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Original Article

Morphologic evaluation of Chinese cervical endplate and uncinate process by three-dimensional computed tomography reconstructions for helping design cervical disc prosthesis

Yu-Hang Zhu [a], Kai-Liang Cheng [b], Zhuan Zhong [c], You-Qiong Li [d], Qing-San Zhu [a,*]

[a] *Department of Orthopedics, China-Japan Union Hospital of Jilin University, Changchun, Jilin, China*
[b] *Department of Radiology, China-Japan Union Hospital of Jilin University, Changchun, Jilin, China*
[c] *Department of Orthopedics, The Second Hospital of Jilin University, Changchun, Jilin, China*
[d] *Department of Human Anatomy, College of Basic Medicine of Jilin University, Changchun, Jilin, China*

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Abstract

Background: Cervical disc prostheses have been used increasingly in recent years. The successful design of cervical disc prostheses depends on accurate morphometric parameters. However, the morphologic dimensions of the cervical endplate area have not been investigated in the Chinese population.
Methods: A total of 1360 cervical endplates and 680 pairs of uncinate processes was retrospectively accessed in 136 Chinese adults. Eleven parameters of each cervical vertebra were measured by three-dimensional computed tomography reconstructions from C3 to C7. These obtained parameters were compared between sexes, bilateral sides, vertebral segments, and different populations.
Results: Five parameters regarding the cervical endplate increased from C3 to C7 in general. Concerning parameters with regard to the uncinate process, the uncinate process distance gradually increased among vertebral segments, and anterior distance was always larger than the posterior distance. The value of left uncinate process angle was on average 0.84° larger than that of the right side, and lower cervical segments had an obviously larger angle. Uncinate process length increased among segments, and no significant difference existed between bilateral sides. Parameters displayed significant difference between sexes. The morphometric parameters of various populations also showed differences.
Conclusion: There is a morphologic discrepancy in dimensions of cervical vertebrae regarding sexes, bilateral sides, vertebral segments, and different populations. It is essential to design cervical disc prostheses suited specifically for Chinese patients, for whom the morphometric parameters in our study concerning the cervical endplate and uncinate process can be utilized.

Keywords: cervical disc prosthesis; cervical vertebra; Chinese; computed tomography; morphology

1. Introduction

With the rapid development of cervical disc arthroplasty, artificial cervical discs are used more and more widely, with advantages shown in short- and long-term efficacy.[1−3] The successful design of disc prostheses depends on accurate morphometric parameters of cervical vertebrae. However, the majority of researches studying cervical vertebral morphology were cadaveric studies with a limited sample size or based on plain radiography.[4−7] Also, most of the studies were derived

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* Corresponding author. Dr. Qing-San Zhu, Department of Orthopedics, China-Japan Union Hospital of Jilin University, 126, Xiantai Street, Changchun, Jilin 130033, China.
E-mail address: zhuqingsan1@foxmail.com (Q.-S. Zhu).

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from the Caucasian population. Some articles have demonstrated that Chinese people have smaller build and stature compared with Caucasians,[8,9] so prostheses designed for Caucasians may not be suitable for Chinese patients. It has also been found that a large discrepancy exists between the footprints of disc prostheses and Chinese cervical endplate anatomic parameters, which possibly leads to complications of disc arthroplasty related to mismatched sizes, such as heterotopic ossification, dislocation, and subsidence.[10] Moreover, the morphology of uncinate processes restricting the shape and size of disc prostheses was ignored in previous studies. The purpose of this study was to provide morphometric references of cervical endplate and uncinate process for designing suitable-sized disc prostheses for Chinese patients. Furthermore, we aimed to validate further the ethnic morphologic diversity of cervical vertebrae by comparing our data with the available data of other populations.

2. Methods

2.1. Patients and sample size

All participants were selected from patients who underwent treatment at our orthopedics clinic and underwent cervical computed tomography (CT) examination as part of the standard examination from January 2014 to October 2015. During the selection, patients with significant vertebral degeneration, vertebral fracture, torticollis, infections, neoplasms, or osteophytes were excluded. Ultimately, 136 individuals (68 men and 68 women) presenting no signs of vertebral degeneration and abnormalities were assessed. The average age was 41.13 ± 9.47 years (range, 22−57 years) for men, with an average height of 171 ± 7.11 cm (range, 159−184 cm), and 39.53 ± 11.42 years (range, 19−71 years) for women, with an average height of 160 ± 6.27 cm (range, 146−173 cm). A sample size of 68 patients per sex group was calculated with a significance 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 depth at C3. The reference values were chosen from a previous study.[5]

2.2. CT technique

All individuals were scanned using an Aquilion ONE 320 scanner (Toshiba Medical Systems, Tokyo, 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 Systems, Fairfield, CT, USA). Then the selected images were sent to a CT workstation (Advantage Workstation 4.5; GE Medical Systems) 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

Eleven parameters of each cervical vertebra were measured from C3 to C7, including five parameters [upper or lower endplate depth (u/lEPD), upper or lower endplate width (u/lEPW), and anterior protrusion length (aPL)] concerning the cervical endplate and six [anterior or posterior uncinate processes distance (a/pUPD), left or right uncinate process length (l/rUPL), and left or right uncinate process angle (l/rUPA)] regarding the uncinate process. A complete parameter list of all measurements performed on the CT workstation is shown in Table 1. The measurement of each parameter was carefully calibrated in different 3D planes, and all the measurements were displayed in the transaxial plane (Fig. 1). All parameters were measured by two independent observers, and the means were calculated and used for analysis. To verify the accuracy of CT measurements, five human cadaver vertebrae 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 vertebrae. Nine linear parameters were measured on each vertebra, giving 45 measurements in total.

2.4. Statistical analysis

SPSS software version 19.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analyses. The statistics were performed as the mean and standard deviation. Independent, single, and paired sample Student *t* tests were separately conducted to compare parameters between sexes, populations, and bilateral sides, 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 two measurements. For intrarater

Table 1
Morphometric parameters of cervical endplate and uncinate process.

Parameter	Measurement	Description
u/lEPD	Upper or lower endplate depth	The anteroposterior diameter of the upper or lower endplate at the midsagittal line
u/lEPW	Upper or lower endplate width	The center mediolateral diameter of the upper or lower endplate excluding bilateral uncinate processes
aPL	Anterior protrusion length	The distance from the anterior border of the upper endplate to the line of aUPD at the midsagittal line
a/pUPD	Anterior or posterior uncinate processes distance	The distance between the medial edges of bilateral uncinate processes at the anterior or posterior margin
l/rUPL	Left or right uncinate process length	The distance from the anteromedial to posteromedial margin of one-sided uncinate process
l/rUPA	Left or right uncinate process angle	The angle formed between the line of l/rUPL & the sagittal line

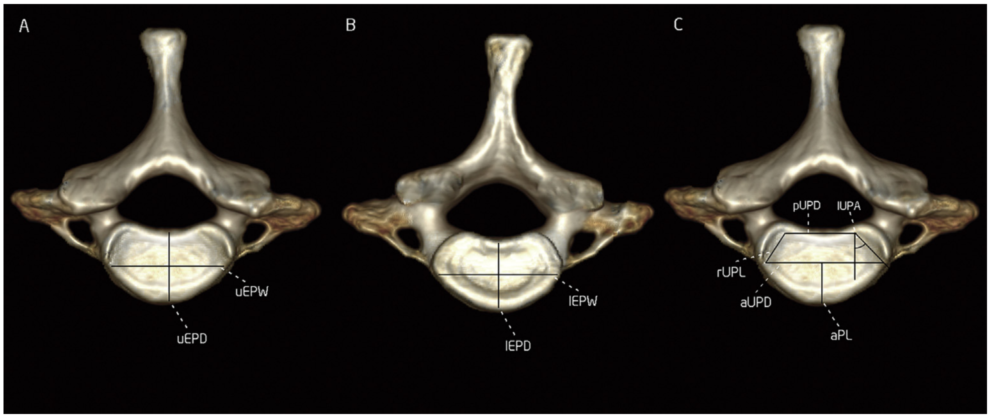

Fig. 1. Measurement of dimensions regarding depth and width on the (A) cervical upper endplate (uEPD and uEPW) and (B) lower endplate (lEPD and lEPW), and (C) measurement of dimensions regarding the uncinate process (a/pUPD, l/rUPL, and l/rUPA) and anterior protrusion length (aPL).

correlation, all 11 parameters were repeatedly measured by one observer for 30 participants. For inter-rater correlation, all the measurements performed by two independent observers were compared. The statistical significance level was set at $p < 0.05$.

3. Results

In total, 1360 cervical endplates and 680 pairs of uncinate processes was accessed in our study. Nine linear and two angular parameters were measured for each vertebral segment. The detailed results regarding the measurements of cervical endplate and uncinate process are presented in Table 2.

3.1. Linear measurements

Five parameters regarding the cervical endplate significantly increased from C3 to C7 ($p < 0.001$). The lEPD decreased at C7, with no statistical significance ($p = 0.063$).

Table 2
Dimensions of parameters with regard to the cervical endplate and uncinate process.

Parameter	Sex	C3	C4	C5	C6	C7
uEPD***	M	14.73 ± 0.88	15.48 ± 1.03	15.73 ± 1.19	16.32 ± 1.05	17.17 ± 1.06
(mm)	F	13.73 ± 1.03*	13.80 ± 1.11*	13.85 ± 1.08*	14.66 ± 1.11*	15.45 ± 1.25*
uEPW***	M	14.26 ± 1.00	15.31 ± 1.03	16.24 ± 1.25	17.03 ± 1.31	18.88 ± 1.49
(mm)	F	13.30 ± 0.93*	13.95 ± 1.02*	14.78 ± 1.05*	15.57 ± 1.13*	17.86 ± 1.34*
lEPD***	M	15.67 ± 1.06	15.91 ± 1.06	17.79 ± 1.01	18.57 ± 1.05	17.22 ± 0.96
(mm)	F	14.51 ± 1.05*	14.75 ± 1.13*	16.27 ± 1.18*	16.53 ± 1.19*	15.48 ± 1.23*
lEPW***	M	17.51 ± 1.14	17.94 ± 1.32	19.45 ± 1.35	22.64 ± 1.49	24.61 ± 1.69
(mm)	F	15.69 ± 1.20*	15.92 ± 1.31*	17.83 ± 1.36*	20.40 ± 1.61*	21.41 ± 1.76*
aPL***	M	2.95 ± 0.71	3.55 ± 0.60	3.75 ± 0.77	4.54 ± 0.67	6.47 ± 0.93
(mm)	F	2.59 ± 0.66*	3.07 ± 0.67*	3.25 ± 0.60*	4.06 ± 0.66*	5.67 ± 0.89*
aPL/uEPD***	M	0.20 ± 0.05	0.23 ± 0.04	0.24 ± 0.04	0.28 ± 0.04	0.38 ± 0.04
(ratio)	F	0.20 ± 0.05	0.22 ± 0.04	0.23 ± 0.04	0.28 ± 0.04	0.37 ± 0.05
aUPD***	M	16.03 ± 1.28	17.05 ± 1.34	18.27 ± 1.50	20.49 ± 1.70	23.07 ± 1.75
(mm)	F	15.15 ± 1.28*	15.91 ± 1.51*	17.25 ± 1.30*	17.79 ± 1.51*	21.69 ± 1.58*
pUPD***	M	8.87 ± 1.31	13.26 ± 0.97	14.65 ± 1.39	15.41 ± 1.51	14.38 ± 1.61
(mm)	F	8.54 ± 1.18	11.42 ± 1.13*	12.41 ± 1.19*	13.37 ± 1.23*	12.43 ± 1.35*
lUPL	M	12.30 ± 1.04	12.83 ± 1.00	12.88 ± 0.92	13.00 ± 1.06	12.56 ± 0.98
(mm)	F	10.50 ± 0.97*	11.17 ± 0.82*	11.42 ± 0.75*	11.42 ± 0.96*	11.10 ± 0.99*
rUPL	M	12.36 ± 1.01	12.86 ± 1.02	12.92 ± 0.99	12.99 ± 1.08	12.53 ± 0.92
(mm)	F	10.52 ± 0.98*	11.20 ± 0.81*	11.44 ± 0.80*	11.45 ± 1.05*	11.09 ± 1.03*
lUPA***	M	14.15 ± 3.22	18.64 ± 3.31	19.06 ± 3.77	22.37 ± 3.90	33.43 ± 4.41
(°)	F	13.41 ± 3.36	18.06 ± 4.17	18.60 ± 3.81	22.11 ± 4.50	32.59 ± 5.29
rUPA**,***	M	13.97 ± 3.65	18.42 ± 3.47	18.06 ± 3.66	21.44 ± 3.54	31.70 ± 4.24
(°)	F	12.86 ± 3.31	17.16 ± 3.81	17.85 ± 3.46	21.12 ± 4.32	31.48 ± 4.62

Data are presented as mean ± standard deviation.
* Significant difference compared with males ($p < 0.05$).
** Significant difference compared with left side ($p < 0.05$).
*** significant difference in one-way ANOVA ($p < 0.05$).
APL = anterior protrusion length; aUPD = anterior uncinate processes distance; lEPD = lower endplate depth; lEPW = lower endplate width; lUPA = left uncinate process angle.
lUPL = left uncinate process length; pUPD = posterior uncinate processes distance; rUPA = right uncinate process angle; rUPL = right uncinate process length; uEPD = upper endplate depth; uEPW = upper endplate width.

There was a significant increase for both aPL and aPL/uEPD ratio at C6 and C7 segments ($p < 0.001$). A significantly increasing distance from C3 to C7 was observed for aUPD ($p < 0.001$), and pUPD increased from C3 to C6 ($p < 0.001$) and decreased at C7 ($p = 0.04$). Moreover, the aUPD was always larger than the pUPD ($p < 0.05$). No significant bilateral difference and segmental difference in uncinate process length (UPL) were found. All linear parameters displayed significant difference between sexes ($p < 0.05$).

3.2. Angular measurements

The l/rUPA significantly increased from C3 to C7 ($p < 0.001$). Significant side-related difference existed at all segments except C3 ($p = 0.175$). The mean value of lUPA was 0.84° larger than that of rUPA. There was no significant difference in l/rUPA between sexes.

3.3. Measurement verification

The mean difference between the vernier caliper measurement and the CT measurement was −0.09 mm ($\sigma = 0.51$, 95% confidence interval: from −0.24 mm to 0.06 mm; Fig. 2). Pearson coefficients of intrarater correlation were greater than those of inter-rater correlation (Table 3). Although Pearson coefficients were relatively lower for the measurements of angular parameters, the intra- and inter-rater correlations were acceptable for all the measurements.

3.4. Comparison with available data for other populations

The morphological measurement results of cervical vertebrae in different populations are displayed in Table 4. The endplate widths (u/lEPW) for Chinese people had no statistically significant difference compared with the data for Koreans, but the endplate depths (u/lEPD) of Chinese people

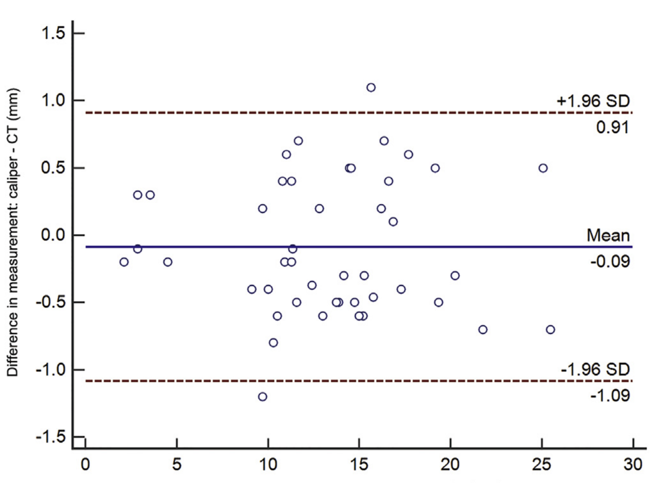

Fig. 2. Bland–Altman plot: the difference in measurements between the vernier caliper measurement and the computed tomography (CT)-based measurement ($n = 45$).

Table 3
Intra- and inter-rater correlations assessed by Pearson coefficient.

Parameter	Intrarater correlation	Inter-rater correlation
uEPD	0.95	0.91
uEPW	0.93	0.86
lEPD	0.98	0.90
lEPW	0.97	0.92
aPL	0.92	0.86
aUPD	0.92	0.83
pUPD	0.90	0.82
lUPL	0.93	0.84
rUPL	0.93	0.85
lUPA	0.89	0.81
rUPA	0.89	0.80

APL = anterior protrusion length; aUPD = anterior uncinate processes distance; lEPD = lower endplate depth; lEPW = lower endplate width; lUPA = left uncinate process angle; lUPL = left uncinate process length; pUPD = posterior uncinate processes distance; rUPA = right uncinate process angle; rUPL = right uncinate process length; uEPD = upper endplate depth; uEPW = upper endplate width.

were smaller than those of other populations. The UPL of Chinese people also presented statistical difference compared with Caucasian data from Lu et al,[11] Korean data from Lee et al,[12] and Turkish data from Ugur et al.[13] There was no significant difference in aUPD between Chinese people and Koreans, and the range of pUPD of Chinese people was statistically narrower than that of Koreans.[14]

4. Discussion

Some investigators have researched the Caucasian cervical vertebral morphology based on cadaveric studies with restricted sample quantity or plain radiography.[4–7] However, a recent study by Thaler et al[15] compared cervical endplate diameters obtained from 2D CT images with footprint sizes of four currently available disc prostheses [Bryan (Medtronic, Minneapolis, MN, USA), Prestige LP (Medtronic, Fridley, Minnesota, USA), Discover (DePuy, Raynham, MA, USA), and Prodisc-C (Synthes, West Chester, PA, USA)], discovering that more than half of the largest device footprints mismatched the cervical endplate diameters. Some articles have demonstrated that Chinese peoples' build and stature are different compared with those of Caucasians.[8,9] Using a similar method, Dong et al[10] also found that there was a large discrepancy between the four footprints of prostheses and the cervical anatomic data of Chinese people, and about 21% of cervical endplate depths and 57% of endplate widths mismatched the largest prostheses. Some biomechanical studies indicated that the mismatch of disc prosthesis could give rise to a few adverse events, such as migration, subsidence, and heterotopic ossification.[16,17] This indication was also reflected in a recent clinical trial, where a high occurrence rate of postoperative complications occurred in Chinese patients who were treated with disc prostheses for cervical disc disease.[18] It was suggested that the artificial cervical disc should cover the largest possible surface area of the endplate to reduce mismatches and complications.[15,17] Hence, it is necessary to design a type of cervical disc prosthesis suitable specifically for Chinese patients.

Table 4
Measurement results of morphological parameters of cervical vertebrae in different populations.

Dimension	Author	C3	C4	C5	C6	C7
uEPD	Panjabi et al[4]	15.0 ± 0.55	15.3 ± 0.75	15.2 ± 0.35	16.4 ± 0.52	18.1 ± 0.66
(mm)	Kim et al[5]	15.25 ± 1.39	15.54 ± 1.66	15.66 ± 1.89	16.35 ± 1.62	17.28 ± 1.92
	This study	14.23 ± 1.27*,**	14.64 ± 1.34*,**	14.79 ± 1.33*,**	15.49 ± 1.35*,**	16.31 ± 1.37*,**
uEPW	Panjabi et al[4]	15.8 ± 0.46	17.2 ± 0.66	17.5 ± 0.58	18.5 ± 0.55	21.8 ± 0.66
(mm)	Kim et al[5]	12.88 ± 1.42	14.83 ± 1.45	15.28 ± 1.68	16.07 ± 1.98	18.65 ± 1.74
	This study	13.78 ± 1.05*,**	14.63 ± 1.05*	15.51 ± 1.20*	16.30 ± 1.34*	18.37 ± 1.62*
lEPD	Panjabi et al[4]	15.6 ± 0.40	15.9 ± 0.38	17.9 ± 0.52	18.5 ± 0.69	16.8 ± 0.32
(mm)	Kim et al[5]	16.61 ± 1.75	16.69 ± 2.00	17.35 ± 1.84	18.25 ± 1.74	17.44 ± 1.91
	This study	15.09 ± 1.26*,**	15.33 ± 1.28*,**	17.03 ± 1.32*,**	17.55 ± 1.38*,**	16.35 ± 1.28*,**
lEPW	Panjabi et al[4]	17.2 ± 0.29	17.0 ± 0.49	19.4 ± 0.40	22.0 ± 0.75	23.4 ± 0.98
(mm)	Kim et al[5]	16.74 ± 1.74	16.99 ± 1.74	18.99 ± 1.93	22.19 ± 2.34	25.08 ± 2.29
	This study	16.60 ± 1.33*	16.93 ± 1.49	18.64 ± 1.72*	21.52 ± 1.91*,**	23.01 ± 2.08*,**
UPL	Lu et al[11]	11.93	12.03	12.41	12.31	11.58
(mm)	Lee et al[12]	12.32	12.74	12.85	13.14	12.59
	Ugur et al[13]	11.2 ± 2.3	11.8 ± 1.3	12.3 ± 1.5	12.8 ± 1.6	13.0 ± 1.9
	This study	11.42 ± 1.42*,**	12.01 ± 1.37**	12.16 ± 1.36**	12.21 ± 1.51**,***	11.82 ± 1.32**,***
aUPD	Kim et al[5]	15.70 ± 2.32	16.81 ± 2.97	18.07 ± 3.15	19.47 ± 3.36	23.21 ± 3.93
(mm)	This study	15.59 ± 1.42	16.48 ± 1.53	17.67 ± 1.58	19.14 ± 1.82	22.38 ± 1.94**
pUPD	Kim et al[5]	7.82 ± 3.28	13.04 ± 5.43	14.40 ± 6.21	15.03 ± 6.49	14.73 ± 5.78
(mm)	This study	8.71 ± 1.24**	12.34 ± 1.06**	13.53 ± 1.29**	14.39 ± 1.39**	13.40 ± 1.48**

* Significant difference compared with Caucasian data ($p < 0.05$).
** Significant difference compared with Korean data ($p < 0.05$).
*** Significant difference compared with Turkish data ($p < 0.05$).
APL = anterior protrusion length; aUPD = anterior uncinate processes distance; lEPD = lower endplate depth; lEPW = lower endplate width; lUPA = left uncinate process angle.
lUPL = left uncinate process length; pUPD = posterior uncinate processes distance; rUPA = right uncinate process angle; rUPL = right uncinate process length; uEPD = upper endplate depth; uEPW = upper endplate width.

It is well known that the successful design of prosthesis depends on accurate morphometric parameters. Although a few studies[10,19] have reported quantified data regarding the dimensions of Chinese patients cervical endplates, there are still some limitations to designing the disc prosthesis using these data. First, data on the dimensions concerning the cervical endplate are not exhaustive enough to define the exact contact area of disc prosthesis. It has been demonstrated that uncinate processes are more anteriorly positioned in the upper cervical spine and become more posteriorly located in the lower vertebral segments.[20] The dimensions of uncinate process can directly affect the size and shape of disc prosthesis on the upper endplate. Second, previous studies concerning the Chinese patients' cervical vertebral morphology were all based on 2D CT scans, where the precise contact area of disc prostheses on cervical 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 small.[21] In our study, the 3D CT measurements were verified by comparing measurements using a vernier caliper on the real cadaver vertebrae, and no significant difference was found between these two gauging procedures. Therefore, we chose 3D CT reconstructions to get a large sample size to measure the dimensions of cervical endplate and uncinate process to provide references for designing the disc prosthesis, particularly for Chinese patients.

Another purpose of this study was to validate further the morphologic diversity of cervical vertebrae by comparing our data with the available data for other populations. The four linear parameters regarding the cervical endplate from Chinese patients were generally smaller than those of Caucasians. Although the dimensions of cervical endplate between Chinese patients and Koreans were similar, the endplate depth of Chinese patients was on average 0.96 mm shorter than that of Koreans. In our study, the aPL value increased noticeably from C5 to C7. The aPL/uEPD ratio had a similar tendency to aPL, which means if considering the anterior margin of uncinate processes as a reference, the extent of anterior protrusion of vertebral body expands in the lower cervical vertebrae. This condition was also found in the Korean population.[5] The a/pUPD values in Korean cadavers with measured values of 15.70−23.21 mm and 7.82−15.03 mm, respectively.[14] The pUPD value of Chinese patients was a little narrower than that of Koreans, and the aUPD values of these two populations were similar. Both the tendencies of aUPD and pUPD among vertebral segments of Chinese patients were consistent with those of Koreans. Four studies measured the anteroposterior UPL, which followed an increasing trend from C3 to C7 in general, and two studies reported that the length of the C7 uncinate process was shorter than that of the adjacent C6 segment.[22] There was no significant difference in UPL between Chinese patients and Caucasians. Compared with the data for Koreans and Turks, Chinese patients dimensions of UPL were a bit smaller. Saringer et al[23] measured the angle between the long axis of the uncinate process and the sagittal plane, and the mean measurement was 5.06° (range, 0.4−11.6°). Dissimilarly, we measured the angle between the line formed from the anteromedial to posteromedial margin of the uncinate process and the sagittal plane. Thus, our values of l/rUPA were commonly larger than those of the previous study. Moreover, we found an asymmetry of UPA between bilateral sides, and we suppose that this phenomenon may be attributed to the asymmetrical degeneration of bilateral uncinate processes. In general, the comparisons indicated that Chinese patients had smaller dimensions of cervical vertebrae compared with the other populations. However, the precision of these comparisons may be affected by insufficient sample sizes, unequal sex ratios and different gauging techniques in different studies. Thus, the comparison results should be cautiously accepted, and further sex-specific studies with more samples are needed to obtain more accurate comparisons.

Although all the measured linear parameters of men were larger than those of women, aPL/uEPD and l/rUPA were similar between sexes, so the designs of disc prosthesis between sexes should be different in size, but not in shape. Due to the always larger distance of aUPD compared with that of pUPD, the footprint of disc prosthesis should be broad in the front and narrow in the back to fit the morphology of the uncinate process. Nowadays, available disc prostheses have various footprint sizes, but the shape of the sort of prosthesis utilized at different vertebral segments are almost the same. However, most of the 11 linear and angular parameters obtained in our study had significant variations at the C6 and C7 segments. During our measurement, we also found that the morphology of cervical endplate and uncinate process changed evidently in the lower cervical spine. Due to greater anterior protrusion of cervical endplate and more inclined angle of the uncinate process, the endplate area of the lower cervical spine is larger, broader, and rounder. Furthermore, the biomechanics of artificial discs may change because of the variation of endplate shape. Thus, we propose that the disc prostheses applied for different vertebral 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 patients cervical endplate and uncinate process based on 3D CT reconstructions. Second, we compared our data with the available data of other populations to indicate the ethnic morphologic diversity. Additional strengths included specific and equal sex ratio, large sample size, and measurement verification by Bland−Altman plot and Pearson coefficient to guarantee consistency and accuracy. However, our study only provided references with regard to the design of the upper and lower joint surface of the artificial disc without considering lateral parameters, such as the disc height and concavity of endplate, which can be assessed directly on 2D sagittal CT scans but not on 3D reconstructions. Thus, to obtain a comprehensive evaluation of cervical vertebrae, our data can be combined with those of the previous studies[10,19] measuring the lateral parameters in the Chinese population.

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