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Accuracy and Safety of Lateral Vertebral Notch-Referred Technique Used in Subaxial Cervical Pedicle Screw Placement

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BACKGROUND: Biomechanical studies revealed that pedicle screw instrumentation has a superior stabilizing effect compared with other internal fixations in reconstructing the subaxial cervical spine. However, severe neurovascular risks preclude surgeons from routinely conducting pedicle screw manipulation in cervical spine.

OBJECTIVE: To evaluate the accuracy and safety of the lateral vertebral notch (LVN)-referred technique used in subaxial cervical pedicle screw (CPS) placement.

METHODS: One hundred thirty-five consecutive retrospective patients with cervical disorders underwent the LVN-referred technique for CPS placements in 3 spine centers. Postoperative pedicle perforations were confirmed by CT scans to assess the technical accuracy. Neurovascular complications derived from CPS misplacements were recorded to evaluate the technical safety.

RESULTS: A total of 718 CPSs were inserted into subaxial cervical spine. Postoperative CT scans revealed that the accuracy of CPS placement was superior. Neither vertebral artery injury nor spinal cord injury occurred. One radiculopathy was from a unilateral C6 nerve root compression. A screw-related neurovascular injury rate of 0.7% occurred in this cohort. Additionally, there was no significant difference in the accuracy of CPS placement among 3 surgeons ($H = 1.460$, $P = .482$). The relative standard deviation values revealed that technical reproducibility was acceptable. Furthermore, there was no significant difference between the patients' pedicle transverse angles and inserted CPS transverse angles from C3 to C7 (all $P > .05$).

CONCLUSION: The LVN is a reliable and consistent anatomic landmark for CPS placement. The accuracy and safety of subaxial CPS placement by using LVN-referred technique are highly acceptable, which may endow this technique to be practicably performed in selected patients.

KEY WORDS: Lateral vertebral notch, Accuracy and safety, Subaxial cervical spine, Pedicle screw

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Pedicle screw (PS) biomechanical instrumentation has been commonly considered to have a superior effect for stabilizing spine and has revolutionized surgical treatment of spinal disorders.[1] Compared with other instrumentations such as lateral mass screw or translaminar screw, cervical PS (CPS) has a significantly lower loosening rate at the bone–screw interface, an increased load sharing, and a higher anti-fatigue strength.[2-4] Thus, CPS instrumentation could contribute to reconstruct cervical spine in particular clinical scenarios such as cervical vertebral tumor, deformity, and severe trauma.[5-8] However, despite its biomechanical benefits, the risks of potential neurovascular complications, including injuries of the vertebral artery, cervical cord, and nerve root due to CPS perforation, still preclude surgeons from wide implementation of CPS placement.[9,10] Hence, the safety and accuracy of CPS placement needs further improvement.

ABBREVIATIONS: CPS, cervical pedicle screw; **CT,** computed tomography; **LVN,** lateral vertebral notch; **MRI,** magnetic resonance image; **PS,** pedicle screw; **PTA,** pedicle transverse angle; **RSD,** relative standard deviation; **STA,** screw transverse angle

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To date, various techniques have been developed to improve the accuracy of CPS placement. As a whole, navigation systems could improve operative accuracy, but several cadaveric studies have revealed a high perforation rate in CPS placement and showed unstable perforation rates ranging from 1% to 20%.[11-13] Moreover, navigation systems are too expensive to be extensively afforded, especially in developing areas; also they are associated with more radiation exposure and time-consuming operations.[14,15] Other CPS fixation techniques such as computed tomography (CT) cutout technique[16] and screw-guide template technique,[17] were also reported to provide a high accuracy of CPS placement, but both need material preparation and configuration before surgery, and are not immediately available in emergent cervical surgery. On the basis of the non-freehand techniques' disadvantages above, the freehand techniques of CPS placement are still prevalent.

Currently, variations in anatomic landmarks referring to CPS placement and individual cognitive differences from landmarks among different surgeons have led to inadequate screw accuracies in freehand CPS techniques, which was identified as lacking a consistent entry point for CPS placement.[18-20] In our preclinical study, we found that the lateral vertebral notch (LVN) could be an anatomic landmark for an entry point on cadaveric specimens, and was consistently at a convergence point between cervical pedicle lateral wall and transitional point from superior articular processes to inferior articular processes in subaxial cervical spine (Figure 1).[21] In our radiological study,[22] the LVN was defined as the most medial part of the ridge of pars interarticularis located on the lateral mass, and was consistently detectable on the coronal multiplane reconstruction images of a CT scan (Figure 2A and 2B). Inspired by this consistent anatomic landmark, the LVN, we developed an innovative technique for subaxial CPS placement. In this study, we aimed to evaluate the accuracy and safety of the LVN-referred technique used in subaxial CPS placements.

METHODS

Surgeries and data collections were performed from October 2014 to December 2016 at 3 spine centers in this retrospective study. With 718 CPS immobilizations, 135 consecutive patients underwent posterior-only or anteroposterior-combined approaches. To decrease surgical heterogeneity, all CPS were placed by 3 experienced spine surgeons with consistent procedures. Patient demographics and etiologies are summarized in Table 1. Patients who suffered cervical fracture/dislocation, kyphosis, tumor, or revisional surgery were included if they underwent the LVN-referred technique in the subaxial cervical spine. Exclusion criteria were patients with an unrecognizable cervical LVN or those who underwent other kinds of CPS placements. This study was approved by 3 institutional Ethics Committees; written informed consents were obtained from eligible patients, and the study was designed to conform to the Declaration of Helsinki.

Study Design

Pre- and postoperative cervical scans from X-ray, CT, and magnetic resonance image (MRI) were performed on all patients. Multiplanar reformation was conducted in case of adjacent structures (such as pedicle and LVN) that were unavailable to be clearly co-delineated on a slice of a CT scan (1 mm interval, Somatom Definition AS, Siemens, Germany). On the basis of the landmark of LVN, pedicle transverse angle (PTA, mediolateral angulation) and cephalocaudal angle were measured on CT images for the trajectory of CPS placement. Transverse angles of the CPS and pedicle were measured for comparison on the axial plane

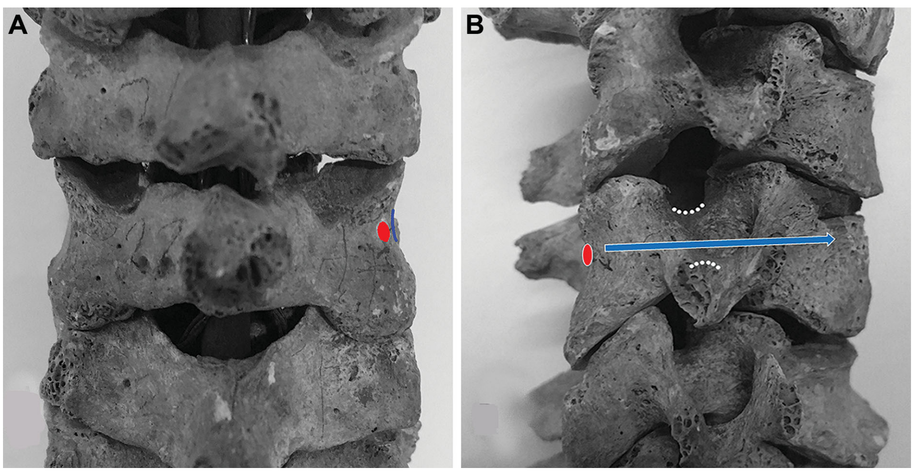

FIGURE 1. *Landmarks on cadaveric vertebra.* **A**, *Viewed posteriorly, the red dot is the right pedicle screw entry point of C4, where it is slightly medial and caudal to LVN (blue arc).* **B**, *Laterally, pedicle screw trajectory (blue arrow) would pass through the C4 pedicle longitude axis between the upper and lower white dotted arc (the upper and lower edges of pedicle).*

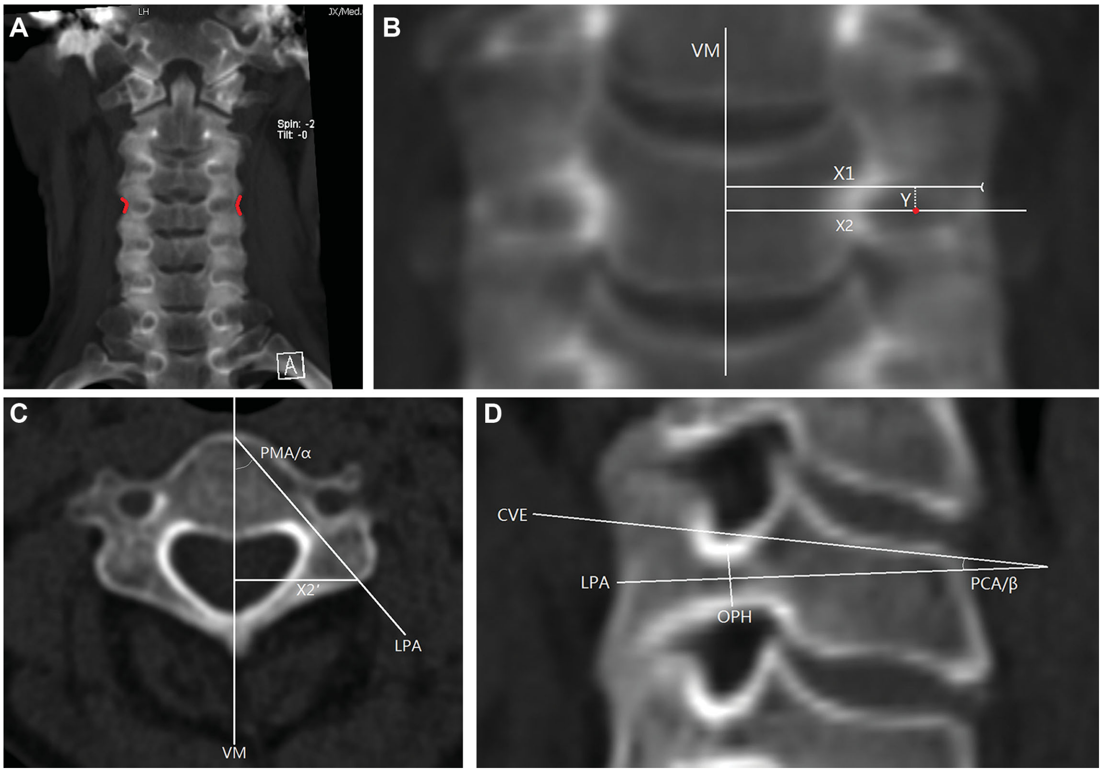

FIGURE 2. *CT images for guiding surgery.* **A**, *The coronal multiplane reconstruction image (CMRI) of the CT scan clearly showed each lateral vertebral notch (LVN) from C3 to C7 (bilateral C4 LVN were marked by red arcs).* **B**, *X1 was the mediolateral distance from the vertebral midline (VM) to the LVN on the CMRI. Line Y was the craniocaudal distance from the pedicle projection center (red dot) to X1.* **C**, *X2' was the mediolateral distance from the VM to the point of the pedicle axis crossing the surface of the vertebral mass. Therefore, the mediolateral distance X from the LVN to the CPS entry point (red dot in Figure B) could be countered according to the formula, X = X1 − X2'. The pedicle transverse angle (PMA/α) was the angle between VM and the longitudinal pedicle axis (LPA) in the axial plane.* **D**, *Pedicle cephalocaudal angle (PCA/β) was the angle between the cranial vertebral endplate (CVE) and the longitude pedicle axis (LPA) in the sagittal plane. LPA is perpendicular to the outer pedicle height (OPH).*

TABLE 1. Patient Demographics and Etiology

Characteristics	Quantity (135 patients)
Age (yr)	43.6 ± 10.8
Gender	
Male	87 (64.4%)
Female	48 (35.6%)
Etiology	
Fractures/dislocation	94 (69.6%)
Kyphosis	20 (14.8%)
Tumor	13 (9.6%)
Revisional surgery	8 (5.9%)

(**Figure**, **Supplemental Digital Content 1**), which was a mediolateral angulation between the line perpendicular to the posterior wall of the vertebral body and the line through the pedicle axis (Figure 2C). Cephalocaudal angulation was the sagittal angle between the line parallel to the upper endplate of the vertebral body and the line through the pedicle axis (Figure 2D).

Postoperative CPS positions were confirmed by CT scans. To control the confounding bias of assessments, 3 fellows who did not join the surgery measured each parameter twice and took a mean value. The extents of CPS penetrating pedicle cortex were classified into 4 grades according to the following definitions indicating the positions of CPS from excellent, to good, to fair, and to poor.

Grade 0: The screw without penetrating the pedicle cortex was considered to be in an excellent position.

Grade I: The screw penetrating cortex between 1% and 24% of the screw diameter was considered to be in a good position.

Grade II: The screw penetrating cortex between 25% and 49% of the screw diameter was considered to be in a fair position.

Grade III: The screw penetrating cortex of more than 49% of the screw diameter was considered to be in a poor position.

In addition, intra- and postoperative screw-related neurovascular complications were recorded to assess the safety of the LVN-referred technique and followed-up for 1 mo.

Surgical Technique and Operative Parameters

After general anesthesia, severe cervical fracture/dislocation patients were prone-positioned with 5 kg Gardner-Well tongs pulled horizontally to stabilize the injured cervical spine. Nonfracture/dislocation patients were prone-positioned in a Concorde position, and the head was fixed with a Mayfield clamp. A posterior midline incision was made, and paravertebral muscles were dissected laterally to expose lateral margins of the involved segments. The capsules had been preserved and were exposed to the LVN for determining the entry point of the CPS. Referring to our previous radiological and cadaveric studies,[21,22] the entry point of the CPS to the LVN is almost consistent with a value of approximately 2.2 mm (from 2.1 to 2.3 mm) medial to the LVN from C3 to C7 and 1.4 mm (1.2 to 1.7 mm) caudal to the LVN from C3 to C6 but 1.2 mm cephalad to the LVN at C7 (Figure 2B). Therefore, generally, the CPS entry point is slightly medial and caudal to the LVN from C3 to C6, except for C7, and is nearly the same as the start point of the longitude pedicle axis on the sagittal plane (Figure 2D). The transverse angle of the CPS placement gradually decreases from C3 to C7 on the axial plane, while the cephalocaudal inclination of CPS placement should be vertical to the posterior wall of the lateral mass. Following this, a pilot hole was made by a 4-mm diameter high-speed burr, a 2.5-mm pedicle probe was used to find the track through the pilot hole, and the probing depth was usually less than 20 mm. A ball-tipped feeler was used to palpate if there was a perforation through the pedicle wall after probing. A CPS was then inserted with a 3.5-mm diameter into the pedicle track, and it was noted that the screw placement was no less than two-thirds of the anteroposterior vertebral body depth. More procedures can be viewed in **Video**, **Supplemental Digital Content 2** and Figure 3. The management of postoperative pain and the employment of a cervical collar were regularly conducted for each patient.

Statistical Analysis

The software package SPSS Statistics 19 (IBM, Armonk, New York) was used for statistical analysis. $P < 0.05$ was considered to be statistically significant, values were expressed as the mean (SD) for continuous variables and number (%) for categorical variables. The intraclass measuring consistency was analyzed by a consistency test. Kruskal-Wallis H test was used to compare the distributions of CPS placement accuracies among the 3 surgical centers. Relative standard deviation (RSD) values were used to evaluate technical reproducibility.

RESULTS

One hundred thirty-five patients (87 males and 48 females with a mean age of 43.6 ± 10.8 yr old) with 718 CPS were enrolled in this 3-center study. Beyond the 135 participants, 4 patients (3.0%) with unrecognizable LVN due to severe cervical fracture/dislocation were excluded. Postoperative CPS penetrating the pedicle cortex mainly occurred from C4 to C6 (Table 2). Excellent and good CPS positions were 92.9% (grade 0 + I, pedicle perforations ≤ 24%), which could be considered as eligible CPS placement. Of the perforation cases, the medial and lateral pedicle perforations accounted for 85.8%, which reminds surgeons to pay more attention to transverse angle when placing CPS.

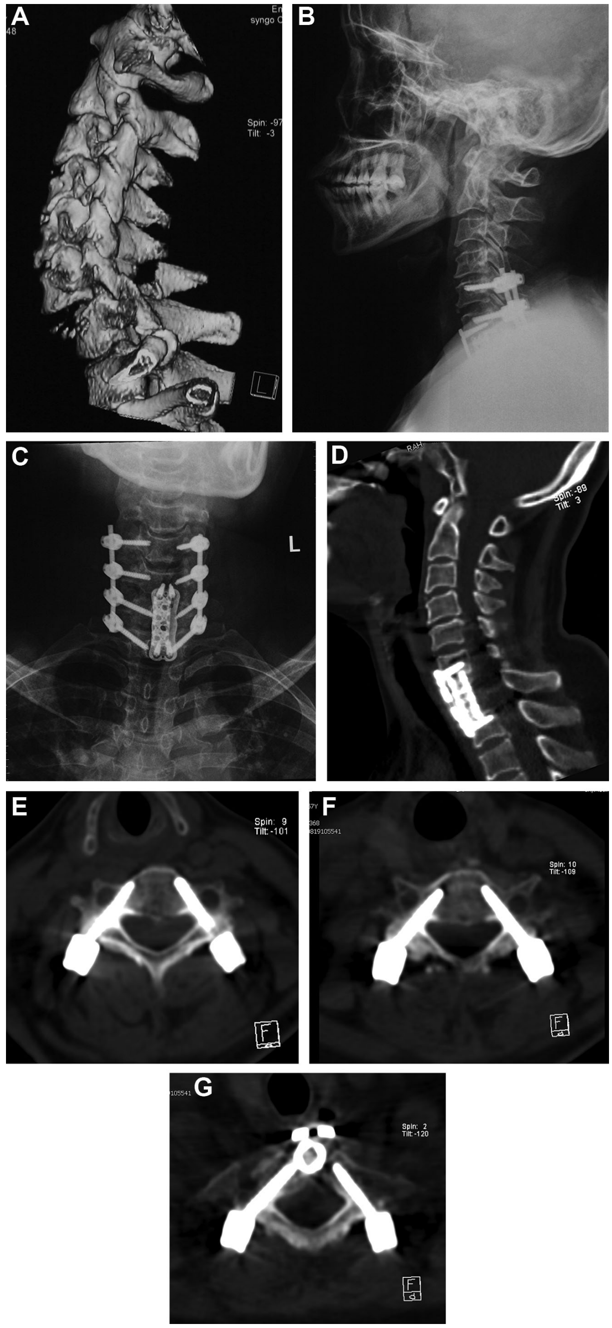

FIGURE 3. *Case presentation 1. A 56-yr-old woman with severe C6/7 fracture and dislocation.* **A**, *Reconstructive CT image showed a cervical 3-column fracture with locked facets and dislocation.* **B** *and* **C**, *Posterior pedicle screw-rod instrumentation combined with anterior corpectomy and fusion were implemented to decompress, reduce, and stabilize the cervical spine.* **D**, *Sagittal CT image demonstrated that the dislocation was reduced, the cervical spine was realigned, and the bone fusion occurred 8 mo after surgery.* **E-G**, *Axial CT scans revealed the positions of the inserted screws by LVN-referred technique were good (grade I) at the C5 left pedicle, excellent (grade 0) at the C5 right pedicle* **E**, *as well as excellent at C6 and C7* **F**, **G**.

TABLE 2. CPS Distributions at Different Segments and Penetrating Orientations

Segment	Inserted number	CPS penetrations at different grades[a]				Penetrating number[b]	Orientations of CPS penetrations			
		0	I	II	III		Superior	Inferior	Lateral	Medial
C3	76 (10.6%)	56	13	5	2	20 (2.8%)	1	3	5	11
C4	172 (24.0%)	135	24	9	4	37 (5.2%)	3	2	13	19
C5	208 (29.0%)	166	25	12	5	42 (5.8%)	4	1	16	21
C6	170 (23.7%)	143	18	6	3	27 (3.7%)	2	2	7	16
C7	92 (12.8%)	77	10	3	2	15 (2.1%)	2	0	4	9
C3-C7	718	577	90	35	16	141 (19.6%)	12	8	45	76
	Proportion	80.4%	12.5%	4.9%	2.2%	Proportion	8.5%	5.7%	31.9%	53.9%

CPS, cervical pedicle screw.
[a]Grade 0: Screw without penetrating pedicle cortex, grade I-III: diameters of screw penetrating pedicle cortex were 1 to 24%, 25 to 49%, and >49%, respectively.
[b]CPS penetrations including grade I, II, and III.

TABLE 3. Transverse Angulations[a] of Pedicles and CPS in Subaxial Cervical Spine

Segment	PTA	STA (RSD)	[b]MD (95% CI)	*P* value
C3	46.7 ± 3.2°	47.1 ± 2.9° (6.2%)	0.42° (–0.42 to 1.26°)	.326
C4	47.9 ± 3.7°	48.2 ± 3.4° (7.1%)	0.28° (–0.41 to 0.98°)	.417
C5	45.7 ± 4.0°	45.4 ± 3.1° (6.8%)	–0.31° (–0.95 to 0.32°)	.335
C6	41.5 ± 3.5°	41.2 ± 2.6° (6.3%)	–0.30° (–0.91 to 0.31°)	.329
C7	32.9 ± 3.1°	33.1 ± 2.3° (6.9%)	0.26° (–0.45 to 0.96°)	.474

CPS, cervical pedicle screw; SD, standard deviation; PTA, pedicle transverse angle; STA, screw transverse angle; RSD, relative standard deviation; MD, mean difference; CI, confidence interval.
[a]Transverse angulation means the mediolateral angle from the plane of spinous process to the plane of pedicle or CPS.
[b]Mean difference between PTA and STA.

TABLE 4. Comparison of Accuracies to CPS Placements Among 3 Surgeons

Study center	Inserted CPS	Grades of CPS penetrating pedicle cortex[a]				Accuracy rate Grade 0 + I[b]	H value	*P* value
		0	I	II	III			
1	294 (40.9%)	242	35	11	6	277 (94.2%)	1.460	.482
2	242 (33.7%)	193	29	14	6	222 (91.7%)		
3	182 (25.3%)	142	26	10	4	168 (92.3%)		
Total	718	577	90	35	16	667 (92.9%)	–	

CPS, cervical pedicle screw.
[a]Grade 0: Screw without penetrating pedicle cortex, grade I-III: Diameters of screw penetrating pedicle cortex were 1% to 24%, 25% to 49%, and >49%, respectively.
[b]Grades of 0 and I were considered as the eligible CPS placement.

Accuracy and Reproducibility of CPS Placements

There was no significant difference between patients' PTA and inserted screw transverse angles (STA) from C3 to C7 (all $P > .05$, Table 3), which indicated that the transverse angles of the CPS placements on the transverse plane were accurate. The RSD values of the STA revealed that the technical reproducibility was acceptable (from 6.2% to 7.1%, Table 3). Additionally, the intraclass measuring consistencies were acceptable (center 1: Kappa = 0.832, $P < .001$, ICC = 0.890, $P < .001$; center 2: Kappa = 0.833, $P < .001$, ICC = 0.924, $P < .001$; Center 3: Kappa = 0.806, $P < .001$, ICC = 0.896, $P < .001$). Moreover, a Kruskal-Wallis H test (H = 1.460, $P = .482$) demonstrated that there was no significant difference in accuracies among CPS placements of the 3 surgeons (Table 4).

We compared this study's occurrence of CPS penetrating pedicle cortex with 8 other freehand techniques used in subaxial

TABLE 5. Comparisons of Different Freehand CPS Placements

Characteristics	Present study	Mahesh et al[23]	Hojo et al[24]	Tofuku et al[20]	Lee[a] et al[25]	Lee[a] et al[26]	Jo et al[19]	Karaikovic et al[27]	Abumi et al[28]
Screw penetration (%)	19.6	21.0	14.9	11.7	22.0	28.8	27.9	16.8	6.7
Penetration grades[b] (%)	A: 17.4	A:16.7	A: 9.6	A: 7.8	A:19.8	A: 23.4	A: 25	A: 9.7	—[c]
	B: 2.2	B: 4.3	B: 5.3	B: 3.9	B:2.2	B: 5.4	B: 2.9	B: 7.1	
Screw-related neurovascular injury (%)	0.74	0	3.2	0	0	0	0	—	1.7
Sample size[d]	S: 718	S: 324	S: 1065	S: 127	S: 277	S: 205	S: 104	S: 113	S: 669
	C: 135	C: 58	C: 283	C: 32	C: 50	C: 48	C: 12	C: 10	C: 169
Technical title	LVN	MCPS	FWLF	Gutter	Keyslot	Plain radiograph	3-step	FT	Abumi's
Segment	C3-7	C3-7	C2-7	C2-7	C3-7	C3-7	C3-7	C2-7	C2-7
Multipathogenesis	y[e]	y	y	Trauma	y	y	y	—	y

CPS, cervical pedical screw; LVN, lateral vertebral notch-referred; MCPS, medial cortical pedicle screw; FWLF, freehand with lateral fluoroscopy; FT, funnel technique.
[a]Lee's team reported 2 different techniques referring to CPS placement in 2012.
[b]Penetration grades: grades of CPS penetrating pedicle cortex, A $\leq$ 50%, B $>$ 50%.
[c]"—" means lacking data in the study.
[d]Sample size: S indicates CPS quantity, C indicates case quantity which including patient or human cadaver.
[e]y means yes, the study's inclusion criteria including multipathogenesis.

CPS placement (Table 5)[10,19,20,23-27] and found that although a total CPS penetration of 19.6% in present study ranked in the middle level among the 9 studies, severe pedicle perforation (grade III, screw penetration > 49%), with a rate of 2.2%, was the lowest level among all compared studies, as well as a screw-related neurovascular complication of 0.74% among the studies with large sample. Meanwhile, our case series were consecutive and included a large sample. **Figures**, **Supplemental Digital Content 3** and **4**, showed that CPS instrumentations were used in reconstruction surgery (cervical aneurysmal bone cyst resection, pre- and postoperatively).

Safety of CPS Placements

There was no postoperative revision surgery conducted due to CPS misplacement. Postoperative CT scan and clinical manifestation revealed no vertebral artery or spinal cord injury derived from CPS misplacement in this cohort except one C6 nerve root that was partly compressed (Figure 4A, grade III). Without screw removal, this patient's radiculopathy was alleviated in 6 wk by dehydrants, neurotrophic drugs, and physical therapies (visual analog scale decreased from 6 to 2). A set of cases with CT images describing screw penetrations from grade I to grade III are shown in Figure 4B-4D.

DISCUSSION

Biomechanical benefits endowed by CPS instrumentation could treat not only common cervical spinal degeneration but also cervical spinal reconstruction and stabilization revision, such as surgeries due to severe trauma, tumors, and deformity; however, cases with severe infection or osteoporosis should be excluded due to surgical complications. Compared with a lateral mass screw, CPS placement would increase potential risks in neuromuscular and vascular structures. So, we tried to develop and demonstrate an innovative, accurate, and safer technique for CPS, which was titled LVN-referred technique, and it seemed superior to traditional CPS placement. By investigating the technique used in this large sample study, we found that the incidence of severe pedicle perforation was as low as 2.2%, and a screw-related neurovascular complication of 0.74% occurred.

Since Abumi et al[28] initially reported the clinical application of CPS, various techniques have been developed to implement PS placement in cervical spine, including techniques relying on anatomical landmarks,[27,29] techniques with a direct exposure of the pedicle,[26,30,31] and techniques with computer image-guided navigation.[11,32] However, most spinal surgeons still advocate freehand techniques to perform CPS placement due to the aforementioned non-freehand technical disadvantages. Also inadequate accuracy of CPS placement has been reported in various freehand techniques, Ludwig et al[30] reported that critical breach of CPS decreased to 39.6% after laminoforaminotomy, compared with 65.5% critical breach in the topographic landmark-based technique. Jeanneret et al[29] reported that 33 CPSs were performed in cervical pedicles with the entry point located in the middle of the articular mass, 3 mm beneath the superior articular process, and found that a minor violation rate of 30% (10/33) occurred in their study. It seems that the funnel technique decreased the overall percentage of critical pedicle perforations to 7.1% (8/113 pedicles)[27]; however, for exposing the entrance of the pedicle cavity, a resection of the outer portion of the articular mass would shorten the track of CPS anchorage, which biomechanically weakens the anti-pullout force of the CPS. Therefore, a biomechanically reliable technique based on a consistent landmark that could diminish the

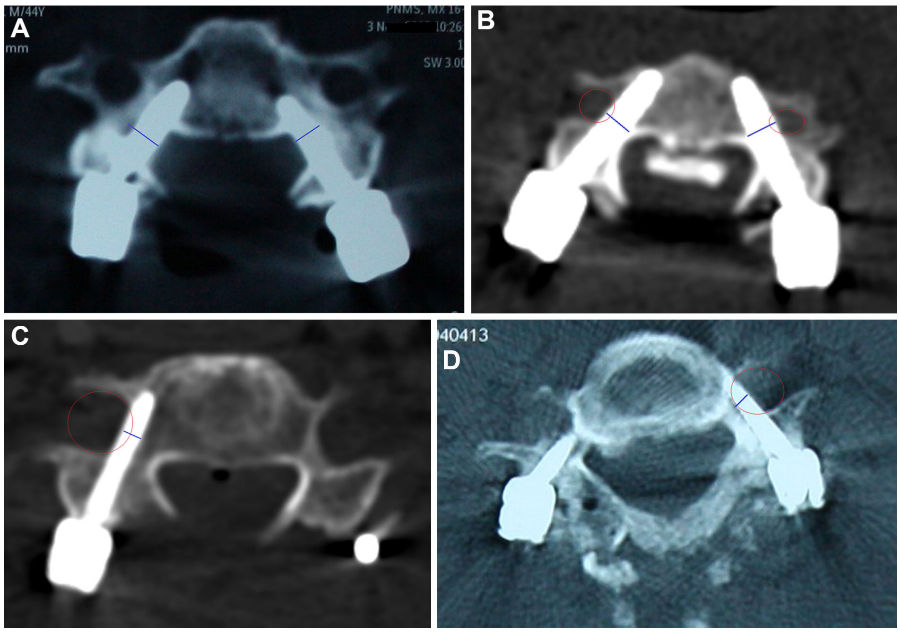

FIGURE 4. *Cervical pedicle screws (CPS) penetrations from grade I to grade III.* **A**, *Bilateral CPS penetrations with grade III at C6 (blue line indicates the diameter of the screw penetration).* **B**, *Bilateral CPS penetrations at grade I (the length of blue line within the red circle indicates the diameter of the screw penetration).* **C**, *CPS penetration at grade II (the length of blue line within the red circle indicates the diameter of the screw penetration).* **D**, *CPS penetration at grade III (the length of blue line within the red circle indicates the diameter of the screw penetration).*

assessment discrepancy between different surgeons is pivotal to be developed.

With an LVN-referred technique used in this cohort, low incidences in severe pedicle perforation and screw-related neurovascular complication as well as no significant differences ($H = 1.460$, $P = .482$) in CPS insertional accuracies among the 3 experienced surgeons may imply that the LVN landmark for different surgeons used in subaxial CPS placement was consistent. Comparing 2 studies including over 500 CPS placements,[10,27] the screw-related neurovascular injury rate in our study was minimal (0.74%). Compared with other freehand technique studies, a serious CPS penetration of 2.2% was also minimal (Table 5). It is worth noting that the PTA is another important parameter in the process of CPS placement because the majority of pedicle perforations are located at the medial or lateral pedicle walls (Table 2). The probable reason that the lateral perforation (31.9%) was less than the medial perforation (53.9%) may result from our intent to select a potential larger mediolateral angle when conducting the CPS placement, because under a potential larger mediolateral angle, the risk of penetrating lateral wall of pedicle and injuring vertebral artery would be less. However, this conduction may bring about more medial perforation. Switching to percutaneous CPS placement may be a safer choice in case of counter pressure from the nuchal muscles when inserting CPS. In grade II and grade III perforation cases, some screws penetrated the lateral pedicle walls and abutted vertebral arteries but did not produce symptoms, which might be attributable to the diameter of vertebral artery being much smaller than the transverse foramen, and the elastic vertebral artery had the character of "escaping" away from the screw invasion. The nerve root in the intervertebral foramen, in addition to the craniocaudal diameters of the subaxial cervical pedicles, was longer than the mediolateral diameters, which accommodated a larger range of PS angulation. Hence, both led to fewer superior and inferior perforations (14.2%). Additionally, the RSD values of the STA implied that CPS placements by using LVN-referred techniques had superior reproducibility (Table 3), which might be attributed to an LVN technique hardly influenced by undistinguished facets in hyperplastic degenerative changes, ankylosing spondylitis, and rheumatoid arthritis.

Limitations

This study had some limitations. First, the technical proficiency used in the early stage was not as high as in the later stage during this study, which might result in a clinical bias, but it was difficult to be eliminated given the study curve. Second, the types of CPS used in the surgeries were not as controllable, as this study was performed in 3 hospitals where different types of CPS were conducted. Thus, confounding factors, such as different types of screw threads and polyaxial or monoaxial screws, might increase bias in this cohort. However, the Kruskal-Wallis H test ($H = 1.460$, $P = .482$) demonstrated no significant difference in accuracies of CPS placements among the 3 surgeons. Third, the retrospective noncontrolled study had some unavoidable clinical heterogeneities, so a prospective and controlled study may better advocate a technical superiority. Moreover, this technique would be more challenging in the obese since the thicker soft tissues would push the probe more toward midline. Despite the above-mentioned limitations, this paper presents the first and largest multicenter case study that investigated the accuracy and safety of a thorough freehand technique referred to as a novel anatomic landmark (LVN) for subaxial CPS placement, and we intend to continue the use of the verified anatomic and statistical outcomes postoperatively.

CONCLUSION

To the best of our knowledge, this is one of the largest multicenter case series with a freehand CPS placement technique used in the subaxial cervical spine. We found that no disastrous neurovascular complications occurred in this cohort, and the LVN is a reliable and consistent anatomic landmark for subaxial CPS placement. The LVN-referred technique is accurate and safe for subaxial CPS placement and scarcely influenced by hyperosteophytic or erosive facet variation.

Disclosures

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Supplemental Digital Content 1. Figure. Measurements of STA and PTA. **A-E,** The angulation between the solid line and midline indicates the pedicle screw transverse angle (STA), the angulation between the dotted line and the midline indicates pedicle transverse angles (PTA). PTA was gradually decreased from the cranial to the caudal in the subaxial cervical spine. Postoperative axial CT scans showed minor differences between STA and PTA from C3 to C7.

Supplemental Digital Content 2. Video. Lateral vertebral notch-referred technique for subaxial cervical pedicle screw placement. –0:21 Preoperative case introduction. In this C6/7 fracture and dislocation case, we used the lateral vertebral notch (LVN)-referred technique to insert the cervical pedicle screw (CPS). —6:30 Surgical procedure. The lateral margins from C5 to T1 were intra-operatively exposed, we then referred the LVN and determined entry point for CPS placement on C6, which was approximately 2 mm medial and 1.4 mm caudal to LVN. After forming a track by the pedicle probe, a ball-tipped feeler was used to palpate to make sure there was no breach through the pedicle wall. Where after a 3.5-mm diameter CPS was inserted into a C6 pedicle track, the same procedures were repeated same procedures for the remaining pedicles from C5 to C7. T1 pedicles were placed by regular thoracic pedicle screws. Intraoperative fluorograph was used to verify the positions of pedicle screws. –6:41 Postoperative imaging outcome. Postoperative X-ray and CT scan images showed that the positions of pedicle screws were excellent.

Supplemental Digital Content 3. Figure. Preoperative presentation of case 2. A 13-yr-old girl suffered myelopathy and left radiculopathy from a C6 aneurysmal bone cyst. **A** and **B**, Radiograph showed a left C6 vertebral lesion **A** and local kyphosis **B**. **C**-**E**, MRI and enhanced CT scan revealed typical bone destruction and multi-cyst formation (arrow).

Supplemental Digital Content 4. Figure. Postoperative presentation of case 2. **A** and **B**, Radiograph showed the reconstructed cervical spine after tumor resection via an anterior-posterior approach. **C** and **D**, MRI revealed that the tumor was completely resected, and the spinal cord was entirely decompressed. **E**-**H**, axial CT scans indicated the excellent positions of the inserted pedicle screws from C5-T1.

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