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Subaxial Cervical Pedicular Screw Insertion via the Nonanatomic Axis: Identification of Entry Point and Trajectory Based on a Radiographic Study and Workshop

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Abstract

Study Design: A radiological study and workshop.

Objective: To propose a novel technique for subaxial cervical pedicle screw (CPS) insertion via the nonanatomic axis (nAA) and identify a new entry point (EP) and trajectory based on a radiological study.

Methods: The new EP was determined to be the center of the upper half of the lateral mass, and the nAA was defined as the line connecting the EP and center of the pedicle. CT images of 493 subaxial cervical pedicles from 51 adults were utilized. The pedicle axis length (PAL/nPAL), pedicle transverse angle (PTA/nPTA), sagittal and transverse pedicle screw depth ratio (S-DO, T-DO), and sagittal and transverse angles (S-angle, T-angle) were measured in the anatomical axis (AA) and nAA. nAA-CPS insertions were conducted on dry specimens, and the positions of the screws were graded.

Results: The nPTA (22.35° $\pm$ 1.57°), nPAL (23.75 $\pm$ 2.07 mm), T-DO (45.61% $\pm$ 3.10%), and S-DO (70.46% $\pm$ 4.44%) of the nAA-CPS were significantly different from the PTA (41.86° $\pm$ 2.77°), PAL (31.98 $\pm$ 2.40 mm), T-DO and S-DO of the AA-CPS (both 100% in ideal conditions), respectively ($P < .05$). The T-angle and S-angle were 92.78° $\pm$ 3.07° and 92.18° $\pm$ 3.78°, respectively. A constant EP and consistent trajectory of the nAA-CPS identified by 2 perpendicular angles were summarized and utilized as the manipulation protocols of the workshop, and a perfect position was achieved in 80.00% (24/30) of screws.

Conclusion: The nAA-CPS is a novel alternative to the classic CPS technique. A constant entry point and 2 perpendicular angles in the sagittal and transverse planes for identifying the trajectory of the nAA-CPS should be taken into account in the establishment of a manipulation protocol.

Keywords
cervical spine, radiology, pedicle screw, trajectory, workshop

Introduction

Rigid internal fixation is mandatory for the treatment of instability in the subaxial cervical spine due to multiple etiologies, such as trauma, tumor, compressive decompression and so on. Abumi et al[1] first proposed the cervical pedicle screw (CPS) technique in subaxial segments. CPS has proven to be superior to any other posterior cervical instruments in terms of mechanical strength.[2,3] However, the risk of malposition of the CPS technique is higher than that of pedicle screw insertion in the thoracic or lumbar spine region, and the precise insertion of CPSs is technically demanding, as the size of the cervical pedicle is much smaller than other spinal regions in any dimension.

The 3-dimensional anatomy of the cervical pedicle should be thoroughly understood by surgeons before clinical practice

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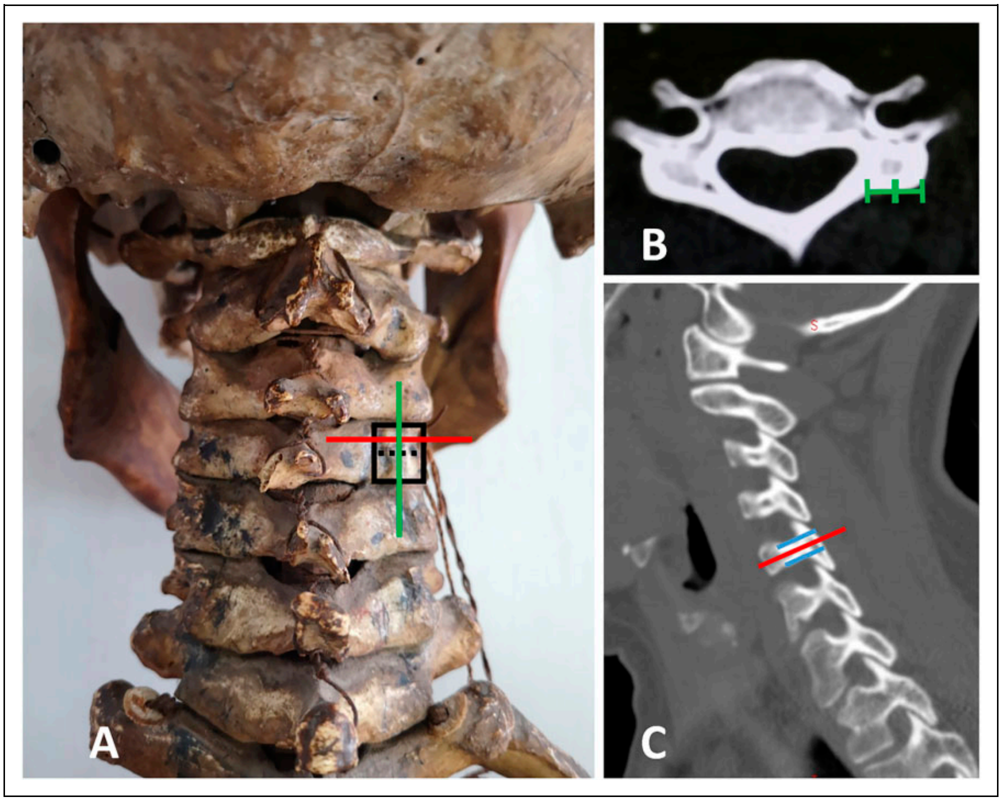

Figure 1. Design of the entry point. A, The EP is marked on a dried cervical vertebrae specimen: the green line is the longitudinal midline of the lateral mass (borders outlined by black lines), and the red line is the horizontal line that bisects the upper half of the lateral mass. B, The EP is located at the midpoint of the lateral mass width (transverse plane of C5 vertebra on CT scan). C, Determination of the horizontal coordinate of the EP on the paramedian sagittal plane of C5: the blue lines are the upper and lower borders of the pedicle, and the red line is the pedicular axis in the sagittal view.

of CPS technique. Morphologically, subaxial cervical pedicles have been studied in detail by imaging or cadaveric measurements,[4-11] in which parameters related to the CPS technique have been reported and analyzed. Notably, the convergence angle of the CPS in the transverse plane is much larger than those of the thoracic and lumbar vertebrae. Onibokun et al[5] measured 610 vertebrae of C3–C7 in 122 patients, and the convergence angle of the pedicular anatomical axis ranged from 37.8° to 45.3°. A large convergence of the CPS imposes difficulty in the course of screw canal preparation, as the convergence of instruments for canal preparation is frequently interfered with by abundant posterior cervical muscles, according to our previous practice. As a result of the decreased convergence angle, malposition of the CPS is more likely to violate the foramina transversaria (laterally) instead of the spinal canal (medially). Hojo et al[12] evaluated 1065 CPSs and found an overall malposition rate of 14.8% (158/1065), of which 79.7% (126/158) were laterally placed.

Aiming to overcome the difficulty of the CPS technique mentioned above, we designed a protocol shifting the entry point (EP) more medially than the traditional CPS protocol, resulting in screw insertion via the nonanatomic axis (nAA) of the pedicle instead of the anatomical axis (AA). We hypothesized that the nAA-CPS technique would lessen the interference from muscles to instruments during screw canal preparation. The purpose of the present study is to propose the concept of the nAA-CPS technique, provide parameters related to the novel technique by performing a radiological study, and summarize the key manipulative procedures by performing a workshop.

Material and Methods

The study was approved by the ethics committee of the Army Medical Center of PLA (IRB approval number: 2 019 115) and was conducted according to the principles of the Declaration of Helsinki. Besides, it was registered in the Chinese Clinical Trial Registry (Registration number: ChiCTR2000033821).

Design of Entry Point

Intentionally, the EP of the nAA-CPS technique was moved medially on the longitudinal midline of the lateral mass compared with the traditional CPS technique (Figure 1A, B). The horizontal line was determined on the paramedian sagittal plane of the CT scan (Figure 1C) in the location that the pedicular axis projects to on the posterior surface of the lateral mass, usually the transverse midline of the upper half of the lateral mass. Therefore, the EP was established as the center of the upper half of the lateral mass.

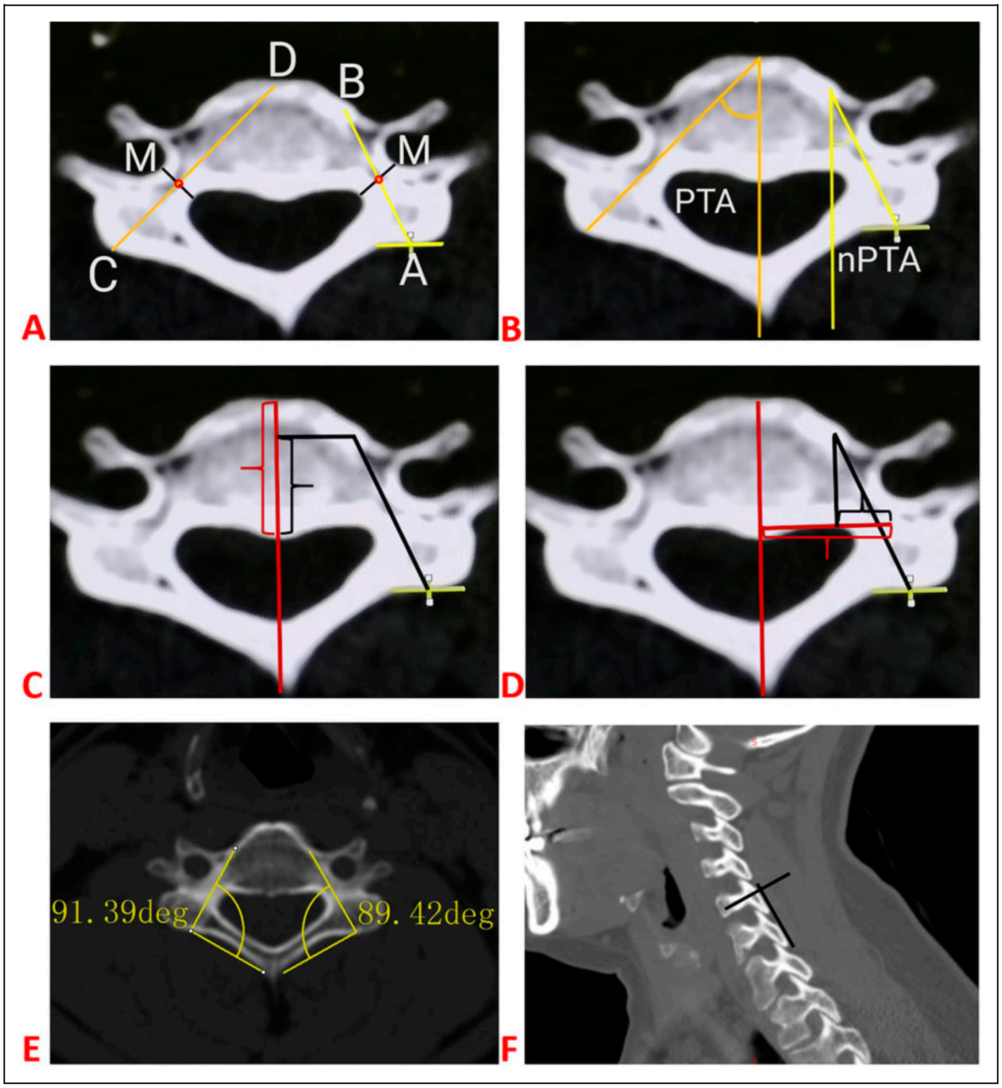

Figure 2. Illumination of the parameters measured on a CT scan. A, The distances from the EP to the anterior border of the vertebral body via the AA (PAL) or nAA (nPAL): A point is the EP of the nAA and M point is the midpoint of the pedicle. A, B are the distance of the nAA (nPAL); C, D are the traditional CPS length via the AA (PAL). B, The angle between the midline of the vertebral body and the AA (PTA) or nAA (nPTA): the orange angle (PTA) is the angle between the midline of the vertebral body and pedicle axis projection and the yellow angle (nPTA) as the angle between the midline of the vertebral body and the nAA pedicle axis projection. C, Sagittal pedicle screw depth ratio (S-DO): the ratio of the pedicle screw length within the vertebral body to the sagittal vertebral length. D, Transverse pedicle screw depth ratio (T-DO): the ratio of the projected width of the screw within the vertebral body to half of the vertebral body width in the coronal view. E, T-angle: the angle between the nAA and the line connecting the EP and the conjunction of the ipsilateral lamina and spinal process in the transverse plane of the C5 vertebra. F, S-angle: the angle between the nAA and tangent line of the posterior surface of the lateral mass and the inferior one in the paramedian sagittal plane of the C5 vertebra.

Definition of the nAA of the Subaxial Cervical Pedicle

The midpoint of the pedicle was determined at its narrowest part in the transverse plane (Figure 2A). The nAA was defined as the line connecting the EP mentioned above and the midpoint of the pedicle (Figure 2A).

Parameters Measurement Based on CT

Patients who underwent cervical CT scans (Brilliance iCT, Philips, Netherlands) in Daping Hospital from July 1, 2020, to July 15, 2020, were included in the primary scope of the study, and CT image data of 61 patients was acquired using 1.0-mm thick slice cuts. After thorough interpretations by a radiologist and spine surgeon, those with a tumor (1), trauma (6) and congenital abnormality (3) were excluded. Ultimately, data from 51 patients was included in the final analysis.

A total of 493 subaxial cervical pedicles in 51 patients (27 males and 24 females, age ranging from 24 to 65 years) were enrolled in the final analysis. A total of 17 pedicles were excluded from measurement due to having a diameter less than 3 mm, which meant they were unsuitable for the CPS technique.

The following parameters were measured on the PACS system (Huahai Medical information corp, Xian, China) by 2 spine surgeons:

Pedicle axis length (PAL): the distance from the EP to the anterior border of the vertebral body via the AA (PAL) or nAA (nPAL) (Figure 2A).

Pedicle transverse angle (PTA): the angle between the midline of the vertebral body and the AA (PTA) or nAA (nPTA) (Figure 2B).

Sagittal pedicle screw depth ratio (S-DO) and transverse pedicle screw depth ratio (T-DO): the ratio of the pedicle screw length within the vertebral body to the sagittal vertebral length, and the ratio of the projected width of the screw within the vertebral body to half of the vertebral body width. The purpose of these 2 parameters were to evaluate the proper pedicle screw depth in the sagittal plane and width in the coronal plane (Figure 2C, D).

Transverse angle (T-angle) and sagittal angle (S-angle): the angle between the nAA and the line connecting the EP and ipsilateral conjunction of the lamina and spinal process or the tangent line of the posterior surface of the lateral mass and inferior one (Figure 2E, F).

Workshop of nAA-CPS With Dried Cervical Spine Specimens

Three sets of the dried bone specimens utilized for the nAA-CPS workshop by one spine surgeon educated on the related rationale for the novel technique were all intact bones, including the skull, spine, pelvis and limbs, and the spine was assembled according to the physiological curvature. The workshop was carried out in the operating room where the specimen is placed in a prone position on a foam cushion with corresponding grooves in which the head and chest are wrapped. To simulate the real posterior cervical spine surgery process, the lateral structure of the cervical spine was covered by the cushion, thus, only the posterior structure of the lower cervical spine (C3–C7) could be seen by the surgeon and the lateral structure of the vertebral pedicle was invisible. The EP was identified and marked according to the measures described above. A burr was used to open a hole of 2 mm in diameter on the cortical surface of the EP, followed by insertion of an awl into the vertebral body the via nAA, with the trajectory determined by the T-angle and S-angle. A CPS with a diameter of 3.5 mm was inserted if the screw canal preparation was successful based on palpation with the probe; otherwise, screw insertion was given up and defined as failed.

The final position of the nAA-CPS was evaluated by gross observation and a CT scan. The grading system of pedicle perforation was as follows: grade 0 was defined when the entire screw was placed within the cortical bone of the pedicle, grade 1 was defined as less than 25% of screw diameter violation, grade 2 was defined as 25% to 50% of screw diameter violation, and grade 3 was defined as more than 50% of screw diameter violation.[13] For analysis of the results, grades 0 and 1 were considered to be correct positions, whereas grades 2 and 3 were considered to be malposition.

Statistical Analysis

All the parameters are presented as the mean and standard deviation. The paired t test was used to analyze changes in the numerical parameters within one vertebra. Student's t test was used to compare the overall means between 2 measured parameters. The nPTA and PTA between C3 and C7 were compared by one-way ANOVA analysis. The SPSS version 19.0 software (IBM Corporation, Armonk, NY) was used for statistical analysis. A P value less than .05 was considered statistically significant.

Results

Parameters of nAA-CPS and AA-CPS Measured on CT

The parameters are summarized in Table 1, Figure 2 and Supplementary Table 1. The nPTA (22.35° ± 1.57°) and nPAL (23.75 ± 2.07 mm) were significantly different from the PTA (41.86° ± 2.77°) and PAL (31.98 ± 2.40 mm), respectively ($P < .05$), regardless of the segment distribution in the subaxial cervical spine, gender, and right/left sides (Tables 1 and 2, Supplementary Tables 1 and 2). All the parameters of the nAA-CPS showed no statistically significant differences in gender or right/left sides ($P < .05$), except the nPAL of males was significantly larger than that of females ($P < .05$) (Supplementary Table 3). The nPTA increased gradually from C7

Table 1. Parameters of the nAA-CPS and AA-CPS.

Parameters	C3	C4	C5	C6	C7	C3–C7
nPAL (mm)	22.22 ± 1.41	22.73 ± 1.42	23.64 ± 1.48	24.36 ± 1.47	25.89 ± 2.20	23.75 ± 2.07
nPTA (°)	22.79 ± 1.56	22.98 ± 1.42	22.78 ± 1.29	22.12 ± 1.32	21.06 ± 1.44	22.35 ± 1.57
T-angle (°)	92.09 ± 1.97	91.31 ± 2.06	91.10 ± 1.96	92.68 ± 2.49	96.79 ± 2.76	92.78 ± 3.07
S-angle (°)	97.44 ± 3.91	92.51 ± 2.98	90.20 ± 1.85	90.06 ± 1.63	90.60 ± 1.60	92.18 ± 3.78
S-DO (%)	67.58 ± 4.80	69.77 ± 4.06	70.01 ± 3.72	71.36 ± 3.96	73.66 ± 3.19	70.46 ± 4.44
T-DO (%)	44.43 ± 3.06	44.98 ± 2.20	45.34 ± 2.78	45.39 ± 2.80	47.93 ± 3.39	45.61 ± 3.10
PAL (mm)	30.25 ± 1.82	30.75 ± 2.05	32.02 ± 1.97	33.07 ± 1.99	33.92 ± 2.05	31.98 ± 2.40
PTA (°)	43.94 ± 1.84	43.37 ± 1.69	42.51 ± 2.00	41.25 ± 2.16	38.15 ± 1.60	41.86 ± 2.77

Abbreviations: nPAL, nonanatomic pedicle axis length; nPTA, nonanatomic pedicle transverse angle; T-angle, transverse angle; S-angle, sagittal angle; S-DO, sagittal pedicle screw depth ratio; T-DO, transverse pedicle screw depth ratio; PAL, pedicle axis length; PTA, pedicle transverse angle.

Table 2. Comparison of the PAL/PTA and nPAL/nPTA Among Segments of C3 to C7.

Level	PAL	nPAL	t	P[a]	PTA	nPTA	t	P[a]
C3	30.25 ± 1.82	22.22 ± 1.41	47.326	< .001	43.94 ± 1.84	22.79 ± 1.56	95.459	< .001
C4	30.75 ± 2.05	22.73 ± 1.42	39.567	< .001	43.37 ± 1.69	22.98 ± 1.42	92.73	< .001
C5	32.02 ± 1.97	23.64 ± 1.48	55.746	< .001	42.51 ± 2.00	22.78 ± 1.29	94.594	< .001
C6	33.07 ± 1.99	24.36 ± 1.47	54.156	< .001	41.25 ± 2.16	22.12 ± 1.32	86.912	< .001
C7	33.92 ± 2.05	25.89 ± 2.20	37.72	< .001	38.15 ± 1.60	21.06 ± 1.44	95.05	< .001

Abbreviations: PAL, pedicle axis length; nPAL, nonanatomic pedicle axis length; PTA, pedicle transverse angle; nPTA, nonanatomic pedicle transverse angle.
[a]Statistically significant *P* values ($P < .05$).

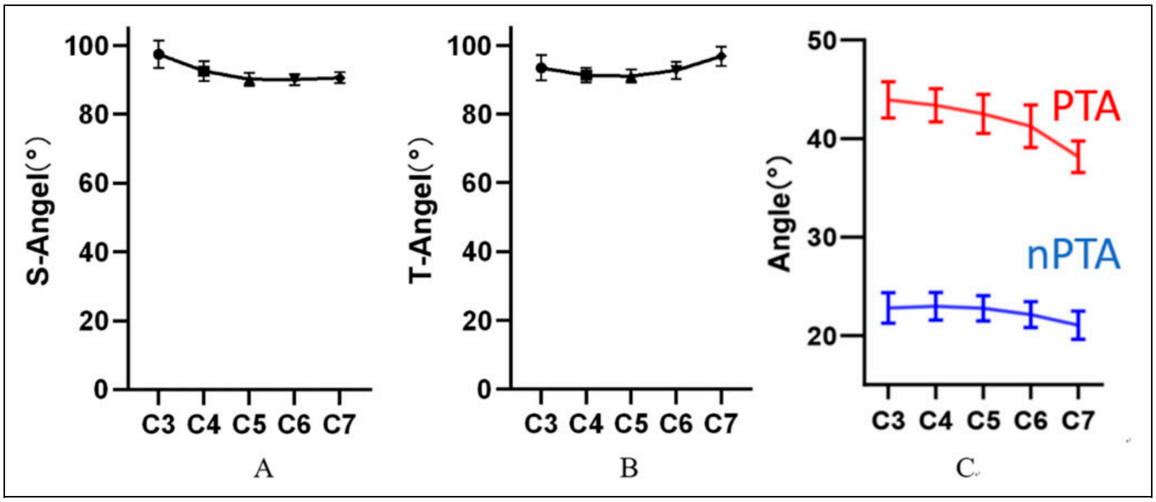

Figure 3. Parameters for determining the trajectory of the nAA-CPS. A and B, Both the S-angle and T-angle are nearly 90 degrees in the range of C3 to C7. C, Segmental difference between the nPTA and PTA. As the curves show, the nPTA had smaller changes among segments than the PTA.

(21.06° ± 1.44°) to C3 (22.79° ± 1.56°), while the nPAL decreased from C7 (25.89 ± 2.20 mm) to C3 (22.22 ± 1.41 mm). Similarly, the T-DO (45.61% ± 3.10%) and S-DO (70.46% ± 4.44%) of the nAA-CPS were significantly different from those of the AA-CPS (both were 100% in ideal conditions) ($P < .05$). This result suggests that the tips of the nAA-CPS should be located at 3/4 length of the vertebral body in the lateral view and 1/4 width of the vertebral body in the AP view.

The T-angle and S-angle were 92.78° ± 3.07° and 92.18° ± 3.78°, respectively. Both angles were closed to 90°, which provided a relatively constant spatial orientation during trajectory determination. The maximum of the S-angle was located in the C3 (97.44° ± 3.91°) segment, while the maximum of the T-angle was located in the C7 (96.79° ± 2.76°) segment (Figure 3A, B). Moreover, Segmental difference between the nPTA and PTA shows that the nPTA had smaller changes among segments than the PTA (Figure 3C).

Evaluation of nAA-CPS Position According to the Workshop

Based on the aforementioned information, a constant EP and a relatively consistent trajectory of the nAA-CPS identified by 2 perpendicular angles were summarized as the rationale for the novel technique. Following the protocol, the preparation of 30 screw canals was repeated, and all but one (which leaked laterally) were successful. Ultimately, 29 nAA-CPS were implanted. On the whole, perfect positioning (grade 0 and 1) of the screw under lateral fluoroscopic guidance was acquired in 80.00% (24/30) of planned screws. The malposition rate was 20.00% (5/30). As to the direction of screw malposition, 60.00% (3/5) of the malpositioned screws were laterally placed (including the one with failed canal preparation) and 40.00% (2/5) were medially placed.

Discussion

There have been some reports on the methods of subaxial CPS placement,[1,10,14-27] but to our knowledge, this is the first radiological and workshop report on CPS insertion via the nAA. As the EP, length of the screw, and sagittal and transverse trajectory angles are concerned, the nAA-CPS technique is technically different from the classic CPS technique proposed by Abumi. Therefore, the nAA-CPS could be regarded as a novel alternative to the traditional CPS technique.

Before application of the nAA-CPS technique, the principle of design should be thoroughly interpreted. The EP is determined subjectively in the transverse plane and objectively in the sagittal plane. The aim of moving the EP medially is to decrease the convergence angle of the screw in the transverse plane, and the sagittal axis of the pedicle determines the location of the EP in this plane. Interestingly, the EP of the nAA-CPS technique was eventually located at the center of the upper half of the lateral mass, which is easily identified in posterior cervical surgery. The nAA-CPS is established based on the EP because the midpoint of the pedicle in the narrowest part should be crossed in any pedicle screw placement technique. The radiological study showed that the convergence angle of the nAA-CPS was significantly smaller than that of the AA-CPS, suggesting that the aim of the novel technique had been achieved.

In any spine region, the trajectory of the pedicle screw changes accordingly with the alternation of EP selection. Therefore, the orientation of the nAA-CPS needs to be determined by an anatomical or a radiological study. We reported that the nPTA ranged from 22.79 $\pm$ 1.56° at C3 to 21.06 $\pm$ 1.44° at C7, which was relatively constant regardless of the segment. However, the angle did not provide much help in precisely identifying the trajectory in the performance of the freehand technique. Extensive studies have focused on searching for consistent anatomic landmarks as references for the determination of the AA-CPS trajectory. Hacker et al[28] employed the contralateral lamina as a reliable guide for CPS placement via the AA, as they found that the axis of the pedicle in the transverse plane was almost always parallel with the contralateral lamina. Bayley et al[18] reported that the angle between the ipsilateral lamina and axis of the pedicle was in the transverse plane and found that the angle formed by the posterior cortex of the lamina and ipsilateral pedicle showed a high level of consistency ranging from 96° to 87°, suggesting that the orientation of the lamina forms a useful reference plane for classical CPS insertion. In our study, we found that the line connecting the EP and conjunction of the lamina and spinal process was almost perpendicular to the nAA of the pedicle in the transverse plane (T-angle with an average value of 92°). Therefore, the aforementioned line could be used as a reference for the determination of the transverse angle of the nAA-CPS. Yan et al[14] found that in the sagittal position, the ipsilateral lamina and superior and inferior lamina connections are perpendicular to the sagittal axis of the pedicle, which is consistent with our findings, despite us choosing the connection between the posterior surface of the ipsilateral lateral mass and the inferior one. Based on the results of the radiological study, we summarized the protocol for the nAA-CPS freehand technique as "one constant EP and 2 perpendicular angles for trajectory determination" with consistent anatomic landmarks from the posterior view of the subaxial cervical spine. The subsequent workshop results showed that the protocol was fairly useful in determining the orientation of the nAA-CPS, and the rate of correct screw positions was comparable with those of the AA-CPS, suggesting the nAA-CPS is feasible in the consideration of technical safety and uniformity.

The novel technique proposed by the present study has several potential advantages. Firstly, the nPTA is much smaller than the PTA, suggesting less interference between the soft tissue and the tools required for screw canal preparation. Secondly, the nPTA was relatively constant in the range of C3 to C7, which is different from the PTA, which has a significant segmental difference (from 37.8° to 45.3°).[5] Thirdly, a constant EP for C3–C7 could be easily identified in a posterior cervical spine surgical view. Fourthly, 2 relatively consistent angles of 90° could be used to identify the trajectory of the nAA-CPS in the sagittal and transverse planes, which provided remarkable information during the manipulation. The process of nAA-CPS placement was simplified and standardized by the protocol of "one constant EP and 2 perpendicular angles," according to our radiological data and the preliminary results of the workshop. Fifthly, the lateral half of the lateral mass was intact, even if the screw canal preparation fails, which means alternation from the CPS to lateral mass screw is feasible. Sixthly, as the convergence of the nAA-CPS was small, extensive corpectomy and anterior instrumentation would not be bothered by the tips of the pedicle screws.

There are several limitations in this study. Firstly, the safety of the novel technique may require a pedicular diameter of more than 4.5 mm as a precondition, while Abumi et al[29] suggested 4 mm as a basic demand for the classic CPS technique. This requirement suggests that the novel technique has a relatively limited scope of application compared to the classic technique. Secondly, the spinal process and lateral mass are important anatomic landmarks for identifying the EP and trajectory determination. Deformity, absence or destruction of one or both structures due to fracture, dislocation, or previous laminectomy would impose difficulty in manipulation. Thirdly, the convergence angle of the novel technique is significantly less than that of the classic one, aiming to lessen the interference from muscles. However, as the workshop was performed on dried bone specimens, the effect of a decreased convergence angle needs to be proved in cadaveric workshops or clinical practice. Fourthly, the shortening of the screw length may have an impact on the biomechanical strength. Considering that the pedicle is the most essential part of the biomechanical strength of the screw, compared with the traditional CPS technique, the reduced part of screw inserted via the nonanatomic axis is mainly located in the cancellous bone. Thus, we may infer that the mechanical strength of the 2 is not much different and intend to do further research to clarify the mechanical difference.

Conclusions

CPS placement via the nAA is a novel alternative to the traditional technique, which inserts screws via the AA. A constant EP and 2 perpendicular angles in the sagittal and transverse planes for identifying the trajectory of the nAA-CPS, could be taken into consideration in the establishment of a manipulation protocol.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Supplemental Material

Supplemental material for this article is available online.

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