Clinical Case Report

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A novel method of C1–C2 transarticular screw insertion for symptomatic atlantoaxial instability using a customized guiding block

A case report and a technical note

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Abstract

Atlantoaxial instability treated with the C1-2 transarticular screw fixation is biomechanically more stable; however, the technique demanding and the potential risk of neurovascular injury create difficulties for clinical usage, and there is still lack of clinical experience till now.

We reported an adult female patient with symptomatic atlantoaxial instability due to rheumatoid arthritis that was successfully treated with a bilateral C1–C2 transarticular screw fixation using a customized guiding block. We preoperatively determined the trajectories for bilateral C1–C2 transarticular screws on a 3-dimensional reconstruction model from the computed tomography (CT) and self-developed computer software, and designed a rapid prototyping customized guiding block in order to offer a guide for the entry point and insertion angle of the C1–C2 transarticular screws.

The clinical outcome was good, and the follow-up period was >3 years. The accuracy of the screws is good in comparison with preoperative and postoperative CT findings, and no neurovascular injury occurred.

The patient was accurately and successfully treated with a bilateral C1–C2 transarticular screw fixation using a customized guiding block.

Abbreviations: 3D = three-dimensional, AAS = atlantoaxial subluxation, CT = computed tomography, RA = rheumatoid arthritis.

Keywords: atlantoaxial instability, customized guiding block, transarticular screw

1. Introduction

The atlantoaxial segments (C1–C2) of cervical vertebrae connect the skull to the cervical spine and are easily fractured or injured by trauma.[1] Fractured C1–C2 segments are stabilized by 2 common methods, the direct anterior screw fixation, and the posterior fusion of C1–C2.[2] Jeanneret B and Magerl F noted a preference for C1–C2 transarticular screw fixation using the posterior fusion technique because it provides increased stability and allows immediate ambulation with minimal head support.[2] In patients with rheumatoid arthritis (RA), atlantoaxial subluxation (AAS) is the most common cervical instability, resulting from trauma, inflammatory disease, tumor, infection, and congenital or acquired abnormalities.[3,4] The clinical symptoms and signs of AAS include pain, stiffness, pyramidal tract involvement, vertebrobasilar insufficiency, and radiculopathy. In 1951, Davis and Markley reported medullary compression as a cause of death in patients with rheumatoid arthritis.[5] Mortality is a significant threat if AAS with cervical myelopathy is left untreated. When a patient has neurological impairment, instability, and pain, posterior C1–C2 fusion is indicated.[3] The transarticular screw fusion technique proposed by Magerl and Seemann in 1979 provides immediate postoperative stability and high fusion rate (>90%) compared with traditional wiring and grafting methods.[4,6–8] The inserted screw facilitates the fusion of adjacent vertebrae. However, this technique is considered dangerous and a technically difficult procedure that requires significant surgical skill and experience to avoid injuring nerves and vessels while providing no measurable improvement in results compared with conventional wiring techniques.[9] The main risk of this method is vertebral artery injury (3%) secondary to screw malposition (7%).[8] Vertebral artery injury usually occurs at the C2 level and may be fatal. To this point, Grob et al[9] reviewed 161 patients receiving 322 C1–C2 transarticular screw fixation, and reported that 25 (7.7%) screws were too far lateral, 7(2.1%) were too far medial, 11 screws (3.4%) were too short, screws inserted at wrong angles, and some did not cross the C1–C2 joint. Further, 6 (1.8%) were too long, protruded through the lateral mass of the atlas ventrally. However, complications

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occurred in only 4 patients with associated malpositioned screws. Only 5.9% of the complications were directly related to the screws, including 3 patients with loose or displaced screws, and 3 other patients with broken screws at follow-up. Only 1 patient developed a unilateral paresis of the hypoglosseal nerve, and 1 patient with pseudarthrosis (0.6%). No injury to the vertebral artery or spinal cord or dura mater was found. Although the rate of complication of this technique is low, no one wants to be the complication case. To minimize the rate of fatal complications, intraoperative fluoroscopy and CT-based computer navigation systems are used to achieve safe and accurate instrumentation in fusion surgery for AAS cases.[10]

In our previous study,[11,12] we developed customized guiding blocks and accurately inserted transpedicular screws in thoracic and lumbar vertebral segments in difficult cases, such as those with scoliosis. The accuracy and reliability of transpedicular screw placement using a guiding block has been verified by computed tomography (CT). We showed the average angle of deviation from the planned trajectory was 1.05°±1.05°. The average distance difference from the planned entry point was 2.99 ± 0.39 mm. Hu and his colleagues also developed a novel rapid prototyping drill template and reported a C1–C2 transarticular screw placement assisted by this template (C1C2TAS) in a cadaveric study. They reported that no significant difference in the entry point and direction between the intended and actual screw trajectory.[13] Based on the previous accuracy and reliability of guiding-block-directed screw insertion achieved in thoracic and lumbar spine,[11,12] we challenged ourselves with bilateral C1–C2 transarticular screw placement for fixation of atlantoaxial subluxation using a customized guiding block.

2. Materials and methods

2.1. Design workflow

The preoperative workflow for the guiding block (template) design is depicted in Fig. 1. The patient's cervical lesion region

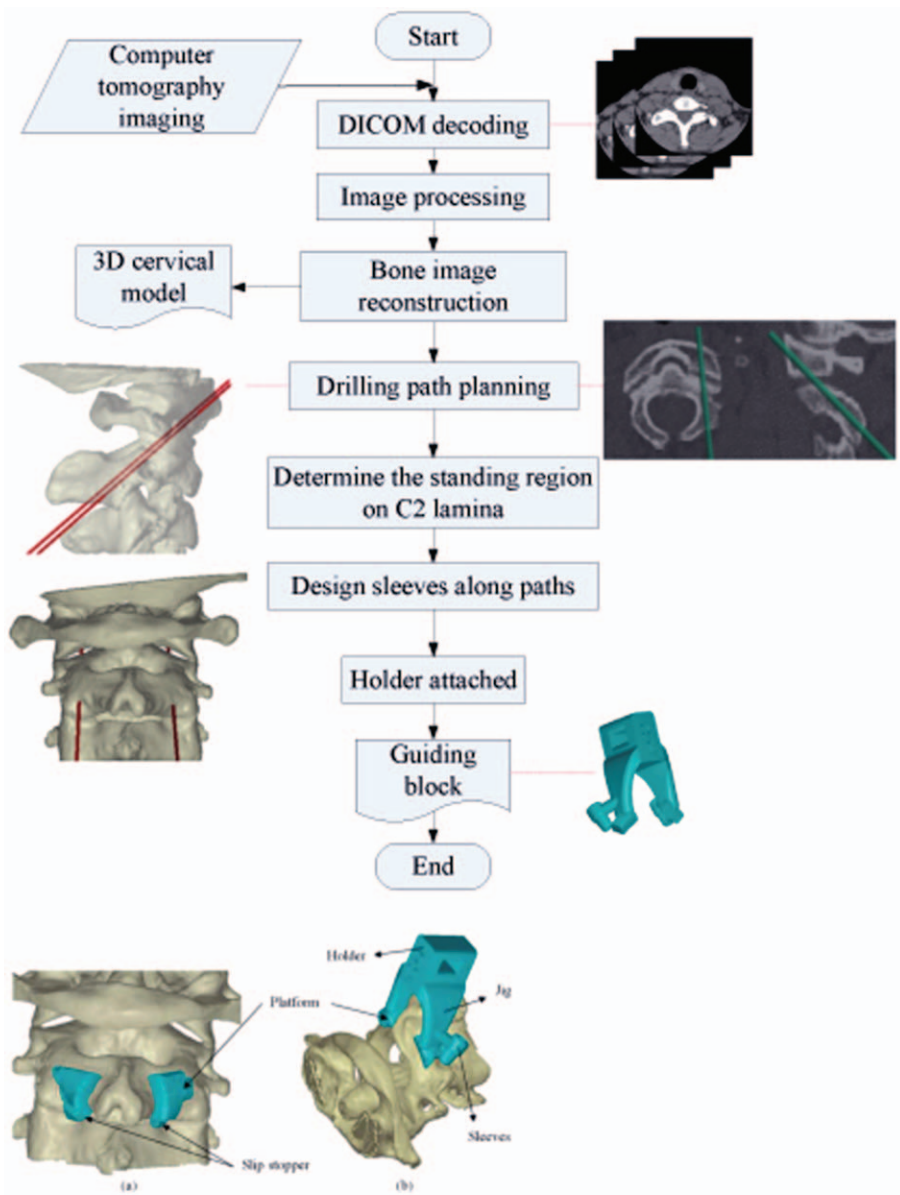

Figure 1. Workflow of guiding templates design and the guiding template.

was scanned by computer tomography at 1.0 mm per slice. We developed an image processing software to decode the DICOM (Digital Imaging and Communications in Medicine) imaging into a personal computer. The marching cube algorithm[14] was applied to reconstruct the cervical model in 3D from a series of CT images. We defined left and right screw trajectories by locating the entry point and potential end point on the cervical model via our developed path planning software. We then determined the desired trajectories of screw insertion in the program's visual environment displaying the patient's 3D reconstruction model of the cervical spine. The platform of the guiding block was designed to cover the surface of the C2 vertebra in a specified position, and the remaining components of the guiding block (jig, sleeves, and holder) can then be designed and added to the platform. Finally, the customized guiding block was manufactured using rapid prototyping.

Our design was a compromise between diverse requests (both small and stable) and complied with the above described principles. To achieve accurate intraoperative localization of the guiding block on the C2 vertebra, the platform of the customized guiding block was designed to rest closely on the laminar surfaces of C2. As shown in Fig. 1, the platform connected with a hook-shape slip stoppers of the guiding block ensuring stability during intraoperative drilling. Based on the planned trajectories, the sleeves could be merged with the platforms and the holder in a correct orientation. The inner diameter of the sleeves is slightly larger than the guide pin to allow smooth passage. The sleeves were offset a short distance above the lamina to facilitate intraoperative observation of the entry point. The holder is made crossing over the spinous process where informational text clearly identifies and can be held in place just above the vertebra.

2.2. Clinical application

This 51-year-old female was healthy until 1 year prior to this study when she started complaining of neck pain and stiffness with occipital radiation. She had no trauma history, no upper limb discomfort, and no limitation of neck flexion or extension. The motor function and deep tendon reflex of upper and lower limbs were normal. The cervical lateral radiograph revealed C1–C2 subluxation (Fig. 2A). The atlantoaxial distance increased during flexion, which signified atlantoaxial instability. Magnetic resonance imaging (MRI) showed irregularity of bilateral C1–C2 joints and soft tissue signal between the anterior arch of the atlas and odontoid process of the axis - hypointense signal on T1-weighted image and hyperintense signal on T2-weighted image. Early rheumatoid arthritis with pannus formation was suspected. The discomfort did not improve after a 1-year course of medication and rehabilitation program. Due to conservative treatment failure, surgical intervention was recommended and accepted by the patient. She volunteered to attend the clinical trial.

Reduction of C1–C2 subluxation was achieved by postural adjustment and traction, and confirmed with fluoroscopy before draping. After posterior midline incision, the lamina of C2-3, the posterior arch of the atlas, and the lower occiput were explored. The laminar surface of C2 and its edge were electrocauterized meticulously to eliminate most of soft tissue attachment to minimize localization error when the guiding block was applied. We identified the C2 entry site, which was located 3-mm rostral and 3-mm lateral to the inferior medial facet joint of C2-3. After opening the cortex with a burr at the estimated entry point on C2 near C2-3 articular surface, the guiding block was placed on the laminar surface and its connective inferior edge of the vertebra. Before the C-2 transarticular screw insertion procedure, we examined the fluoroscopic imaging to confirm the K-wire trajectory (Fig. 2B). We ensured well-fitted contact between the platform and the laminar surface by precise locating the guiding block and a firm pressure applied onto the holder of the guiding block against the C2 lamina before advancing 2 Kirschner wires (K-wires) (1.2 mm in diameter) through bilateral sleeves of the guiding block and pre-burred entry point to a proper depth (Fig. 3). We checked the orientation and depth of the K-wires by anteroposterior and lateral fluoroscopy to prevent trivial deviation of the guiding block (Fig. 2B). The K-wire trajectory needed to cross the C1–C2 facet joint and was aimed at the anterior tubercle of the atlas in lateral view of fluoroscopy, and was directed approximately 15 degrees medially in anteroposterior view of fluoroscopy.

With the use of the customized guiding block and fluoroscopic guidance, if the guiding block is moved upward or laterally slightly, it is possible to identify the mismatch and adjust accordingly, even to steady stand and hook on the lamina surface and inferior edge. We did not remove the C2/C3 interspinal ligaments. The tract was tapped using a cannulated tap device after removing the guiding block. After removing the K-wires, the transarticular screw was applied carefully, strictly abiding by the trajectory created. The orientation and the depth of the screw were checked fluoroscopically at final insertion (Fig. 2B). Posterior instrumented fusion of C1–C2 with bilateral transarticular screws guided by the customized template was accomplished after posterolateral fusion with the autogenous iliac bone graft between C1–C2. No vertebral artery injury was found intraoperatively.

The patient's symptoms of neck pain, stiffness, and occipital radiation were completely and immediately resolved. A neck collar was worn for 3 months. At the 3-month follow-up, she had no neck pain or occiput radiation pain and returned to her normal activities. Three years postoperatively, there were no symptoms or neurological deficit, and the atlantoaxial alignment was good without loss of reduction (Fig. 2C).

2.3. Validation

For validation, the model of cervical vertebrae was reconstructed from postoperative CT scan data. The iterative closest points algorithm (ICP)[15] was employed to fuse the preoperative and postoperative vertebral models reconstructed by different scanning data. This method iteratively transforms the spatial coordinates from 1 vertebra to the other until both models overlap completely. Three-dimensional (3D) deviation distance between 2 entry points and 3D deviation angle between the planned trajectory and transarticular screws can be calculated. Two-dimensional deviation angle and distance between 2 entry points on the coronal plane and sagittal plane (a commonly used estimation of difference in clinics) were defined and calculated.

Table 1 shows the deviation from planned trajectories of bilateral transarticular screws was small. The absolute angle deviation was less than 3 degrees and the distance difference of 2 entry points was <1.5 mm. The deviation of 2 transarticular screws from their planned trajectories in 3D space was calculated (Table 2). The angle deviation was 3 to 4 degrees and distance deviation between 2 entry points was <2 mm in 3D space.

Figure 2. (A) The atlantoaxial subluxation with increased atlantoaxial distance was demonstrated in flexion position of lateral radiograph of cervical spine. (B) Intraoperative fluoroscopic examination of upper cervical spine after completion of insertion of 2 C1–C2 transarticular screws. (C) Three years postoperatively, the atlantoaxial alignment was good without loss of reduction.

3. Discussion

The transarticular screw fusion technique proposed by Magerl and Seemann in 1979 provides immediate postoperative stability and higher fusion rate (>90%) compared with traditional wiring and grafting methods.[4,6–8] The technique has been used for atlantoaxial instability, with impressive outcomes reported by Dickman and Sonntag[6] and Haid et al[16] with 96% and 98% osseous fusion rates, respectively, and with a low incidence of complications. Haid et al[16] suggested that their successful outcome was attributed to the careful preoperative anatomic

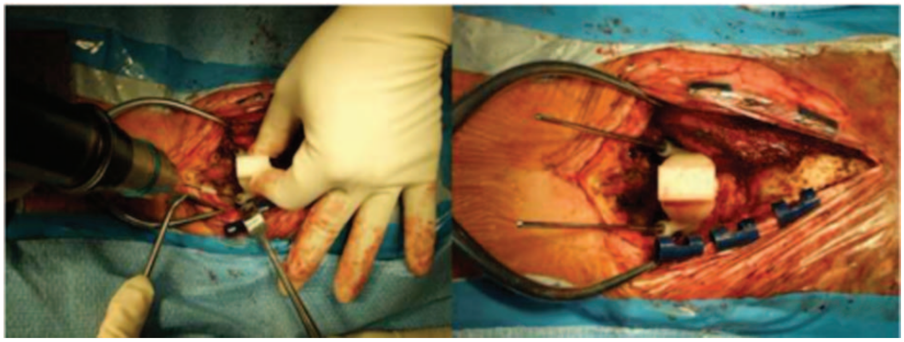

Figure 3. Intraoperatively, we applied the customized guiding block on the C2 lamina surface with a well-fitted contact, and then advanced 2 Kirschner wires through bilateral sleeves of the guiding block before insertion of bilateral C1–C2 transarticular screws to ensure the accuracy of the screw trajectory.

structure relationship study, skilled surgical techniques to expose the critical landmarks intraoperatively and good image guidance. The choice of screw entry point might still be a difficult issue. However, this problem can be solved with the customized guiding block.

The customized surgical guide was developed in the early 1990s by Prof. Klaus Radermacher and has been applied clinically for preoperative 3-dimensional planning and precise surgeries in spine, hip, knee, and pelvic repositioning osteotomies in acetabular dysplasia therapy using individual templates based on the computerized tomographic images.[17] We also used the customized guiding block to direct the insertion of transpedicular screws to thoracic and lumbar spine in difficult clinical cases, and had good clinical results.[11,12] Hu et al also developed a similar drill template and displayed accuracy in placement of a C1–C2 transarticular screw in a cadaveric study. Small deviations do occur due to technical or human factors, often from incomplete removal of the soft tissue or image software used to design the template.[13] In the current study, we broadened the use of this system to the upper cervical spine for atlantoaxial subluxation in a patient with early rheumatoid arthritis. We validated the screw tracts by comparison to planned trajectories on 3D models derived from CT reconstruction. Our results show accuracy of both entry point and insertion angle of bilateral transarticular screws for atlantoaxial fixation, and the clinical result showed immediate postoperative relief, lasting for >3 years.

Our data show a small angle deviation and distance difference of the entry points calculated by comparing planned trajectory and postoperative screw tracts in 2D projections and 3D models reconstructed from CT data. The incidence of screw misposition was reported between 2% and 15% and vertebral artery injury in 2.5%.[9,18,19] Although the incidence of vertebral artery injury was not high, the consequence is critical. Apfelbaum reported bilateral vertebral artery injuries leading to death in a series of 40 patients.[19] High accuracy achieved by guiding block-directed insertion of the screws greatly improves the safety of transarticular atlantoaxial fixation. Paramore et al[20] reported that 18% of the patients had a high-riding transverse foramen at least on one side of the C2 vertebra, which would prohibit ideal trajectory of screw placement. In our system, the surgeon determined the planned trajectory in a 3D model reconstructed from preoperative CT and likely circumvented the potential hazard of injuring anomalous vertebral artery by working out a safe trajectory.

These findings show our system saves time and reduces radiation exposure. Traditionally, the transarticular screw insertion for C1–C2 is directed by repeat intraoperative fluoroscopy in 2 planes. With our method, fluoroscopy is needed only once, theoretically, after insertion of Kirschner wires. Compared with CT-based computer navigation system, our device does not need intraoperative registration. Further, inexperienced surgeons find our system user friendly, which has a shorter learning curve compared with tradition techniques. Finally, our device is custom-made by 3D printing, which reduces cost significantly compared with expensive O-arm and computer navigation systems.

The human factors of patient uniqueness had considerable influence in our study. The angle deviation was larger compared to the average angle deviation in thoracic and lumbar spine. Inadequate soft tissue clearance and narrower platform of the guiding block for smaller C2 laminar surface were 2 potential causes of angle deviation. Other errors included the accuracy of the computer tomography (Siemens Somatom Sensation 16 CT scanner, with slice thickness of 0.7 mm and display field of view of 166 mm in a 512 × 512 pixel image), model reconstruction from the CT scan (all reconstructed models were calculated in sub-pixel to reduce the errors arising from image threshold selection, and the errors generated from the modeling method were negligible), and ICP registration (average error below 0.1 mm). Another potential source of deviation came from inserting the screw without direct guide of Kirschner wire, and adoption to cannulated screws would ameliorate such deviation. More cases

Table 1

The angle deviation and distance deviation of the entry points of transarticular screws.

Transarticular screw	Angle deviation (α°)	Angle deviation (β°)	Distance deviation of 2 entry points on AP view, mm	Distance deviation of 2 entry points on lateral view, mm
C2 left	2.26	2.25	0.817	0.149
C2 right	3.17	1.06	0.907	1.328

Table 2

Comparison of the preoperative planning and postoperative outcomes in 3D space.

Transarticular screw	Angle deviation in 3D space, °	Distance deviation of 2 entry points, mm
C2 left	3.197	0.823
C2 right	3.622	1.575

3D = three dimensional.

are needed to thoroughly establish the reliability of our customized guiding block system in C1–C2 transarticular -assisted fusion scenario.

In this case, we successfully extended the technique to the most critical and skill-demanding spinal segments of C1–C2 in an adult female patient with symptomatic atlantoaxial instability due to rheumatoid arthritis using a customized guiding block.

4. Conclusion

The customized guiding block for C1–C2 transarticular screw insertion is clinically feasible and may provide advantages of accuracy, safety, reliability, time-saving, radiation-saving, and economically more efficient. Spine surgeon would benefit greatly from our system especially in difficult cases, such as those with vertebral artery anomaly, by planning a safe trajectory preoperatively. In addition, the learning curve for spine surgeons will be shortened, requiring less time and resources for training. The operator must clear laminar surface thoroughly and match the platform of the guiding block perfectly on the bare target bone surface to minimize angle deviation and distance difference of the entry points.

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