Short Monocortical Screws at C4-C6 Lateral Masses as Novel Mid-cervical Anchor in Cervical Laminoplasty with Instrumented Fusion: Surgical Outcomes Compared with C5 Pedicle Screws as Mid-cervical Anchor

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Abstract:

Introduction: This retrospective study compared rates of bony fusion and screw loosening after multilevel posterior decompression and fusion (PDF) with short monocortical screws (SMS) as a novel mid-cervical anchor versus C5 pedicle screws (PS) as a mid-cervical anchor.

Methods: We analyzed 15 consecutive patients who underwent C2-T1 PDF with C5 PS as mid-cervical anchor (PS group) and 18 consecutive patients who underwent the procedure with SMS at C4-C6 as mid-cervical anchor (SMS group). Radiological outcomes, including rates of bony fusion at each level and screw loosening, and clinical outcomes, including Japanese Orthopedic Association (JOA) score, neck pain, neck disability index (NDI), and EuroQol 5 Dimension (EQ-5D), were compared between groups. In the SMS group, screw perforation types and appropriate screw insertion procedure were also investigated.

Results: The fusion rate at C2/3 in the SMS group (56%) was significantly higher than that in PS group (13%; P = 0.0272). None of the patients had SMS loosening postoperatively. Clinical outcomes, including JOA score, neck pain, NDI, and EQ-5D, did not differ between the groups. In the SMS group, facet perforation was the most common type of perforation. The recommended direction for SMS insertion at C4-C6 was 35°-37° in the cranial direction and 25°-30° in the medial direction; the recommended screw length was 10 mm.

Conclusions: SMS at C4-C6 was as effective as C5 PS as a mid-cervical anchor in PDF, according to clinical and radiological outcomes. The fusion rate at C2/3 in the SMS group was significantly higher than that in the PS group. There was no postoperative loosening of the C5 PS or C4-C6 SMS in either group.

Keywords:

Posterior decompression and fusion, Lateral mass screw, Mid-cervical anchor, Pedicle screw, Posterior fusion

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Introduction

In multilevel posterior decompression and fusion (PDF) of the cervical spine with C2 and C7 pedicle screws (PS), lateral mass screws (LMS) or PS are usually used as the mid-cervical anchor[1)]. Conventional bicortical LMS are inserted in a lateral direction to avoid injury to the vertebral artery (VA)[2-4)]. The LMS head interferes with the lateral gutter and the lifted lamina in cervical laminoplasty and instrumented fusion because the insertion positions are at the center[2)] or within 1 mm of the center[3,4)] of the lateral mass. Since 2013, we have used C5 PS, which provides strong fixation[5)], as the mid-cervical anchor in PDF using C2, C7, and T1 PS (Fig. 1)[1)]. However, fusion rates at each level, especially at C2/C3, are low. Furthermore, C5 PS insertion is not possible in patients with a very narrow C5 pedicle. Insertion of C5 PS be-

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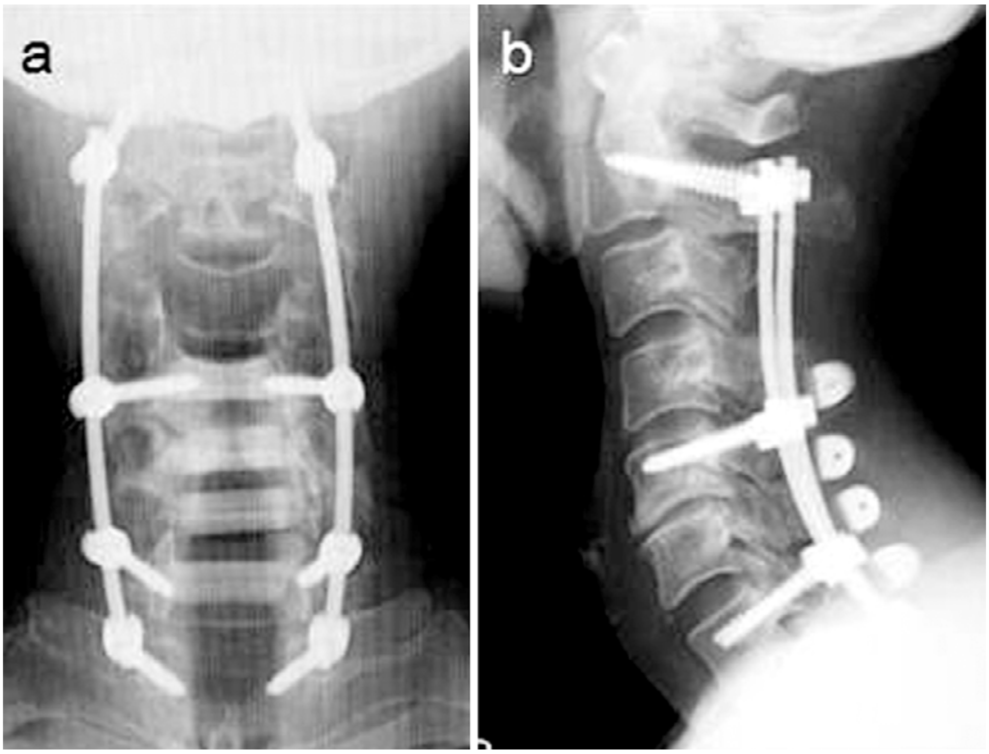

Figure 1. C5 pedicle screws as mid-cervical anchor in cervical laminoplasty and instrumented fusion. **a** Anteroposterior radiograph of cervical spine. **b** Lateral radiograph of cervical spine.

tween the VA and spinal cord is dangerous[6]. Rod design is also complicated by the need to design in both the coronal and sagittal plane because the lateral insertion point of the C5 PS does not form a straight line between the PS at C2 and C7 (Fig. 1). Therefore, in 2015 we changed the mid-cervical anchor from C5 PS to short monocortical screws (SMS) at the C4-C6 lateral masses. A mid-cervical SMS at C4, which may provide additional stabilization from C2-C5, can be added. The SMS are inserted from the outside 1-2 mm from the center of the lateral mass at C4-C6 in a craniomedial direction (Fig. 2). The SMS head does not interfere with the lateral gutter or the lifted laminae because the SMS insertion point is 1-2 mm outside the center of the lateral mass. SMS insertion is safe and easily performed because the short 10-12 mm screws are inserted into cancellous bone of the lateral mass without fluoroscopy. Furthermore, designing the rod for the sagittal plane alone is easy because the SMS insertion points at C4-C6 line up on a straight line between the C2 and C7 PS.

The main purpose of this retrospective study was to compare the rates of bony fusion and screw loosening between PDF with SMS as mid-cervical anchor and PDF with C5 PS as mid-cervical anchor. The second purpose was to describe SMS perforation types and appropriate SMS insertion procedures.

Materials and Methods

Patients

This study included 18 consecutive patients (12 men, six women) who underwent C2-T1 PDF with C4-C6 SMS as mid-cervical anchor (SMS group) from February 2015 to June 2017 (Fig. 2). Average patient age at the time of surgery was 59 years (range, 34-87 years). Cervical spondylotic myelopathy (CSM) was clinically evident in four cases; ossification of the posterior longitudinal ligament (OPLL) was seen in 14 cases.

Fifteen consecutive patients (nine men, six women) who underwent C2-T1 PDF with C5 PS as mid-cervical anchor from June 2013 to January 2015 were included as the control group (PS group; Fig. 1). Average patient age at the time of surgery in the control group was 63 years (range, 41-77 years). CSM was clinically evident in five cases; OPLL was observed in ten cases.

All patients in both groups were investigated 1 year postoperatively; the follow-up rate was 100%.

Surgical indications, surgical techniques, and postoperative management

Patients with cervical myelopathy and OPLL that was K-line (−) in the neck-flexed position[7] and those with CSM with a longitudinal distance index[8] ≥ 5.0 and K-line (−) alignment in the neck-flexed position underwent C2-T1 PDF and were included in the present study.

In both groups, PS were inserted in the bilateral pedicles

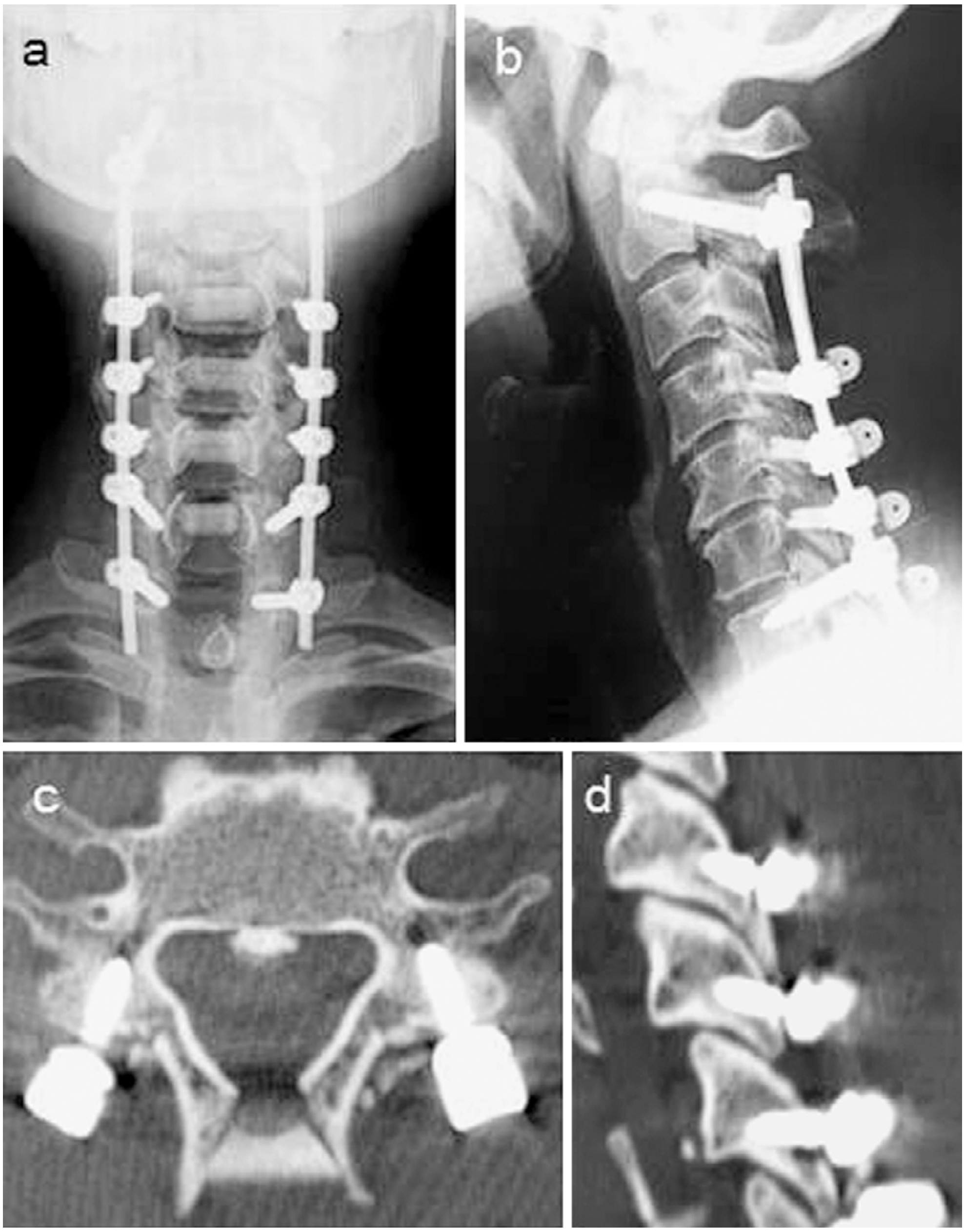

Figure 2. Short monocortical screws (SMS) at C4-C6 as mid-cervical anchor in cervical laminoplasty and instrumented fusion. **a** Anteroposterior radiograph of cervical spine. **b** Lateral radiograph of cervical spine. **c** Axial computed tomographic (CT) view of SMS. **d** Sagittal CT image of SMS.

of C2, C7, and T1 (except in one patient in the SMS group, in whom a unilateral C2 intralaminar screw was inserted due to difficulty inserting the C2 pedicle screw because of a high-riding VA), preserving the attachment of the rectus capitis posterior major, the oblique capitis inferior, and the semispinalis cervicis to the C2 spinous process[1] (Fig. 3). In all patients in the PS group, the C5 pedicle screws were inserted as mid-cervical anchors with direct visualization of the cancellous bone of the C5 pedicle, which was determined by extension of prophylactic bilateral C4/5 foraminotomy, using pedicle axis view techniques on intraoperative fluoroscopy[9]. In two patients, a unilateral C5 PS could not be inserted because of very narrow pedicle. SMS were inserted as mid-cervical anchors in the lateral mass at C4-C6 without fluoroscopy in the SMS group. Before SMS insertion, the points of the lateral gutter were marked with a surgical drill at C4-C6 (Fig. 3-a). SMS were inserted from the outside 1-2 mm from the center of the lateral mass surface, in a 30° cranial and 20° medial direction. The bilateral rods were passed under the semispinalis cervicis in both groups (Fig. 3-b). Next, laminectomy was performed at C3 for complete preservation of the semispinalis cervicis at C2[10]; spinous process-splitting laminoplasty was performed with hydroxyapatite spinous process spacers[11] (Fig. 3-c). Local bone grafting was performed from C2/C3 to C7/T1 in all patients. No specific graft bed preparation was performed from C2 to T1. Local bone chips were placed around the C2 PS, on the lateral masses under the rods at C2-C4, on the

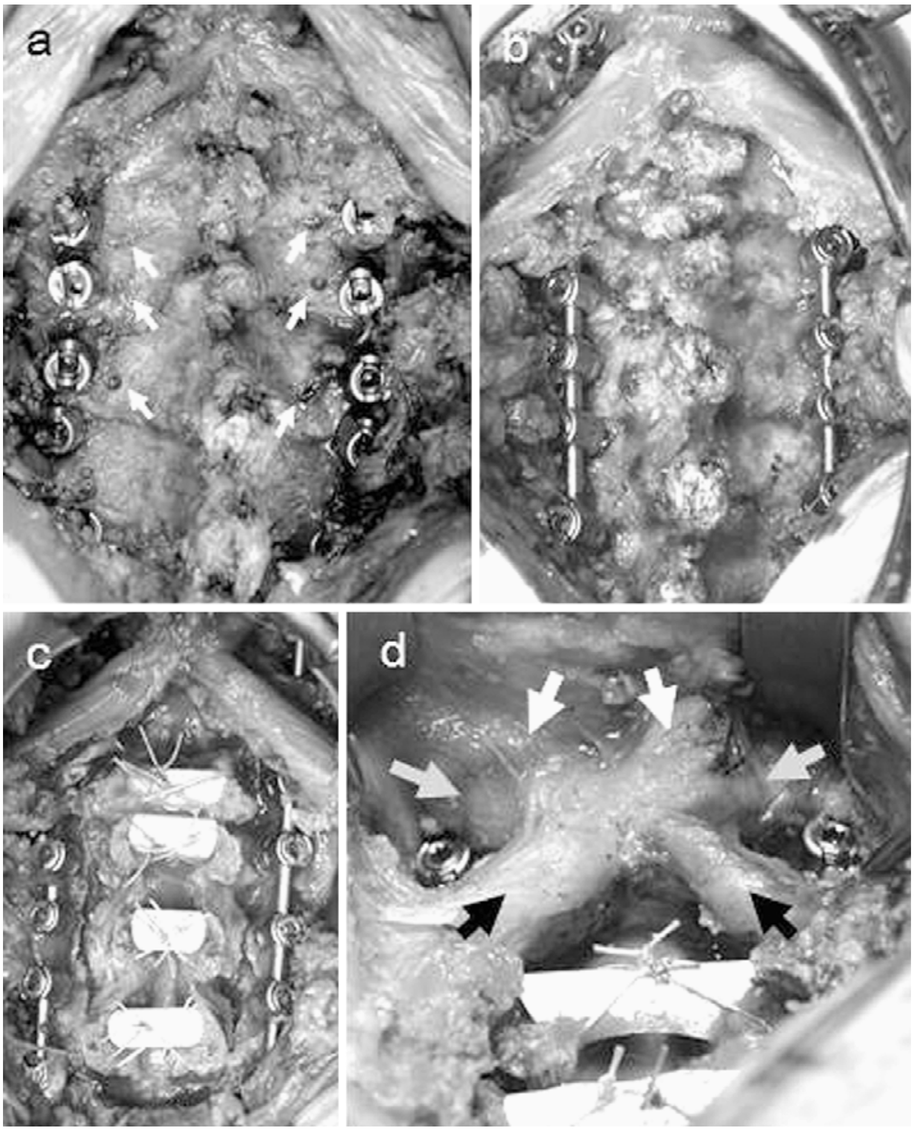

Figure 3. C2-T1 posterior decompression and fusion performed at our institution. **a** Bilateral C2, C7, and T1 pedicle screws and short monocortical screws (SMS) at C4-C6 lateral masses (marking of lateral gutter positions [arrows] before SMS insertion). **b** Passing the bilateral rods under the semispinalis cervicis. **c** Double-door laminoplasty with hydroxyapatite spinous process spacers. **d** Preservation of three muscle attachments (rectus capitis posterior major [white arrow], oblique capitis inferior [gray arrow], and semispinalis cervicis [black arrow]) to C2.

C4-C7 gutters, and on the lateral masses at C7-T1.

None of the patients in either group had postoperative immobilization with a collar. Patients were permitted to sit up and walk within 1 week postoperatively; exercise was started within 1 week postoperatively.

Radiologic evaluation

Bony fusion from C2/3 to C7/T1 was evaluated by assessing trabecular bone formation on either side in the sagittal view on computed tomography (CT). These factors were evaluated at 1 year after surgery. In each group, loosening of C5 PS or C4-C6 SMS was evaluated by assessing radiolucent space on CT. Problems with C2 PS (loosening of C2 PS or of the rod from C2 PS head) were evaluated. The rates of bony fusion and screw loosening in the SMS group and PS group were compared retrospectively.

The accuracy of SMS positioning was evaluated with postoperative CT, using the classifications of Uehara et al.[12]: grade 1, no perforation; grade 2, minor perforation (less than 50% of screw diameter); and grade 3, major perforation (50% or more of screw diameter). Perforation types are shown in Fig. 4.

All radiographic measurements were made with XTREX VIEW (J-MAC System, Sapporo, Japan), which was accurate to 0.01°.

Clinical evaluation

Pre- and postoperative Japanese Orthopedic Association

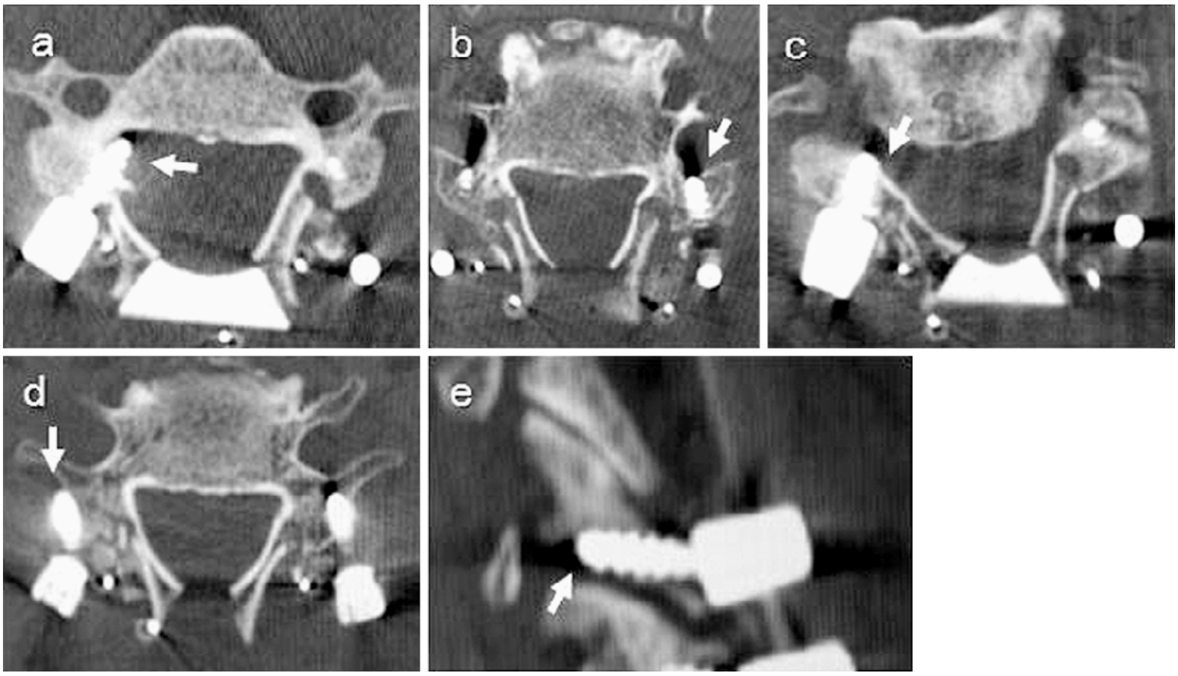

Figure 4. Types of perforation with short monocortical screw (**a-e**). **a** Spinal canal type. **b** Foramen transversarium type. **c** Foramen type. **d** Outside type. **e** Facet-type.

(JOA) scores and JOA score recovery rates (%) were investigated. The JOA score recovery rate 1 year after surgery was calculated as follows: recovery rate (%) = (postoperative JOA score−preoperative JOA score) / (17−preoperative JOA score) × 100. The pre- and 1-year postoperative NDI values were evaluated. Pre- and postoperative axial pain were evaluated with a visual analog scale. Pre- and postoperative EuroQol 5 Dimension results were examined to evaluate health-related quality of life[13]. The descriptive system comprises five dimensions: mobility, self-care, usual activities, pain/discomfort, and anxiety/depression.

Measurements of appropriate SMS insertion

In all 31 patients in both groups, appropriate direction of SMS insertion was measured on CT images at C4, C5, and C6. In the sagittal view, the upper and lower angles were measured (Fig. 5). In the axial view, the inner and outer angles were measured (Fig. 5). The upper and lower angles were defined as the angles between a vertical line along the facet surface and lines connecting the SMS insertion point with the anterosuperior or anteroinferior edge of the lateral mass, respectively. The inner and outer angles were defined as the angles between a vertical line along the facet surface and lines connecting the SMS insertion point with the inner edge of the spinal canal and the inner edge of the foramen transversarium, respectively. The centers of the upper and lower angles, and the centers of the inner and outer angles, were defined as the recommended directions for SMS insertion.

The shortest distances between the SMS insertion point and the spinal canal or the foramen transversarium were measured on the axial CT view (Fig. 5). The rate of VA passage into the foramen transversarium was examined at each C4, C5, and C6 with contrast-enhanced CT.

All radiographic measurements were made with XTREX VIEW (J-MAC System, Sapporo, Japan), which was accurate to 0.01°.

Statistical analysis

Fisher's exact test, the Mann-Whitney U test, and Wilcoxon's signed-rank test were applied in statistical analyses. Differences with a P value < 0.05 were considered statistically significant.

Results

Radiologic evaluation

The rates of bony fusion from C2/3 to C7/T1 are shown in Table 1. The SMS group had a significantly higher fusion rate at C2/3 than the PS group (56% versus 13%; P = 0.0272). There was no postoperative loosening of C5 PS or C4-C6 SMS in either group. Problems with C2 PS are shown in Table 2. The distribution of problems with C2 PS did not differ between groups. Of 19 screw perforations in the SMS group, 12 (63%) were facet-type perforation (Fig. 4-e) as shown in Table 3.

Clinical evaluation

JOA scores improved significantly from preoperatively to 1 year postoperatively in both groups (from 10.7 to 12.9 in PS group and from 10.4 to 13.4 in SMS group; P = 0.0106 and P = 0.0003, respectively). The mean JOA score recovery rate was 33.8% in the PS group and 45.3% in the SMS

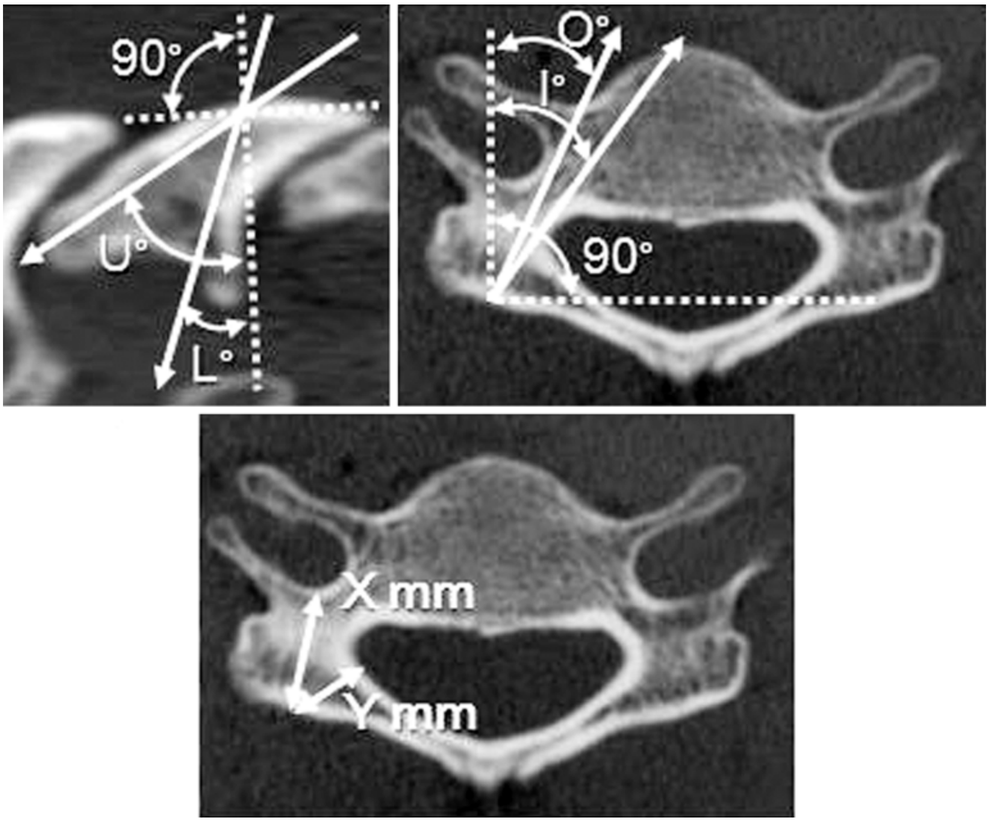

Figure 5. Measurement of insertion directions of short monocortical screws (SMS) on computed tomography images. **U**, upper angle; **L**, lower angle; **I**, inner angle; **O**, outer angle; **X**, shortest distance between SMS insertion point and foramen transversarium; **Y**, shortest distance between SMS insertion point and spinal canal.

Table 1. Bony Fusion at Each Level, According to Group.

	PS group (*n*=15)	SMS group (*n*=18)	*P*-value
C2/3	2 (13%)	10 (56%)	**0.0272**
C3/4	10 (67%)	13 (72%)	>0.9999
C4/5	15 (100%)	18 (100%)	
C5/6	13 (87%)	16 (89%)	>0.9999
C6/7	11 (73%)	16 (89%)	0.3747
C7/T1	11 (73%)	7 (39%)	0.0801

Values shown are number of patients (%).
n, number of patients
Bold indicates a significant *P*-value.
PS, pedicle screw; SMS, short monocortical screw

Table 2. Problems with C2 Pedicle Screws at 1 Year after Surgery.

	No problem	Problems
PS group (*n*=30)	26 (87%)	Four (13%) (screw loosening, two; rod loosening, two)
SMS group (*n*=35)	32 (91%)	Three (9%) (screw loosening, three)

Values shown are number of screws (%).
n, number of screws
PS, pedicle screw; SMS, short monocortical screw

group; this difference was not significant.

The visual analog scale score for neck pain (9.9 mm in PS group and 12.1 mm in SMS group preoperatively) did not improve postoperatively in either group (11.7 and 8.9 mm, respectively). Preoperative NDI (11.5 in the PS group and 16.2 in the SMS group) also did not improve postoperatively in either group (14.7 and 13.3, respectively). Preoperative EuroQol 5 Dimension results (0.54 in the PS group and 0.51 in the SMS group) also did not improve postoperatively (0.61 and 0.70, respectively).

Appropriate SMS insertion

Measurements of four angles in the lateral mass at C4-C6 for SMS insertion and the calculated directions for appropriate SMS insertion are shown in Table 4 and Fig. 6. SMS insertion points at C4-C6 were on the straight line connecting C2, C7, and T1 PS (Fig. 6-a). The recommended direction for SMS insertion was 35°-37° in a cranial direction (Fig. 6-b) and 25°-30° in a medial direction (Fig. 6-c). The shortest distances to the foramen transversarium and the spinal canal were 11.0-11.4 mm and 8.1-8.6 mm, respectively (distance to foramen transversarium at C4: 11.0 ± 1.4 mm, C5: 11.4 ± 1.4 mm, and C6: 11.3 ± 1.6 mm; distance to spinal at C4: 8.1 ± 1.4 mm, C5: 8.3 ± 1.3 mm, and C6: 8.6 ± 1.2 mm).

Table 3. Perforation of Screws as Mid-cervical Anchor.

	Grade 1	Grade 2	Grade 3
C4 SMS (*n*=36)	28 (78%)	Six (17%) (four facet, one foramen, one foramen transversarium)	Two (6%) (one spinal canal, one facet)
C5 SMS (*n*=36)	34 (94%)	0	Two (6%) (two facet)
C6 SMS (*n*=36)	27 (75%)	Six (17%) (three foramen transversarium, two facet, one outside)	Three (8%) (three facet)

Values shown are number of screw (%).
n: number of screws
SMS: short monocortical screw

Table 4. Measurement of Four Angles in Lateral Mass in Both Groups.

	Upper angle (degrees)	Lower angle (degrees)	Inner angle (degrees)	Outer angle (degrees)	Recommended sagittal angle (degrees)	Recommended axial angle(degrees)
C4	54.1±5.2	20.0±7.0	34.7±6.6	24.3±5.2	37	30
C5	52.9±8.5	17.7±7.5	33.9±5.1	23.0±4.7	36	29
C6	52.9±8.3	16.9±7.6	31.1±5.5	19.2±5.0	35	25

Values shown are mean±standard deviation.
PS, pedicle screw; SMS, short monocortical screw

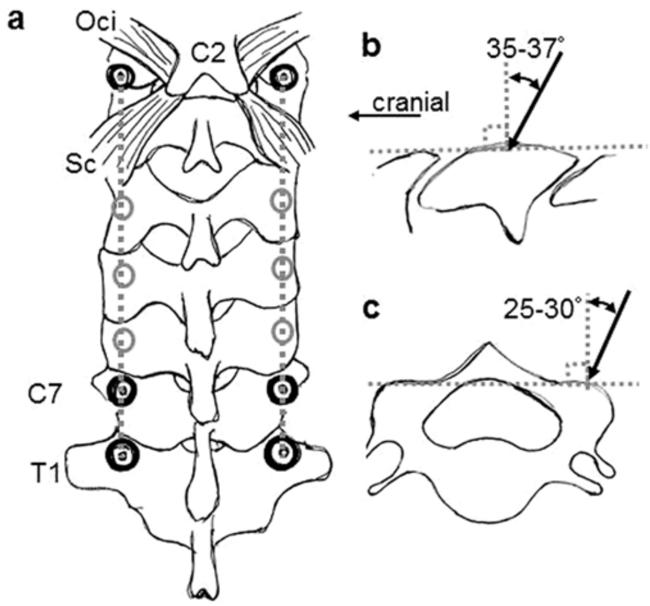

Figure 6. Schematic drawings of appropriate short monocortical screw (SMS) insertion procedure. **a** SMS insertion points at C4-C6 (gray circles) were on the straight line (gray dotted line) connecting C2, C7, and T1 pedicle screws (black circles). Oci, oblique capitis inferior; Sc, semispinalis cervicis. **b** Cranial direction of 35°-37°. **c** Medial direction of 25°-30°.

The rates of passage of 66 VA into the foramen transversarium were 100%, 100%, and 95% at C4, C5, and C6, respectively.

Discussion

The C2/3 fusion rate in the SMS group (56%) was significantly higher than that in the PS group (13%). This finding indicates that C2 and C5 PS fixation is insufficient to achieve bony fusion at C2/3. This finding might be attributed to the flexibility of the rod with the long lever arm from C2 to C5 in the PS group[1]. A C4 SMS provides a biomechanically superior environment for bony fusion at C2/3. The rate of bony fusion at C2/3 was lower than fusion rates at C3/4-C6/7 in both groups. It was difficult to place a large bone graft mass at C3 because the spinal cord was exposed by C3 laminectomy with preservation of the semispinalis cervicis insertion on C2. Therefore, meticulous bone graft bed preparation was needed at the C2 and C3 lateral masses in both groups. Because the bony fusion rate from C3/4 to C6/7 was high near the lateral gutters, which serve as a good bone graft bed, it is possible that meticulous bone graft bed preparation may produce higher rates of bony fusion at C2/3 and C7/T1 even if the bone graft is only local bone.

There were no differences in problems with the C2 PS. Furthermore, none of the patients had SMS loosening. Although our SMS fixation may be weaker biomechanically than PS and conventional bicortical LMS, SMS at three levels had sufficient strength clinically as a mid-cervical anchor in the present study. Furthermore, SMS as mid-cervical anchor in PDF may be suitable as salvage fixation for failed mid-cervical anchoring with LMS because the insertion points and directions differ. We found no significant differences between groups in clinical outcomes, including JOA score, neck pain, NDI, or EuroQol 5 Dimension score. In addition, the SMS insertion procedure reduces stress related to safety for operator because the SMS are short monocortical screws. The head of the SMS does not interfere with the lateral gutters or the lifted laminae, and the sagittal plane-only design of the rod is easy because the insertion position 1-2 mm outside the center of the lateral mass lines up on a straight line between the C2 and C7 PS.

Recently, Maki et al.[14] reported a novel technique for subaxial cervical fusion surgery using paravertebral foramen screws (PVFS) in a biomechanical study of fresh-frozen cadaver specimens. Their findings suggest that PVFS provided stronger fixation than LMS for initial applications and that the fixation was equal to LMS for salvage applications. The PVFS was inserted in the relatively hard cancellous bone around the entry zone of the pedicle under lateral fluoroscopic imaging and was used as the main fixation device in posterior cervical fusion. Although biomechanical testing of SMS was not performed in the present clinical study, we clarified that SMS at C4-C6 had adequate strength as mid-cervical anchor in C2-T1 PDF. The authors think that the SMS insertion technique is easier than PVFS insertion, which must be highly precise, because the SMS may be inserted in the any cancellous bone in the lateral mass without fluoroscopic imaging.

Ideally, an initial radiographic anatomical study should have been performed to determine the trajectory and length of SMS before application of this SMS technique in a clinical setting. However, we thought that most SMS could be safely inserted into the cancellous bone of the lateral mass without a precise direction measurement because of the large cancellous bone area and the short screw. After investigating the accuracy of SMS in this study, we understand that some types of perforation can occur with SMS. Therefore, we must determine appropriate SMS insertion procedures. We recommend a cranial direction of 35°-37° and a medial direction of 25°-30° for SMS insertion. In the SMS group, facet-type perforation was the most common. Although we inserted the SMS in a cranial direction of 30° to be parallel with the facet joint, following the method of Magerl[3], facet-type perforation might occur more often with this smaller angle than with the recommended angle of 35°-37° calculated in the present study. Although facet-type perforation may increase the risk of premature facet joint degeneration, it may also provide more rigid fixation similar to that provided by a bicortical or tricortical screw such as a transarticular screw[15]. The shortest distances to the foramen transversarium and the spinal canal were 11.0-11.4 mm and 8.1-8.6 mm, respectively. The rates of VA passage into the foramen transversarium were 100%, 100%, and 95% at C4, C5, and C6, respectively. Therefore, there was a risk of injury to the VA and cervical spinal cord at all levels from C4 to C7. In this series, there were four grade 1 foramen transversarium perforations at C4 and C6 and one grade 2 spinal canal perforation at C4. To avoid injury to the VA and spinal cord, we recommend a short SMS length of 10 mm. In the future, we must investigate whether the accuracy of SMS improves with our recommended directions of SMS insertion.

This study had several limitations. The biggest limitation was the small study population. Furthermore, the follow-up period in the present study was short; long-term monitoring is needed to determine if facet fusion rates increase or SMS instability occurs over time. Biomechanical pullout testing of SMS at three levels as mid-cervical anchor in PDF will also be helpful as an indicator of long-term outcome.

Conclusion

SMS at C4-C6 was as useful as C5 PS as a mid-cervical anchor in PDF, according to clinical and radiological outcomes. The fusion rate at C2/3 in the SMS group was significantly higher than that in the PS group. There was no postoperative loosening of the C5 PS or C4-C6 SMS in either group. The recommended direction for SMS insertion at C4-C6 was a cranial direction of 35°-37° and a medial direction of 25°-30°; the recommended screw length was 10 mm.

Conflicts of Interest: The authors declare that there are no relevant conflicts of interest.

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Author Contributions: Kazunari Takeuchi wrote and prepared the manuscript, and all of the authors participated in the study design. All authors have read, reviewed, and approved the article.

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