

# A Review of the Historical Evolution, Biomechanical Advantage, Clinical Applications, and Safe Insertion Techniques of Cervical Pedicle Screw Fixation

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## Abstract:

Cervical spine instrumentation is evolving with an aim of stabilizing traumatic and non-traumatic cases of the cervical spine with a beneficial reduction, better biomechanical strength, and a strong construct with minimal intraoperative, as well as immediate and late postoperative complications. The evolution from interspinous wiring till cervical pedicle screws has changed the outlook in treating the cervical spine pathologies with maximum 3D stability, decreasing the duration of postoperative immobilization and hospital stay. Some complications associated with the use of cervical pedicle screw can be catastrophic. This review article discusses the morphometry of cervical pedicle; indications, biomechanical superiority, tricks, and pitfalls of cervical pedicle screw; complications and technical advancements in targeting safe surgery; and future directions of cervical pedicle screw instrumentation.

## Keywords:

Cervical pedicle screw, Biomechanics, Navigation-assisted screws, 3D templates

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## Introduction

Before the introduction of the spinal instrumentation, patients with cervical spine pathology were treated conservatively with traction, postural reduction, and external orthoses<sup>1)</sup>. The early 20th century witnessed significant advancements in instrumentation surgeries. Interspinous wiring and cervical pedicle screw, which enhance the stability of cervical spine instrumentation and reduce the duration of postoperative immobilization, were increasingly used. The use of lateral mass screws (LMS) and cervical pedicle screws (CPS) formed the basis for rigid fixation in cervical spine pathologies in traumatic and non-traumatic cases, including degenerative conditions, tumors, rheumatoid arthritis, and in the correction of occipitocervical and cervical deformities<sup>2-7)</sup>. In this review, we describe the evolution, biomechanical superiority, and associated complications of CPS. We also discuss the need for preoperative radiological evaluation in vertebral artery (VA) anomalies such as high-riding VA and safe screw insertion techniques for the surgeons to

consider CPS in stabilizing cervical spine pathologies.

## Historical Evolution of Cervical Instrumentation Surgery

Posterior cervical instrumentation has been modified in the process of understanding the cervical spine anatomy and biomechanical stability of the construct<sup>8)</sup>. In 1891, Hadra introduced spinous process wiring for treating Pott spine<sup>9)</sup>. He emphasized the use of posterior interspinous wiring in the early and moderate stages of bone destruction, and not in patients with severe bone destruction caused by the progression of local kyphosis. Rogers successfully used the interspinous wiring for treating fracture dislocations of the cervical spine and described in detail the wiring techniques, which were later improvised by other surgeons to enhance the stability of interspinous wiring<sup>10-12)</sup>. Luque rods with sublaminar wires for the stabilization of multilevel and occipitocervical instability were introduced in the late 1970s<sup>13)</sup>. In 1975, Tucker described Halifex interlaminar clamps for

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C1-C2 fusion<sup>14</sup>). However, their use in the subaxial cervical spine was not popularized because of the narrow diameter of the spinal canal in the cervical spine. In addition, wires and clamps cannot be used in patients requiring posterior decompression procedures for removing posterior spinal elements. To overcome these problems, screws with plates or rods were used for cervical spine stabilization.

In 1964, Roy-Camille introduced the use of lateral mass screws for internal fixation of an unstable cervical spine with plates and screws<sup>2</sup>. He designed plates for lateral mass screws, which was later modified by Louis, Fuentes, and Magerl<sup>15</sup>. Two different techniques with regard to the entry point and screw trajectories were proposed by Roy-Camille<sup>2</sup> and Magerl<sup>16</sup> with the advantages of the lower risk of nerve root injury and lower risk of facet joint violation, respectively. Over time, these techniques became popular as they can be performed in patients with deficient laminae and defective pedicle<sup>17</sup>. In the late 1980s, screw and rod systems were developed for treating complex trauma and degenerative disorders in which the screw and plate systems were difficult to use<sup>13</sup>.

Although pedicle screw fixation for stabilization of thoracic and lumbar spine has been extensively used in posterior cervical instrumentation, its attempt has always been hesitant. Leconte<sup>18</sup> first reported pedicle screw insertion in C2 for stabilizing Hangman fractures. Pedicle screws have been used for the stabilization of C2 and C7 levels, as C2-C7 pedicles are wider than C3-C6 pedicles. Abumi et al. first described the use of pedicle screws in the subaxial cervical spine for treating traumatic cervical spine injuries and later for treating degenerative disorders and correcting cervical spine deformities<sup>5,19</sup>.

In 2004, Wright introduced translaminar screw fixation for stabilizing C2<sup>20</sup>. Laminar screws are used when lateral masses and pedicles are destroyed especially in trauma and tumor cases; however, because of their poor bony purchase at C3-C6 levels, they are usually used in salvage procedures when other screw placements are difficult.

### Biomechanical Strength of Cervical Instrumentation

Posterior interspinous wiring stabilizes the posterior tension band construct and provides stability only in flexion-distraction injuries or flexion instabilities. It does not provide stability against extension, rotation, or lateral bending<sup>8</sup>. Posterior screw and plate systems provide better stability in all directions. Although laminar screws have a major role in C1-C2 fixation, they have lesser biomechanical stability than LMS and CPS<sup>21</sup>.

Studies have proved the greater pullout strength of cervical pedicle screws than lateral mass screws in having the advantage of a more stable construct and thereby restricting the number fusion levels<sup>22-24</sup>. LMS has biomechanical limitations because of the small amount of bony purchase and thereby lesser pullout strength especially in the presence of

osteoporosis. Pullout strength of LMS is more in the upper middle cervical spine than in the lower cervical spine (Table 1)<sup>25</sup>. In many cases, because unstable spines cannot rely only on LMS, an additional anterior procedure is required to achieve three-column stability, by using CPS alone<sup>3,22,23,26,27</sup>. CPS offers more stable construct for stabilization of subaxial cervical spine, occipitocervical fusion, and cervicothoracic fixation, with reliable fusion<sup>28</sup>. Biomechanical studies have proven a greater pullout strength of CPS than LMS, and the failure of CPS is most often because of the fracture at the pedicle than screw loosening, which is frequently seen in LMS<sup>22,25</sup>.

In the study on 20 C3-C7 fresh frozen disarticulated vertebrae, Todd et al. used 3.5-mm screws to compare the pullout strength of CPS and LMS by cylindrical loading in flexion and extension. The results showed a rapid loosening of LMS compared to the stable CPS, and the pullout strengths of LMS and CPS were 332 and 1214 N, respectively. Ito et al. compared the pullout strength of CPS and LMS at C3-C6 after a period of cyclic loading in flexion-extension and torsional loading<sup>29</sup>. They reported CPS had a superior pullout strength compared with LMS and stated that the overall shape of the cervical pedicle influences the resistance of CPS to force in axial direction. Studies have shown that 2.7-mm screws in pedicles less than 5-mm width have the same pullout strength as that of 3.5-mm screws in pedicles greater than 5-mm width, as the pullout strength depends on the cortical purchase of the screw<sup>25,30</sup>. A suitable screw is supposed to provide a best compromise between the optimal screw size (more chances of pedicle breach with thicker screws) and screw pullout strength<sup>30</sup>.

### Clinical Indications of CPS

The reported indications of CPS include trauma; primary or metastatic spine tumor; degenerative spondylotic myelopathy; anterior pseudarthroses; destructive lesions such as rheumatoid arthritis (RA) and destructive spondyloarthropathy (DSA) in patients receiving hemodialysis; drop head syndrome; and cervical kyphosis with various pathologies requiring both spinal cord decompression and posterior fusion.

In trauma, the pedicles are least affected and provide good anchor points for the stabilization of the cervical spine. However, when the pedicles are fractured, an alternative procedure should be planned. Correcting kyphosis in the cervical spine can be performed in conjunction with posterior osteotomy especially in ankylosing spondylitis<sup>24</sup>. CPS are a best option for salvage procedures in cases of loose LMS screws or in failed anterior fusion or pseudarthrosis<sup>31</sup>. Because of their stable construct and adequate space to accommodate bone graft, they provide a high rate of fusion<sup>28</sup>. In rheumatoid cervical spine, there is a severe destruction of the facet joints and most often the lateral mass is left with limited bony purchase. Therefore, the use of CPS is recommended as the strong initial fixation that eliminates the ne-

**Table 1.** Difference in Biomechanical Strength between CPS and LMS from C3-C7.

	The difference in pullout strength of CPS vs LMS (Jones et al. <sup>25</sup> )	The difference in pullout strength of CPS vs LMS (Ito et al. <sup>29</sup> )
C3	217 N	440 N
C4	236 N	376 N
C5	464 N	487 N
C6	402 N	497 N

**Table 2.** Morphology of CPS from C3-C7.

	Average Pedicle Chord Length (entry point to the anterior aspect of the vertebral body) mm	Average Pedicle Length (pedicle exit into the facet to the posterior aspect of the vertebral body)	Mean Transverse Angulation (Panjabi et al. <sup>37</sup> )	Mean Transverse Angulation (Ludwig et al. <sup>53</sup> )	Mean Sagittal Angles
C3	35.53 mm	16.28 mm	-	43.97°	+8.63° (Superior oriented pedicle)
C4	36.11 mm	15.73 mm	45°	44°	+4.67° (Superior oriented pedicle)
C5	37.20 mm	17.10 mm	39°	41.28°	-1.33° (Inferiorly oriented pedicle)
C6	37.40 mm	15.75 mm	29°	37.32°	-4.02° (Inferiorly oriented pedicle)
C7	36.57 mm	14.41 mm	33°	36.75°	-1.67° (Inferiorly oriented pedicle)

cessity of postoperative external fixation such as halo vest or neck collar<sup>32</sup>.

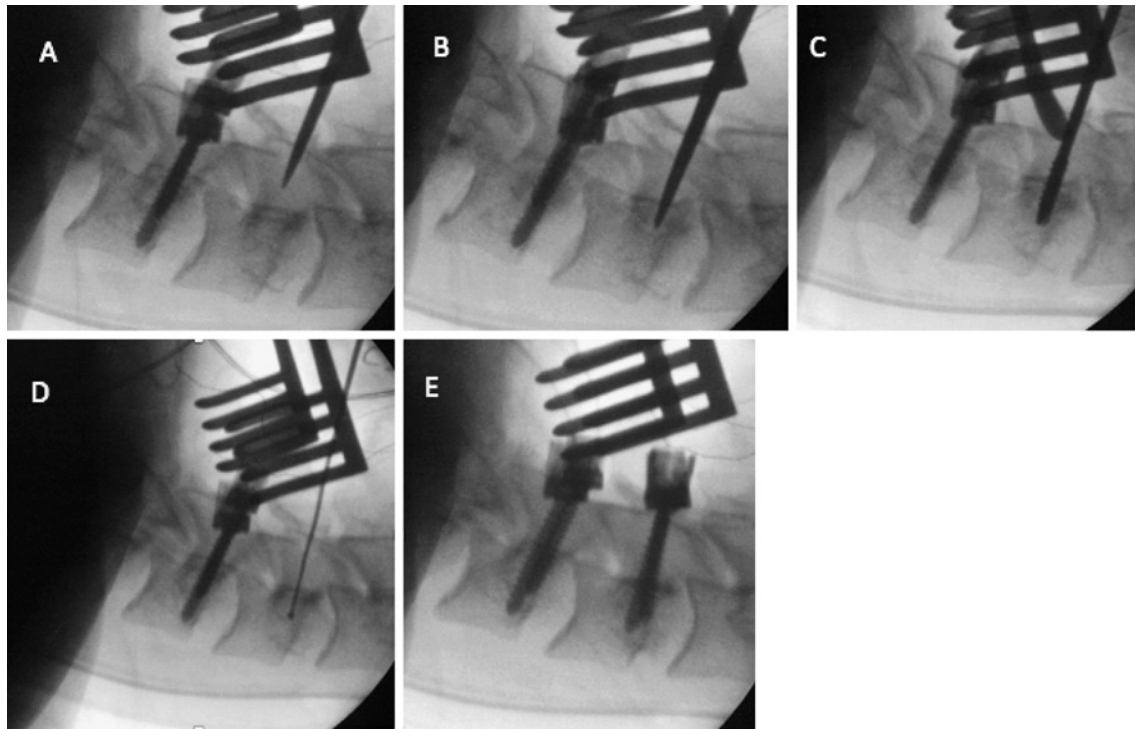
Hasegawa et al.<sup>28</sup> evaluated the clinical results of patients with non-traumatic lesions treated using CPS. Comparison of the two groups with destructive lesion and kyphosis and without destructive lesion showed fusion results of 100% and 95%, respectively. The pedicles of the cervical spine are intact in destructive spondyloarthropathy, even after the destruction of other spinal components, providing an adequate stability<sup>33</sup>. When the bone is severely fragile, CPS is the preferred option for posterior stabilization<sup>34</sup>. In metastatic tumors, where the anterior body is destroyed, CPS stabilization offers a palliative management<sup>35,36</sup>.

### Morphometric Analysis and Surface Landmarks

It is imperative for a surgeon to have the anatomical knowledge of the cervical pedicle and a thorough preoperative radiological assessment is mandatory, as the pedicle size and orientation cannot be visualized from the posterior approach. It also enables the surgeon to know the pedicle or vertebral body damage that precludes the insertion of CPS. The medial wall of the pedicle is thick and the lateral wall is thin, which can easily cause pedicle violation during instrumentation and may injure the vertebral artery.

In 1991, Panjabi et al. published the first three-dimensional anatomic study of human cervical spine in which he demonstrated the capacity of cervical pedicle to accept CPS<sup>37</sup>. The authors also described the anatomical dimensions and pedicle orientation, of which C2 pedicle is the largest and C3 is the smallest of all the cervical spine pedicles<sup>37,38</sup>. Following the above-mentioned data, Roy Camille et al. successfully used C2 pedicle as an insertion point without any neurovascular deficit<sup>39</sup>. However, the vertebral artery (VA) injury with C2 pedicle screw is 5.3%-21%<sup>40,41</sup>.

The factors that contribute to the VA injury are VA groove anomaly and surgical technique. The two anatomic variations associated with VA injury are high-riding VA and narrow C2 pedicle, and the chances of VA injury are more in the latter. The prevalence of high-riding VA is 16.54%<sup>41</sup>. Stanescu et al., in their cadaveric study, mentioned that there is a slight increase in the pedicle height width and length and a decrease in the transverse angle of 4°-6° between adjacent C5-C7 vertebral levels<sup>42</sup>. Kramer et al. reported their morphometric analysis and showed similar inclinations with the values reported by Panjabi et al.. These studies were conducted with the objective of localizing the entry point and orientation of pedicles from C3-C7 for CPS insertion. The studies showed that the sagittal height of the pedicle was the largest at C4 (7.72 mm) and smallest at C6 (7.15 mm), with no significant interlevel difference, and the transverse diameter was the smallest at C3 (5.38 mm) and largest at C7 (6.51 mm). They also reported the average pedicle length, mean transverse angulation, and sagittal angulation from C3-C7 (Table 2). Transverse and sagittal offsets showed no significant interlevel differences. The course of the nerve roots of the cervical spine is anterolaterally 45° and inferiorly 10° with respect to the pedicle axis and is located at and below the inferior half of neural foramina<sup>43</sup>. Exiting nerve root position is at the superior part of the caudal pedicle, and therefore superior perforation of CPS has to be avoided<sup>43</sup>. Studies have shown that 5% of the patients showed VA anomaly<sup>44,45</sup>. The VA entrance into C4, C5, and C7 are 1.6%, 3.3%, and 0.3%, respectively; it is sometimes associated with extraosseous abnormal medial loop at the entrance and wide transverse foramen, which precludes the use of CPS. In 18.2% of patients, characteristic variations in the Circle of Willis with unilateral VA stenosis or a dominant vertebral artery is seen, indicating that an injury may cause lethal complications; therefore, preoperative assess-



**Figure 1.** Images of fluoroscopic lateral views.

A, B-Pedicle probe insertion.

C-Tapping of the tract.

D-Pedicle sounder (Ball tip probe) to check pedicle wall integrity.

E-Screw insertion.

ment of VA and circle of Willis with CT angiogram are recommended in patients undergoing CPS instrumentation procedure<sup>46</sup>.

Fredrickson et al. investigated to determine the safe transpedicular screw fixation at C7 and mentioned the pedicle entry point at 1 mm inferior to the midpoint of the facet joint with 20°-30° medial direction and perpendicular to superoinferior plane<sup>47</sup>. Abumi et al.<sup>3</sup> stated that the direction of the screw insertion is not so severely restricted because of the small depth of the pedicle. Also, the entry point should be slightly lateral to the center of the articular mass and close to the inferior articular process of the superior vertebra (Fig. 1). The lateral margin of the articular mass of cervical spine has a notch, which is approximately at the pedicle level. The C2 pedicle level is slightly below, C3-C6 at, and C7 slightly above the lateral vertebral notch (Fig. 2). Karaikovic et al.<sup>48</sup> introduced the lateral notch for the first time, saying that it did not provide the exact co-ordination of entry point with this landmark and true pedicle axis. The screw insertion points are slightly medial to the notch. Lee et al.<sup>49</sup> in their study mentioned that it is not appropriate to use the inferior border of cephalad facet as tomographic landmark because it moves along with neck position and instead one has to consider lateral notch, superior ridge of lateral mass, and center of lateral mass as the landmarks and obtain an entry from 2.0-2.4-mm medial and 0-0.9-mm inferior to the lateral notch. They also mentioned that the entry point should be adjusted according to the transverse angle of

pedicle at that level. If the transverse angle is less than 35°, the entry point is 3-mm medial to the lateral notch, and if the transverse angle is greater than 55°, the entry point is 1-mm medial to the lateral notch. Because the study included only Asians, these values could not be extrapolated to other races.

### Safe Techniques of Placing CPS

CPS insertion technique has a high learning curve and is technically demanding<sup>50</sup>. Accurate and safe insertion technique prevents potential neurovascular injuries, which is the foremost concern for the treating surgeon<sup>26,51</sup>. The accuracy in CPS insertion has significant variations in the literature, ranging from 16.8% to 97%<sup>52,53</sup>. Because of the variation in the pedicle anatomy of the cervical spine, surface landmarks alone are not adequate for screw placement. With the gradual increase in popularity of CPS, different techniques of CPS insertion have been proposed to improve the accuracy. VA anomaly makes it vulnerable to injury during CPS insertion. The objective risk stratification of VA helps in reducing the chances of its injury during a surgery<sup>54</sup>.

Surgeon experience and technique is essential in increasing the accuracy rate by free hand technique of screw insertion<sup>55</sup>. Zheng et al.<sup>56</sup> used fluoroscopic oblique views for the pedicle size assessment and achieved a significant overall success rate of cervical pedicle screw insertion in their study. Abumi et al.<sup>3,4</sup> described the technique in which the

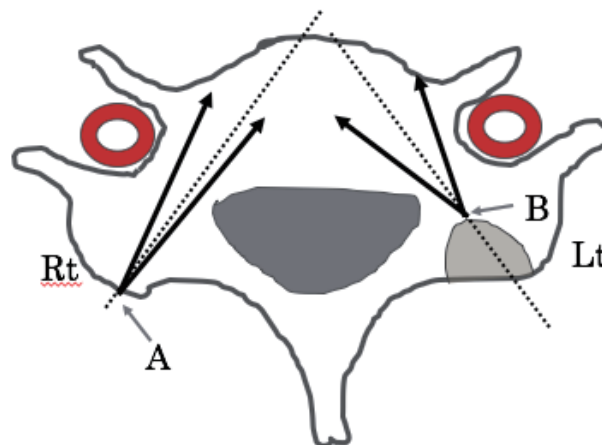


**Figure 2.** Pedicle screw starting points in the cervical spine.

Dots (.) represent the entry point for the cervical pedicle screw.

Arrows (←) represent lateral notch.

cortex at the entry point is drilled, which helps in the direct observation of the pedicle entrance and improves the range of the trajectory for screw placement, and reported a perforation rate of 6.7% (Fig. 3). Karaikovic<sup>57)</sup> used funnel technique for screw insertion in 10 fresh frozen cadavers using the medial cortex of cervical pedicle as a guide for screw insertion with an accuracy of 83.2%. Many other authors have presented their studies in CPS insertion accuracy by visual-tactile guidance by performing partial laminectomy<sup>58)</sup> or laminoforaminotomy<sup>44,53)</sup>, which showed a lesser pedicle wall violation rate than the conventional free hand technique. Ludwig et al. stated that a large standard deviation in C7 pedicle screw insertion angle of  $40.6^\circ \pm 7.1^\circ$  reveals a high degree of variability. They used the technique of direct palpation of the medial border of pedicle for a visual and tactile feedback for CPS insertion. Ebrahim et al. stated that the combined use of CT scan and conventional radiograph might augment the safety of pedicle screw insertion at C3-C6. The angulation to place the pedicle screw is difficult because of the presence of soft tissues, and a separate lateral stab incision may be necessary for CPS insertion. Minimally invasive cervical pedicle screw insertion technique by paraspinal approach was used by Komatsubara et al.<sup>59)</sup> In their studies, they showed a decreased complication rate by placing the screws more horizontally compared to the conventional technique ( $P = 0.0039$ ). Neither of the misplaced screws was laterally deviated in the minimally invasive group. Sugimoto et al.<sup>36)</sup> compared conventional technique with minimally invasive technique of CPS in midcervical spine for stabilizing metastatic cervical spinal tumors. The minimally invasive technique was beneficial with less blood loss (average of 750 mL in the conventional method and



**Figure 3.** Direction of the cervical pedicle screw.

Points A and B on the right (Rt) and (Lt) sides, respectively, of the lateral mass are the screw insertion points. Black arrows show the freedom of trajectory, at which the screw can be introduced. Point B (where the entry point is drilled with a high-speed burr) has more freedom of angle compared to that of point A, at which the screw can be introduced.

180 mL in the minimally invasive technique), more horizontal insertion (average of  $52^\circ$  in the minimally invasive technique and  $39^\circ$  in the conventional technique) of the screws, and reduced screw deviation.

In a cadaveric study, Kantelhardt et al. performed intraluminal scanning with an endovascular ultrasound transducer in order to ensure the accuracy of the pedicle screw hole position. In their study, out of 54 pedicle screw holes, 23 were intentionally mismatched; they were able to differentiate the correctly placed screw from the breached screw in 96% cases<sup>60)</sup>. However, they concluded that disruption or direct neurovascular injury is unavoidable by this technique.

### Technical Advances in the Placement of CPS

Technical advancements in the recent years, such as 3D screw insertion templates and computer-assisted image-guided navigation surgical system, have enabled improved accuracy in CPS placement<sup>61-63)</sup>. Although C-arm fluoroscopic technique is economical and the most widely used method of screw insertion, it is associated with a lower accuracy, and increased radiation to the patient and operating staff. CT-based navigation helps in correlating with the preoperative CT; however, it cannot provide anatomical relationships between preoperative and intraoperative findings because of the change in spinal alignment intraoperatively<sup>64)</sup>. Computer-assisted image-guided screw system (CAS) has significantly improved the accuracy of screw placement. On comparing the free hand technique with CAS, Kotani et al.<sup>65)</sup> reported better accuracy and lower complication rates with CAS (free hand technique: 6.7%; CAS: 1.2%). Krammer et al. instrumented 12 human anatomic specimens with 3.5-mm screws from C3-C7 and found a lower complication rate with CAS than with topographic landmarks and lamino-

foramotomy<sup>52</sup>). Comparative studies have shown consistently better accuracy results with CAS<sup>65-68</sup>. The downside with the use of CAS is that it is expensive and that intraoperative tracer loosening and position change cause a drift of the navigation map, leading to the malpositioning of the screws. Goffin et al. first described 3D CT-based drill guides for C1-C2 fusion, and this technique was improved with screw insertion templates<sup>61,69</sup>. The 3D templates for use in subaxial cervical spine are economical, easy to use, reduce the operation time, decrease radiation exposure, and capable of multi-center use. However, this technique requires complete removal of the soft tissue over the bone.

### Surgery-Related Complications

The close proximity of the spinal cord, nerve root, and vertebral artery to the cervical pedicle imposes a huge risk and may cause catastrophic complications while placing CPS. Complications associated with CPS temporizes its wide acceptance; hence, safe insertion techniques of cervical pedicle screw have been proposed by many authors<sup>3,4,57,58,60,64-66</sup>. The complications related to CPS insertion are pedicle breach leading to neurovascular injury (most common), indirect nerve root injury (foraminal stenosis), screw loosening or avulsion, loss of reduction, pseudoarthrosis, and infection. Anomalous VA has more chances of iatrogenic injury and the anomaly as such may lead to intracerebral disorders by altering the vascular hemodynamics, thereby placing patients at a greater risk of thrombosis, aneurysm, occlusion, arterial dissection, and, potentially, atherosclerosis<sup>70</sup>. Very few studies have shown the safety of CPS at C3-C6. Because of the narrow dimensions of the cervical pedicle from C3-C6, efficacious placement of CPS needs accurate identification of the pedicle trajectory from the entry point. Roy-Camille stated that the placement of transpedicular screw into C3-C6 pedicles could lead to unacceptable injury to neural tissue and vertebral artery. Karaikovic et al.<sup>50</sup> reported the anatomic limitations of pedicle in some patients, as the diameter of the pedicle is too narrow to accommodate the pedicle and the lateral cortex of the pedicle is thinnest toward the vertebral artery; therefore, the surgeon has to be careful while probing or tapping during CPS insertion.

In the postoperative radiological assessment of the inserted screws, Abumi et al.<sup>63</sup> reported that the incidence rates of screw perforation were lowest in C2, highest in C4, and second highest in C7 because of the difficult intraoperative radiological assessment of the pedicle due to shoulder superimposed image. In their study, 9 pedicle screw breaches were encountered with no vertebral artery injury, as the vertebral artery does not occupy the complete foramen transversarium and mild breach would not usually cause complications. On the contrary, Uehara et al. reported that a perforation of more than 50% of the screw diameter in the preoperative CT navigation procedure was observed at the highest frequency at C4 and at the lowest frequency at C3 and C6<sup>71</sup>.

The course of the nerve root and its position inside the foramen prevent neural injuries due to the sufficient room between neural elements and surface of medial and inferior pedicle wall<sup>43,72</sup>. However, in gross pedicle wall violation, the complications are to be expected. The pedicles in the degenerated cervical spine are sometimes sclerotic and are more prone to pedicle breach, making it more challenging to place CPS compared to that in a traumatic case<sup>73</sup>. Study on perforation rates of CPS in different diseases showed a highest percentage of pedicle violation in cervical spondylosis myelopathy compared to rheumatoid arthritis and destructive spondyloarthropathy and maximum in C4 and next in C3 level<sup>32</sup>.

In a study by Jeanneret et al. with 7 year follow up, the clinical outcome by putting cervical pedicle screws (4 mm) was not associated with any post-operative complication<sup>27</sup>. Abumi et al. performed a more extensive study by using a modified Steffee variable screw placement system, with 3.5-, 4-, and 4.5-mm cancellous screws for C2-T1, in 53 patients. The postoperative CT showed silent 7%-8% of pedicle wall violation<sup>25</sup>. Hojo et al.<sup>74</sup> later published the results of 227 cases of cervical pedicle screw fixation. In their study, late neurologic deficits occurred as an indirect complication in 2.6% of cases. Yukawa et al.<sup>75</sup> used oblique views for pedicle screw fixation and had 10.3% of incomplete and 4% of complete perforation. Neo et al.<sup>51</sup> reported a 25% pedicle perforation rate when Abumi's technique was used in their 18 case series. Complications related to CPS have been published by many authors in their studies comparing different techniques (Table 3, 4).

Indirect complications such as nerve root injury as a result of iatrogenic foraminal stenosis<sup>63,76</sup> are seen in the correction of cervical kyphosis usually exceeding 9.7° per segment. Hence, preoperative CT scan is essential in assessing and predicting the postoperative foraminal stenosis in degenerative cases prescribed with prophylactic decompression. Whenever the vertebral artery injury is unavoidable, an alternative method of stabilization should be considered for the opposite side. The unacceptable and heterogeneous complications associated with CPS malpositioning warrant the justification of the risk-to-benefit ratio of the technique.

### Future Directions of CPS

Because the use of CPS has been gaining wide acceptance in recent years, significant efforts have been undertaken to prevent undesirable complications. The use of intraoperative neuromonitoring helps in detecting the neurological injury, navigation-assisted surgery aids in the accuracy of CPS placement, and intraoperative CT allows for detecting the screw breach, which precludes second surgery and prevents a delay in screw repositioning. However, surgical skills and experience are still needed and the surgeon should not completely rely on the technology.

Although many studies have shown low complication rates with the technological advancement, it is still necessary

**Table 3.** Studies Showing the Percentage of CPS Breach and Complications.

Authors	Pedicle Breach and Complications
Yukawa et al. <sup>75</sup> (X rays - oblique views)	NCB: 10.3% CB: 4%
Neo et al. <sup>51</sup> (Abumi technique)	C: 25%
Kotani et al. <sup>65</sup>	
Free hand	C: 6.7%
CAS	C: 1.2%
Karaikovic et al. <sup>57</sup>	NCB: 9.7%
(Funnel technique)	CB: 7.1%
Ludwig et al. <sup>53</sup>	
Surface landmarks	NCB: 21.9%, CB: 65.5%
Laminoforaminotomy	NCB: 15.4%, CB: 39.6%
CAS	NCB: 13.4%, CB: 10.6%
Richter et al. <sup>67</sup>	
Conventional	C: 8.6%
CAS	C: 3%
Yoshimoto et al. <sup>78</sup>	NCB: 7.3% CB: 3.7%
Ito et al. <sup>79</sup>	C: 2.8%
(CAS)	
Ishikawa et al. <sup>66</sup>	
Conventional	C: 27%
CAS	C: 18.7%
Nakashima et al. <sup>73</sup>	C: 5.9%
Uehara et al. <sup>71</sup>	NCB: 20.0%, CB: 6.7%

NCB, non-critical breach; CB, critical breach; C, complications

**Table 4.** Complications of CPS.

Study	Abumi et al. <sup>63</sup>	Kast et al. <sup>26</sup>	Yukawa et al. <sup>75</sup>	Nakashima et al. <sup>73</sup>	Fehlings et al. <sup>80</sup>	Graham et al. <sup>17</sup>	Heller et al. <sup>76</sup>	Levine et al. <sup>81</sup>	Swank et al. <sup>82</sup>
No. of screws	180	26	100	84	44	164	654	24	43
Nerve root injury (direct)	2	2	1	3	0	3	4	6	0
Spinal cord injury	0	0	0	0	0	0	0	0	0
Vertebral artery injury	1	0	1	2	0	0	0	0	0
Nerve root injury (indirect)	1	0	0	0	0	0	2	0	0

to further improve the accuracy of CPS placement. The future of CPS runs toward the safety of the procedure. The idea of using the electrical pedicle probe that analyses electrical conductivity of the tissue with variation in pitch and cadence might be helpful in decreasing pedicle violation<sup>77</sup>.

### Conclusion

Cervical pedicle screw fixation is used in various kinds of cervical spine pathologies with biomechanical superiority and aims at correcting and preventing additional changes in spinal alignment, enhance fusion rates, and allow early mobilization of the patient without cumbersome external immobilizers. The complications associated are not to be overlooked and could be prevented by a detailed preoperative radiological and 3D bone model assessment of the pedicle anatomy in conjunction with improved surgical techniques

and technology. Future advances should aim at further increasing the accuracy of CPS insertion and decreasing the complication rates.

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Abumi Kuniyoshi - Revising the manuscript critically for important intellectual content.

Manabu Ito - Moderating and revising the manuscript.

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