

Quantitative assessment of vertebral artery anatomy in relation to cervical pedicles: surgical considerations based on regional differences

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ABSTRACT

الأهداف: لتحديد العلاقة التشريحية بين المسامير العنقية العنقي (CPS)، الشريان الفقري (VA)، والبنية التشريحية ذات الصلة في السكان السعوديين.

الطريقة: اشتملت هذه الدراسة ذات المركز الواحد بأثر رجعي 50 مريضاً متتابعاً (35 ذكراً) مع نتائج عنق عادية على التصوير المقطعي المحوسب تم إجراؤه لتقييم الصدمة أو الأوعية الدموية بين عامي 2012م و 2014م. تم تقييم المعالم الإشعاعية وارتباطها بالعمر، والوزن، والطول، وكتلة الجسم مؤشر (BMI).

النتائج: بلغ كلا من متوسط العمر، والوزن، والطول، ومؤشر كتلة الجسم 45.74 ± 18.93 عام، 79.72 ± 21.80 كجم، 164.74 ± 11.53 سم، 29.38 ± 6.13 كجم/م²، على التوالي. متوسط القطر عنق العنقية (PD) زاد من الفقرات القحفية إلى الذيلية ($p=0.0001$). متوسط قيمة المنطقة الحرة (FZ)، التي تم تعريفها على أنها المسافة بين حدود CP الثانوية وحدود VA med، كانت 1 ملم (المدى $0.95 - 1.16$ ملم). كان دخول VA في الثقب المستعرض في مستوى C6 على كلا الحقتين 92% والجانب الأيسر في معظم المرضى 94%. ومع ذلك، اختلف مستوى الجانب الأيسر والأيمن من إدخال VA في 14% من الأفراد.

الخلاصة: إن PD و FZ أقل قيمة في السعوديين من سكان الغربية. يجب إجراء تقييم دخول VA على كل مستوى على أساس فردي حيث يمكن أن يختلف مستوى الإدخال VA في نفس المريض. يجب دراسة التغيرات التشريحية بين المناطق الجغرافية المختلفة لتقديم إرشادات جراحية أفضل.

Objectives: To quantify the anatomic relationship between the Cervical pedicle screw (CPS), vertebral artery (VA), and related anatomic structures in the Saudi population.

Methods: This retrospective single center study included 50 consecutive patients (35 males) with normal neck findings on computed tomography angiography performed for trauma or vascular evaluation between 2012 and 2014. Radiologic

parameters were assessed and correlated with age, weight, height, and body mass index (BMI).

Results: Mean age, weight, height, and BMI were 45.74 ± 18.93 years, 79.72 ± 21.80 kg, 164.74 ± 11.53 cm, and 29.38 ± 6.13 kg/m², respectively. Mean cervical pedicle diameter (PD) increased from the cranial to caudal vertebrae ($p=0.0001$). Mean free zone (FZ) value, defined as the distance between the lateral CP border and medial VA border, was 1 mm (range 0.95–1.16 mm). The VA entry into the transverse foramina was at C6 level on both the right 92% and left side in most patients 94%. However, the right and left side level of VA entry differed in 14% of individuals.

Conclusion: The PD and FZ are smaller in Saudi Arabians than in western populations. Assessment of VA entry at each level should be performed on an individual basis as the level of VA entry can differ in the same patient. Anatomic variations between different geographic areas should be studied to provide better surgical guidance.

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Cervical spine instrumented fusion is a common treatment for a variety of pathologic conditions.¹ Several approaches for cervical spine stabilization have been developed, including anterior or posterior approaches.²⁻⁴ Currently, posterior fixation of the

subaxial cervical spine is performed using lateral mass screws (LMS) or cervical pedicle screws (CPS).⁴ The CPS has the advantage of a stronger pullout strength than LMS.^{5,6} However, CPS is more technically demanding and is associated with a potentially higher risk of injury to the neurovascular structures.⁶⁻¹¹ Precise anatomic knowledge is paramount for preventing a potentially life threatening vertebral artery (VA) injury during CPS insertion.¹²⁻¹⁵ The close proximity of the VA to the bony structures increases the risk of VA injury. Previously, anatomic studies identified a distance of 1–2 mm between the VA and the lateral wall of the cervical pedicle (CP).¹⁶ Additionally, the VA occupies one- to two-thirds of the axial diameter of the transverse foramen (TF), narrowing the space around the VA for potential screw misplacement.^{16,17} Additionally, variability in vertebral artery anatomy or osseous anatomy exists and should be assessed on an individual basis.¹⁶ Good knowledge of anatomic details combined with modern intra-operative imaging technology with navigation could reduce the risk of VA injury during CPS insertion.^{18,19} The purpose of this study was to quantify the relationship between anatomic structures of the subaxial spine and the VA and the CP in the Saudi population and to compare the results with published data from other geographic areas. These findings are relevant to the instrumentation of the spine, showing regional variations in the spinal anatomical structures measurement. Moreover, the data is critical for surgical planning, decision-making, and safety of cervical spine instrumentation.

Methods. *Basic design and outcome.* This retrospective study included 50 consecutive adult Saudi patients (35 males and 15 females) with normal computed tomography angiography (CTA) findings between 2012 and 2014. Indications for CTA served vertebral-basilar system evaluation in trauma, tumor, or suspected vascular insufficiency. Approval was obtained from the institutional review board prior to the beginning of the study. The main outcome of the study was the quantitative evaluation of the VA anatomy in

relation to the CP and osseous structures relevant to CPS insertion from C3 to C7. A neuroradiologist, blinded to patient's demographic data, assessed all CTA images for the included parameters. The CT machine used in this study was a GE LightSpeed 64-slice HD system (GE Healthcare, Wauwatosa, WI, USA) with targeted area slice thickness of 0.625 mm × 0.625 mm. Oblique axial and oblique sagittal reconstructions were performed using standard bone algorithm. Oblique axial images were reconstructed parallel to the superior and inferior border of each pedicle using AW VolumeShare 4.6 (GE Healthcare).

Demographic data including patients' age, weight, height, and body mass index (BMI) were collected and correlated with anatomic variables of the cervical vertebrae. Height and BMI data were missing in 5 patients and weight was missing in 3 patients.

Radiologic variables. Assessment of osseous parameters. All included cervical spine levels, from C3 to C7, were assessed bilaterally. Cervical spine bony structures relevant to the VA, including the pedicle diameter (PD) at the isthmus, maximum transverse foramen's coronal (TFC) and sagittal (TFS) diameters, maximum spinal canal's coronal (SCDC) and sagittal (SCDS) diameters measured from bone boundaries, were evaluated.

Assessment of VA parameters and the free zone. Variables concerning VA anatomy (Figure 1) were determined, including the lowest level of VA entry into the transverse foramina of cervical spine, and VA sagittal (VADS) and coronal (VADC) diameters. The free zone (FZ) (the space available for the CPS screw before it encroaches into VA following a perforation the lateral pedicle wall) was defined as the distance between the lateral pedicle border to the medial border of VA (Figure 1). Previous literature considered this space as a safety area for CPS.^{16,17} The FZ was examined from C3 to C6.

The VA occupancy was identified as the space in the TF that is occupied by VA. This was determined by determining the ratio of the VADC to the TFC. The following parameters were not measured due to technical considerations and were considered missing variables: SCDC in 4 patients, SCDS at C7 in 3 patients, and FZ at C6 in 5 patients.

Statistical analysis. Statistical analysis was performed using the Statistical Package for Social Science software (SPSS PC+ version 19.0; SPSS Inc., Chicago, IL, USA). Descriptive statistics (mean, standard deviation) were used. Paired t-test was used to compare between males and females and right and left sides. Pearson's

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correlation coefficient was calculated to explore the relationship among different parameters and patient's age and height at different levels from C3 through C7. A *p*-value < 0.05 was considered statistically significant.

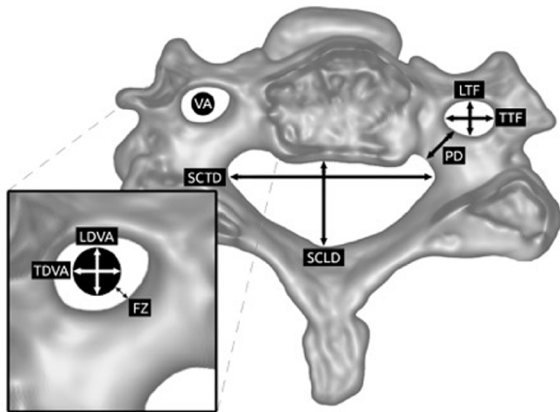


Figure 1 - Radiological measurements of different parameters. TFC - transverse foramen on coronal image; FZ- free zone defined as the distance between the lateral border of the pedicle and medial border of vertebral artery (safe zone for pedicle screw insertion); PD - cervical pedicle diameter at the level of isthmus; SCDC - spinal canal diameter on coronal image; SCDS - spinal canal diameter on sagittal image, LTF - longitudinal diameter of transverse foramen, TTF - transverse diameter of transverse foramen, SCLD - spinal canal longitudinal diameter, SCTD - spinal canal transverse diameter, LDVA - longitudinal diameter of vertebral artery, TDVA - transverse diameter of vertebral artery

Results. Patient demographics. The mean patients' age, weight, height, and BMI were 45.74±18.93 years, 79.72±21.80 kg, 164.74±11.53 cm, and 29.38±6.13 kg/m², respectively.

Relevant cervical vertebrae anatomy as demonstrated in Table 1, the mean PD increased significantly from the cranial to caudal vertebrae (from 4.29±0.81 mm at C3 to 5.78±1.02 mm at C7, *p*=0.0001). The TFC was significantly larger in the upper levels than in the lower levels (*p*=0001) (for example TFC measured 6.09±0.68 mm at C3 compared to 5.89±0.77 mm at C6 and 3.90±1.48 mm at C7).

The mean SCDS, which represents the anterior-posterior diameter of the spinal canal, was significantly larger in males than in females at all levels (Table 3). The SCDC, which represents the transverse diameter of the spinal canal, was significantly larger in males at C4, C5, and C6 (Table 3). However, sex differences in spinal canal measurements were not adjusted for patients' height, weight, BMI, or age.

Quantified assessment of cervical VA anatomy.

A summary of included parameters is presented in Table 1. The transverse diameter of the VA (represented in this study on the coronal view as the VADC) was significantly variable among the different levels, for example VADC measured 3.83 mm at C7 compared to 3.58 mm at C3 (*p*=0.001). This sub-millimeter difference in VA status however, could be attributed to VA pulsation difference during image acquisition. The VADC was significantly larger in males than in females

Table 1 - Patients' bone anatomy parameters at different levels of the cervical spine.

Level	C3				C4			
	Overall bilateral	Right	Left	<i>P</i> -value	Overall bilateral	Right	Left	<i>P</i> -value
TTF (mm)	6.09±0.68	6.01±0.81	6.17±0.77	0.160	5.90±0.74	5.72±0.98	6.08±0.84	0.021
LTF (mm)	5.22±0.52	5.13±0.72	5.3±0.63	0.174	5.22±0.58	5.12±0.83	5.32±0.67	0.150
PD (mm)	4.29±0.81	4.36±0.95	4.21±0.89	0.238	4.30±0.75	4.34±0.91	4.26±0.86	0.519

SD - standard deviation, TTF - transverse diameter of transverse foramen, LTF - longitudinal diameter of transverse foramen, PD - cervical pedicle diameter at the level of isthmus

Table 1 (continued) - Patients' bone anatomy parameters at different levels of the cervical spine.

Level	C5				C6				C7			
	Overall bilateral	Right	Left	<i>P</i> -value	Overall bilateral	Right	Left	<i>P</i> -value	Overall bilateral	Right	Left	<i>P</i> -value
TTF (mm)	5.81±0.76	5.66±0.97	5.94±0.97	0.108	5.89±0.77	5.82±1.1	5.94±1.1	0.610	3.90±1.48	3.81±1.6	3.98±1.8	0.486
LTF (mm)	5.50±0.75	5.43±1.0	5.57±0.89	0.424	5.82±0.77	5.75±1.1	5.87±1.1	0.618	4.08±1.14	3.96±1.4	4.21±1.6	0.374
PD (mm)	4.69±0.75	4.78±0.90	4.60±0.84	0.155	5.44±3.63	5.01±7.2	5.86±7.0	0.389	5.78±1.02	5.88±1.07	5.68±1.1	0.146

SD - standard deviation, TTF - transverse diameter of transverse foramen, LTF - longitudinal diameter of transverse foramen, PD - cervical pedicle diameter at the level of isthmus

Table 2 - Spinal canal diameter variability between males and females at different cervical spine levels.

Level	SCTD				SCLD			
	Mean±SD (mm)			P-value	Mean±SD (mm)			P-value
	All patients	Male	Female		All patients	Male	Female	
C3	23.57±1.99	23.75±1.51	23.15±2.85	0.332	14.33±1.55	14.65±1.49	13.60±1.45	0.027
C4	24.27±1.74	24.65±1.69	23.39±1.56	0.017	13.78±2.27	14.34±1.74	12.45±2.85	0.006
C5	24.97±1.72	25.44±1.57	23.87±1.59	0.002	14.0±1.88	14.58±1.79	12.81±1.47	0.002
C6	25.07±1.58	25.49±1.55	24.08±1.21	0.003	14.29±2.04	14.88±2.05	12.93±1.21	0.001
C7	24.46±1.8	24.78±1.54	23.82±2.16	0.094	14.62±1.67	14.97±1.58	13.88±1.66	0.035

SD - standard deviation, SCTD - spinal canal transverse diameter, SCLD - spinal canal longitudinal diameter

Table 3 - Patients' vertebral artery parameters at different levels of the cervical spine.

Level	C3				C4			
	Overall bilateral	Right	Left	P-value	Overall bilateral	Right	Left	P-value
TDVA (mm)	3.58±0.63	3.42±0.82	3.75±0.69	0.010	3.65±0.65	3.45±0.95	3.85±0.74	0.016
LDVA (mm)	3.30±0.62	3.15±0.88	3.46±0.63	0.020	3.38±0.56	3.22±0.90	3.54±0.56	0.029
FZ (mm)	0.98±0.25	1.01±0.34	0.95±0.32	0.397	0.95±0.27	0.93±0.31	0.96±0.34	0.659
TDVA/ TTF (%)	58.78±8.36	56.84 ±11.53	60.72 ±8.54	0.021	61.66±7.98	59.99±12.55	63.32±8.59	0.120

SD - standard deviation; TDVA - transverse diameter of vertebral artery; LDVA - longitudinal diameter of vertebral artery; FZ - Free zone (see text for definition); N/A - not applicable

Table 3 (continued) - Patients' vertebral artery parameters at different levels of the cervical spine.

Level	C5				C6				C7			
	Overall bilateral	Right	Left	P-value	Overall bilateral	Right	Left	P-value	Overall bilateral	Right	Left	P-value
TDVA (mm)	3.70±0.67	3.57±0.90	3.82±0.75	0.089	3.62±0.61	3.54±0.89	3.69±0.70	0.288	3.83±0.76	3.73±1.1	3.93±0.76	0.262
LDVA (mm)	3.59±0.63	3.51±0.92	3.68±0.67	0.226	3.66±0.70	3.57±0.97	3.74±0.76	0.236	3.75±0.76	3.59±0.99	3.89±0.82	0.039
FZ (mm)	1.16±0.63	1.04±0.41	1.27±1.2	0.218	0.99±0.41	0.94±0.29	1.05±0.71	0.313	N/A	N/A	N/A	N/A
TDVA/ TTF (%)	64.29±11.35	63.68±17.01	64.89±12.59	0.671	63.09±13.15	61.86 ±17.48	64.32±19.54	0.514	N/A	N/A	N/A	N/A

SD - standard deviation; TDVA - transverse diameter of vertebral artery; LDVA - longitudinal diameter of vertebral artery; FZ - Free zone (see text for definition); N/A - not applicable

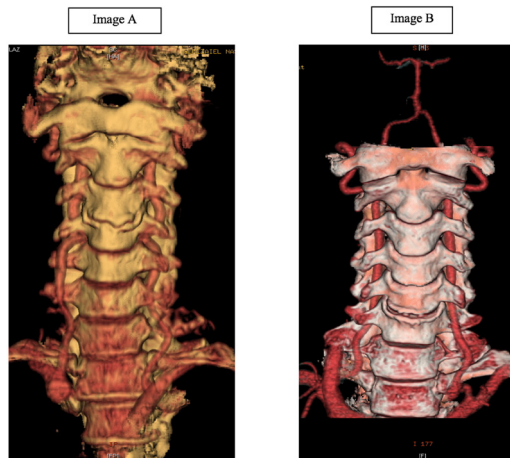


Figure 2 - Vertebral artery entry to the transverse foramina of the cervical spine at different levels within the same patients. Image A shows VA entry at C6 level on the left side and at C4 level on the right side. Image B shows another patient with VA entry at C5 level on the left side and at C6 level on the right side.

in both the right ($p=0.001$) and left sides ($p=0.005$) (Table 2). The level of VA entry into TF on the right side was mostly at C6 (92%) followed by 4% at C5, and 2% at both C4 and C7. On the left side, VA entry was mostly at C6 (94%), followed by 4% at C5, and 2% at C4. Within individual cases, VA level of entry was variable in 14% when comparing right to left sides (Figure 2A and B).

Significantly more space surrounded VA within TF in the upper cervical spine compared to lower cervical spine (VADC/TFC ratio was 58.78% at C3 vs. 63% at C6, $p=0.028$). This is probably related to the decreasing diameter of the transverse foramen (TFC) from cranial to caudal direction (Table 1). On the other hand, FZ was around 1 mm across all levels (Table 1), with no significant differences between the right and left sides (Table 3).

Correlation between patient demographic data anatomic variables. The PD was larger as the patient's

height increased; only C3, C4, and C5 demonstrated a significant correlation ($p=0.002$, 0.023 , and 0.014 respectively). On the other hand, PD did not correlate significantly with the patients' weight or BMI. The TFS and TFC increased significantly with increased patients' height at all levels ($p=0.005$ and 0.0001 for TFS and TFC respectively at C3 level; $p=0.005$ and 0.0001 for TFS and TFC, respectively, at C4 level; $p=0.008$ and 0.004 for TFS and TFC, respectively, at C5 level; $p=0.004$ for both TFS and TFC at C6 level) except for C7 level ($p=0.588$ and 0.436 , respectively).

Parameters for spinal canal diameter were smaller with advancing age; however, significant correlations were identified only for SCDS at C3 level ($p=0.025$) and SCDC at C6 level ($p=0.045$). The spinal canal diameter (both SCDC and SCDS) significantly increased with increasing patient height at all levels ($p=0.018$ for SCDC at C3 level; $p=0.0001$ and 0.047 for SCDC and SCDS, respectively, at C4 level; $p=0.0001$ and 0.023 for SCDC and SCDS, respectively, at C5 level; $p=0.001$ and 0.019 for SCDC and SCDS, respectively, at C6 level; $p=0.038$ and 0.041 for SCDC and SCDS, respectively, at C7 level) except for SCDS at C3 level ($p=0.86$). On the other hand, significant positive correlation between patient's weight and spinal canal measurements was only found for the levels of C5 ($p=0.031$) and C6 ($p=0.043$). No correlation was found between spinal canal diameter and BMI. The FZ was not related to patient's age, height, weight, or BMI.

Discussion. *Cervical pedicle diameter at the level of isthmus and FZ.* Instrumentation of the cervical spine requires precise knowledge of the patient's anatomy, inclusive geographical anatomical variations. The findings of the present study agree with those of previous studies in terms of variability in the anatomy of the cervical spine in different geographic areas.^{6,11,21-23} The PD in the current study population was smaller than that reported by western literature (4.29 mm at C3 level and 5.78 mm at C7 level vs. 4.5 mm at C3 level and 6.5 mm at C7 level).^{6,16} The PD in our study population was also smaller than that reported in the Korean publication (4.29 mm vs. 5.67 mm at C3 level).²⁴ Furthermore, the FZ, measured during CPS insertion, was smaller in the current study population than that reported in published data on western populations. For example, FZ at C6 level was 0.99 mm in the current study and 1.7 mm in western population.¹⁶ On the other hand, FZ measurement from this study was comparable to data for the Chinese population.²⁵ In addition, the current study demonstrated a higher ratio of TF occupation by the VA, from C3 to C6 level, compared to that in

published data (58.8% to 64.3% vs. 36.5% to 34.5% respectively).¹⁶ The smaller pedicle size and narrow FZ demonstrate a potentially higher risk for CPS insertion. While larger sample size may be more representative of the true measurements of cervical spine anatomy in a particular population, the current study demonstrates that knowing regional anatomic differences is essential when planning for instrumentation.

Variability in the entry of the VA into the cervical spine. Careful study of the anatomy of individual cases is necessary to avoid VA injury during anterior or posterior cervical spine instrumentation.²⁶ Variability in VA anatomy was found in the current study and in published literature.¹⁶ VA entry into the TF of the cervical spine was found mostly at the C6 level (93% of patients) in the present study and in up to 95.6% of patients in published studies.^{16, 27} However, both sides should be carefully assessed given the 14% variability in the VA entry into the TF within the same patient. The left VA was dominant in 64% of our cases, which is similar to that in published data.¹⁶

Outcome of cervical pedicle screws. Cervical pedicle screws technique was first used clinically by Abumi et al²⁸ in 1994 for cervical spine fractures. Cervical pedicle screws insertion for cervical spine fixation has several advantages and potential risks. Cervical pedicle screws fixation provides better biomechanical stability and pullout strength.³ It has a significantly higher load-to-failure resistance than LMS fixation, with a lower risk of screw loosening.⁶ However, CPS fixation is not without risks, VA injury being the most critical and life-threatening complication.²⁰ In their study of 207 pedicle screws in 64 patients, 78.5% of CPS insertions in the subaxial spine were associated with pedicle wall perforation within 2 mm.²⁹ Three of their patients had VA injury, which resulted in death in one case. In a systematic review, Yoshihara et al²⁰ reported superior biomechanical properties for CPS than LMS fixation with a higher risk of VA injury (0.15% vs. 0%, $p=0.012$).³

Relevance of patient demographic data. The PD was found to correlate with the height of the individual in our study population. Ample literature is available regarding stature estimation from bone measurements in different geographic areas in forensic literature since 1952.³⁰⁻³⁶ Many studies used CT and magnetic resonance imaging measurements.³⁷⁻³⁹ Estimation of individual's height was possible from analyzing the cervical and lumbosacral vertebrae.³⁷⁻⁴¹ Considering the current study findings, the relatively smaller measurements of the concerned anatomic bony structures could be

related to the smaller population height in this study's geographic area compared to western population.⁴²

Study limitations. The present study was limited by several factors that have to be considered when interpreting the results. The number of patients recruited may not represent the population at large. However, it brings the attention of the operating surgeons to review individual patient's characteristics and not rely only on published data. It also encourages larger studies addressing spine anatomy variability. In addition, measurement reliability was not addressed and variability could exist between different individuals. The measurement of the VA diameter could also be variable, given the variability of the arterial pulsation. However, such variability is not possible to assess using current imaging technology. The surgeon should keep such factors in mind while addressing the exact location of the VA during cervical spine surgery.

In conclusions, PD is smaller in the Saudi population than in western populations. An approximately 1 mm safety zone is available for CPS insertion in the subaxial cervical spine. The PD has a direct relationship with body height. Assessment of VA entry in each level should be performed on an individual basis, as different levels of VA entry in the same patient can occur. Further studies in different geographic areas with larger sample sizes are necessary for better assessment and guidance of cervical spine surgical procedures.

References

- Slone RM, MacMillan M, Montgomery WJ. Spinal fixation. Part 1. Principles, basic hardware, and fixation techniques for the cervical spine. *Radiographics* 1993; 13: 341-356.
- Ebraheim NA, Rupp RE, Savolaine ER, Brown JA. Posterior plating of the cervical spine. *J Spinal Disord* 1995; 8: 111-115.
- Kast E, Mohr K, Richter HP, Börm W. Complications of transpedicular screw fixation in the cervical spine. *Eur Spine J* 2006; 15: 327334.
- Fouad W, Elzawawy E. An anatomical study of the different neurosurgical approaches of the cervical spinal cord. *AJM* 2011; 47: 43-51.
- Panjabi MM, Duranceau J, Goel V, Oxland T, Takata K. Cervical human vertebrae. Quantitative three-dimensional anatomy of the middle and lower regions. *Spine* 1991; 16: 861-869.
- Jones EL, Heller JG, Silcox DH, Hutton WC. Cervical pedicle screws versus lateral mass screws: anatomic feasibility and biomechanical comparison. *Spine* 1997; 22: 977-982.
- Karaikevic EE, Daubs MD, Madsen RW, Gaines RW Jr. Morphologic characteristics of human cervical pedicles. *Spine* 1997; 22: 493-500.
- Kamimura M, Ebara S, Itoh H, Tateiwa Y, Kinoshita T, Takaoka K. Cervical pedicle screw insertion: assessment of safety and accuracy with computer-assisted image guidance. *J Spinal Disord* 2000; 13: 218-224.
- Ludwig SC, Kramer DL, Balderston RA, Vaccaro AR, Foley KE, Albert TJ. Placement of pedicle screws in the human cadaveric cervical spine: comparative accuracy of three techniques. *Spine* 2000; 25: 1655-1667.
- Tanaka N, Fujimoto Y, An HS, Ikuta Y, Yasuda M. The anatomic relation among the nerve roots, intervertebral foramina, and intervertebral discs of the cervical spine. *Spine* 2000; 25: 286-291.
- Ugur HC, Attar A, Uz A, Tekdemir I, Egemen N, Caglar S, et al. Surgical anatomic evaluation of the cervical pedicle and adjacent neural structures. *Neurosurgery* 2000; 47: 1162-1169.
- Smith MD, Emery SE, Dudley A, Murray KJ, Leventhal M. Vertebral artery injury during anterior decompression of the cervical spine. A retrospective review of ten patients. *Bone Joint J* 1993; 75: 410-415.
- Farey ID, Nadkarni S, Smith N. Modified Gallie technique versus transarticular screw fixation in C1-C2 fusion. *Clin Orthop Relat Res* 1999; 359: 126-135.
- Burke JR, Gerszten PC, Welch WC. Iatrogenic vertebral artery injury during anterior cervical spine surgery. *Spine J* 2005; 5: 508-514.
- Onibokun A, Khoo LT, Bistazzoni S, Chen NF, Sassi M. Anatomical considerations for cervical pedicle screw insertion: the use of multiplanar computerized tomography measurements in 122 consecutive clinical cases. *Spine J* 2009; 9: 729-734.
- Tomasino A, Parikh K, Koller H, Zink W, Tsiouris AJ, Steinberger J, et al. The vertebral artery and the cervical pedicle: morphometric analysis of a critical neighborhood. *J Neurosurg Spine* 2010; 13: 52-60.
- Huang D, Du K, Zeng S, Gao W, Huang L, Su P. The security analysis of transpedicular screw fixation in the lower cervical spine and a case report. *Spine* 2011; 36: E1702-E1708.
- Lang Z, Tian W, Yuan Q, He D, Yuan N, Sun Y. [Percutaneous minimally invasive pedicle screw fixation for cervical fracture using intraoperative three-dimensional fluoroscopy-based navigation]. *Zhonghua Wai Ke Za Zhi* 2015; 53: 752-756. Chinese
- Al-Habib AF, Al-Akkad S. Segmental surface referencing during intraoperative three-dimensional image-guided spine navigation: an early validation with comparison to automated referencing. *Global Spine J* 2016; 6: 765-770.
- Yoshihara H, Passias PG, Errico TJ. Screw-related complications in the subaxial cervical spine with the use of lateral mass versus cervical pedicle screws: a systematic review. *J Neurosurg Spine* 2013; 19: 614-623.
- Misenhimer GR, Peek RD, Wiltse LL, Rothman SL, Widell EH Jr. Anatomic analysis of pedicle cortical and cancellous diameter as related to screw size. *Spine* 1989; 14: 367-372.
- Liu J, Napolitano JT, Ebraheim NA. Systematic review of cervical pedicle dimensions and projections. *Spine* 2010; 35: E1373-E1380.
- Chazono M, Tanaka T, Kumagai Y, Sai T, Marumo K. Ethnic differences in pedicle and bony spinal canal dimensions calculated from computed tomography of the cervical spine: a review of the English-language literature. *Eur Spine J* 2012; 21: 1451-1458.
- Oh SH, Min WK. Analysis of cervical pedicle with reconstructed computed tomography imaging in Korean population: feasibility and surgical anatomy. *J Spinal Disord Tech* 2014; 27: E99-E103.
- Ruofu Z, Huilin Y, Xiaoyun H, Xishun H, Tiansi T, Liang C, et al. CT evaluation of cervical pedicle in a Chinese population for surgical application of transpedicular screw placement. *Surg Radiol Anat* 2008; 30: 389-396.

26. Cheung JP, Luk KD. Complications of anterior and posterior cervical spine surgery. *Asian Spine J* 2016; 10: 385-400.
27. Wakao N, Takeuchi M, Kamiya M, Aoyama M, Hirasawa A, Sato K, et al. Variance of cervical vertebral artery measured by CT angiography and its influence on C7 pedicle anatomy. *Spine* 2014; 39: 228-232.
28. Abumi K, Itoh H, Taneichi H, Kaneda K. Transpedicular screw fixation for traumatic lesions of the middle and lower cervical spine: description of the techniques and preliminary report. *J Spinal Disord* 1994; 7: 19-28.
29. Bredow J, Oppermann J, Kraus B, Schiller P, Schiffer G, Sobottke R, et al. The accuracy of 3D fluoroscopy-navigated screw insertion in the upper and subaxial cervical spine. *Eur Spine J* 2015; 24: 2967-2976.
30. Torimitsu S, Makino Y, Saitoh H, Sakuma A, Ishii N, Hayakawa M, et al. Stature estimation in Japanese cadavers based on scapular measurements using multidetector computed tomography. *Int J Legal Med* 2015; 129: 211-218.
31. Ruff CB, Holt BM, Niskanen M, Sladěk V, Berner M, Garofalo E, et al. Stature and body mass estimation from skeletal remains in the European Holocene. *Am J Phys Anthropol* 2012; 148: 601-617.
32. Mondal MK, Jana TK, Giri Jana S, Roy H. Height prediction from ulnar length in females: a study in Burdwan district of West Bengal (regression analysis). *J Clin Diagn Res* 2012; 6: 1401-1404.
33. Menezes RG, Nagesh KR, Monteiro FN, Kumar GP, Kanchan T, Uysal S, et al. Estimation of stature from the length of the sternum in South Indian females. *J Forensic Leg Med* 2011; 18: 242-245.
34. Mahakkanukrauh P, Khanpetch P, Prasitwattanseree S, Vichairat K, Troy Case D. Stature estimation from long bone lengths in a Thai population. *Forensic Sci Int* 2011; 210: 279.e1-7.
35. Dida BC, Nduka EC, Adele O. Stature estimation formulae for Nigerians. *J Forensic Sci* 2009; 54: 20-21.
36. Trotter M, Gleser GC. Estimation of stature from long bones of American Whites and Negroes. *Am J Phys Anthropol* 1952; 10: 463-514.
37. Rodríguez S, Rodríguez-Calvo MS, González A, Febrero-Bande M, Muñoz-Barús JI. Estimating height from the first and second cervical vertebrae in a Spanish population. *Leg Med* 2016; 19: 88-92.
38. Torimitsu S, Makino Y, Saitoh H, Sakuma A, Ishii N, Hayakawa M, et al. Stature estimation in Japanese cadavers based on the second cervical vertebra measured using multidetector computed tomography. *Leg Med* 2015; 17: 145-149.
39. Pelin C, Duyar I, Kayahan EM, Zagyapan R, Ağildere AM, Erar A. Body height estimation based on dimensions of sacral and coccygeal vertebrae. *J Forensic Sci* 2005; 50: JFS2004010–JFS2004014.
40. Nagesh KR, Pradeep Kumar G. Estimation of stature from vertebral column length in South Indians. *Leg Med (Tokyo)* 2006; 8: 269-272.
41. Porter AM. Estimation of body size and physique from hominin skeletal remains. *Homo* 2002; 53: 17-38.
42. Duncan MJ, Al-Hazzaa HM, Al-Nakeeb Y, Al-Sobayel HI, Abahussain NA, Musaiger AO, et al. Anthropometric and lifestyle characteristics of active and inactive Saudi and British adolescents. *Am J Hum Biol* 2014; 26: 635-642.

Ethical Consent

All manuscripts reporting the results of experimental investigations involving human subjects should include a statement confirming that informed consent was obtained from each subject or subject's guardian, after receiving approval of the experimental protocol by a local human ethics committee, or institutional review board. When reporting experiments on animals, authors should indicate whether the institutional and national guide for the care and use of laboratory animals was followed.