C2 medial pedicle screw: a novel “in-out-in” technique as an alternative option for posterior C2 fixation in cases with a narrow C2 isthmus

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OBJECTIVE The authors describe a novel “in-out-in” technique as an alternative option for posterior C2 screw fixation in cases that involve narrow C2 isthmus. Here, they report the preliminary radiological and clinical outcomes in 12 patients who had a minimum 12-month follow-up period.

METHODS Twelve patients with basilar invagination and atlantoaxial dislocation underwent atlantoaxial reduction and fixation. All patients had unilateral hypoplasia of the C2 isthmus that prohibited insertion of pedicle screws. A new method, the C2 medial pedicle screw (C2MPS) fixation, was used as an alternative. In this technique, the inner cortex of the narrow C2 isthmus was drilled to obtain space for screw insertion, such that the lateral cortex could be well preserved and the risk of vertebral artery injury could be largely reduced. The C2MPS traveled along the drilled inner cortex into the anterior vertebral body, achieving a 3-column fixation of the axis with multicortical purchase.

RESULTS Satisfactory C2MPS placement and reduction were achieved in all 12 patients. No instance of C2MPS related vertebral artery injury or dural laceration was observed. There were no cases of implant failure, and solid fusion was demonstrated in all patients.

CONCLUSIONS This novel in-out-in technique can provide 3-column rigid fixation of the axis with multicortical purchase. Excellent clinical outcomes with low complication rates were achieved with this technique. When placement of a C2 pedicle screw is not possible due to anatomical constraints, the C2MPS can be considered as an efficient alternative.

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KEYWORDS basilar invagination; atlantoaxial dislocation; C2 screw fixation; vertebral artery; alternative techniques; pedicle screw; cervical; surgical techniques

INSTABILITY of the atlantoaxial facet joint, which can arise in a variety of pathologies, including congenital malformation, trauma, neoplasms, and inflammatory diseases, may cause neurological deterioration and require surgical stabilization.¹ For atlantoaxial fixation, early posterior wiring methods are less frequently used because of their poor stiffness and high fusion failure rates.^{2,3} The C1–2 transarticular screw fixation offers superb biomechanical stability, but the procedure is technically demanding and carries a high risk of vertebral artery (VA) injury in approximately 20% of patients due to aberrant vascular anatomy.⁴ Presently, the C1 lateral mass and C2 pedicle screw fixation, first described by Goel and Laheri and popularized by Harms and Melcher, has been widely

used for atlantoaxial fixation.^{5,6} This technique provides greater stability and significantly reduces the risk of VA injury in comparison with transarticular screw fixation.^{7,8} Nevertheless, the use of C2 pedicle screws is still not always feasible, especially in cases involving basilar invagination (BI) and atlantoaxial dislocation (AAD), because a narrow C2 isthmus of the pars interarticularis with high-riding or medialized VA is commonly seen among these patients (Fig. 1).^{9,10}

Several alternative strategies, including C2 translaminar screw fixation and C2 pars/short pedicle screw fixation, have been reported when placement of C2 pedicle screws is prohibited.^{11,12} These alternative strategies, however, could only achieve posterior column fixation and showed

ABBREVIATIONS AAD = atlantoaxial dislocation; BI = basilar invagination; C2MPS = C2 medial pedicle screw; VA = vertebral artery.

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FIG. 1. CTA images of a patient with BI and AAD. **A:** Midsagittal view showing BI, AAD, and atlas assimilation. **B:** Sagittal view with the cut passing through the left facet, demonstrating a high-riding VA with narrow height of the C2 isthmus. **C:** Axial view showing left-sided medialized VA with narrow width of the C2 isthmus. **D and E:** Three-dimensional reconstruction views demonstrating a left-sided, high-riding, and medialized VA with a narrow C2 isthmus. Figure is available in color online only.

inferior biomechanical properties and increased risks for nonunion than C2 pedicle screws.^{13–15} For patients with BI and AAD, high biomechanical stability is demanded at the craniovertebral junction to maintain the reduction and to facilitate bone fusion. Therefore, when insertion of

C2 pedicle screws is not possible, an ideal alternative fixation technique that would offer rigid vertebral immobilization while minimizing the risk of neurovascular injury is needed.

In this report, we describe the novel use of C2 medial pedicle screws (C2MPSs) as an alternative for C2 fixation in a series of 12 patients with BI and AAD who also had hypoplasia of C2 pedicle-pars region and VA variations. This technique can provide 3-column stability and avoid the aforementioned limitations of potential foramen transversarium violation and VA injury. To the best of our knowledge, the use C2MPSs to effect stabilization of the axis has not been previously reported in patients with BI and AAD.

Methods

Patient Data

During the period of January 2017 to December 2018, C2MPSs were used in 12 patients for atlantoaxial fixation. All 12 patients had BI with AAD and atlas assimilation, and all required atlantoaxial reduction and stabilization. Unilateral hypoplasia of the C2 isthmus was found in all patients. Preoperatively, flexion-extension lateral radiographs, CT scans with reconstruction views, and MR images were obtained for all patients to confirm diagnosis. CTA with multiplanar reconstruction was used to identify anatomical anomalies in C2, including hypoplasia of the isthmus, VA variations, and other unexpected malformations. Patient demographic, clinical, and radiological data are summarized in Table 1.

Surgical Technique

All patients underwent posterior atlantoaxial facet joint release, reduction, and fixation for the treatment of BI with AAD. Under general anesthesia, patients were placed in

TABLE 1. Demographic, clinical, and radiological data of patients treated with C2MPSs

Case No.	Sex	Age (yrs)	Chief Complaints	Radiological Anomalies	Narrow C2 Isthmus
1	F	36	Neck pain, extremity weakness, ataxia	BI, AAD, C1 assimilation	Rt sided
2	M	32	Extremity weakness, paresthesia	BI, AAD, C1 assimilation, congenital C2–3 fusion	Rt sided
3	F	25	Ataxia	BI, AAD, C1 assimilation	Lt sided
4	F	49	Dyspnea, extremity weakness	BI, AAD, C1 assimilation	Lt sided
5	F	42	Paresthesia	BI, AAD, C1 assimilation	Rt sided
6	M	58	Ataxia, lower cranial nerve dysfunction	BI, AAD, C1 assimilation, congenital C2–3 fusion	Lt sided
7	F	16	Lower cranial nerve dysfunction	BI, AAD, C1 assimilation	Rt sided
8	M	31	Neck pain	BI, AAD, C1 assimilation, congenital C2–3 fusion	Rt sided
9	F	47	Extremity weakness, paresthesia	BI, AAD, C1 assimilation	Rt sided
10	F	64	Occipital pain, paresthesia	BI, AAD, C1 assimilation	Lt sided
11	M	22	Neck pain, extremity weakness, paresthesia	BI, AAD, C1 assimilation	Rt sided
12	F	39	Extremity weakness, paresthesia	BI, AAD, C1 assimilation	Rt sided

FIG. 2. Illustrations of C2MPS placement. **A:** The entry point of the C2MPS (red dot) is 1–2 mm medial to the standard C2 pedicle screw. **B:** The pilot hole is prepared using a 2-mm high-speed diamond burr in a convergent and cephalad direction, guided by the superomedial surface of the C2 isthmus. The inner cortex of the C2 isthmus is drilled to facilitate screw insertion while preventing lateral cortex perforations and VA violation. **C:** The trajectory of the C2MPS is along the drilled inner cortex of C2 isthmus, through the lateral rim of the spinal canal, and into the anterior vertebral body, without violation of the vertebral foramen. Figure is available in color online only.

the prone position with their head fixed with a Sugita head holder. A posterior midline incision was made to expose the cervical spine from occiput to C3. The occipitalized C1 and C2 complex was exposed to the lateral border of the articulation. The dorsal root ganglion of C2 was cut off to expose the facet joint. After hemostasis was attained, the capsule of C1–2 facet joint was opened, and the cartilage endplate was removed with a curette to release the joint. During joint manipulation, we tried to push the C2 superior facet downward and forward. Once the joint was released, atlantoaxial reduction and spinal cord decompression were largely achieved. Bilateral occipitalized C1 lateral mass screws (3.5 × 18–24 mm; Vertex, Medtronic Sofamor Danek) were inserted as previously described.¹⁶ Because all patients had unilateral hypoplasia of the C2 pars, which prohibits insertion of pedicle screws, a standard pedicle screw (3.5 × 22–26 mm) was only placed in the normal side, as described,⁶ and the C2MPS was placed in the hypoplastic side as an alternative.

Prior to C2MPS insertion, the medial and lateral borders of the C2 pars interarticularis should be clearly delineated and the space between the inner cortex of the C2 pars and the dural sac should be dissected. The entry point of C2MPS was 1–2 mm more medial than the standard C2 pedicle screw and was marked with an awl or burr (Fig. 2A). Then, using a 2-mm high-speed diamond burr, the pilot hole was prepared. The trajectory was kept approximately 20° in a convergent and cephalad direction guided by the superomedial surface of the C2 isthmus and kept about 1–2 mm medial to the foramen transversarium and VA. The key point of this technique is to ensure that the trajectory is always medial to the foramen transversarium, and the lateral cortex of the C2 isthmus should keep intact during preparation of the pilot hole to avoid VA violation. Therefore, the inner cortex of the C2 isthmus was drilled slowly and meticulously using a sharp diamond drill to facilitate screw insertion while preventing lateral cortex perforations. The trajectory finally entered into the anterior vertebral body with the medial rim penetrating the spinal canal (Fig. 2B). During drilling, the handle must be held tight to avoid slipping, and the dural sac should be slightly retracted to the medial direction by the assistant

using a Penfield dissector to protect the dura from injury. A blunt ball probe was used to verify the integrity of the lateral cortex repeatedly. The hole was carefully tapped, and a polyaxial screw (3.5 × 24–28 mm) was inserted (Fig. 2C). After the screw insertion, a sheet of artificial dura was placed between the dural sac and the screw.

Reduction of the AAD and BI was performed by repositioning the patient's head and directly manipulating C1 and C2 using the screw and rod constructs. After fixation, a cross-link was connected between rods to strengthen the stability, and massive cancellous bone taken from the posterior iliac crest was placed over the decorticated surfaces of occipital bone and C2. Postoperatively, CT and MRI scans were reviewed to check the extent of reduction and decompression, bone fusion, and the position of implants.

Results

Surgical results are provided in Table 2. Satisfactory C2MPS placement and reduction were achieved in all 12 patients (Figs. 3 and 4). No instance of the vertebral foramen violation, VA injury, or dural laceration was observed. Ten of 12 patients had improvement in their neurological status, and in 2 patients it remained stable. One patient experienced severe neck pain, and another experienced swallowing discomfort after surgery, which had all resolved by the 3-month visit. The mean follow-up was 19.5 months. There were no cases of implant failure, and sagittal CT scans demonstrated evidence of solid fusion in all patients at final follow-up.

Discussion

The technique of C1 lateral mass and C2 pedicle screw fixation, known as the Goel-Harms technique, has been considered as an applicable and relatively safe procedure and is widely used in atlantoaxial fixation.^{16,17} This technique can provide rigid atlantoaxial immobilization and mitigate technical challenges compared with early atlantoaxial stabilization methods. However, during placement of the C2 pedicle screw, risk of VA injury still persists due to variations in pedicle and vascular anatomy.¹⁸ Anatomical studies have shown that approximately 20% of patients

TABLE 2. Surgical technique and clinical outcomes of patients treated with C2MPSs

Case No.	Fixation Performed (lt, rt)	Postop Neurological Status	Vertebral Foramen Violation	Bone Fusion Confirmed	FU (mos)	Complications
1	C1LM-C2PS, C1LM-C2MPS	Improved	No	Yes	20	Severe neck pain
2	C1LM-C2PS, C1LM-C2MPS	Improved	No	Yes	33	None
3	C1LM-C2MPS, C1LM-C2PS	Improved	No	Yes	24	None
4	C1LM-C2MPS, C1LM-C2PS	Improved	No	Yes	17	None
5	C1LM-C2PS, C1LM-C2MPS	Improved	No	Yes	26	None
6	C1LM-C2MPS, C1LM-C2PS	Improved	No	Yes	22	None
7	C1LM-C2PS, C1LM-C2MPS	Improved	No	Yes	13	None
8	C1LM-C2PS, C1LM-C2MPS	Stable	No	Yes	14	None
9	C1LM-C2PS, C1LM-C2MPS	Improved	No	Yes	12	Swallowing discomfort
10	C1LM-C2MPS, C1LM-C2PS	Stable	No	Yes	23	None
11	C1LM-C2PS, C1LM-C2MPS	Improved	No	Yes	18	None
12	C1LM-C2PS, C1LM-C2MPS	Improved	No	Yes	12	None

C1LM = C1 lateral mass; C2PS = C2 pedicle screw; C2MPS = C2 medial pedicle screw; FU = follow-up.

have variations in the course of the VA, and in the osseous structure at least on one side.^{6,19,20} In patients with craniovertebral junction anomalies, such as BI, AAD and C1 assimilation, the rate of variation is even higher and up to about 60%.²¹ When the placement of a C2 pedicle screw is

precluded, the C2 pars screw and translaminar screw are often considered as alternatives. However, the short pars screw and contralateral intralaminar screw fail to achieve anterior purchase of the C2 vertebral body, and they have been demonstrated to exhibit inferior biomechanical sta-

FIG. 3. Case 5. This 42-year-old woman presented with paresthesia. **A:** Preoperative sagittal CT scan revealing BI, AAD, and atlas assimilation. **B:** MR image showing ventral compression of the cervicomedullary junction and severe syringomyelia. **C and D:** Axial and sagittal CT scans with the cut passing through the C2 isthmus, demonstrating a right-sided, narrow isthmus in width and height. **E:** The patient underwent posterior atlantoaxial reduction and fixation using a right-sided C2MPS as an alternative to the conventional pedicle screw. **F and G:** Postoperative axial and coronal CT scans showing successful placement of the C2MPS without violation of the vertebral foramen (arrowheads). **H:** Postoperative sagittal CT scan showing reduction of the basilar BI and AAD. **I:** Solid bone fusion was confirmed on the CT scan at follow-up. **J:** Postoperative MR image demonstrating satisfactory decompression of the spinal cord and regression of the syringomyelia. Figure is available in color online only.

FIG. 4. Case 12. This 39-year-old woman presented with extremity weakness and paresthesia. **A:** Preoperative sagittal CT scan revealing BI, AAD, and atlas assimilation. **B–D:** Axial, sagittal, and coronal CT scans with the cut passing through the C2 isthmus, showing a right-sided narrow isthmus in width and height. **E:** The patient underwent posterior atlantoaxial reduction and fixation using right-sided C2MPS as an alternative to the conventional pedicle screw. **F and G:** Postoperative axial and coronal CT scans demonstrating placement of the C2MPS without violation of the vertebral foramen (arrowheads). **H:** Postoperative sagittal CT scan showing reduction of the basilar BI and AAD and solid bone fusion. Figure is available in color online only.

bility as well as lower fusion rates. Elliott et al.²² reported that pseudarthrosis occurred in a greater proportion of patients treated with C2 pars screws (4.4%) compared with C2 pedicle screws (0.22%). In a series presented by Chang et al.,²³ translaminar screws significantly lowered the success rate of C1–2 fixation (57.1% in cases of bilateral translaminar screws, and 78.9% in cases of unilateral translaminar screws) compared with bilateral C2 pedicle screws (100%). Therefore, C2 pars screws and laminar screws may not be ideal alternative options for patients with atlantoaxial instability requiring extra-rigid immobilization to maintain reduction and achieve fusion.^{13,22} It is essential to consider a salvage technique that should provide long and strong purchase for the whole C2 vertebral body when patients have a hypoplastic C2 isthmus.

In this study, we introduce an alternative technique of C2 fixation with a case series of 12 patients. This novel technique can offer 3-column rigid fixation of the axis and eliminate the risk of VA injury. In our series, all screws were safely inserted without vertebral foramen violation or dural laceration. All patients demonstrated solid fusion and the long-term clinical results are satisfactory.

Anatomically, the lateral cortex of the C2 isthmus is significantly thinner and weaker than the inner cortex.²⁴ Thus, the lateral cortex could be breached inadvertently

without any free-hand feeling during preparation of the pilot hole using a hand drill, especially when the isthmus is hypoplastic, posing threats to the VA. In this technique, we try to drill the inner cortex of the narrow C2 isthmus to obtain enough space for insertion of a 3.5-mm screw. The screw trajectory should be kept about 1–2 mm medial to the foramen transversarium based on preoperative design to prevent lateral violation. Because the lateral cortex can be well preserved and there is about 1- to 2-mm distance from the screw trajectory to the foramen transversarium, the chance of VA violation is relatively low, especially for an experienced surgeon.

Bone fusion is strongly affected by the mechanical stability of the involved segment.²⁵ As a result, rigid internal fixation methods should be used to achieved higher fusion rates. The C2MPS that travels along the drilled inner cortex of the C2 isthmus, through the lateral rim of the spinal canal into the anterior vertebral body could achieve a tricortical or even quadricortical purchase. By virtue of its long traverse in the firm cortical bone with multiple anchoring points, this “in-out-in” screw could provide excellent stability and serve as an optimal alternative for C2 fixation. With rigid atlantoaxial fixation, bone fusion was achieved in all 12 patients in our series.

However, there may be concerns about the potential

FIG. 5. Illustration of C2MPS placement and dural protection. Before screw placement, the space between the medial border of the C2 pars and dura should be carefully dissected. During pilot hole drilling, the dural sac is slightly and gently retracted inward to avoid laceration. Figure is available in color online only.

risks of dural lacerations because the spinal canal is violated during cortical drilling and screw placement. Based on a CT scan anatomical study, the distance from the medial rim of the pars to the dura is 3.53 ± 1.57 mm, which could accommodate a 3.5-mm screw.²⁶ Before screw insertion, the space between bone and dura should be carefully dissected. During the pilot hole drilling, the dural sac was slightly and gently retracted inward with a Penfield dissector (Fig. 5). A microscope is recommended in the use of high-speed burr. With better visualization and magnification, intraoperative dural lacerations can be largely averted.

Once dural laceration occurs, intraoperative primary repair should be the first choice. Direct suture to achieve a watertight closure of the dura is most favorable. If direct suture is difficult or the dural defect is large, autogenous fascia or artificial dura could be patched and sutured on the defect for repair. Postoperatively, we strongly recommend placing a lumbar drain for 5–7 days, which could decrease the distension of the dural sac and facilitate healing of dural edges. Intraoperative dural defect repair and postoperative lumbar drainage have been proven an effective strategy in treating CSF leaks in anterior cervical surgery, which should be also efficient in the treatment of CSF leaks in posterior atlantoaxial surgery.²⁷

In this technique, fluoroscopy or navigation was not used during screw insertion. Intraoperative fluoroscopy cannot demonstrate the precise dimension of the narrow C2 isthmus and the position of the foramen transversarium due to the image overlap of surrounding structures. It is time consuming, may cause disruption of workflow, and increases radiation exposure to the patient and surgeon.²⁸

Intraoperative navigation system could provide real-time intraoperative information of the trajectory during screw insertion.²⁹ However, after facet joint release, the C2 vertebra is mobile, and the navigation requires reregistration, which may cause navigation errors and prevent the accurate placement of screws.^{30,31} In fact, the whole process of the C2MPS placement could be done under direct visualization. After dissecting the space between the dural sac and the C2 pars, the superior and medial border of the C2 isthmus can be clearly exposed. An in-out-in screw can be inserted, guided by the superomedial surface of the C2 isthmus under direct visualization. With the help of the operative microscope, the free-hand screw insertion is feasible.

There are limitations to this study. This study is a preliminary technical report with limited cases, and the biomechanical properties of this technique have not yet been tested. However, based on our clinical experience, the firm nature of the cortex makes the purchase of the multicortical C2MPS significantly strong. We believe that this novel technique could have important implications for fixation of the axis. Further biomechanical studies, as well as large-sized clinical studies, would be required to provide a more exhaustive evaluation of this technique.

Conclusions

This novel in-out-in technique can provide 3-column rigid fixation of the axis with multicortical purchase. Excellent clinical outcomes with low complication rates were achieved with this novel technique. When the placement of a C2 pedicle screw is not possible due to anatomical constraints, the C2MPS can be considered as an efficient alternative.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Qiao, Yu. Acquisition of data: Du. Analysis and interpretation of data: Du. Drafting the article: Du, Yin. Critically revising the article: Yin. Administrative/technical/material support: Qiao. Study supervision: Qiao, Yu.

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