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Morphologic analysis of Chinese lumbar endplate by three-dimensional computed tomography reconstructions for helping design lumbar disc prosthesis

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Abstract

Lumbar disc prostheses have been used increasingly in recent years. The successful design of lumbar disc prostheses depends on accurate morphometric parameters. However, the morphologic dimensions of lumbar endplate area have not been investigated in Chinese population.

A total of 1800 lumbar endplates were retrospectively accessed in 150 Chinese adults. Eighteen parameters of each lumbar segment were measured by three-dimensional computed tomography reconstructions from T12/L1 to L5/S1. These obtained parameters were compared between genders, bilateral sides, vertebral segments, and different populations.

Endplate length and width increased in general, and there was a significant decrease for length/width ratio from T12 to S1 ($P=.03$). The average concavity depth of the lower lumbar endplate (2.09 ± 0.93 mm) was usually larger than that of the upper lumbar endplate (1.61 ± 0.74 mm) ($P=.02$). The percentage of the most concave point of the upper and lower lumbar endplate was 50.01 ± 10.76% and 56.41 ± 9.93%, respectively. Anterior, medium, or posterior intervertebral endplate height was severally 10.01 ± 1.98 mm, 10.46 ± 2.03 mm, and 6.41 ± 1.74 mm, and increased among vertebral segments ($P=.01$).The intervertebral endplate angle significantly increased from T12-L1 to L5-S1 ($P=.01$). Parameters displayed significant difference between genders. The morphometric parameters of different populations also showed differences.

In conclusion, there is a morphologic discrepancy in dimensions of lumbar endplate regarding genders, vertebral segments, and different populations. It is essential to design the lumbar disc prosthesis suited for Chinese patients specially, for which the morphometric parameters in our study can be utilized.

Abbreviations: 2D = two-dimensional, 3D = three-dimensional, CT = computed tomography, ECA = endplate concavity apex location, ECD = endplate concavity depth, EPL = endplate length, EPW = endplate width, EQL = endplate quartering length, IEA = intervertebral endplate angle, IEH = intervertebral endplate height, PEA = posterior endplate angle.

Keywords: Chinese, computed tomography, lumbar disc prosthesis, lumbar endplate, morphology

1. Introduction

Lumbar total disc arthroplasty (LTDA) has become an increasingly popular modality for the treatment of lumbar degenerative disc disease and has been suggested as an alternative to lumbar fusion.[1–3] The successful design of disc prostheses depends on accurate morphometric parameters of lumbar endplate. However, the majority of researches studying the lumbar vertebral morphology were cadaveric studies with a limited sample size or based on plain radiography.[4–6] Previous studies using two-dimensional (2D) analysis have shown that endplate shape is not flat and the dimensions of many implants poorly match the

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The datasets generated during and/or analyzed during the current study are publicly available.

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dimensions of the lumbar endplates.[7,8] Hence, studying the three-dimensional (3D) shape of vertebral endplates could provide useful information that may help in designing implants that have an improved fit.

Moreover, most previous studies were derived from the Caucasian population.[4–8] Some articles have demonstrated that Chinese vertebrae have a smaller build and different morphology compared with Caucasians.[9,10] So the prosthesis designed for Caucasians may not be suitable for Chinese patients. It has also indicated that a large discrepancy exists between the footprints of disc prostheses and Chinese cervical endplate, which possibly leads to complications related with mismatch sizes, such as heterotopic ossification, dislocation, and subsidence.[11] However, comprehensive 3D morphometric information about Chinese lumbar endplates is lacking. Therefore, the purpose of this study was to provide morphometric references of lumbar endplate for designing a suitable size of disc prostheses for Chinese. Besides, we aimed to further validate the ethnic morphologic diversity of lumbar endplate by comparing our data with the available data of other different populations.

2. Materials and methods

2.1. Patients and sample size

All participants were selected from patients who underwent treatment at our orthopedics clinic and underwent lumbar CT examination as part of the standard examination from January 2018 to March 2020. The experimental design was approved by the ethics committee of Jilin University, and informed consent was given to all the participants. During the selection, patients with symptomatic diagnosed lumbar degenerative diseases were included, and patients with lumbar fracture, infections, neoplasms, or osteophytes were excluded. Ultimately, 150 individuals (75 males and 75 females) presenting no signs of vertebral degeneration and abnormalities were assessed. The average age was 39.13 ± 8.44 years (21–59 years) for males with an average height of 173 ± 7.52 cm (158– 186 cm), and 38.53 ± 9.42 years (19–56 years) for females with an average height of 162 ± 7.27 cm (144–175 cm). A sample size of 75 patients per gender group was calculated with a significant level of 0.01 to yield 0.99 power for detecting a mean difference of 1.0 mm to reject the null hypothesis when comparing upper endplate length at L1. The reference values were chosen from a previous study.[12]

2.2. Computer tomographic technique

All individuals were scanned by using an Aquilion ONE 320 scanner (Toshiba Medical Systems, Japan) with parameters of 120 kV, 300 mA source, rotation 0.75 seconds and a slice thickness of 0.5 mm. All images were stored in the picture archiving communication system (PACS, GE Medical System, USA). Then the selected images were sent to a CT workstation (advantage workstation 4.5, GE Medical System, USA), and reformatted to three-dimensional (3D) reconstructions. During the measurement of each vertebra, the adjacent vertebrae were sheared by using the segment tools.

2.3. Measurement

Eighteen parameters of each lumbar vertebra were measured from T12 to S1, including 12 parameters (u/lEPL, u/lEPW, u/lECD, u/lECA, u/lEQL, and u/lPEA) concerning the lumbar endplate and 6 (a/m/pIEH, l/rIEH, IEA) regarding the intervertebral space. A complete parameter list of all measurements performed on the CT workstation was showed in Table 1. The measurement of each parameter was carefully calibrated in different 3D planes, and all the measurements were displayed in the transaxial, mid-sagittal, and mid-coronal plane (Fig. 1). All parameters were measured by 2 independent observers, and the means were calculated and used for analysis.

2.4. Measurement verification

To verify the accuracy of CT measurements, 6 human cadaver spines were scanned and reconstructed using the same CT settings. The CT measurements were verified by comparing measurements using a vernier caliper (Mitutoyo, Kawasaki, Japan, accuracy ± 0.05 mm) on the real cadaver lumbar vertebrae. Thirteen linear parameters (u/lEPL, u/lEPW, u/lECD, u/lEQL, a/m/pIEH, and l/rIEH) were measured on each vertebra, giving 78 measurements in total.

2.5. Statistics

SPSS software version (IBM Corp. Released 2010. IBM SPSS Statistics for Windows, Version 19.0. Armonk, NY: IBM Corp.) was used for statistical analyses. The statistics were described as the mean and standard deviation (Mean ± SD). Independent sample Student *t* tests were conducted to compare parameters

Table 1

Morphometric parameters of lumbar endplate and intervertebral space.

Parameter	Measurement	Description
u/lEPL	Upper or lower endplate length	The antero-posterior length of the upper or lower endplate at the mid-sagittal line
u/lEPW	Upper or lower endplate width	The center mediolateral diameter of the upper or lower endplate
u/lECD	Upper or lower endplate concavity depth	The concavity apex to the line connecting the anterior and posterior margins of the endplate
u/lECA	Upper or lower endplate concavity apex location	The percentage of total endplate diameter divided by distance of apex from the anterior cortex
u/lEQL	Upper or lower endplate quartering length	The antero-posterior length of the upper or lower endplate at the quartation of center mediolateral diameter
u/lPEA	Upper or lower posterior endplate angle	The angle formed between the trailing edge of EPL and EQL
a/m/pIEH	Anterior, medium or posterior intervertebral endplate height	The height of intervertebral endplate at anterior, medium or posterior margin at the mid-sagittal line
l/rIEH	Left or right intervertebral endplate height	The height of intervertebral endplate at left or right margin at the mid-coronal line
IEA	Intervertebral endplate angle	The angle formed between the line of upper or lower endplate at the mid-sagittal line

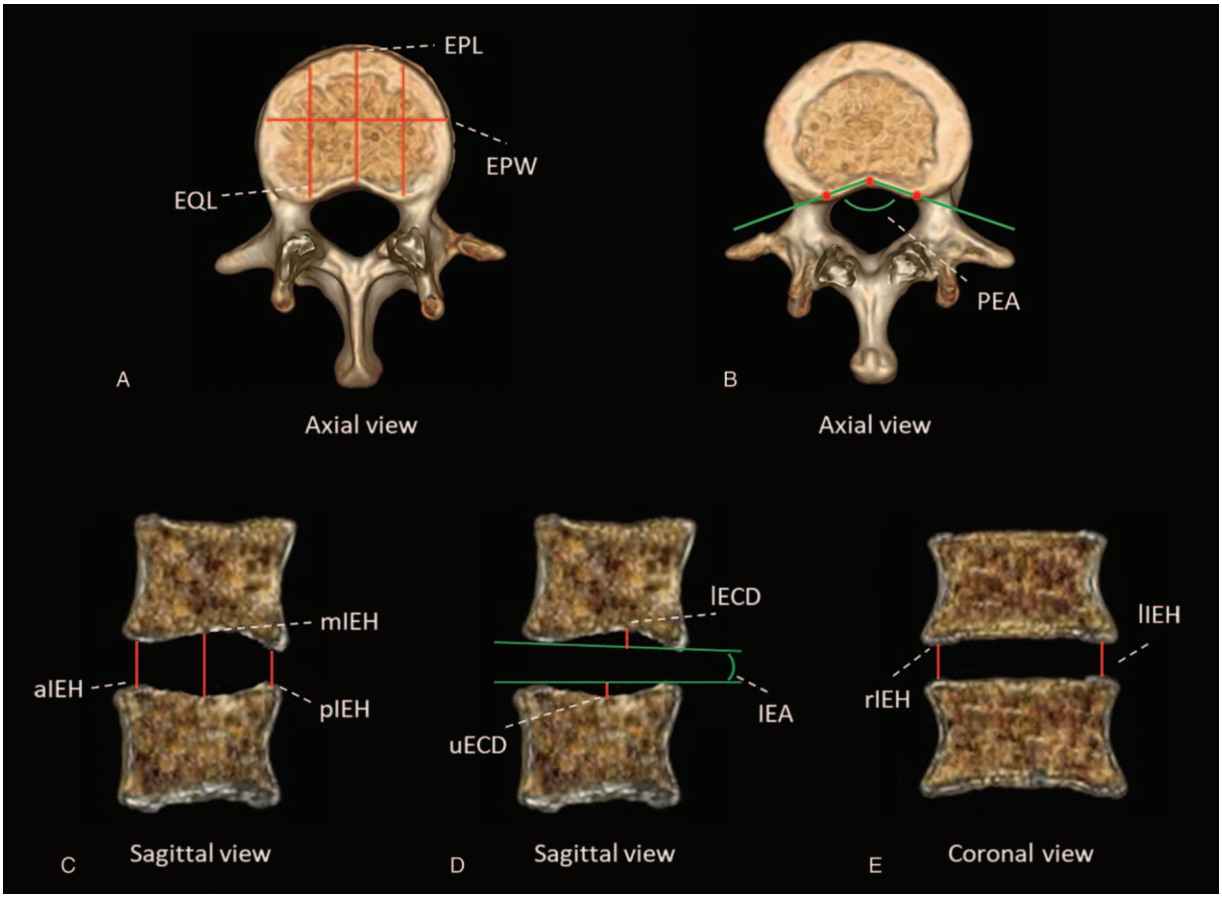

Figure 1. Measurement of dimensions of lumbar vertebrae: (A) endplate depth (EPD), endplate width (EPW) and endplate quartering length (EQL); (B) posterior endplate angle (PEA); (C) anterior, medium, or posterior intervertebral endplate height (a/m/pIEH); (D) upper or lower endplate concavity depth (u/lECD) and intervertebral endplate angle (IEA); and (E) left or right intervertebral endplate height (l/rIEH).

between genders, and single sample Student *t* tests were carried out to compare parameters between populations. The differences between bilateral sides were compared by paired sample Student *t* tests, and one-way analysis of variance (ANOVA) was applied for the comparison of parameters among vertebral segments. Intra- and inter-rater correlations were assessed by using Pearson coefficient. A coefficient of 1.0 indicated perfect agreement between 2 measurements. For intra-rater correlation, all 18 parameters were repeatedly measured by 1 observer for 30 subjects. For inter-rater correlation, all the measurements performed by 2 independent observers were compared. Bland-Altman plot was used to observe the difference between vernier caliper measurements and CT-based measurements. The statistically significant level was set at $P<.05$.

3. Results

The total number of 1800 lumbar endplates was accessed in our study. Fifteen linear and 3 angular parameters were measured at each vertebral segment. The detailed results regarding the measurements of the lumbar endplate and intervertebral space were respectively presented in Tables 2 and 3.

3.1. Linear measurements

Upper endplate length and width regarding the lumbar endplate significantly increased from L1 to L5 ($P=.01$), and decreased at S1 ($P=.03$). Lower endplate length and width significantly increased from T12 to L4 ($P=.02$), and decreased at L5 with no statistical significance ($P=.06$) (Fig. 2A). There was a significant decrease for EPL/EPW ratio from T12 to S1 ($P=.03$) (Fig. 2B). A significant increasing distance from T12 to L3 was observed for upper and lower EQL ($P=.04$), and decreased at lower lumbar vertebrae (L4-S1) (Fig. 2C). The average concavity depth of the upper and lower lumbar endplate was 1.61 ± 0.74 mm and 2.09 ± 0.93 mm, respectively. The average concavity depth of the lower lumbar endplate was usually larger than that of the upper lumbar endplate ($P=.02$). The lower endplate concavity depth increased from T12 to L5 ($P=.02$), whereas the upper endplate concavity depth turned to no apparent pattern ($P=.15$). The percentage of the most concave point of the upper and lower lumbar endplate was 50.01 ± 10.76% and 56.41 ± 9.93%, respectively. The location of endplate concavity apex moved dorsally as the lumbar vertebra moved down ($P=.07$) (Fig. 2B).

Anterior, medium, or posterior intervertebral endplate height at the mid-sagittal line significantly increased from T12/L1 to L4/L5 ($P=.01$) (Fig. 2D). Medium intervertebral height was the highest, and the values of aIEH and mIEH were significantly larger than that of pIEH ($P=.02$). No significant bilateral difference and segmental difference in intervertebral endplate height at the mid-coronal line (l/rIEH) were found. The parameters of u/lEPL, u/lEPW, u/lEQL, and mIEH of males were significantly larger than those of females ($P<.01$).

Table 2

Dimensions of parameters with regard to the lumbar endplate (Mean±SD).

Parameter	Sex	T12	L1	L2	L3	L4	L5	S1
uEPL**	M	–	32.55±2.01	34.46±2.15	35.92±2.45	36.26±2.56	36.57±2.69	33.27±1.99
(mm)	F	–	28.98±1.98*	30.47±2.15*	32.44±2.41*	32.93±2.55*	33.17±2.59*	30.83±2.14*
uEPW**	M	–	44.00±2.70	46.56±2.92	49.06±2.99	51.98±2.81	54.01±3.01	52.79±4.18
(mm)	F	–	39.39±2.49*	41.47±2.80*	44.01±3.15*	46.85±3.55*	49.82±4.12*	47.94±4.07*
lEPL**	M	31.91±2.04	33.59±2.14	35.18±2.37	35.74±2.45	36.36±2.53	34.43±2.07	–
(mm)	F	28.51±2.19*	29.73±2.17*	31.71±2.49*	32.44±2.46*	32.67±2.39*	31.75±1.81*	–
lEPW**	M	43.58±3.07	47.11±3.09	49.48±3.14	52.71±2.99	54.69±2.64	54.41±2.85	–
(mm)	F	38.97±2.41*	41.90±2.76*	44.42±3.03*	47.56±3.52*	49.96±3.39*	49.76±3.37*	–
EPL/EPW**	M	75.21±4.23	73.92±9.43	73.22±6.45	74.07±5.67	71.04±8.66	70.34±7.53	67.82±5.53
(%)	F	74.25±5.67	73.53±7.87	73.71±7.44	73.24±5.23	71.34±7.54	70.21±6.45	68.23±4.34
uEQL**	M	–	30.42±2.78	32.01±2.43	34.64±2.77	35.17±3.11	34.38±2.54	31.42±2.12
(mm)	F	–	28.12±2.34*	30.02±2.46*	32.18±2.98*	33.05±2.87*	32.31±2.34*	28.64±2.42*
lEQL**	M	29.62±2.63	31.21±3.11	32.52±2.93	34.63±2.56	34.38±2.48	33.65±3.11	–
(mm)	F	27.11±2.34*	29.15±3.03*	29.99±3.21*	32.35±2.38*	32.18±2.35*	31.11±3.22*	–
uPEA**	M	–	159.06±7.12	165.95±6.36	171.45±7.54	−178.96±9.87	-168.24±9.42	−171.72±12.02
(degrees)	F	–	162.13±5.23	166.43±5.95	175.04±7.75	−178.54±17.95	−171.96±7.22	−171.13±11.32
lPEA**	M	158.02±7.22	162.72±5.64	171.84±5.84	−179.03±7.93	−164.83±5.84	−155.14±6.38	–
(degrees)	F	163.01±5.53	164.46±4.65	171.13±5.33	−179.85±9.76	−168.86±12.14	−155.27±8.23	–
uECD	M	–	1.57±0.54	1.75±0.55	1.72±0.80	1.69±0.78	1.58±0.62	1.14±1.19
(mm)	F	–	1.80±0.52*	1.81±0.52	1.70±0.46	1.71±0.54	1.70±0.51	1.18±0.73
lECD**	M	1.82±0.43	1.67±0.52	1.88±0.58	2.06±0.73	2.04±0.73	2.41±1.03	–
(mm)	F	2.12±0.53*	2.01±0.52*	2.11±0.56	2.34±0.56	2.26±0.53	2.32±0.64	–
uECA**	M	–	43.83±14.21	45.12±11.82	49.16±12.38	52.13±9.35	60.16±10.22	50.28±12.22
(%)	F	–	42.23±13.11	47.29±12.67	49.32±9.63	52.26±11.76	58.25±11.23	48.32±14.62
lECA**	M	48.12±11.11	54.23±14.42	57.34±9.65	56.92±7.24	56.21±8.63	65.63±7.36	–
(%)	F	52.32±10.37	55.67±10.29	59.26±6.97	56.87±5.62	55.27±8.87	63.73±7.32	–

* Significant difference compared with males ($P < .05$).

** Significant difference in one-way ANOVA ($P < .05$).

("+" means an angle protruding ventrally, and "−" means an angle protruding dorsally).

u/lECA = upper or lower endplate concavity apex location, u/lECD = upper or lower endplate concavity depth, u/lEPL = upper or lower endplate length, u/lEPW = upper or lower endplate width, u/lEQL = upper or lower endplate quartering length, u/lPEA = upper or lower posterior endplate angle.

3.2. Angular measurements

PEA protruded ventrally and increased from T12 to the upper endplate of L3 ($P = .04$); conversely, PEA protruded dorsally at the lower endplate of L3 and decreased gradually as the lumbar vertebrae moved down ($P = .03$) (Fig. 3A). There was no significant difference in PEA between genders. The intervertebral endplate angle significantly increased from T12/L1 to L5/S1 ($P = .01$) (Fig. 3B). The IEA values of males were significantly larger than those of females at T12/L1 ($P = .02$), L1/L2 ($P = .01$), and L2/L3 ($P = .01$).

3.3. Measurement verification

The mean difference between vernier caliper measurements and CT measurements was −0.06 mm ($P = .33$, 95% confidence interval [−0.16 mm, 0.04 mm]) (Fig. 4). Pearson coefficients of intra-rater correlation were greater than those of inter-rater

Table 3

Dimensions of parameters with regard to the intervertebral space (Mean±SD).

Parameter	Sex	T12/L1	L1/L2	L2/L3	L3/L4	L4/L5	L5/S1
aIEH**	M	7.40±1.10	8.64±1.32	10.22±1.43	11.54±1.35	12.05±1.62	11.33±2.00
(mm)	F	7.34±0.96	8.39±1.09	9.83±1.16	11.17±1.30	11.42±1.27	11.02±1.82
mIEH**	M	8.11±1.08	9.07±1.33	11.39±1.47	12.15±1.81	13.99±1.85	12.92±2.47
(mm)	F	7.05±1.01*	7.46±1.27*	9.75±1.23*	10.93±1.53*	11.42±1.92*	11.77±2.46*
pIEH**	M	3.94±1.41	5.13±1.35	6.48±1.41	7.41±1.57	7.84±1.85	7.82±5.22
(mm)	F	4.43±1.44*	5.43±1.50	6.53±1.60	7.58±1.95	7.63±1.84	6.71±1.65
lIEH	M	4.54±1.12	5.13±1.37	6.09±1.21	6.68±1.11	6.78±1.29	4.78±1.13
(mm)	F	4.34±1.23	5.09±1.45	6.10±1.26	6.45±1.23	6.67±1.35	4.74±1.16
rIEH	M	4.58±1.26	5.18±1.26	6.12±1.29	6.60±1.32	6.80±1.30	4.80±1.32
(mm)	F	4.31±1.12	5.11±1.30	6.03±1.42	6.54±1.24	6.62±1.23	4.66±1.31
IEA**	M	6.50±1.94	6.77±1.86	7.57±2.35	8.15±2.55	10.03±3.27	14.29±4.30
(degrees)	F	4.45±1.98*	5.18±2.06*	6.23±1.95*	7.46±2.66	9.67±3.26	13.56±4.27

* Significant difference compared with males ($P < .05$).

** Significant difference in one-way ANOVA ($P < .05$).

a/m/pIEH = anterior, medium, or posterior intervertebral endplate height, IEA = intervertebral endplate angle, l/rIEH = left or right intervertebral endplate height.

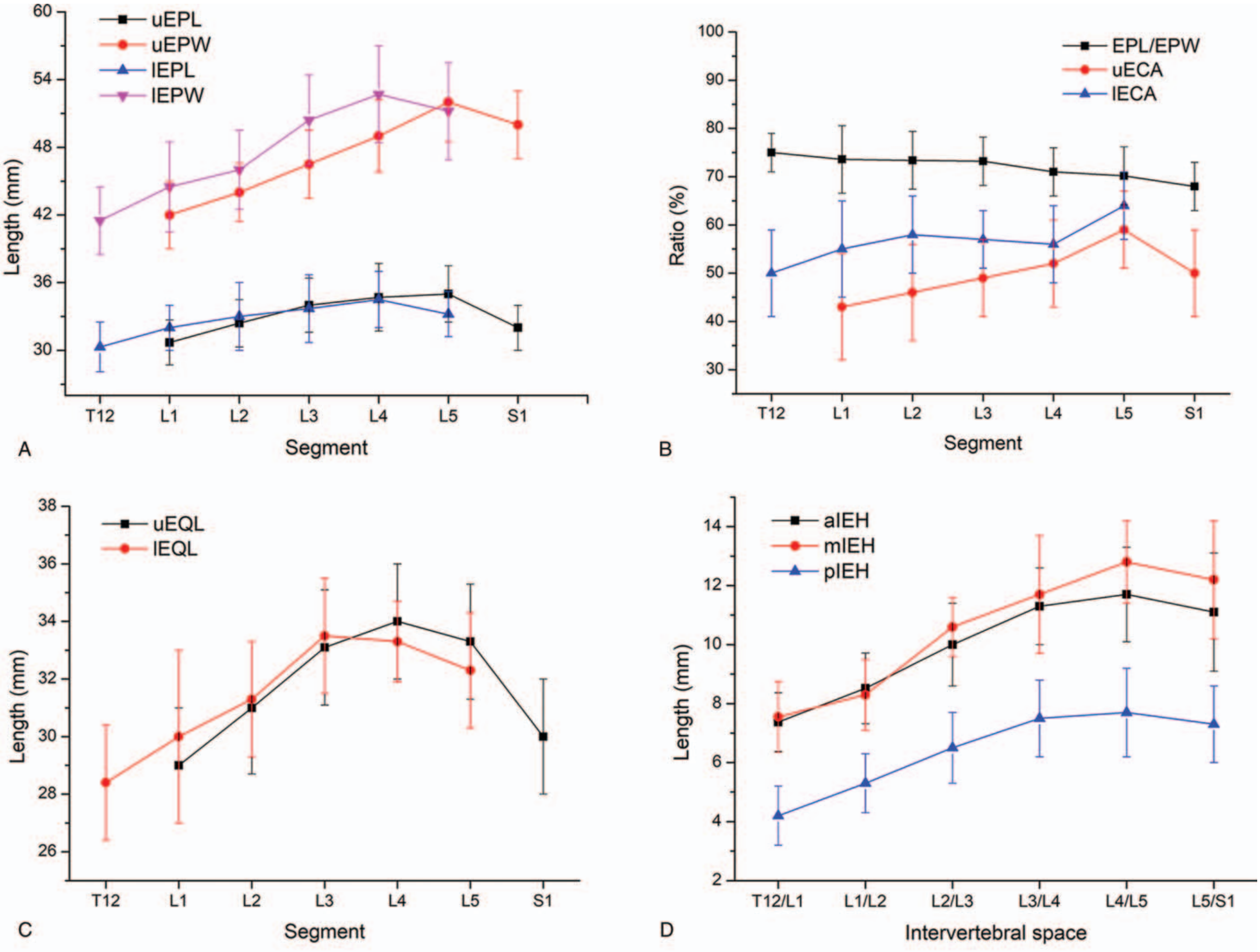

Figure 2. Tendency of linear measurements with regard to the segments (A-C) and intervertebral spaces (D). a/m/pIEH = anterior, medium, or posterior intervertebral endplate height, u/lECA = upper or lower endplate concavity apex location, u/lEPL = upper or lower endplate length, u/lEPW=upper or lower endplate width, u/lEQL = upper or lower endplate quartering length.

correlation (Table 4). Although Pearson coefficients were relatively lower for the measurements of angular parameters, most correlations exceeded 0.80, which meant the intra- and inter-rater measurements were acceptable.

4. Discussion

Some investigators have researched the Caucasian lumbar vertebral morphology based on cadaveric studies with restricted sample quantity or two-dimensional images.[4–7] A recent study by Michaela et al[8] compared lumbar endplate diameters with footprint sizes of 5 currently available disc prostheses (Charite, Prodisc L, Maverick, Activ L, and Mobi-disc), discovering that more than half of the largest device footprints mismatched the lumbar endplate diameters. From a biomechanical point of view, an implant with the largest possible surface area appears to be best to avoid subsidence into the vertebral body, as the circumference would provide a brace for the strongest areas in the periphery.[8] Some biomechanical studies also indicated that the mismatch of disc prostheses could give rise to quite a few adverse events such as migration, subsidence, and heterotopic ossification.[13–15] Some articles have demonstrated that Chinese vertebrae are different compared with Caucasians.[9,10] Moreover, it has indicated that a large discrepancy exists between the footprints of disc prostheses and Chinese cervical endplate, which possibly leads to complications related with mismatch sizes.[11] Hence, it is necessary to design a type of lumbar disc prosthesis suitable specially for Chinese patients.

It is well known that the successful design of prostheses depends on accurate morphometric parameters. Some previous studies[7,8] concerning the Caucasian lumbar vertebral morphology were all based on two-dimensional CT scans, where the precise contact area of disc prostheses on lumbar endplates could not be directly seen and determined. Although the morphometric measurements made with calipers on fresh-frozen cadaveric specimens may be more accurate, the sample sizes are generally quite small. In our study, the 3D CT measurements were verified by comparing measurements using a vernier caliper on the real cadaver vertebrae. From Bland-Altman plot, the fixed bias was 0.06 mm, and most measurements (49/52, 94%) were within the 95% confidence interval. The measurement error was within the consistency range, hence no significant difference was found

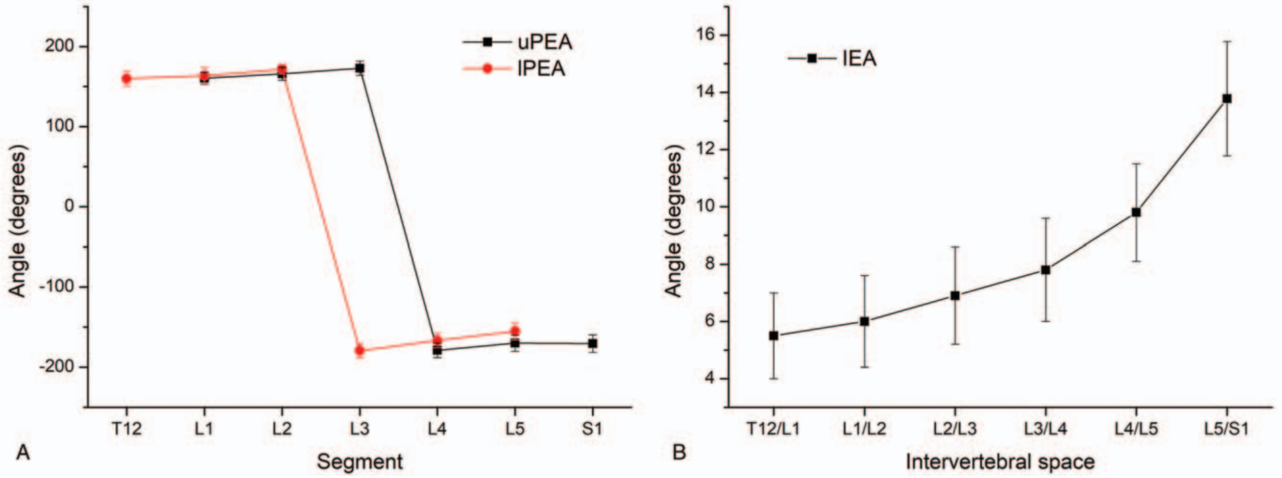

Figure 3. Tendency of angular measurements with regard to the segments (A) and intervertebral spaces (B). IEA = intervertebral endplate angle, u/lPEA = upper or lower posterior endplate angle.

between these 2 gauging procedures (*P* = .33). Therefore, we chose 3D CT reconstructions to get a large sample size to measure the dimensions of lumbar endplate and intervertebral space to provide references for designing lumbar disc prostheses particularly for Chinese.

Another purpose of this study was to further validate the morphologic diversity of lumbar endplate by comparing our data with the available data of different populations. Wang et al[12] and Aharinejad et al[16] reported the endplate length and width (EPL/EPW), and intervertebral endplate height (IEH) of Caucasian cadavers by CT digitizer, respectively. The morphological measurement results of lumbar vertebrae in different populations were displayed in Table 5. The EPL (*P* = .02) and EPW (*P* = .04) parameters regarding the endplate surface from Chinese were generally smaller than those of Caucasians. The aIEH of Chinese was averagely 1.50 mm larger than that of Caucasians; conversely, the pIEH of Chinese was averagely 2.36 mm smaller than that of Caucasians (*P* = .01). No statistical difference was observed in mIEH between Chinese and Caucasians at lower lumbar segments except T12/L1 (*P* = .03) and L1/L2 (*P* = .04). In total, the endplate surface of Chinese was smaller compared with Caucasians; an oblong intervertebral endplate shape was observed in Caucasians, whereas the intervertebral space of Chinese was close to the trapezoid due to larger aIEH and smaller pIEH. Lakshmanan et al[17] measured the concavity depth (ECD) of Caucasians from L3–S1 on magnetic resonance imaging (MRI) scans. Similarly, the ECD of Chinese was smaller than that of Caucasians, especially for L5/S1 segments (*P* < .01). In our study, the lower endplate of each vertebra was more concave than the upper endplate. Moreover, the lower endplates of caudal lumbar vertebrae were more concave than those in cranial lumbar vertebrae, which was in accordance with the measuring result of previous studies.[18,19] However, the precision of comparisons may be affected by insufficient sample sizes, unequal gender ratios, and different gauging techniques in different studies. Thus, the comparison results should be cautiously accepted, and further gender-specific studies with large sample are needed to perform to get more accurate comparisons.

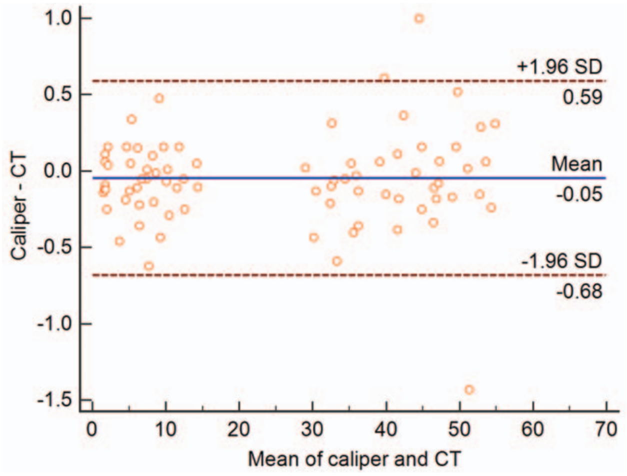

Figure 4. Bland-Altman plot: the difference between vernier caliper measurements and CT-based measurements (n = 52).

Nowadays, available disc prostheses have various footprint sizes, but the shape of prostheses utilized at different vertebral segments are almost the same. Although most linear parameters of males were larger than those of females, no significant difference was observed in EPL/EPW ratio, location of concavity apex (ECA), and posterior endplate angle (PEA) between genders. So the designs of disc prosthesis between genders should be different in size, but not in shape. However, in our study, the EPL/EPW ratio significantly decreased from 75% to 68% as the lumbar vertebrae moved down, which meant that the endplate surface gradually changed into a more oval shape from T12/L1 down to L5/S1 disc. The PEA protruded ventrally from T12/L1 to L2/L3 disc, and protruded dorsally from L3/L4 to L5/S1 disc. The variation in the posterior area of lumbar endplate should be considered when designing disc prostheses. Some studies have indicated that the lumbar endplate concavity was symmetrical in the coronal plane but showed considerable variability in the sagittal plane.[17,20] In this study, the apex of the concavity was located in the posterior half of the endplate, and the ECA moved dorsally from T12 to S1. The intervertebral endplate angle (IEA) of males was averagely 1.65° larger than that of females at upper lumbar vertebrae, and we suppose that this phenomenon may be attributed to the stronger muscles and

Table 4

Intra- and inter-rater correlations assessed by Pearson coefficient.

Parameter	Intra-rater correlation	*P* value	Inter-rater correlation	*P* value
uEPL	0.94	<.01	0.90	<.01
uEPW	0.93	<.01	0.89	<.01
lEPL	0.96	<.01	0.88	<.01
lEPW	0.95	<.01	0.90	<.01
uECD	0.92	<.01	0.86	<.01
lECD	0.93	<.01	0.87	<.01
uECA	0.90	<.01	0.83	<.01
lECA	0.91	<.01	0.81	<.01
uEQL	0.92	<.01	0.86	<.01
lEQL	0.93	<.01	0.87	<.01
uEPA	0.89	<.01	0.76	<.01
lEPA	0.88	<.01	0.79	<.01
aIEH	0.95	<.01	0.90	<.01
mIEH	0.94	<.01	0.89	<.01
pIEH	0.96	<.01	0.93	<.01
lIEH	0.93	<.01	0.91	<.01
rIEH	0.93	<.01	0.89	<.01
IEA	0.89	<.01	0.77	<.01

a/m/pIEH = anterior, IEA = intervertebral endplate angle, l/rIEH = left or right intervertebral endplate height, medium or posterior intervertebral endplate height, u/lECA = upper or lower endplate concavity apex location, u/lECD = upper or lower endplate concavity depth, u/lEPL = upper or lower endplate length, u/lEPW = upper or lower endplate width, u/lEQL = upper or lower endplate quartering length, u/lPEA = upper or lower posterior endplate angle.

ligaments of males to better maintain lumbar physiological lordosis. Due to the increase of IEA from T12/L1 to L5/S1, the disc prostheses for lower lumber vertebrae should be designed to be higher in front and narrower in back to fit the variation of lumbar curvature. Furthermore, the biomechanics of artificial discs may change because of the variation of endplate and intervertebral shape.[21,22] Thus, we propose that the disc prostheses applied for different lumbar segments should be separately designed to fit the morphologic and biomechanical variations.

There are some strengths in our study. First, to the best of our knowledge, this is the first study gauging the morphology of Chinese lumbar endplate based on 3D CT reconstructions. Second, we compared our data with the available data of Caucasians to indicate the ethnic morphologic diversity. Additional strengths included specific and equal gender ratio, large sample size, and measurement verification by Bland-Altman plot and Pearson coefficient to guarantee consistency and accuracy. Although these findings may be technical for neurosurgeons to use in clinical practice directly, this data would be useful for prosthesis manufacturers to design suitable disc prostheses for Chinese.

In conclusion, the data of this study provide the morphometric guideline for helping design suitable disc prostheses for Chinese patients. This study also indicates that morphologic diversity of lumbar vertebrae exists among different populations, which should be noticed by prosthesis manufacturers. We also suggest that the disc prostheses for different lumbar segments should be

Table 5

Measurement results of morphological parameters of lumbar endplate in different populations (Mean±SD).

Dimension	Data	T12/L1	L1/L2	L2/L3	L3/L4	L4/L5	L5/S1
EPL	Caucasian[12]	-/ 34.8±3.2	35.5±2.9/ 35.7±2.3	36.2±2.8/ 35.7±3.1	35.6±2.8/ 35.8±2.8	36.1±2.8/ 35.5±2.9	34.7±3.2/ 33.8±3.5
(mm)	Chinese	30.15±2.71/ 30.70±2.67*	31.60±2.89*/ 32.40±2.93*	33.39±2.98*/ 34.12±2.98	34.03±2.95*/ 34.54±3.04	34.45±3.07*/ 34.81±3.13	33.36±2.45/ 32.16±2.38
EPW	Caucasian[12]	-/ 45.3±3.7	47.6±4.0/ 47.0±3.5	50.3±3.6/ 48.0±3.1	51.5±3.4/ 51.3±3.7	53.6±3.7/ 53.0±4.1	52.3±4.7/ 51.2±5.3
(mm)	Chinese	41.20±3.58/ 41.61±3.47*	44.42±3.92*/ 43.93±3.82*	46.87±3.98*/ 46.45±3.97	50.05±4.16/ 49.33±4.10*	52.25±3.86/ 51.84±4.18*	52.56±3.98/ 50.59±4.77
aIEH	Caucasian[16]	7.57±2.63	8.22±1.91	8.63±1.87	9.07±1.97	9.41±2.10	9.41±2.10
(mm)	Chinese	7.37±1.03	8.51±1.21	10.02±1.30*	11.35±1.33*	11.73±1.59*	11.35±1.90*
mIEH	Caucasian[16]	9.96±1.78	10.33±1.87	10.97±2.06	11.61±1.96	12.20±2.29	12.20±2.29
(mm)	Chinese	7.58±1.24*	8.27±1.52*	10.57±1.58	11.54±1.77	12.71±2.03	11.85±2.49
pIEH	Caucasian[16]	8.06±1.75	8.17±1.85	8.63±1.92	9.01±2.0	9.39±2.34	9.39±2.34
(mm)	Chinese	4.19±1.44*	5.29±1.43*	6.51±1.50*	7.50±1.77*	7.73±1.84*	7.16±3.65*
ECD	Caucasian[17]	-/-	-/-	-/-	2.479/1.965	2.547/1.529	2.942/1.9
(mm)	Chinese	1.97±0.63/ 1.69±0.61	1.84±0.55/ 1.78±0.60	2.00±0.57/ 1.71±0.71	2.20±0.66/ 1.70±0.81	2.15±0.72/ 1.64±0.70	2.37±0.61*/ 1.16±0.86*

* Significant difference compared with Caucasian data ($P < .05$).

a/m/pIEH = anterior, medium or posterior intervertebral endplate height, ECD = endplate concavity depth, EPL = endplate length, EPW = endplate width.

separately designed to fit the morphologic and biomechanical variations. The gauging method of this study, based on 3D CT reconstructions, can also be applied in other populations to help design population-specific implant devices.

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