A novel screw guiding method with a screw guide template system for posterior C-2 fixation

Clinical article

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Object. Accurate insertion of C-2 cervical screws is imperative; however, the procedures for C-2 screw insertion are technically demanding and challenging, especially in cases of C-2 vertebral abnormality. The purpose of this study is to report the effectiveness of the tailor-made screw guide template (SGT) system for placement of C-2 screws, including in cases with abnormalities.

Methods. Twenty-three patients who underwent posterior spinal fusion surgery with C-2 cervical screw insertion using the SGT system were included. The preoperative bone image on CT was analyzed using multiplanar imaging software. The trajectory and depth of the screws were designed based on these images, and transparent templates with screw guiding cylinders were created for each lamina. During the operation, after templates were engaged directly to the laminae, drilling, tapping, and screwing were performed through the templates. The authors placed 26 pedicle screws, 12 pars screws, 6 laminar screws, and 4 C1–2 transarticular screws using the SGT system. To assess the accuracy of the screw track under this system, the deviation of the screw axis from the preplanned trajectory was evaluated on postoperative CT and was classified as follows: Class 1 (accurate), a screw axis deviation less than 2 mm from the planned trajectory; Class 2 (inaccurate), 2 mm or more but less than 4 mm; and Class 3 (deviated), 4 mm or more. In addition, to assess the safety of the screw insertion, malpositioning of the screws was also evaluated using the following grading system: Grade 0 (containing), a screw is completely within the wall of the bone structure; Grade 1 (exposure), a screw perforates the wall of the bone structure but more than 50% of the screw diameter remains within the bone; Grade 2 (perforation), a screw perforates the bone structures and more than 50% of the screw diameter is outside the pedicle; and Grade 3 (penetration), a screw perforates completely outside the bone structure.

Results. In total, 47 (97.9%) of 48 screws were classified into Class 1 and Grade 0, whereas 1 laminar screw was classified as Class 3 and Grade 2. Mean screw deviations were 0.36 mm in the axial plane (range 0.0–3.8 mm) and 0.30 mm in the sagittal plane (range 0.0–0.8 mm).

Conclusions. This study demonstrates that the SGT system provided extremely accurate C-2 cervical screw insertion without configuration of reference points, high-dose radiation from intraoperative 3D navigation, or any registration or probing error evoked by changes in spinal alignment during surgery. A multistep screw placement technique and reliable screw guide cylinders were the key to accurate screw placement using the SGT system.

Key Words: • spinal fixation • screw guide template • C-2 vertebra • cervical

RIGID anchoring and fixation techniques in the C-2 vertebra have been reported since 1964 in the form of pedicle screws and transarticular screws. Because of the strong biomechanical structure of the C-2 vertebra, the use of anchor screws in these techniques has been widely accepted not only for atlantoaxial fixation but also for occipitocervical fixation or multiple segmental fixation to treat various cervical instability pathologies. In addition to these techniques, safer options of screwing methods into C-2, such as pars or intralaminar screws, have been used in cases in which there are extremely narrow pedicles or anomalous paths of the vertebral arteries. Although there have been some reports about the ideal trajectory of C-2 screws, recognition of the ideal trajectory in cases...
of severe deformity or abnormality are considered to be difficult, challenging, and dangerous even with the aid of fluoroscopy.\(^6\),\(^30\) Therefore, 3D navigation systems are currently recommended for assistance in safely placing screws.\(^5\) However, intraoperative 3D navigation systems have their own problems, such as high radiation exposure,\(^3\),\(^31\) long operation time, relative inaccuracy,\(^10\),\(^36\) and high cost.\(^31\)

To solve these issues, we developed the patient-specific screw guide template (SGT) system, aiming for more accurate and safer placement of screws into the spine. We have reported the accuracy of this system for insertion pedicle screws into the thoracic spine.\(^32\) The purpose of this study is to report on the suitability of our novel SGT system for placement of C-2 cervical screws.

**Methods**

Before the present investigation, we obtained approval from the ethics committees at our institution. Written informed consent was obtained from each patient after oral explanations regarding the details of the present study were given.

**Study Population**

Twenty-three consecutive patients who underwent posterior spinal fusion surgery with C-2 cervical screw insertion using the SGT system since 2011 were included in this study. There were 10 males and 13 females, and the average age was 69.4 years (range 54–86 years). There were 7 patients with cervical kyphosis, 5 with basilar invagination due to rheumatoid arthritis and 1 due to idiopathic cervical deformity, 4 with atlantoaxial subluxation due to rheumatoid arthritis, 2 with ossification of the posterior longitudinal ligament, 2 with odontoid, 1 with metastatic tumor of the cervical spine, 1 with spinal deformity due to destructive spondyloarthropathy, and 1 with cervical spine fracture with ankylosing spondylitis.

A total of 48 C-2 cervical screws were inserted using the SGT system. There were 26 pedicle screws, 12 pars screws, 6 laminar screws, and 4 C1–2 transarticular screws. The diameters of the screws were adjusted to the width of the pedicle, pars, or lamina. The Synapse system (Synthes, Inc.) was used for cervical posterior fusion.

**Imaging and Template Production**

As previously described,\(^5\) preoperative bone images on CT were exported in DICOM format to 3D/multiplanar imaging software (ZioStation, Ziosoft) and analyzed. The ideal trajectories of the screws were designed 3-dimensionally to insert as long screws as possible and pass at least 2 mm inside the cortical wall. The locations of the screw tips were planned to be close to the anterior cortex of the vertebral body but not to perforate the cortex. The coordinates of the bone entry points and the tips of the screws were determined, and the diameters and lengths of the screws were calculated using computer simulation adjusting to the widths of the pedicle, pars, or lamina (Fig. 1). For accurate guidance of the screws, 3 templates were produced for each screw. Location templates with 3-mm-diameter holes were made to mark the screw entry points on the lamina. Drill guide templates with drill guide sleeves, 3- to 4-mm-diameter cylindrical structures (depending on the diameter of the drilling tool), were created to drill the screw trajectory before screw insertion. Additionally, SGTs with screw guide cylinders, 13- to 15-mm-diameter cylindrical structures (depending on the diameter of the screw driver) 30 mm in length, were made for screw insertion. These templates were designed to fit and lock the patient-specific 3D shape of the lamina using 3D modeling software (Freeform, Data Design) (Fig. 2) and were then made from nonsoluble acryl by a 3D printing system (Connex500, Objet Ltd.) with patient-specific 3D bone models (Fig. 3). The fitting of the templates to the laminae was examined, and simulation of screw placement was performed before surgery.

**Surgery**

These templates and bone models were sterilized using a plasma sterilizer and were used for intraoperative navigation. During the operation, the spinous process and lateral margin of the C-2 lamina were exposed. Soft tissues were completely removed so that the template fit accurately. Screw navigation was then carried out with the SGT system as follows. First, the location template was firmly press-fitted to the surface of the lamina, and a 2.0-mm-diameter insertion hole was made using a high-speed drill (Fig. 4A). Second, the drill guide template with a drill guide sleeve was set in the same manner, and then the drilling and tapping of the screw holes were carried out through the guide sleeve (Fig. 4B). Finally, the SGT was set, and the screw was inserted following the screw guide cylinder (Fig. 4C). Fluoroscopic assistance was generally unnecessary during screw insertion, and it was used only after all the C-2 screws had been inserted just for confirmation.

**Follow-Up Evaluation**

The placement of the screws was examined by postoperative CT and was classified according to 2 criteria. For the assessment of screw insertion accuracy with the SGT system, we measured the distance from the planned trajectory to the axis of the inserted screw on postoperative CT in the sagittal and axial planes using the 3D/multiplanar imaging software described above. We then used the following classification system: Class 1 (accurate), the screw axis deviates less than 2 mm from the planned trajectory; Class 2 (inaccurate), the screw axis deviates 2 mm or more but less than 4 mm; and Class 3 (deviated), the screw axis deviates 4 mm or more. If there is a discrepancy in the class of deviation between the sagittal and axial planes, the worse finding is adopted. Additionally, to assess the safety of screw insertion with this device, any malpositioned screws in the sagittal and axial planes were evaluated with the modified grading system used by Miyamoto and Uno\(^37\) and Yukawa et al.\(^38\) as follows: Grade 0 (containing), the screw is completely within the wall of the bone structure such as pedicle, pars, or lamina; Grade 1 (exposure), the screw perforates the wall of the bone structure, but more than 50% of the screw diam-
Screw guide template system for posterior C-2 fixation

Results

Postoperative CT scanning confirmed that the mean screw deviations were $0.36 \pm 0.62$ mm in the axial plane (range 0.0–3.8 mm) and $0.30 \pm 0.24$ mm in the sagittal plane (range 0.0–0.8 mm). All pedicle screws, pars screws, and transarticular screws and 5 of 6 laminar screws were classified into accuracy of Class 1 and safety of Grade 1, whereas 1 laminar screw was classified into Class 3 and Grade 2. In total, 47 (97.9%) of 48 screws were placed accurately into the preplanned position, and they did not perforate the cortex of the target portion (Tables 1 and 2).

Illustrative Cases

Case 1

An 84-year-old woman suffering from progressive tetraplegia caused by basilar impression due to idiopathic craniocervical kyphoscoliotic deformity underwent posterior fusion from the occipital bone to T-2 with the resection of the posterior arch of the atlas. We planned to insert a pars screw into the left pars, a pedicle screw into the right pedicle, and a laminar screw into the right lamina with the templates. Intraoperatively, the templates fit the patient’s lamina, and the screw navigation procedure was successful. Postoperative CT confirmed that all screws were placed perfectly at the planned location, and

Fig. 1. A screen shot of 3D/multiplanar imaging software for planning the trajectories of the screws. The ideal trajectories and their coordinates of the bone entry points and the tips of the screws were determined in a 3D manner.

Fig. 2. The 3D computer model of the SGT system.
there was no invasion of the vertebral artery or the spinal canal (Fig. 5).

**Case 2**

An 84-year-old woman presented with complaints of a dropping head and gait instability because of vertical subluxation and subaxial subluxation due to rheumatoid arthritis. Occipitothoracic fusion with crossed C-2 laminar screws was planned for this patient. The laminar thickness was barely 3.5 mm, and the laminar height was just 7.0 mm. No deviation of the screws was acceptable when inserting 2 crossed laminar screws because the screw diameter was 3.5 mm. The operation with the SGT system proceeded uneventfully, and postoperative CT confirmed that both laminar screws were placed perfectly at the planned location without interference (Fig. 6).

**Case 3**

A 64-year-old woman with headache and subclinical myelopathy due to os odontoideum underwent occiput–C2 fusion. During the operation, skin and muscle could not be retracted adequately because of a relatively narrow exposure, which resulted in the muscle wall obstructing the proper placement of the templates and the accurate aiming of the drill. We made other incisions to insert the pars screws. However, we tried to insert the laminar screw without a further incision because the pressure from the muscle wall seemed to be weak. As a result, both pars screws were placed perfectly at the planned location without interference (Fig. 6).
screws were inserted accurately, whereas the laminar screw deviated 4.1 mm from the planned trajectory (Class 3 deviation) and perforated the inner cortex of the lamina by half a screw diameter (Grade 2 malpositioning) (Fig. 7). Fortunately, no neurological complication occurred.

**Discussion**

It is imperative to insert C-2 cervical screws accurately; however, the procedures for C-2 screw insertion are technically demanding and carry a risk of iatrogenic injury to the vertebral artery, which may be lethal.\(^\text{19,26,28,35,37}\) In a cadaveric study, Helgeson et al.\(^\text{8}\) reported that the accuracy of free-hand C-2 cervical screw insertion was 89.1%. In a clinical study, Bransford et al.\(^\text{6}\) reported that 83.3% of screws were placed completely within the bony cortex by a free-hand procedure under intraoperative C-arm fluoroscopy, whereas 0.3% of screws were associated with injury to the vertebral artery. Yang et al.\(^\text{36}\) proposed that the high screw-breath rate during screw placement for the upper cervical area using conventional C-arm fluoroscopy might result from the difficulty in recognizing an anatomical landmark and insisted on the efficacy of isocentric C-arm 3D navigation (Iso-C). However, it is clear that screw malpositions\(^\text{8,36}\) still occur even when recently developed intraoperative CT-based navigation (Iso-C or O-arm) is used. The inaccuracy of the screw insertion using intraoperative 3D navigation could result from a change in the spinal alignment, such as torsion during drilling/screwing. This issue seems difficult to manage because the image-based navigation is not a real-time navigation.

This study demonstrates that the SGT system allows for extremely accurate insertion of C-2 cervical screws. The SGT system appears to describe the best screw trajectory in a 3D manner by simply attaching to the laminae, which does not require the configuration of reference points or a high dose of radiation during intraoperative 3D navigation. In addition, the direct adjustment of the templates to the target laminae in the SGT system may avoid the registration or probing error evoked by changes in spinal alignment during the surgery.

Recently, several navigation template systems have been reported. The concept of personalized image-based 3D templates was first described by Berry et al.\(^\text{4}\) Owen et al. and Ryken and colleagues followed the concept with their cadaveric studies,\(^\text{25,29,30}\) and then Lu and colleagues\(^\text{16-18}\) and Kawaguchi et al.\(^\text{12}\) applied the templates for clinical use as drill guide templates. However, these templates were only used as a drilling guide. There remained a chance for error because the screw procedure consists of 3 steps: entry point marking, screw hole drilling, and screw insertion. Errors can occur at each of these steps. Therefore, we propose that a multistep procedure should be used to minimize technical errors.

Our SGT system uses a multistep template process. First, location templates were used to pinpoint and mark the entry point on the laminae. Second, drill guide templates were used to drill holes for the screws. Third, SGTs were used to guide the screw direction to the planned screw tip points. Through those 3 steps, the SGT system provides an ideal location and trajectory of the screw at all points of the screw insertion procedure. We speculate that the multistep screw placement technique with fit-and-lock templates was the key to accurate screw placement.

### TABLE 1: The accuracy of screw insertion with the SGT system

<table>
<thead>
<tr>
<th>Screw Type</th>
<th>No. of Screws</th>
<th>Class 1 (accurate)</th>
<th>Class 2 (inaccurate)</th>
<th>Class 3 (deviated)</th>
<th>Accuracy (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>pedicle</td>
<td>26</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>26/26 (100.0)</td>
</tr>
<tr>
<td>pars</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12/12 (100.0)</td>
</tr>
<tr>
<td>laminar</td>
<td>5</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>5/6 (83.3)</td>
</tr>
<tr>
<td>transarticular</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4/4 (100.0)</td>
</tr>
<tr>
<td>total</td>
<td>47</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>47/48 (97.9)</td>
</tr>
</tbody>
</table>

* Presented as the number of Class 1 screws/total number of screws per category.

### TABLE 2: Safety of screw insertion with the SGT system

<table>
<thead>
<tr>
<th>Screw Type</th>
<th>No. of Screws</th>
<th>Grade 0 (containing)</th>
<th>Grade 1 (exposure)</th>
<th>Grade 2 (perforation)</th>
<th>Grade 3 (penetration)</th>
<th>Safety (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>pedicle</td>
<td>26</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>26/26 (100.0)</td>
<td></td>
</tr>
<tr>
<td>pars</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12/12 (100.0)</td>
<td></td>
</tr>
<tr>
<td>laminar</td>
<td>5</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>5/6 (83.3)</td>
<td></td>
</tr>
<tr>
<td>transarticular</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4/4 (100.0)</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>47</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>47/48 (97.9)</td>
<td></td>
</tr>
</tbody>
</table>

* Presented as the number of Grade 0 screws/total number of screws per category.
We have already reported that this SGT system achieved extremely high accuracy and reliability in insertion of thoracic pedicle screws, and we have proved the feasibility of this system for C-2 cervical screw insertion. With this extremely high accuracy and reliability, the SGT system can be applied to patients with small-diameter bone structures or severe spinal malalignment as we have shown in this study.

We had only 1 screw deviate from the planned trajectory (Case 3). In this case, we had inserted the screws...
with the incompletely fitted template due to muscle wall obstruction. We consider that the engagement of the template free from muscle wall obstruction is the key to accurate screw insertion.

**Conclusions**

We have demonstrated the efficacy of the SGT system for the insertion of C-2 cervical screws. The SGT system is reliable and applicable for any screw insertion, even in cases of severely deformed C-2 vertebrae. This study points to the feasibility of applying the SGT system to pedicle screw insertion for the mid- or lower cervical spine.

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**Disclosure**

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Author contributions to the study and manuscript preparation include the following. Conception and design: Kaneyama, Sugawara. Acquisition of data: Kaneyama, Sugawara. Analysis and interpretation of data: Kaneyama, Sugawara. Drafting the article: Kaneyama. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Kaneyama. Statistical analysis: Kaneyama. Administrative/technical/material support: Sugawara, Higashiyama, Takabatake. Study supervision: Sugawara, Sumi, Mizoi.

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