An anatomical study of the spinous process of the seventh cervical vertebrae based on the three-dimensional computed tomography reconstruction

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Abstract. Palpation of the seventh cervical vertebra (C7) is important for the diagnosis and treatment of neck and chest conditions. However, the spinous process of C7 (C7-SP) displays an anatomical deviation among individuals. The present study aimed to clarify anatomic characteristics of C7-SP by using a three-dimensional (3D) computed tomographic (CT) reconstruction technique. A total of 245 subjects meeting the selection criteria were examined. After CT scanning, the images were reconstructed in 3D. All subjects were grouped according to their deviation of C7-SP: Deviating to the right (DR group), deviating to the left (DL group) and no deviation (ND group). Three distances and three angles were recorded on C7-SP. The vertical distances between the borders of the left and right transverse processes and the tip of the SP, were termed DLTS and DRTS, respectively. The length of the SP was also determined. The angle of the SP deviation was referred to as \( \angle \alpha \), the angle between the SP axis and the line crossing the tips of the transverse processes was referred to as \( \angle \beta \) and the angle between the vertebral body axis and the SP axis was referred to as \( \angle \gamma \). Among the three groups, differences in \( \angle \alpha \) and \( \angle \beta \) were statistically significant (P<0.05). Furthermore, the DLTS was significantly different between the DL and ND groups (P<0.05). In addition, a significant difference in the DRTS was identified between the DR and ND groups (P<0.05). 3D CT reconstruction was reliable for studying anatomic characteristics of C7-SP. Based on this, patients may be preliminarily grouped according to the deviation of their C7-SP and the measurement of the C7-SP may guide clinical diagnoses and treatments.

Introduction

Upon lowering the head, the spinous process (SP) of the seventh cervical vertebra (C7) of humans bulges to the skin and forms a significant eminence on the back of the neck. The C7 is usually identified by a long, club-shaped and unbranched SP (1-3), referred to as vertebra prominens (4). The C7 represents the bottom of the cervical spine and connects with the top of the thoracic spine, T1, to form the cervicothoracic junction, also referred to as C7-T1. Thus, the C7 marks the level of transition from the dynamic cervical segment to the relatively inflexible thoracic segment of the vertebral column (1). Furthermore, it is the point where cervical lordosis reverses into thoracic kyphosis, making C7 anatomically unique (5). Of all cervical injuries, 9% occur at the C7 segment, and the morphology of C7, which displays inter-regional, inter-ethnic and individual variations, may affect surgical approaches (6). Thus, the morphology of the C7 is a clinically significant area of interest in clinical practice (1).

In addition, C7-SP is of vital importance for clinical examinations, diagnostic and therapeutic interventions and various types of surgery involving the neck. For instance, C7-SP is used as a point of reference for determining the level to insert epidural catheters by anesthesiologists, and a C7-T1 level of entry is recommended for cervical interlaminar epidural steroid injection (7). In addition, owing to the
complex attachment of nuchal muscles to the spinous process, the SP should be preserved to reduce the incidence of postoperative axial pain (8). For the most part, decisions regarding surgical treatment made by the physician are affected by the anatomic characteristics of C7-SP. For instance, when performing posterior cervical surgical procedures, surgeons often rely on the morphology of C7-SP if the operation only involves the lower cervical area. However, if the patient has a bifid C7-SP, this may mislead the surgeon, which may result in undesired outcomes (2). In addition, due to the inter-individual deviation of C7-SP, the identification of suitable approaches for inserting the screws when performing a posterior fixation of the neck is challenging. Certain studies stressed that a new pedicle screw should be inserted based on the three-dimensional (3D) reconstruction as well as individualization (9). Although numerous studies have assessed the structures of C7-SP, most of them focused on the dimensions and angulations of the pedicle, bifid condition and the accurate ways to locate C7 (10-13). However, the detailed anatomic characteristics of C7-SP have remained to be elucidated.

Only a few reports have assessed the inter-individual variation of C7-SP. In the present study, the anatomic characteristics of the C7-SP were preliminarily measured based on 3D computed tomography (CT) reconstruction, an imaging tool that has been validated in a variety of applications for the practice of spine surgery (14). The objective of the present study was to explore the anatomic features of C7-SP, which may facilitate the diagnosis and treatment of conditions involving the cervical spine.

Patients and methods

Subjects. A total of 245 subjects were enrolled from January 2016 to August 2017 at the Affiliated Traditional Chinese Medicine Hospital of Southwest Medical University (Luzhou, China). Prior to the start of the study, approval was obtained from the Ethical Inspection Committee of the Affiliated Traditional Chinese Medicine Hospital of Southwest Medical University, which waived the requirement for informed consent due to the retrospective nature. The CT data of the C7 were collected at the Radiology Department of the Affiliated Traditional Chinese Medicine Hospital of Southwest Medical University. All patients were Han Chinese and >18 years of age. Subjects of the present study were grouped according to the deviational direction of C7-SP (Fig. 1). Group distribution, the Kolmogorov-Smirnov and Shapiro-Wilk tests were used to determine the normal distribution of the Kolmogorov-Smirnov and Shapiro-Wilk tests

3D reconstruction CT. A spiral CT scanner (Somatom Emotion; Siemens AG, Munich, Germany) was used with the following scan conditions: Voltage, 130 kV; current, 180 mA; thickness, 0.75 mm; and matrix size, 512×512. In addition, the CARE Dose 4D technique was used in the examination. All patients were kept in the supine position during scanning. The 3D images were stored on the Picture Archiving Communication System (PACS version 4.0; DJ HealthUnion Systems Corporation, Shanghai, China). This was a system for recording and storing radiographic images, permitting storage of large numbers of images and allowing access from any networked station. In addition to these storage facilities, PACS also incorporated a sensitive measuring tool. After 3D reconstruction, the C7 was individually analyzed. Typical C7 images were acquired by adjusting the position and size, increasing the contrast and making other image adjustments on the CT workstation prior to measuring.

Measurement of C7-SP parameters. All measurements were performed by three radiologists who had performed in CT-associated work for >5 years at the Radiology Department of the Affiliated Traditional Chinese Medicine Hospital of Southwest Medical University. The lateral, superior and posterior aspects of C7 images were saved separately in the PACS. Prior to measurement, the C7 was placed in different planes for each parameter. The minimal distance was 0.01 cm and the minimal angle was 1°. The distance between the borders of the left or right transverse process and the tip of SP in the superior aspect (DLTS or DRTS), and the distance between the tip of C7-SP and the medial point of the rear of spinal canal in lateral aspect, termed the length of SP (LSP), were determined. The angle of the SP deviation (∠α) was measured as the angle between the long axis of SP and the median line of the vertebra in the superior aspect. ∠β was defined as the angle between the long axis of the SP and the line that crossed the tips of bilateral transverse processes. ∠γ was measured as the angle between the vertical axis and the long axis of the SP in the lateral aspect. All of the abovementioned measurements are indicated in Fig. 1. All subjects of the present study were grouped according to the deviational direction of C7-SP: Deviating to the right (DR group), deviating to the left (DL group) and no deviation (ND group) (Fig. 2).

Statistical analysis. A statistical analysis was performed using SPSS, version 20.0 (IBM Corp., Armonk, NY, USA). The amounts of males and females in each group were expressed as frequencies and percentages and were analyzed by the χ² test. The age and parameters of C7 were expressed as the mean ± standard deviation. In order to determine the normal distribution, the Kolmogorov-Smirnov and Shapiro-Wilk tests

Table I. Number of males and females, and their age in the three groups.

| Group | Male | Female | Age (years) |
|-------|------|--------|-------------|
| DL    | 43 (17.55) | 51 (20.82) | 47.23±12.78 |
| DR    | 64 (26.12) | 69 (28.16) | 47.95±14.27 |
| ND    | 5 (2.04%)  | 13 (5.31)  | 47.95±14.27 |

Values are expressed as the mean ± standard deviation or as n (%). There was no statistically significant difference in the age and the male-to-female ratio among the three groups (P>0.05). Groups: DL, C7-SP deviating to left; DR, C7-SP deviating to right; ND, no deviation in C7-SP. C7-SP, spinous process of the seventh cervical vertebra.
were performed. One-way analysis of variance was used to compare the age and parameters of C7 among the three groups, and the Student-Newman-Keuls test was the post hoc test. P<0.05 was considered to indicate a statistically significant difference.
is a form of pain around the neck and shoulders and often plays a crucial role in preventing axial symptoms. According to various studies, the preservation of C7-SP has a significant impact as the C7 vertebra, attaches at the tip of the spinous process, of the neck and connects the occipital bone of the skull to the end of the nuchal ligament, which supports the muscles of the neck, including the trapezius and spinalis muscles. The SP extends from the posterior of the vertebral arch to the caudal edge of the transverse processes of the cervical vertebrae C3-7 in a population from Northeastern Mexico, other studies had been performed to measure the LSP. Bazaldua et al. (30), studied the morphometry of the cervical vertebrae C3-7 in a population from Northeastern Mexico and measured the distance from the superior border to the tip of the SP in the sagittal plane to determine a mean value of 29.12±5.86 mm, which was in accordance with the results of other studies. However, other studies obtained measures of 22.19±2.02 and 22.78±2.03 mm (29, 21), which was smaller than the result of the present study. These discrepancies may be the result of the various measuring criteria, inter-regional or -ethnic differences and statistical errors.

Furthermore, in the present study, the difference in the DRTS between the DR and ND groups was statistically significant (4.69±0.53 vs. 4.41±0.54 cm; P<0.05). A statistically significant difference in the DRTS between the DR and ND groups was observed (4.69±0.53 vs. 4.41±0.54 cm; P<0.05). In addition, protection of the C7-SP and anatomical structures around the cervical spine, including the muscles attached to the spinous process, as well as the supraspinous and interspinous ligaments, provides better results regarding the range of movement and cervical axial pain. In addition, it was reported that adequate knowledge of C7 morphology is necessary for the spinal surgeon in order to avoid damage to the vertebral arteries, spinal cord or nerve roots during fixation interventions involving the posterior cervical spine (29). The cervicothoracic junction is a challenging anatomical transition in spine surgery. Compared with all other cervical vertebrae, C7 has relatively broader laminae, larger pedicles, smaller lateral masses and a long non-bifid spinous process. These characteristics allow for a variety of surgical methods to be performed to apply posterior rigid instrumentation in the form of different types of screw, including lateral mass, pedicle, transfacet and intralaminar screws (1).

In the present study, all subjects were grouped according to the angle of SP deviation. Compared with that in the ND group, the \( \alpha \) of the DL and DR groups was significantly different. It was indicated that a deviation of the C7-SP existed, and that it was possible to preliminarily group all C7s according to their \( \alpha \). Furthermore, as the age and male-to-female ratio did not significantly differ between the groups, the grouping was not affected by the age and the male-to-female ratio.

After the grouping, no significant differences were noted in \( \gamma \) and LSP among the three groups (P>0.05). Numerous other studies had been performed to measure the LSP. Bazaldua et al (30), studied the morphometry of the cervical vertebrae C3-7 in a population from Northeastern Mexico and measured the distance from the superior border to the tip of the SP in the sagittal plane to determine a mean value of 29.12±5.86 mm, which was in accordance with the results of the present study. However, other studies obtained measures of 22.19±2.02 and 22.78±2.03 mm (31, 32), which was smaller than the result of the present study. These discrepancies may be the result of the various measuring criteria, inter-regional or -ethnic differences and statistical errors.

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### Table II. Measurements in the three groups.

| Group | DLTS (cm) | DRTS (cm) | LSP (cm) | \( \alpha \) (˚) | \( \beta \) (˚) | \( \gamma \) (˚) |
|-------|-----------|-----------|----------|----------------|----------------|----------------|
| DL    | 4.69±0.53 \(^a\) | 4.59±0.51 | 3.03±0.37 | 4.30±2.96 \(^b\) | 69.33±10.04 | 86.30±3.70 |
| DR    | 4.57±0.50 | 4.72±0.47 \(^b\) | 3.08±0.36 | -5.17±3.35 \(^b\) | 70.64±8.13 | 69.33±10.04 |
| ND    | 4.41±0.54 | 4.44±0.45 | 2.98±0.28 | 0.00±0.00 | 89.72±2.02 | 70.64±8.13 |

\(^a\)P<0.05 vs. DR; \(^b\)P<0.05 vs. ND. Values are expressed as the mean ± standard deviation. Groups: DL, C7-SP deviating to left; DR, C7-SP deviating to right; ND, no deviation in C7-SP. DLTS/DRTS, vertical distances between the borders of the left/right transverse processes and the tip of SP, respectively, in the superior aspect; LSP, the distance between the tip of the C7-SP and the rear of the spinal canal in lateral aspect; \( \alpha \), angle of SP deviation, measured as the angle between the long axis of the SP and the median line of the vertebra in the superior aspect; \( \beta \), angle between the long axis of the SP and the line which crossed the tips of the bilateral transverse processes in the superior aspect; \( \gamma \), angle between the vertical body axis and the SP axis in the lateral aspect; C7-SP, spinous process of the seventh cervical vertebra.

### Results

A total of 245 subjects were enrolled in the present study, and the number of patients in the DL group was 94, which comprised 43 males (17.55%) and 51 females (20.82%), and the average age was 47.23±12.78 years (range, 21-80 years). The DR group consisted of 133 patients with an average age of 47.95±14.27 years (range, 19-89 years), and included 64 males (26.12%) and 69 females (28.16%). The ND group included 18 subjects, comprising 5 males (2.04%) and 13 females (5.31%) with an average age of 47.95±14.27 years (range, 25-86 years). No statistically significant difference in the age and the male-to-female ratio among the three groups was determined (Table I).

A statistically significant difference in the DLTS between the DL and ND groups was observed (4.69±0.53 vs. 4.41±0.54 cm; P<0.05). In addition, the DRTS in the DR group was significantly different from that in the ND group (4.72±0.47 vs. 4.44±0.45 cm; P<0.05). Compared with that in the ND group, the \( \alpha \) in the DL and DR groups was significantly different (0 vs. 4.30±2.96 and -5.17±3.35; P<0.05); furthermore, the \( \alpha \) in the DL group was significantly different from that in the DR group (P<0.05). More importantly, \( \beta \) was significantly different among the three groups (93.09±3.39, 86.30±3.70 and 89.72±2.02, respectively; P<0.05). The differences in the LSP and \( \gamma \) among the three groups were not significant (P>0.05; Table II).

### Discussion

The accuracy in identifying C7 using manual palpation by clinicians is limited due to the inter-individual variation in the morphology of C7-SP (15-19). While several studies have assessed the anatomic structures of C7-SP, most of them focus on the mechanisms of diseases affecting it (8, 20, 21). The SP extends from the posterior of the vertebral arch to provide connection points for the muscles that extend from the neck, including the trapezius and spinalis muscles. The end of the nuchal ligament, which supports the muscles of the neck and connects the occipital bone of the skull to the C7 vertebra, attaches at the tip of the spinous process. According to various studies, the preservation of C7-SP has a crucial role in preventing axial symptoms (22-25). This is a form of pain around the neck and shoulders and often remains a major concern for several years postoperatively, even in patients with excellent neurologic recovery (26, 27). In addition, protection of the C7-SP and anatomical structures around the cervical spine, including the muscles attached to the spinous process, as well as the supraspinous and interspinous ligaments, provides better results regarding the range of movement and cervical axial pain (28). In addition, it was reported that adequate knowledge of C7 morphology is necessary for the spinal surgeon in order to avoid damage to the vertebral arteries, spinal cord or nerve roots during fixation interventions involving the posterior cervical spine (29). The cervicothoracic junction is a challenging anatomical transition in spine surgery. Compared with all other cervical vertebrae, C7 has relatively broader laminae, larger pedicles, smaller lateral masses and a long non-bifid spinous process. These characteristics allow for a variety of surgical methods to be performed to apply posterior rigid instrumentation in the form of different types of screw, including lateral mass, pedicle, transfacet and intralaminar screws (1).

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After the grouping, no significant differences were noted in \( \gamma \) and LSP among the three groups (P>0.05). Numerous other studies had been performed to measure the LSP. Bazaldua et al (30), studied the morphometry of the cervical vertebrae C3-7 in a population from Northeastern Mexico and measured the distance from the superior border to the tip of the SP in the sagittal plane to determine a mean value of 29.12±5.86 mm, which was in accordance with the results of the present study. However, other studies obtained measures of 22.19±2.02 and 22.78±2.03 mm (31, 32), which was smaller than the result of the present study. These discrepancies may be the result of the various measuring criteria, inter-regional or -ethnic differences and statistical errors.
ND groups was also observed (4.72±0.47 vs. 4.44±0.45 cm; P<0.05). This indicated that the orientation that SP deviated to had a longer distance between the transverse process and SP. This may be due to the rotation of the vertebral body. Stricter measuring methods are required to be formulated to reduce these errors. More importantly, statistically significant differences were also observed in $\beta$ among the three groups (P<0.05). This parameter reflects the angle between the transverse process and SP, and it is of vital importance for surgeries involving the exposure of the posterolateral part of C7. In addition, it was reported that the most effective type of posterior fixation at the cervicothoracic junction was a pedicle screw fixation due to the specific characteristics of the C7 (7,33-36). Kajino et al (37), studied the surgical anatomy for pedicle screw placement in the cervical spine. They confirmed that the ideal posterior entrance for screw insertion was 2.5 mm medial to the lateral margin of the lateral masses, the correct insertion angle was ~45˚ and the critical value of depth of insertion was 13-14 mm. Lee et al (38), studied the anatomic feasibility of posterior cervical pedicle screw placement in children with CT analysis, arguing that the possibility of subaxial lateral mass screw fixation must be investigated with a more tailored method. In this study, before the measurement, all the objectives accepted CT scan. The value of CT in detecting spinal fractures is well known. Unlike conventional X-ray analysis, CT scanning provides detailed images of numerous types of tissue as well as the bones and blood vessels. Thus, CT has been used in clinical fields including diagnosis of diseases and anatomical analysis (39-41). According to the Food and Drug Administration, CT scanning is a rapid procedure and offers accurate evaluation of bone and most soft tissues. Using the latest equipment, the spine may be displayed in multiple planes and 3D images may be reconstructed. In the present study, the scan images were reconstructed in 3D models. Compared with conventional 2D images, 3D images may provide more advancement in the clinic. In addition, these CT images were taken from helical CTs, which provided adequate data for creating 3D images.

The present study had certain limitations. First, the parameters of the C7-SP were measured on the PACS, in which the tips or medial parts of the structures were determined by three radiologists. A more advanced measuring tool is required to provide accurate results. In addition, only the C7-SP of Chinese patients from the Affiliated Traditional Chinese Medicine Hospital of Southwest Medical University were assessed, and patients aged <18 years were excluded; further studies may be performed at other hospitals for other populations/ethnicities and underage subjects. Furthermore, no cadaveric study of the C7-SP was performed in the present study, which may be the aim of a future study.

In conclusion, based on the 3D CT, several parameters of the C7-SP were precisely measured. It was identified that despite of the different age and gender of the patients, it was possible to preliminarily group all of them according to the deviation of C7-SP. These results may support future diagnoses and treatments, and reduce the incidence of misdiagnosis. In addition, the present study may provide a basis for further studies on C7. Apart from the deviation of C7-SP, it remains to be determined whether there is an association with any other parameters. Therefore, more study is required for assessing the association between C7-SP, the bony structures and tissues surrounding it.

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Availability of data and materials
The analysed data sets generated during the study are available from the corresponding author on reasonable request.

Authors' contributions
The study was designed by LZ. Patients were recruited by ZL, HW, LR, FY, TG and SF. The imaging measurements were made by ZL, LR and FY. The statistical analysis was conducted by LZ and HW. LZ, ZL, TG and SF wrote the manuscript.

Ethical approval and consent to participate
All of the procedures were approved by the Ethical Committee of the Affiliated Traditional Chinese Medicine Hospital of Southwest Medical University (Luzhou, China; no. SWMCTCM2017-0810) and registered as a clinical trial (ChiCTR-BOC-17012270), and were performed in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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