.93

PDW	L3 L4 L5	8.49 ± 1.70 10.25 ± 1.82 13.46 ± 2.15	10.54 10.54 13.53	9.56 9.56 12.19	14.1 ± 2.3 15.5 ± 2.2 20.5 ± 3.5	9.6 ± 2.2 12.1 ± 2.2 16.2 ± 2.8	-	8.97 ± 1.09 11.12 ± 1.01 13.91 ± 1.16	11.00 13.00 18.00	9.1 ± 1.7 10.1 ± 1.7 11.1 ± 1.7	8.9 ± 1.6 9.7 ± 1.4 10.6 ± 1.5	11.68 ± 2.54 14.2 ± 1.59 17.28 ± 2.92	9.28 ± 2.08 11.52 ± 2.3 14.88 ± 2.99
PH	L3 L4 L5	13.79 ± 1.43 12.75 ± 1.40 11.61 ± 1.49	12.03 12.03 11.53	11.71 11.71 10.94	13.2 ± 2.0 13.1 ± 2.6 12.9 ± 1.9	14.5 ± 1.6 14.3± 1.5 14.0 ± 2.2	-	-	15.00 15.00 14.00	14.7 ± 1.3 15.0 ± 1.8 20.2 ± 2.3	14.2 ± 1.1 15.0 ± 1.8 20.2 ± 2.3	-	-
Information		N=300	N=33	N=16	Using dry bones N=12 cadavers	N=126 patients with LBP	N=103	N=50	N=14	N=56	N=47	N=48	N=48

The present study showed that the vertebral body posterior height increased gradually from L3-L5 and showed statistically significant level-dependent differences (p-value<0.05), whereas the anterior height of the L3 and L4 failed to show significant differences with L5. Moreover, we found a significant weak negative correlation between age and VBHp (L3-L5) (p-value 0.009;0.005;0.02 respectively) and VBHa (L4) (r -0.117, p-value 0.043), which indicated that older people have a relatively smaller vertebral body. This might be due to the progression of the vertebral body collapse and deterioration in older people. Vertebral body anterior-posterior heights and ratios are used in the assessment of vertebral fractures and related to the deformity changes across the vertebrae. A study reported that increased vertebral anterior and posterior height loss was associated with the extent of canal encroachment resulting in further neurologic sequelae [17]. In addition, another study reported that this deformity index was significantly related to the diffuse paravertebral pain found in degenerative disorders [18]. Concerning the structural changes, especially in the case of vertebral fractures due to osteoporosis, malignancy, trauma, or even metabolic imbalance, this dimensional aspect needs to be restored to its normal value to re-establish constructional support of the vertebra. Restoration of the vertebral body height, whether using vertebroplasty, kyphoplasty or implant insertion was directly associated with better outcomes [19-21]. Besides, vertebral body height is a critical dimension in designing prosthesis as another study showed that unsuitable size served as the risk factor of postoperative cage migration [8].

Disc height also becomes one of the essential parameters to be evaluated. The present study showed similar results of the L3/4, L4/5, L5/1 discs (with a mean value of 9.86 ± 1.32 mm; 10.54 ± 1.47 mm; 10.04 ± 1.43 mm respectively) with the English and Turkish population with mean differences between studies less than two millimeters (**TABLE 5**). Changes across the intervertebral discs are associated with much clinical relevances, especially low back pain. This condition mostly affects the lumbar spine, particularly found in L3/4, L4/5, and L5/1 discs. A decrease in disc height was found in patients liable to symptoms of low back pain. Persistent root pain was also reported due to the foraminal encroachment, even without significant prolapse of the disc [22,23]. Regarding the already existed implant and graft material with a variety of types, normal disc height in a symptom-free individuals can be used as the base of data to design spinal or intervertebral disc implants. The size of the implant is critical since a smaller size will result in the structural collapse and a larger implant will make the insertion more difficult [24-26]. There is a need for 30%-40% graft coverage of the total endplate cross-sectional area to provide an adequate outcome. Besides, a coverage area of less than 21% of the endplate might result in further progression to a fracture in anterior lumbar spinal fusion [27]. However, as mentioned earlier, the vertebral endplate showed wide differences among populations (**TABLE 5**) and thus population-specific morphometry becomes necessary. Further, the condition demands a restoration of the normal disc height to relieve the symptoms and repair the dynamical and anatomical support of the spinal structure.

A vertebral body consists of two main structural components, the trabecular and the cortical shell. It was postulated that the lumbar vertebral cortex contributed to 45-75% of the vertebral strength, yet, in contrast, another study stated that when the cortex was removed, it caused a 10% loss of the vertebral strength [28]. However, the quality of vertebral structures proves to be necessary for the performance of implants such as vertebral cages and total disc replacement. Thus, evaluating the bone quality of the lumbar helps to optimize the bone-implant interface in designing implants to achieve better performance. In our study, the cortical bone thickness of L3-L5 showed to be within the normal range with a mean value of 1.80 mm; 1.80 mm; 1.88 mm respectively and was greater in males. Yet, it is to be noted that Palepu, reported vertebral cortical thickness varied circumferentially depending on the region measured (anterior, posterior, left, right), while the present study only assessed one region [29]. Our results were consistent with the study by Gulek et al. and Zhou et al. [11,12].

Further, we also noted a significant weak positive correlation with age in L4 and L5 (r 0.114 p-value 0.048; r 0.154 p-value 0.008), which contradicts the age-related bone loss theory. Chen et al. stated that between 60-90 years old, bone volume fraction declined by 22%-24% in both males and females [30]. This contradiction, however, can be explained as peak bone mass is between ages 25-30 years old and remains constant until the degenerative process starts (>50 years old) [31]. Moreover, as described above, the age of our subjects was less than 50 years old, with a median of 35 years old.

The Spinal Canal Width (SCW) increased craniocaudally from L3-L5 in the present study, as also described by studies from Pakistan, Singapore, the United Kingdom, Turkey, Japan and Iran (**TABLE 5**) [32,33]. The SCW, also regarded as the interpedicular distance, is important to estimate the transverse fixation length between two consecutive holes of fixation plates, which has to be precisely coincided with the center of the pedicle to prevent complications [34]. The present study reported the distance of the transverse fixative system at the lower lumbar will range from 20.13-43.65 mm depending on the lumbar level and sex. These values were similar to a study by Gulek et al. Reported the range values of 21-43 mm [12]. The narrowest site of the spinal canal depth was located at the L5 level (with a median value of 15.61 (10.20-25.45)), whereas studies in English and Turkish populations reported the L5 level as the widest site [11,12]. The spinal canal depth can be used as the diagnosis criteria for central lumbar stenosis, with a cut-off level of spinal canal depth defined by most studies below 10 mm, or less than 7 mm by several other studies, as reported in the systematic review by Steurer, et al. [35].

Pedicle screw fixation has been widely used for posterior spine fixation to treat spinal instability caused by various spinal disorders. It aims on achieving long-lasting fixation and strength, providing a framework for bony fusion. However, screw loosening due to insufficient pull-out resistance has been a common challenge for a surgeon. This pullout resistance is associated with the bone-screw interfacial strength, related to the proper screw diameter selection. Smaller screw diameter reduces the pullout strength of the screw, yet, the oversized diameter would potentially injure the pedicle. Thus, the recommendation on the screw diameter is 80% of the pedicle diameter, sparing at least 0.5 mm from the pedicle inner cortex [36]. In this study, in accordance with other studies, the pedicle width gradually increased from L3-L5, whereas, contrarily, the height decreased. The pedicle dimensions showed significant level-dependent differences (p-value<0.05). The widest outer cortical pedicle width in this study had a mean value of 13.46 mm (SD ± 2.15 mm) in males, following the results of Christodoulou et al., Avuthu, Acharya and Lotfinia with a mean of 13.61 mm (range 10.29-16.21); 13.03 mm; and 13.91 mm respectively [37]. However, Grivas et al. who conducted one of the largest measurements of pedicles in the Western, showed significantly greater pedicle width with a mean value of 17.08 mm (SD ± 1.97 mm) in L5 in males [5].

Our study showed statistically significant differences in several dimensions between males and females or between the vertebral levels. Despite that fact, we believe that these conditions did not significantly affect the changes in a clinical setting in determining the exact model of vertebral body prosthesis for the lower lumbar area in males and females. This idea was consistent with previous studies in which sex-specific prosthesis did not significantly affect the surgery results [38-41]. However, in regard to intervertebral disc implant, better pain relief and mechanical strength were associated with the use of the implant with larger sizes [42-44]. This could result from increased for aminal dimension decompressing exiting root of neural structures and larger contact area towards the endplates. In addition, other factors of prosthesis design, positioning, and approach of insertion could also exert influences and play important roles in spinal biomechanical and functional outcomes of the patients [45-50].

The value of morphometry study depends highly on the number of samples and the measurement accuracy, considering the anatomical variations of the vertebra. This study provided a large data series of 900 bones from 300 subjects with a normal spine condition, with equal gender distribution. Thus, this study serves as a reliable anatomical reference for the Asian population and is the first study to be done in the Indonesian population. However, we are also aware of several limitations of the study. Our study used a two-dimensional CT scan to measure three-dimensional bones. Besides, future studies on a more comprehensive assessment of lumbar parameters for the pedicle screw insertion technique would complement this study in clinical practices.

Conclusion

In conclusion, this study serves as the database of morphometric characteristics on the lower lumbar vertebrae, from L3 to L5, and is the first database of the Indonesian population. The results showed significant gender-related and level-dependent differences and age correlation in various dimensions of the lumbar vertebrae. The large data series of 900 vertebrae allows a reliable database for forthcoming comparative studies. This database may serve as an anatomical reference in designing lumbar endoprosthesis and instrumentations in the Asian population and to plan spine surgical interventions.

Data Availability

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

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the research, authorship, and/or publication of this article.

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