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REVIEW ARTICLE

Ethnic differences in pedicle and bony spinal canal dimensions calculated from computed tomography of the cervical spine: a review of the English-language literature

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Abstract
Purpose The aims of this study were to review published data on pedicle dimensions and bony spinal canal diameters calculated from CT examinations of the cervical spine through the English-language literature and analyze these data for ethnic disparities and similarities.
Materials and methods The authors reviewed the literature on "pedicle" and "spinal canal" by conducting a bibliographic search using PubMed, Ovid MEDLINE, and Science Direct from January 1985 to December 2010. After evaluating all of the selected abstracts, we ultimately selected 19 studies involving living subjects: 12 studies on pedicle dimensions and 7 on spinal canal diameters. The four parameters, pedicle width (PW), pedicle transverse angle (PTA), anterior-posterior diameter of the spinal canal (APD), and transverse diameter of the spinal canal (TD), were analyzed at the relevant levels from C3 to C7. In addition, the values for pedicle dimensions and spinal canal diameters in the European/American populations were compared using the data from Asian populations as a baseline.
Results The smallest mean PW was found at C4 in the male (5.1 mm) and female populations (4.1 mm); the largest mean PW was found at C7 in both male (7.7 mm) and female populations (7 mm). The PW in males was greater than in females at the majority of levels. The smallest mean PTA was found at C7 in both male (33.4°) and female populations (33°); the largest mean PTA was found at C4 in both male (53.2°) and female populations (52.1°). The overall PW, PTA, APD, and TD ratio of European/American to Asian populations was 91.4–98.8, 99.6–106.2, 110.7–122, and 100–108.3 %, respectively.
Conclusion Although our cervical spine CT data were suggestive of possible ethnic differences in spinal canal morphology, our analysis failed to identify significant ethnic disparity in pedicle dimensions despite potential differences in physique between populations.

Keywords Cervical spine · Anatomy · Computed tomography · Pedicle · Spinal canal

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Introduction

Spurred on by a remarkable evolution in spinal instrumentation technology and increasingly detailed knowledge of the surgical anatomy of the cervical vertebrae, posterior reconstructive surgery using cervical pedicle screw (CPS) as well as lateral mass screw, transarticular screw, and laminar screw has been gaining popularity and is now being used for multiple unstable spinal conditions resulting from degenerative, traumatic, and inflammatory etiologies. CPS is considered to be the most rigid anchor for posterior reconstructive surgery; however, the safety and accuracy of CPS placement have remained controversial due to the narrowness of pedicles and the potential risks of neurological and vascular injury. Because of these concerns, preoperative radiographic data, especially data derived from computed tomography (CT) scans, are essential for successful intraoperative CPS placement.

Recent CT studies of CPS dimensions have included European and American populations in addition to Asian populations. Despite increasing utilization of posterior anchors for unstable cervical spinal disorders, marked differences exist in the treatments for these disorders among populations of different races and ethnicities. Up to now, little attention has been paid to possible ethnic differences in pedicle and bony spinal canal dimensions in the cervical spine, which in turn may have impeded the development of consistent methodologies for assessing the feasibility of CPS placement among different ethnic populations. Therefore, to fill the gaps in our knowledge regarding ethnic differences, we obtained published data on pedicle dimensions and bony spinal canal diameters calculated from CT examinations of the cervical spine through the English literature, and we then analyzed these data for ethnic similarities and disparities.

Materials and methods

We reviewed the English-language literature on "pedicle" and "spinal canal" by conducting an online bibliographic search for articles published from January 1985 to December 2010. The keywords "cervical spine", "anatomy", "computed tomography", and "pedicle" or "spinal canal" were used to search for relevant articles. The search initially yielded 106, 471, and 506 articles related to pedicle dimensions and 220, 418, and 798 articles related to spinal canal dimensions from PubMed, Ovid MEDLINE, and Science Direct, respectively. From these listings, we excluded case reports, animal and cadaveric studies, and rheumatoid arthritis or pediatric patient series. That is, we selected for further evaluation only articles on anatomical considerations regarding pedicle and spinal canal dimensions of the subaxial cervical spine in living subjects, along with additional studies that we identified from checking the references linked to these articles.

Two reviewers (M.C. and T.S.) independently reviewed articles based on their title and abstract, and then met together to reach a consensus regarding their disagreements. After evaluating all of the selected abstracts, we ultimately selected 19 studies involving living human subjects: 12 studies on pedicle dimensions and 7 on spinal canal diameters [1–17]. The following four parameters were analyzed at the relevant levels from C3 to C7: pedicle width (PW) and pedicle transverse angle (PTA) for the pedicle dimension studies; mid-sagittal anterior–posterior diameter (APD) and transverse diameters (TD) of the spinal canal for the studies. Continuous variables were expressed as mean values. Data of pedicle dimensions and spinal canal diameters were assigned to the two ethnic categories between European/American and Asian populations, referring to the institution of published articles, despite that European/American populations may include small part of Asian population. Subsequently, the ratios of the European/American population mean values to the Asian population mean values were expressed as percentages.

Results

Of the 19 articles meeting the search criteria, 12 pedicle dimension articles included 5 Asian (3 Japanese, 1 Chinese, and 1 Malaysian) and 7 European/American populations (3 American, 2 German, 1 Turkish, and 1 England) comprising 734 patients (412 males, 322 females) ranging in mean age from 24.8 to 67.1 years (Table 1). Axial CT scans of the 3,670 vertebrae from C3 to C7 from these 734 patients were evaluated. Mean values of the linear and angular measurements were expressed for each level separately for the entire group and also for male and female subgroups.

The seven spinal canal dimension articles included 4 Asian (3 Japanese and 1 Chinese) and 3 European/American (2 American and 1 Belgian) populations, comprising a total of 420 patients ranging in age from 28.8 to 67.1 years (Table 2). Axial CT scans of 2,065 vertebrae from C3 to C7 (Debois' article did not contain C3 data [3]) from these 420 patients were evaluated. Mean values of the linear and angular measurements were calculated for each level for the entire group only. Details on the year of publication, CT machine used, X-ray detector, and slice thickness in each article are also summarized in Tables 1 and 2.

Pedicle width (PW)

Among the 12 pedicle dimension articles, the overall mean PW ranged from 4.7 to 7.4 mm. The smallest mean PW was at C4 in the Asian male population (5.1 mm) and the European/American female population (4.1 mm); the largest mean PW was at C7 in the Asian male population (7.7 mm) and the Asian female population (7 mm). All 12 pedicle dimension articles observed that the mean value gradually increased as one proceeded caudally. PW for males was greater than for females at all levels, and the male-to-female differences were significant at the majority of relevant levels (37/45 levels; 82.2 %) (Fig. 1a–c).

Pedicle transverse angle (PTA)

The overall mean PTA ranged from 30.6° to 52.1°. The smallest mean PTA was at C7 in the Asian male population (33.4°) and the European/American female population (33°); the largest mean PTA was at C4 in the Asian male

Table 1 Literature review data of pedicle dimensions providing patient's demographics, CT machine used, X-ray detector, and slice thickness

References	Populations	Regions	Patients (M, F)	Mean age	CT machine	X-ray detector (rows)	Slice thickness (mm)
Tomashino et al. [15]	German	European	127 (56, 71)	61.8	N/A	N/A	2.5
Miyazaki et al. [8]	Japanese	Asian	52 (29, 23)	67.1	Toshiba Aquilion	MDCT (16)	0.5
Abuzayed et al. [1]	Turkish	European	19 (7, 12)	45.5	Phillips, MX 8000	MDCT (10)	3
Onibokun et al. [9]	American	American	122 (66, 56)	48	GE, light speed helical scanner, Siemens, SOMATOM sensation 4	Helical, MDCT (4)	2.5, 1.25
Koller et al. [6]	German	European	29 (20, 9)	44.8	GE, light speed plus	N/A	1
Ruofu et al. [12]	Chinese	Asian	60 (30, 30)	49	Siemens, SOMATOM	MDCT (64)	1
Rao et al. [10]	American	American	98 (63, 35)	24.8	Siemens, SOMATOM	MDCT (4)	3
Hacker et al. [4]	England	European	54 (25, 29)	48.2	GE, light speed VCM	MDCT (64)	0.625
Yusof et al. [16]	Malaysian	Asian	40 (24, 16)	43.8	GE, helical scanner	Helical	2.5
Chazono et al. [2]	Japanese	Asian	63 (46, 17)	58	Siemens, SOMATOM	MDCT (4)	1.25
Sakamoto et al. [13]	Japanese	Asian	30 (18, 12)	57	GE, lemage supreme	Helical	1, 2
Rexcallah et al. [11]	American	American	40 (28, 12)	35.7	GE, helical scanner	Helical	3

Table 2 Literature review data of spinal canal dimensions providing patient's demographics, CT machine used, X-ray detector, and slice thickness

References	Populations	Regions	Patients	Mean age	CT machine	X-ray detector (rows)	Slice thickness (mm)
Miyazaki et al. [8]	Japanese	Asian	52	67.1	Toshiba Aquilion	MDCT (16)	0.5
Chazono et al. [2]	Japanese	Asian	63	58	Siemens, SOMATOM sensation 4	MDCT (4)	1.25
Debois et al. [3]	Belgian (healthy)	European	35	N/A	N/A	N/A	N/A
Inoue et al. [5]	Japanese (healthy)	Asian	36	33.9	N/A	N/A	5
Matsuura et al. [7]	American (healthy)	American	100	28.8	GE8800	1	1.5
Matsuura et al. [7]	American	American	42	30.8	GE8800	1	1.5
Zeng et al. [17]	Chinese (healthy)	Asian	50	N/A	GE8600	1	5
Stanley et al. [14]	American (healthy)	American	42	42	GE8800	1	10

population (53.2°) and the Asian female population (52.1°). The only statistically significant male-to-female difference in PTA was at the C4 level in the American male population (Fig. 2a–c).

Anterior–posterior diameter of the bony spinal canal (APD)

Among seven spinal canal dimension articles, the overall mean APD ranged from 10.7 to 15.2 mm. Mean APD was smallest at C4, followed by C5. The majority of articles reported that mean APD progressively increased in the caudal direction, although these data included both healthy patients and patients with myelopathy or radiculopathy. When dividing the data into these latter two groups, APD values among the healthy populations showed a tendency to be larger than the those among the myelopathy and radiculopathy populations (Fig. 3).

Transverse diameter of the bony spinal canal (TD)

The overall mean TD ranged from 22.6 to 27.5 mm over the entire group. The smallest mean TD was at C3 in the Asian population (22.6 mm); the largest mean TD was at C5 in the European/American population (27.5 mm). Most articles identified C3 as the level with the smallest mean TD and C5 as the level with the largest mean TD. These data also included both healthy patients and patients with myelopathy or radiculopathy, but no differences in TD among these subgroups were evident (Fig. 4).

Ethnic similarity and disparity of pedicle and spinal canal dimensions

We compared pedicle and spinal canal dimensions between Asian and European/American populations in order to

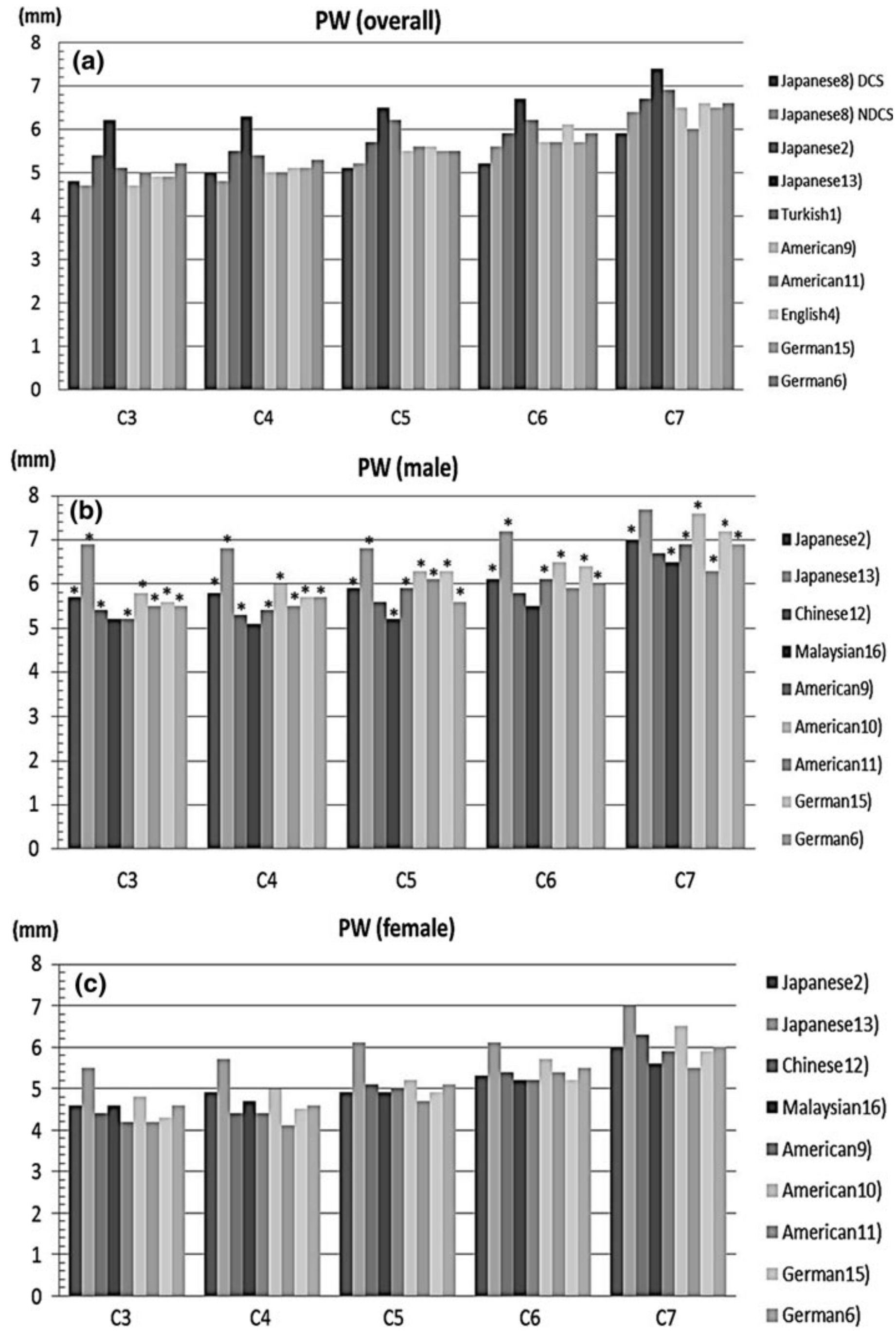

Fig. 1 Overall mean pedicle width(PW) of the cervical spine (**a**). Mean pedicle width (PW) of the cervical spine in male patients (**b**). Mean pedicle width (PW) of the cervical spine in female patients (**c**). *DCS* developmental canal stenosis, *NDCS* non-developmental canal stenosis. *Significant sex difference ($p < 0.05$)

investigate the interethnic difference. First, we divided separately the 12 pedicle dimension studies and the 7 spinal canal dimension articles into Asian and European/American categories. Second, we added up the measurements for all the patients in each ethnic group and finally calculated the mean value for that group by dividing the measurement sum by the number of patients. Regarding pedicle dimensions, the overall PW ratios of European/American to Asian populations were 91.4–98.8 %. The PTA ratios of European/American to Asian populations were 99.6–106.2 %, except for the C7 level. Unexpectedly, no apparent interethnic differences in PW and PTA values were observed. On the other hand, the APD ratios of European/American to Asian populations were 110.7–122 %, exceeding 110 % at all levels. However, the TD ratios of European/American to Asian populations were 100–108.3 %. Unlike the PW and PTA values, which showed no significant ethnic differences, the trend for ethnic difference between the APD values but not between TD values was identified (Table 3).

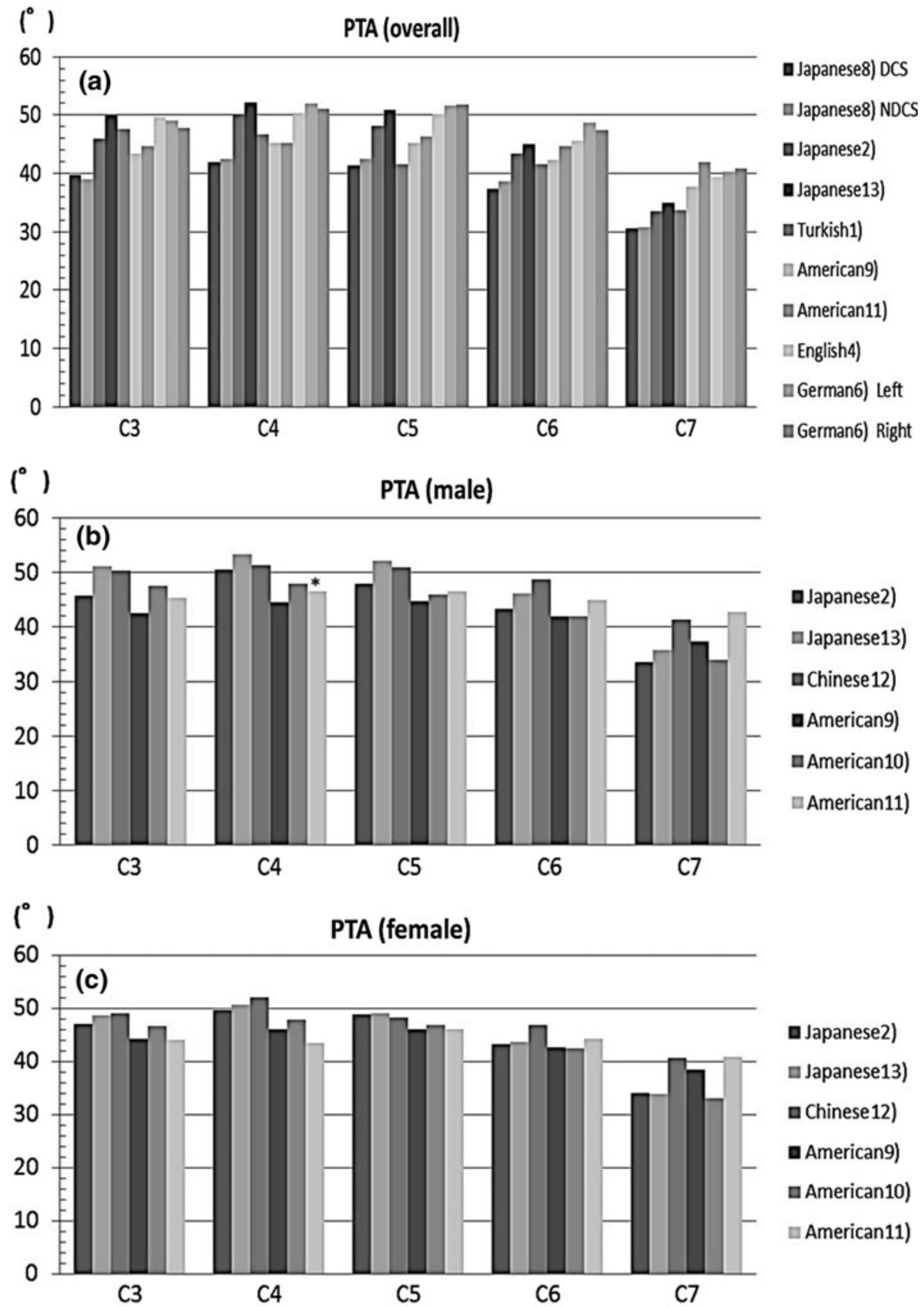

Fig. 2 Overall mean pedicle transverse angle (PTA) of the cervical spine (**a**). Mean pedicle transverse angle (PTA) of the cervical spine in male patients (**b**). Mean pedicle transverse angle (PTA) of the cervical spine in female patients (**c**). *DCS* developmental canal stenosis, *NDCS* non-developmental canal stenosis. *Significant sex difference ($p < 0.05$)

Discussions

Our literature search found multiple cadaveric and imaging studies involving pedicle and spinal canal dimensions. Quantitative measurements of the cervical spine have been performed since Panjabi et al. [18] described the three-dimensional anatomy of the cervical spine using cadaver specimens. In contrast to the manual measurement data from cadaver specimens, the ability of CT to perform measurements in living subjects offers the prospect of acquiring information that is more accurate. One report from comparison of CT data with cadaver data found that the cadaver measurements of pedicle diameter were significantly smaller than CT measurements [19]. In other words, the long time that cadavers are preserved in embalming fluid may cause morphologic changes that could affect the measurements. Therefore, only acquired data on pedicle dimensions and spinal canal dimensions from living persons were compared in the present study. Recent advances in CT modalities could have made the anatomical measurements in the human body more feasible and accurate.

First, the articles that we used in this study showed that mean PW was significantly greater in males than in females

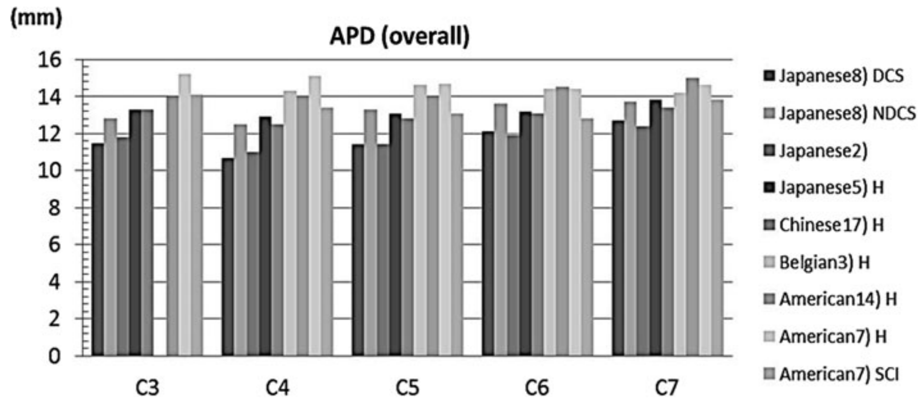

Fig. 3 Overall mean anterior–posterior diameter (APD) of the spinal canal of the cervical spine. *DCS* developmental canal stenosis, *NDCS* non-developmental canal stenosis, *H* healthy people, *SCI* spinal cord injury

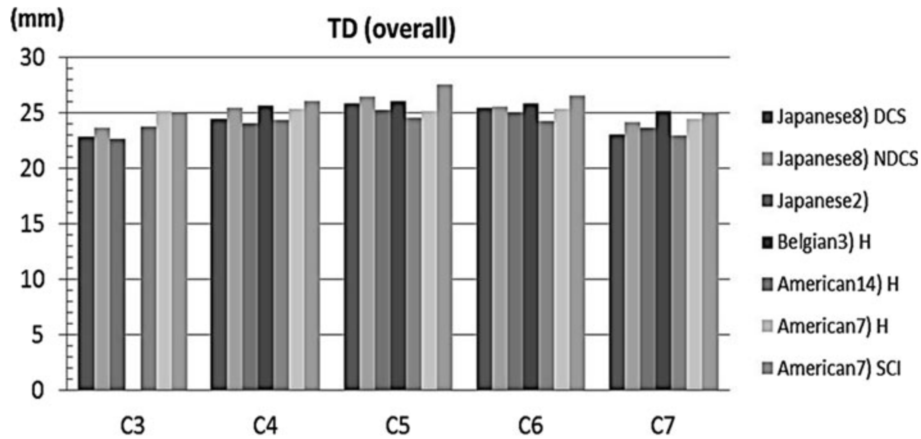

Fig. 4 Overall mean transverse diameter (TD) of the spinal canal of the cervical spine. *DCS* developmental canal stenosis, *NDCS* non-developmental canal stenosis, *H* healthy people, *SCI* spinal cord injury

Table 3 The ratio of pedicle and spinal canal dimensions in European/American populations to those in Asian populations

Level	Mean overall PW ratio (%)		Mean overall PTA ratio (%)		Mean overall APD Ratio (%)		Mean overall TD ratio (%)	
	Asian	European/American	Asian	European/American	Asian	European/American	Asian	European/American
C3	100	91.4	100	103.4	100	117.6	100	108.3
C4	100	93.2	100	99.6	100	122	100	104.1
C5	100	98.2	100	102.8	100	116.4	100	100
C6	100	98.8	100	106.2	100	111.9	100	100.8
C7	100	98.2	100	118.6	100	110.7	100	103.4

Measurements are presented as the percentage

at the majority of levels. This finding indicates that sex differences in pedicle diameters should be carefully taken into account when performing CPS fixation. With respect to possible racial or ethnic disparities, Tan et al. reported that the PW dimensions of cervical, thoracic, and lumbar vertebrae were smaller in Singaporeans than in Caucasians (Panjabi's data [18]), and that in the cervical spine, the mean PW difference for Singaporeans was −25.7 % when compared with the Caucasian values [20]. In this study, we showed no substantial interethnic difference in PW values and the ratios of European/American to Asian populations ranged from 91.4 to 98.8 %, depending on the cervical level. When considering the normal growth of vertebrae, vertebral ossification initiates within three ossification centers in utero: single center in the centrum (vertebral body) and one in each half of the neural arch. Juxtaposition between the body and arches occurs anterior to the anatomic pedicle at the site of neurocentral synchondrosis. Subsequently, the synchondroses usually close between 5 and 8 years of age. Finally, longitudinal growth occurs from the anterior element and continues until 16–18 years of age [21]. From these findings, we would hypothesize that the pedicle, which is the anterior part of the neural arch adjacent to the intervening cartilage, does not develop as much as the vertebral body and posterior part of the neural arch. One cadaveric examination of cervical pedicle morphology may support our hypothesis that the pedicle length remains relatively constant and the value of PW increases just around 1.5 mm from the age of 3–5 years to the age of 18 years across growth [22]. Thus, no ethnic difference in PW in the cervical spine might exist.

Secondly, mean PTA obtained from the published data ranged around 45° from C3 to C6 and decreased to around 35° at C7 in our study. The overall PTA ratio of European/American to Asian populations was 99.6–106.2 % except for the C7 level. We also observed no substantial racial difference with regard to the PTA. The PTA value in the Asian population was consistent with published data for European/American populations, although the reference line to the axial pedicle axis differs somewhat, depending on the data reported.

Lastly, with regard to spinal canal dimensions, our study found that the overall APD ratio of European/American to Asian populations was 110.7–122 %, suggesting a possible ethnic difference, but the overall TD ratio of European/American to Asian populations was 100–108.3 %. As is commonly recognized, mid-sagittal canal diameter was larger in European/American than Asian populations, but we observed no substantial interethnic differences in the TDs of the bony cervical spinal canal.

One of the limitations of this study was that our data set was inadequate in assembling size- and age-matched patients, which might affect cervical spinal geometry. Unfortunately, the data from the articles in our study did not contain sufficient details about the patient demographics to perform size matching. A further anatomical study of cohorts with size and age matching would be needed to either confirm or disprove the results of this study. Another limitation includes difficulty in clearly distinguishing two geographical categories defined as the European/American and Asian groups to identify the ethnic difference in the pedicle and bony spinal canal in the cervical spine. We classified the materials into the two categories in the present study. Although European/American populations might include a small part of Asian populations and the categories could not be considered logical, no ethnical differences of the cervical pedicle measurements including PD and PTA, possible ethnic difference regarding the APD, and gender-related difference exist in the present study.

Conclusion

Our cervical spine CT data were suggestive of possible ethnic differences in spinal canal morphology, but failed to identify significant ethnic disparities in pedicle dimensions despite potential differences in physique between populations. We conclude that methodologies for assessing the feasibility of CPS placement at this time may need to take into account sex differences more than potential ethnic differences.

Conflict of interest None.

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