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Morphological analysis of C2–C7 spinous process bifurcation in Chinese population: a study using three-dimensional reconstruction of computed tomography

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Background: *This study aimed to investigate the anatomical morphology of the C2 to C7 spinous process (SP) bifurcation (SPB) in the Chinese population and reveal its potential clinical significance.*

Materials and methods: *Measurement parameters of the three-dimensional (3D) reconstructions of neck computed tomography scans (n = 92 scans) were retrospectively analysed. The 3D reconstruction and measurements were performed using Mimics Research 19.0 and 3-Matic Research 11.0. Two independent investigators reviewed all the data, including parameters such as the length and angle of the SPB. The effects of age and sex were also analysed.*

Results: *We identified four morphological types of SPB: fully bifid (n = 252, 45.65%), partially bifid (n = 65, 11.78%), non-bifid (n = 226, 40.94%) and unilateral branch (n = 9, 1.63%). The Kappa coefficients indicated good inter-observer reproducibility (0.776), and the intraclass correlation coefficients (ICC) values demonstrated excellent intra-rater reliability (ICC = 0.9, p < 0.0001) in the classification and measurement of SPB parameters. The percentage of general bifid SP was more than 70% in C2–5 and about 21% in C6, while all C7 SPs presented non-bifid. Morphology was symmetrical in bifid and partially bifid SP, while unilateral SP was not.*

Conclusions: *The classification system of SPB in this study proved consistent and reliable, despite the subjective bias. Identifying the cervical level by C6 bifurcation is unreliable, as nearly 80% of C6 SP is non-bifid. Our work provides an accurate and effective anatomical reference for SPB studies in the Chinese population.* (Folia Morphol 2023; 82, 3: 596–602)

Key words: cervical vertebra, spinous process, spinous process bifurcation, anatomy

INTRODUCTION

Previous research on cervical spinous process bifurcation (SPB) has focused on its application in archaeology, anthropology, and forensic medicine. Nevertheless, little literature discussed its importance in clinical medicine [4, 8, 10, 14]. In clinical practice, the spinous process (SP) is generally used as an essential bony landmark for vertebral level determination,

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either by palpation or during open operation. SP bifurcation could alter the practitioner's judgment in level determination [10]. Previous research describes cervical SPB as a morphological feature that can be easily identified in C2 to C6 vertebrae, while nearly all C7 presents no bifurcation [6, 11]. Few studies have reported a rare occurrence of truly bifid C7 and non-bifid C2 in SP [3, 6, 11, 14]. However, the incidence of bifurcation in the C3 to C6 SP varies according to gender, region, and race [14].

Additionally, morphology varies among different types of SPs [6, 11, 14]. According to Shore [14], Duray et al. [4], and Okuwa [13], the spinous process could be divided into fully bifid, partially bifid, and non-bifid types. To our best knowledge, very few articles described the quantification of SPB while most research determines morphological types by observation [6]. The incidence and quantification of SPB in the Chinese population have not been reported in detail. Thus, this study aimed to investigate the repeatability of the SP classification system and to describe the morphology of SPB by measurements.

MATERIALS AND METHODS

Materials

This retrospective study involved 92 cervical computed tomography (CT) scans of Chinese adults performed in Nanfang Hospital of Southern Medical University from January 2018 to December 2019. The inclusion criteria were: no cervical deformity, no fracture, and no history of neck surgery. The exclusion criteria: pathological conditions of the cervical spines, such as osteomyelitis, tuberculosis, severe osteoporosis, and bone tumour, were excluded. This study had approval from the institutional review board; the requirement for informed patient consent was waived. This study was compliant with the current regulations of our country. Ethical approval for this study was obtained from the Chinese Ethics Committee of Registering Clinical Trials (Reference number: ChiECRCT20210191).

Table 1. Description of anatomical landmarks in specimen

Landmarks	Description
a	The apex of the right bifid branch
b	The deepest point of the bifid groove
c	The apex of the left bifid branch
d	The tip of the posterior tubercles of the left transverse process
e	The midpoint of line df (the transverse reference line)
f	The tip of the posterior tubercles of the right transverse process

Methods

The data for cervical spine CT scans were obtained in a DICOM format file and then transferred to Mimics 19.0 software to generate a three-dimensional (3D) reconstruction model of C2 to C7 vertebrae. The landmarks and parameters were defined in Tables 1 and 2. Measurements were conducted by 2 researchers independently using Mimics Research 19.0 and 3-Matic Research 11.0 software, including the length of bifid branches (left and right), angle α, angle β, angle γ, the distance between two branch tips, and the depth of the bifurcation (Fig. 1). Cervical SPB was divided into four categories: fully bifid, partially bifid, unilateral branch, and non-bifid. The unilateral branch is an unusual type of bifid SP that only has one branch and lacks another on the other side (Fig. 2).

Ethics approval and consent to participate

This study had approvals from the institutional review board. The requirement for informed patient consent was waived. This study was also compliant with the current regulations of our country.

Table 2. Measurement parameters of spinous process bifurcation

Parameters	Definition	Bifid	Partially bifid
The length of the left branch	Distance of bc	7.34 ± 2.37*	4.74 ± 1.42*
The length of the right branch	Distance of ba	7.56 ± 2.54*	4.74 ± 1.41*
The distance between two SPB tips	Distance of ac	10.87 ± 3.38*	8.56 ± 2.36*
The depth of bifurcation	h	4.77 ± 2.05*	1.84 ± 0.8*
The angle between two bifid SP branches	Angle α	96.91 ± 24.25*	132.66 ± 17.59*
The angle between the left branch and the transverse baseline	Angle β	81.66 ± 3.72#	83.38 ± 3.49#
The angle between the right branch and the transverse baseline	Angle γ	81.91 ± 3.71#	83.22 ± 3.79#

*$p < 0.001$, using t-test; #$p < 0.05$, using t-test

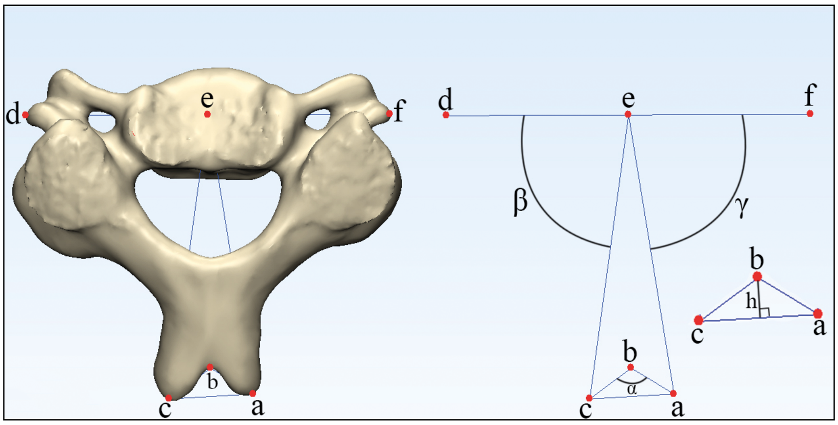

Figure 1. Measurement of spinous process bifurcation; a — the apex of the right bifid branch; b — the deepest point of the bifid groove; c — the apex of the left bifid branch; d — the tip of the posterior tubercles of left transverse processes; e — the midpoint of the straight line df; f — the tip of the posterior tubercles of right transverse processes; ba — the length of the right branch; bc — the length of the left branch; ac — the distance between two spinous process bifurcation tips; h — the depth of bifurcation; α — the angle of two branches; β — the angle of deviation of the left branch; γ — the angle of deviation of the right branch.

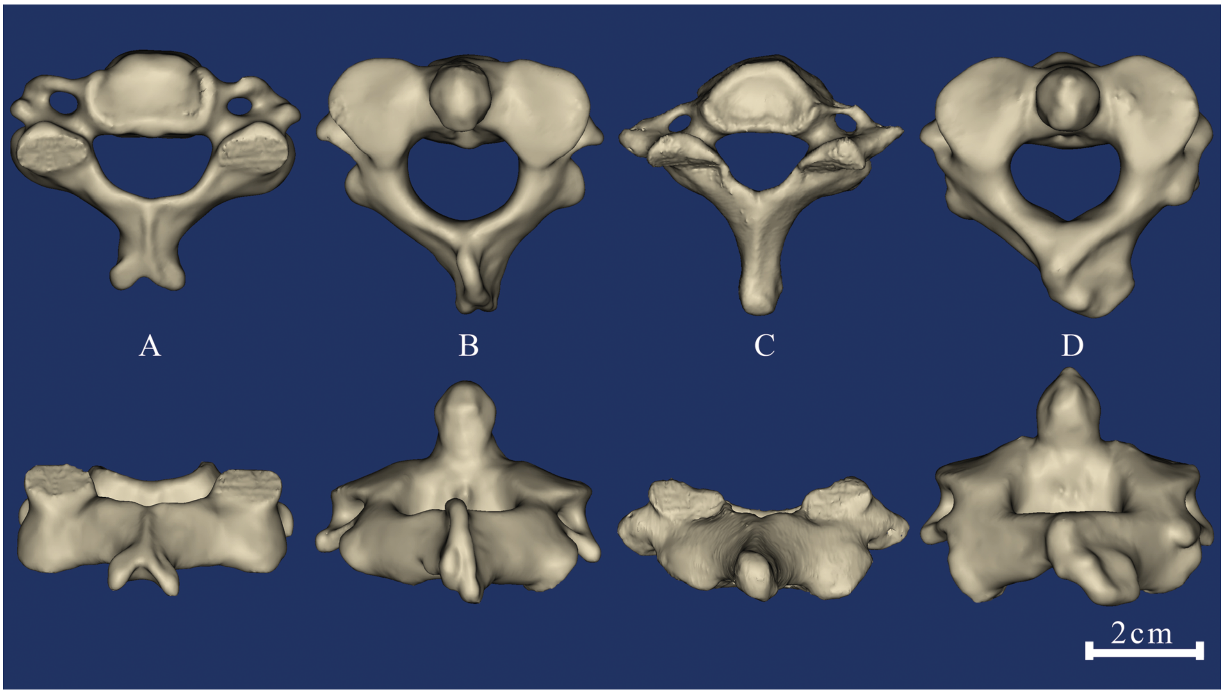

Figure 2. The superior view of cervical vertebra (the upper row) and posterior view of cervical vertebra (the lower row). Four types of spinous process: A — fully bifid; B — partially bifid; C — non-bifid; D — unilateral branch.

Statistical analysis

All statistical analyses were performed with the SPSS 20.0 software (IBM SPSS Statistics for Windows, IBM Corp, Armonk, New York). Qualitative data were expressed as percentages and quantitative data were expressed as mean ± standard deviation (SD). The consistency of the four SPB types was evaluated using the weighted kappa coefficient. To evaluate inter-observer reproducibility, Cohen's Kappa statistic was used to analyse the consistency of SPB types identification results of 2 investigators and intraclass correlation coefficients (ICC) were used to evaluate the inter-observer variability of measurements. Group differences of SPB types in gender were evaluated with Fisher's exact test of significance, and age differences among four SPB types were assessed with a Kruskal Wallis H test (multiple independent samples). Intergroup differences in parameters between

Table 3. Contingency table of classification of 552 spinous processes by two experimenters

		Experimenter A				Total
		Fully bifid	**Partially bifid**	**Non-bifid**	**Unilateral branch**	
Experimenter B	Fully bifid	244	40	0	0	284
	Partially bifid	2	28	31	0	61
	Non-bifid	0	0	198	1	199
	Unilateral branch	0	0	1	7	8
Total		246	68	230	8	552

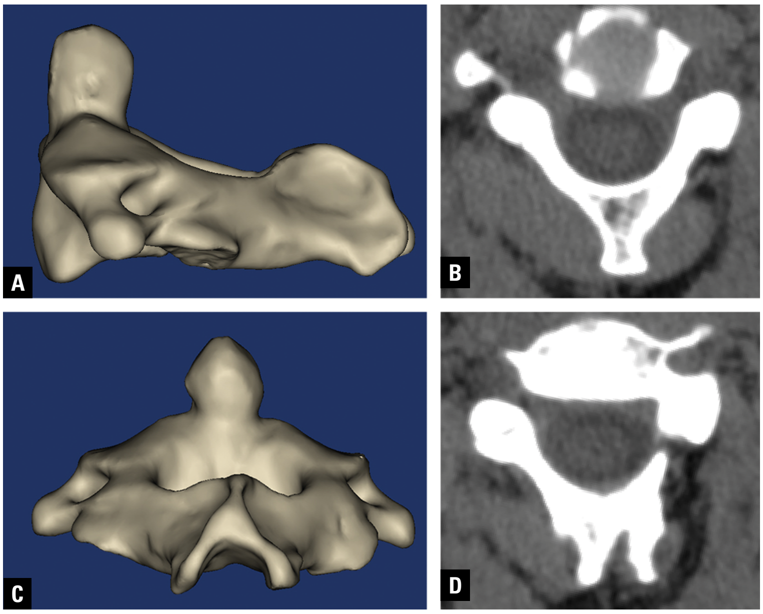

Figure 3. These four pictures are all from the same vertebra (C2). Different transverse slices of computed tomography scan presented different morphological types of spinous process bifurcation in C2. The lateral view (**A**) and posterior view (**C**) of three-dimensional reconstructed C2 vertebra; **B.** Non-bifid; **D.** Fully bifid.

the bifid group and the partially bifid group were evaluated by an independent sample t-test and paired t-test. Differences were considered statistically significant when p values were < 0.05.

RESULTS

Classification of spinous processes bifurcation

In this study, SPB was divided into four morphological types by two independent investigators, including fully bifid, partially bifid, non-bifid, and the unilateral branch. Results showed that the weighted kappa coefficient of inter-observer agreement on type judgment was 0.776 ($p < 0.001$), indicating strong consistency (Table 3). Each SP was considered a case (552 cases in total), and 2 investigators have made a consistent judgment on 477 cases, which means 75 cases were inconsistent. Inconsistent decisions were noted and further discussed by the 2 investigators. Observing the 3D reconstruction of all cervical vertebras in this study, it is found that the cervical SPB is located at the back of the spinous process (Fig. 3). There are different types of spinous process bifurcation in CT films at different levels of the same spinous process (Fig. 3).

The frequency of SPB morphological types according to age, sex and cervical level

This study enrolled 92 samples, including 42 (45.65%) females and 50 (54.35%) males. The overall age was 41 ± 9.5 years, ranging from 19 to 60. Fisher's exact tests showed sex differences among four SPB types are significant ($p = 0.008$). Men showed a slightly larger percentage of fully bifid type than women, while women had a slightly larger percentage of partially bifid type. The age differences between SPB types were compared by the Kruskal Wallis H test

Table 4. Frequency and percentage of spinous process bifurcation morphological types in age, sex and cervical level

Morphological types	Fully bifid	Partially bifid	Unilateral branch	Non-bifid	Total (cases)
Age (mean ± SD)	40.78 ± 9.55	40.15 ± 11.18	46.67 ± 6.87	40.31 ± 9.15	40.61 ± 9.61
Male (cases)	149 (49.67%)*	26 (8.67%)*	7 (2.33%)	118 (39.33%)	300
Female (cases)	103 (40.87%)*	39 (15.48%)*	2 (0.80%)	108 (42.86%)	252
C2 (cases)	85 (92.39%)	3 (3.26%)	4 (4.35%)	0	92
C3 (cases)	40 (43.47%)	26 (28.26%)	2 (2.17%)	24 (26.08%)	92
C4 (cases)	55 (59.78%)	15 (16.30%)	2 (2.17%)	20 (21.74%)	92
C5 (cases)	57 (61.96%)	16 (17.40%)	0	19 (20.65%)	92
C6 (cases)	15 (16.30%)	5 (5.43%)	1 (1.09%)	71 (77.17%)	92
C7 (cases)	0	0	0	92 (100%)	92
Total (cases)	252 (45.65%)	65 (11.78%)	9 (1.63%)	226 (40.94%)	552

Each of 92 samples has 6 cases corresponding to six cervical levels. *Fisher exact test (2×C) showed significant sex difference between fully bifid and partially bifid types ($p = 0.008 < 0.008333$, the α level was adjusted according to Bonferroni method, $\alpha = 0.008333$); SD — standard deviation

which showed no statistical significance ($H = 3.358$, $p = 0.340$).

The frequency and percentage of SPB morphological types are shown in Table 4. The number of cases in each type was as follows: fully bifid 252 (45.65%) cases, partially bifid 65 (11.78%) cases, unilateral branch 9 (1.63%) cases, and non-bifid 226 (40.94%) cases.

If we combine fully bifid and partially bifid types as general bifid the frequency of general bifid SP in overall 92 samples was as follows: 88 (95.65%) samples at C2, 66 (71.74%) samples at C3, 70 (76.09%) samples at C4, 73 (79.35%) samples at C5, 20 (21.74%) samples at C6. The percentage of general bifid SP in C2–5 was more than 70%. C7 spinous process was non-bifid in all cases while C2 did not present any non-bifid case (Table 4, Fig. 4). The frequency and percentage of SPB morphological types in age, sex, and cervical level are shown in Table 4.

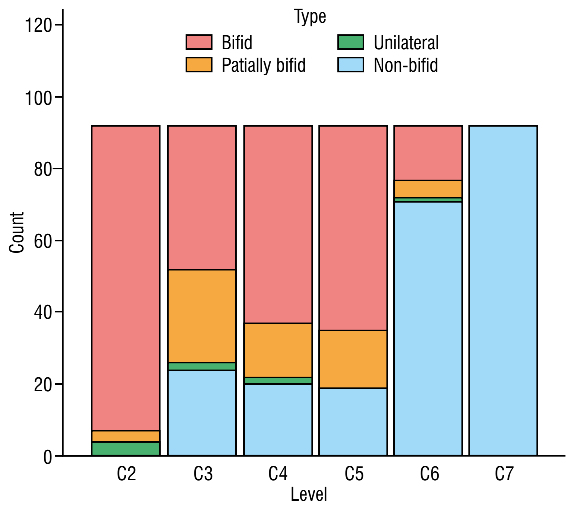

Figure 4. Counts of four spinous process bifurcation morphological types in six cervical levels.

The measurement of cervical SPB

In this experiment, SPB was divided into four categories. To be specific, measurements were only designed for fully bifid and partially bifid types (Table 3). The ICC value showed excellent inter-observer variability for measurements of two investigators ($ICC > 0.85$). The quantification of non-bifid and unilateral branch types was undone.

Results showed that the fully bifid type has greater branch length on both sides, greater distance between two SPB tips, and greater depth of bifurcation than those of the partially bifid type ($p < 0.05$). Whereas, the angle between two branches (angle α) and angle between the branches and the transverse baseline (angle β and angle γ) were all smaller in fully bifid type than in partially bifid type ($p < 0.05$). In general, the morphology of SPB was characterized by two long branches with a sharp angle between them. In contrast, the partially bifid type presented two short branches with a larger angle in between (Table 3).

As for the symmetry of SPB, the paired t-test showed no statistical significance in the length and deflection angles (angle β and γ) between left and right sides in fully bifid and partially bifid types ($p > 0.05$). However, 9 cases of SP presented a unilateral branch, which was asymmetrical.

DISCUSSION

Previous studies commonly divide cervical SPB into three types: fully bifid, partially bifid, and non-bifid [14]. According to Shore's criterion, any dorsal groove of SP deeper than 1 mm is defined as bifid [14]. Duray classified SPB as bifid, partially bifid, or non-bifid according to the following criteria: 1. Bifid: the SP includes clearly distinct cleft results in two elongate projects. The bifurcation must separate both the tubercles and part of the SP itself; 2. Partially Bifid: two distinct tubercles at the end of the SP are present. The SP itself is not bifurcated and no cleft is present; 3. Nonbifid: the end of the SP is rounded or flattened. A median groove may be present but two distinct tubercles are not present [4]. Cho's classification method of SPB is based on Duray's method [3]. Cho found that there are different types of SPB in CT films at different levels of the same SP, so he comprehensively judged the SPB types on multiple planes of the same SP. Singh B's specific description of SPB classification: partially bifid refers to two distinct tubes at the end of the SP are present and SP itself is not bifurcated and no cleft is present [15]. Fully bifid refers to the bifurcation that must separate both the tubercles and part of the SP itself [15]. Non-bifid refers to the end of the SP being rounded or flattened [15]. A specific description of SPB by Asvat: SP was classified as bifid (bifurcate and clear subtypes) and non-bifid (obtuse, pediculate, acinate, and clavate subtypes) [2]. However, Greiner believes that the classification of cervical SPB is relatively loose and has not reached a unified understanding [6, 14]. How deep, wide, and long should an SP be defined as bifurcation has not been determined [6, 14]. Most former researchers classify SPB only by subjective judgment [6].

In this study, we put forward a modified classification system of four SPB types based on previous literature. Criteria were as follows: 1. Non-bifid: the bifurcation depth of the spinous process is less than 1mm, or the end of the spinous process is rounded or flattened; 2. Partially bifid: the bifurcation depth of the spinous process is greater than 1 mm, but no distinct branches were observed; 3. Fully bifid: the bifurcation depth of the spinous process is greater than 1 mm, with distinct branches present; 4. Unilateral branch: not conforming to the above criteria, lacks SPB branch on one side. Due to the potential subjective bias in this classification system, we performed a test to evaluate the consistency of the two investigators in using this classification system. The weighted kappa coefficient was 0.776 ($p < 0.001$), which showed good repeatability and consistency. This result demonstrated that this modified classification system is an ideal method despite subjective judgment exists.

Previous works studying SPB often chose materials such as dry cervical bone specimens, plain films, CT, and magnetic resonance imaging [3, 4, 6, 10, 11, 14]. Few used the reconstructed 3D model to study SPB. There were limitations with materials and methods in previous research. Dry bone specimens were often not reserved in sequence, and some may even lack data on gender and age. Plain films, CT, and magnetic resonance imaging slices failed to show the overall view of SPB. Cho also agreed that sectional images of SP were inadequate for analysis of SPB morphology [3]. As we mentioned above, there are different types of SPB morphology in CT films at different levels of the same SP [3]. This conclusion was intelligible under the 3D reconstruction model which clearly shows the complicated position of SP in the posterior vertebral region. Only a two-dimensional image is insufficient for SPB identification. Therefore, we suggest using the 3D reconstruction method for anatomical research in future SPB studies.

As described in many textbooks, SPB is a distinctive feature of the cervical vertebra compared to other spinal vertebras. However, cervical vertebrae are not always bifid [6]. In the studies of the European population, C3 and C6 are the most common cervical levels with SPB [14, 15]. According to Allbrook [1], SPB is most likely to occur in C2 and C5 levels. In our research, we came to the same conclusion. The occurrence rate of general bifurcation in the C2 and C5 levels was high (including fully bifid and partially bifid), which were 95.65% and 79.35%, respectively. In contrast, the C6 level had only a 21.74% occurrence rate of SP bifurcation, and C7 was all non-bifid. In addition, several studies have found gender differences between fully bifid and partially bifid. In the African population, fully bifid is more common in men than in women while partially bifid is on the contrary [4, 11]. This conclusion is consistent with our study of the Chinese population.

During open cervical operation, especially with the posterior cervical approach, it is often necessary to determine the cervical level with the most caudal level of SPB. However, there are arguments about the most caudal level of SPB, and some researchers suggest C5 [7, 16] and some suggest C6 [5]. According to our study, the occurrence rate of C5 and C6 SPB was 79.35% and 21.74%, respectively. Obviously, C5 is more likely to be the most caudal level of SPB in the Chinese population. Nevertheless, more than one-fifth of individuals have a bifid SP at the C6 level. In other populations, some researchers even reported an occurrence of bifid C7, probably at a rate of 0.3% [3, 11]. In our study, all C7 SPs present non-bifid, which leaves us a mystery about the existence of bifid C7 in the Chinese population. Thus, the reliability of cervical level identification with the most caudal SPB still remains unclarified.

Spinous process is also an essential bony landmark in palpation of the cervical spine, commonly used by clinicians, manual therapists and chiropractic practitioners. In some theories, checking whether the SP is located in the posterior median position is a diagnosis procedure of cervical spine mal-alignment [10, 12]. Lewit [9] even advocated that the deviation of the SPs can be the source of neck pain. The direction of SP deviation is thus vital for the adjustment of spine alignment with manual therapy [10, 12]. However, we noticed that the asymmetry of bifurcation may have affected the results of SP palpation from the posterior neck region [6]. Few articles reported the symmetry of SPB [10]. Thus, the symmetry of SPB was analysed with quantitative parameters in our study. As described above, no significant difference was found in the angle between the two bifid branches and the angle between the branch and the transverse baseline on both sides. The results indicated that SPB was not likely to affect the results of palpation. However, the type of unilateral branch may have unknown effects on palpation. But then again, the accuracy and consistency of the palpation method are still questionable.

Limitations of the study

Our study has limitations. First, we only have 92 specimens for analysis, which means that some results in this study may not represent the entire population. Second, we only investigated the Chinese population but did not compare all results with different ethnic groups. Third, the study data are subject to the limitations and biases of retrospective analysis.

CONCLUSIONS

The classification system of SPB in this study proved consistent and reliable, despite the subjective bias. Identifying cervical level by C6 bifurcation is unreliable since nearly 80% of C6 SP is non-bifid. Our work provides an accurate and effective anatomical reference for SPB studies in the Chinese population.

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Conflict of interest: None declared

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