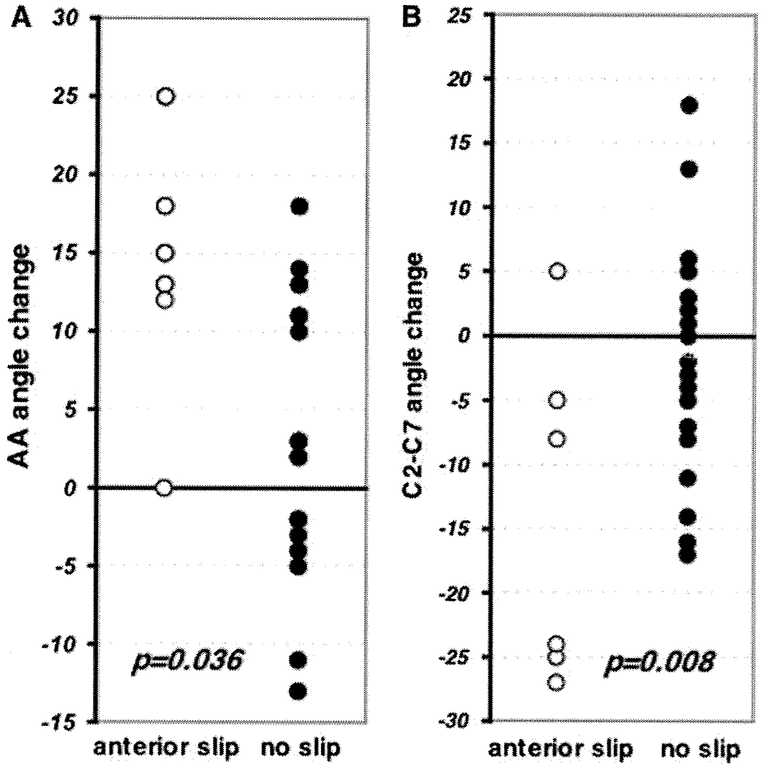

Fig. 4 **a** Difference in AA angle changes between patients with anterior subluxation (slip) and those with no slip. **b** Difference in C2–C7 angle changes between patients with anterior slip and those with no slip

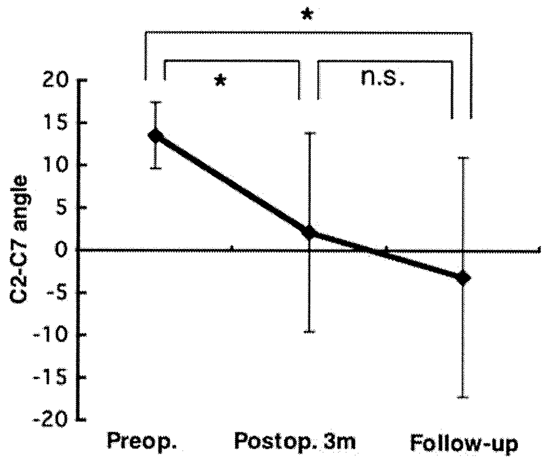

Fig. 5 C2–C7 angle changes at the preoperative, the immediate postoperative (3 months after the operation) and the latest follow-up in patients with anterior subluxation (slip). * $P < 0.05$; *n.s.* not statistically significant

C2 relative to C7, a progressive decrease in C2–C7 lordosis and a tendency for C1 inclination to return to preoperative inclination. However, none of the previous reports analyzed more crucial subaxial subluxations. Here, we demonstrate for the first time the importance of perioperative AA angle changes along with subsequent changes in C2–C7 angles, possibly leading to subaxial subluxation.

Another reason may be that causative factors of subaxial subluxation are too many to dray any conclusion from a cohort study. For one, an argument could be that subaxial subluxation is one of the possible deformities associated with RA in the natural course, similar to atlantoaxial subluxation, and is not a late complication. In RA patients, anterior subaxial subluxation does indeed tend to occur in the lower cervical spine without C1–C2 fixation, compared with posterior subluxation in patients with cervical spondylosis [22]. However, before the operations in this study, RA patients predominantly had posterior rather than anterior subluxations and developed new or aggravated anterior subluxations after the operation (Fig. 1), and the change occurred within a relatively short time (3 months) after the operation but not thereafter (Fig. 5). Moreover, the anterior subluxation followed a significant decrease in the perioperative C2–C7 angle (Fig. 5), not vice versa. In addition, the levels of anterior subluxation were significantly different between pre- and postoperative changes (Fig. 2b), as previously reported [22]. Thus, those sequential changes indicate that anterior subluxation should be considered as a late complication of this operation or, at least, can be accelerated by C1–C2 fixation. This complication probably results from the broken balance of the entire cervical alignment if an inadvertent correction of anterior atlantoaxial subluxation is performed.

On the other hand, one can easily name some of the possible causative factors such as osteoporosis in rheumatoid arthritis, the activity of the disease, the effect of medication, or the age of the patient. Indeed, Yonezawa et al. [22] reported that anterior subaxial slip significantly correlated with the average daily dose of corticosteroid and the class or stage of RA among RA patients without any operation during their follow-up period. However, we have found no difference in the medical treatment between anterior slip and no slip patients (data not shown), and the sequential changes after the operation described above strongly indicate the direct relationship between the C1–C2 fusion and the subaxial subluxation. Indeed, Yoshimoto et al. [23] demonstrated that postoperative AA and C2–C7 angles showed a negative linear correlation and that C2–C7 angle changes showed a negative correlation with AA angle changes, and Yonezawa et al. [22] demonstrated a positive association between a lordo-kyphotic deformity and anterior slip occurrence, both of which supports our finding of the sequential changes that an increase of AA angle leads to a decrease of C2–C7 angle, resulting in anterior subaxial subluxation. With all possible factors taken into account, not denied are the probable effects from the disease activity and the medication to cervical deformities in RA patients, and even preventive contributions from recently developed or developing medications such as biologics are expectable. We have no definite data or published reports on that issue, but it is hopeful that sufficient subsidence of the disease by medication will enables the cervical spine of RA patients to resist any deformative forces and to behave as if the one of non-RA patients, as described in this study.

One of the limitations of this study was the definition of a subluxation. One could define a subluxation as 2.0, 2.5, or 3.0 mm and possibly draw different statistical results. However, Yonezawa et al. [22] reported that even 2 mm of anterior subluxation is more likely to occur in RA patients than non-RA patients, and the present study clearly showed that more substantial subluxations (3 mm or more) than smaller subluxations (2–2.4 mm) were observed in RA patients. Thus, RA patients will probably be shown to have a greater risk of postoperative subaxial subluxation if a sufficient number of cases are collected and if the degree of the subluxation is defined broadly enough. As Yonezawa et al. [22] showed that even 2 mm of anterior subluxation can lead to damage in the cervical spinal cord in RA patients, the higher rate of subluxation among RA patients must not be underrated. Taken together, our study apparently indicates that AA angle should be carefully decided with reference to C2–C7 angle when C1–C2 fixation is performed in RA patients. Otherwise, subaxial subluxation is likely to occur within several years of follow-up, and neurological deterioration can be expected.

Conclusions

RA patients are more likely than non-RA patients to develop subaxial subluxations after atlantoaxial transarticular screw fixation. The increase in the AA angle occurring during the operation can lead to a decrease in the C2–C7 angle followed by anterior subluxation of the upper cervical spine and possibly neurological deterioration.

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References

1. Agarwal AK, Peppelman WC, Kraus DR, Pollock BH, Stolzer BL, Eisenbeis CH Jr et al (1994) Recurrence of cervical spine instability in rheumatoid arthritis following previous fusion: Can disease progression be prevented by early surgery? J Rheumatol 19:1364–1370
2. Arnett FC, Edworthy SM, Bloch DA, McShane DJ, Fries JF, Cooper NS et al (1988) The American Rheumatism Association 1987 revised criteria for the classification of rheumatoid arthritis. Arthritis Rheum 31:315–324
3. Clarke MJ, Cohen-Gadol AA, Ebersold MJ, Cabanela ME (2006) Long-term incidence of subaxial cervical spine instability following cervical arthrodesis surgery in patients with rheumatoid arthritis. Surg Neurol 66:136–140
4. Dreyer SJ, Boden SD (1999) Natural history of rheumatoid arthritis of the cervical spine. Clin Orthop Relat Res 366:98–106
5. Eleraky MA, Masferrer R, Sonntag VK (1998) Posterior atlantoaxial facet screw fixation in rheumatoid arthritis. J Neurosurg 89:8–12
6. Gallie WE (1939) Fractures and dislocations of the upper cervical spine. Am J Surg 46:495–499
7. Gluf WM, Schmidt MH, Apfelbaum RI (2005) Atlantoaxial transarticular screw fixation: a review of surgical indications, fusion rate, complications and lessons learned in 191 adult patients. J Neurosurg Spine 2:155–163
8. Haid RW Jr, Subach BR, McLaughlin MR, Rodts GE Jr, Wahlig JB Jr (2001) C1–C2 transarticular screw fixation for atlantoaxial instability: a 6-year experience. Neurosurgery 49:65–68
9. Hamilton JD, Johnston RA, Madhok R, Capell HA (2001) Factors predictive of subsequent deterioration in rheumatoid cervical myelopathy. Rheumatology 40:811–815
10. Ito H, Neo M, Fujibayashi S, Miyata M, Yoshitomi H, Nakamura T (2008) Atlantoaxial transarticular screw fixation with posterior wiring using polyethylene cable: facet fusion despite of posterior graft resorption in rheumatoid patients. Spine 33:1655–1661
11. Kato Y, Itoh T, Kanaya K, Kubota M, Ito S (2006) Relation between atlantoaxial (C1/2) and cervical alignment (C2–C7) angles with Magerl and Brooks techniques for atlantoaxial subluxation in rheumatoid arthritis. J Orthop Sci 11:347–352
12. Kraus DR, Peppelman WC, Agarwal AK, DeLeeuw HW, Donaldson WF III (1991) Incidence of subaxial subluxation in patients with generalized rheumatoid arthritis who have had previous occipital cervical fusions. Spine 16:S486–S489
13. Magerl F, Seeman PS (1987) Stable posterior fusion of the atlas and axis by transarticular screw fixation. In: Kehr P, Werdner PA (eds) Cervical spine I. Springer, Vienna, pp 322–327
14. Matsunaga S, Sakou T, Onishi T, Hayashi K, Taketomi E, Sunahara N et al (2003) Prognosis of patients with upper cervical lesions caused by rheumatoid arthritis: comparison of occipitocervical fusion between c1 laminectomy and nonsurgical management. Spine 28:1581–1587

15. Mukai Y, Hosono N, Sakaura H, Fujii R, Iwasaki M, Fuchiya T et al (2007) Sagittal alignment of the subaxial cervical spine after C1–C2 transarticular screw fixation in rheumatoid arthritis. J Spinal Disord Tech 20:436–441
16. Naderi S, Crawford NR, Song GS, Sonntag VK, Dickman CA (1998) Biomechanical comparison of C1–C2 posterior fixations. Cable, graft, and screw combinations. Spine 23:1946–1955
17. Neo M, Matsushita M, Iwashita Y, Yasuda T, Sakamoto T, Nakamura T (2003) Atlantoaxial transarticular screw fixation for a high-riding vertebral artery. Spine 28:666–670
18. Neo M, Fujibayashi S, Miyata M, Takemoto M, Nakamura T (2008) Vertebral artery injury during cervical spine surgery. Spine 33:779–785
19. Neo M, Sakamoto T, Fujibayashi S, Nakamura T (2005) A safe screw trajectory for atlantoaxial transarticular fixation achieved using an aiming device. Spine 30:E236–E242
20. Shen FH, Samartzis D, Jenis LG, An HS (2004) Rheumatoid arthritis: evaluation and surgical management of the cervical spine. Spine J 4:689–700
21. White AP, Biswas D, Smart LR, Haims A, Grauer JN (2007) Utility of flexion-extension radiographs in evaluating the degenerative cervical spine. Spine 32:975–979
22. Yonezawa T, Tsuji H, Matsui H, Hirano N (1995) Subaxial lesions in rheumatoid arthritis: radiographic factors suggestive of lower cervical myelopathy. Spine 20:208–215
23. Yoshimoto H, Ito M, Abumi K, Kotani Y, Shono Y, Takeda T et al (2004) A retrospective radiographic analysis of subaxial sagittal alignment after posterior C1–C2 fusion. Spine 29:175–181

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Navigated Anterior Approach to the Upper Cervical Spine After Occipitocervical Fusion

Masashi Neo, MD, PhD,* Ryo Asato, MD, PhD,† Shunsuke Fujibayashi, MD, PhD,* Hiromu Ito, MD, PhD,* Mitsuru Takemoto, MD, PhD,* and Takashi Nakamura, MD, PhD*

Study Design. Technical note.

Objective. To introduce the application of navigation system with software for brain surgery to the upper cervical spine of patients who have previously had occipitocervical (O-C) fusion.

Summary of Background Data. The anterior approach to the spine using a navigation system with software for spine surgery is difficult because the registration tends to be inaccurate. However, after O-C fusion, the upper cervical spine is considered part of the skull, and a navigation system with software for brain surgery in which the registration is performed using the head with several markers attached to it can be applied.

Methods. Three patients with previous O-C fusion—2 with upper cervical chordoma and 1 with a disc herniation at C2/3—were treated using this technique.

Results. In the first case, with a huge retropharyngeal C1 chordoma, this technique was very helpful in blindly dissecting the nonvisible parts of the tumor. In the second case, with a C2 chordoma, the vertebral arteries were successfully exposed under the guidance of the navigation system at both primary and revision surgery. In the third case, with disc herniation at C2/3, the herniated disc was removed successfully with the totally fused spine. In this application, computed tomography images can be merged freely with magnetic resonance images, which is helpful to clarify the soft tissues such as tumor, disc herniation, or the dural tube.

Conclusion. This technique greatly supports surgeons inexperienced in the anterior approach to the upper cervical spine or surgeons at revision surgery who may be lost in and daunted by an unfamiliar operation field surrounded by important structures. Although an anterior approach to the upper cervical spine in the patient with O-C fusion may rarely be required, this application should be considered.

Key words: computer-assisted navigation, upper cervical spine, anterior approach, occipitocervical fusion. **Spine 2009;34:E800–E805**

In recent years, computer-assisted navigation systems have been popularized as essential tools for some spine surgeries. They optimize preoperative planning, allow safe implantation, clarify resection limits of a lesion, decrease radiograph exposure, and reduce overall surgical morbidity. However, an anterior approach to the spine using a navigation system is limited because of technical difficulties.[1] That is, there are no suitable parts on which to fix the reference arc and the anterior surface of the vertebral body has few anatomically characteristic landmarks, which makes registration inaccurate. Although a few articles have reported that a navigation system with software designed for brain surgery can be used successfully in the anterior approach to the upper cervical spine,[2,3] obtaining acceptable accuracy is often difficult because of occipitocervical (O-C) or atlantoaxial (C1–C2) mobility.[4,5] However, if there is O-C fixation, the upper cervical spine is then considered part of the skull, and navigation software for brain surgery should be able to be applied more accurately in the anterior approach to the upper cervical spine. Although such cases are rarely encountered, we report 4 successful trials of the application in 3 patients, and discuss its utility.

Materials and Methods

From 2003 to 2008, 2 patients with a chordoma in the upper cervical spine and 1 patient with C2/3 disc herniation were selected for a navigated operation using software designed for brain surgery, and the navigation system was applied successfully 4 times. A rigid O-C fusion with metal implants had been performed before the operation in all patients.

A frameless stereotactic image guidance system (StealthStation Tria; Medtronic Sofamor Danek, Memphis, TN) was used. In this system, the software for brain surgery allowed possible error of within 2 mm, while the software for spine surgery allowed that of within 1 mm. On the day before the operation, 6 to 10 markers were attached to the head, and computed tomographic (CT) and magnetic resonance images (MRI) of the cranium, including the upper cervical spine, were taken. The imaging data sets were transferred to the workstation of the navigation system. On the day of operation, the patients were positioned in the supine position with the head fixed in a Mayfield clamp. A reference arc was fixed to the Mayfield clamp, and point registration was performed using the attached markers on the head, followed by surface registration (Figure 1). In all patients, the registration was done successfully with a possible error of less than 1 mm. After disinfection, the operation field was covered with sterile drapes, and the reference arc was exchanged for a sterile one, enabling intraoperative navigation. Then, the upper cervical spine was explored anteriorly, and the accuracy of the navigation in the upper cervical region was confirmed using spinal landmarks, tumor surface or implants, if any, as markers. In all trials, this revealed that the navigation was accurate enough to continue the operation.

From the Departments of *Orthopaedic Surgery and †Otolaryngology and Head-Neck Surgery, Graduate School of Medicine, Kyoto University, Kyoto, Japan.

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The device(s)/drug(s) is/are FDA-approved or approved by corresponding national agency for this indication.

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Address correspondence and reprint requests to Masashi Neo, MD, PhD, Department of Orthopaedic Surgery, Kyoto University Graduate School of Medicine, 54 Kawahara-cho, Shogoin, Sakyo-ku, Kyoto 606-8507, Japan; E-mail: neo@kuhp.kyoto-u.ac.jp

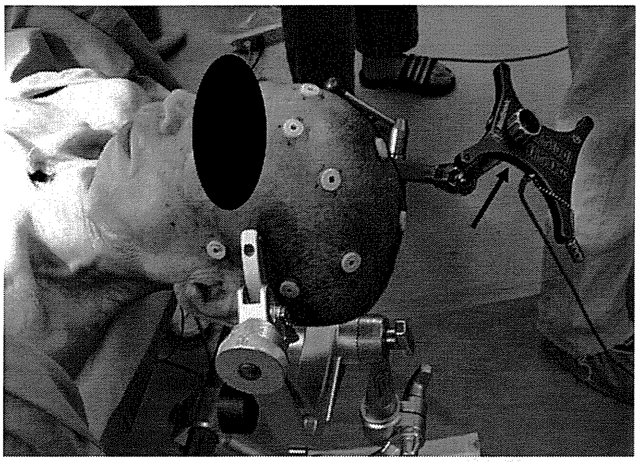
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Figure 1. Preparation for registration. Patients with several head markers were positioned in the supine position with the head fixed in a Mayfield clamp, to which a reference arc (arrow) was fixed.

■ Case Presentations

Case 1

A 19-year-old man with a large retropharyngeal chordoma was introduced to us following a transoral biopsy. The details of this case were reported elsewhere, focusing on the utility of transmaxillary and transmandibular approaches.[6] In short, the tumor originated on the right side of the anterior arch of C1 and was large (about 6 cm in diameter) and ossified. It extended from the clivus to the C2–C3 intervertebral disc in the sagittal plane.

A posterior occipitocervical (O-C3) fusion and an iliac bone graft were performed first to prevent any instability that resection of the anterior arch of C1 would produce.

Ten days after the fusion, the tumor was resected through a transmaxillary and transmandibular approach. Because the tumor was large, hard, and immovable due to adhesion to the anterior arch of C1, it was impossible to see or identify the tissues behind it. Therefore, the dissection was continued under the guidance of a computer-assisted navigation system with software for brain surgery. Checking the location of the anterior arch of C1 and the bilateral vertebral arteries (VAs) on the navigation monitor (Figure 2), blind *en bloc* resection of the main part of the tumor from the anterior arch of C1 was performed using an osteotome. The right part of the C1 anterior arch, the origin of the tumor, was then resected *en bloc*. The navigation system was also helpful in deciding the range of the C1 osteotomy. The retropharyngeal mucosa was reconstructed using a vascularized radial forearm flap.

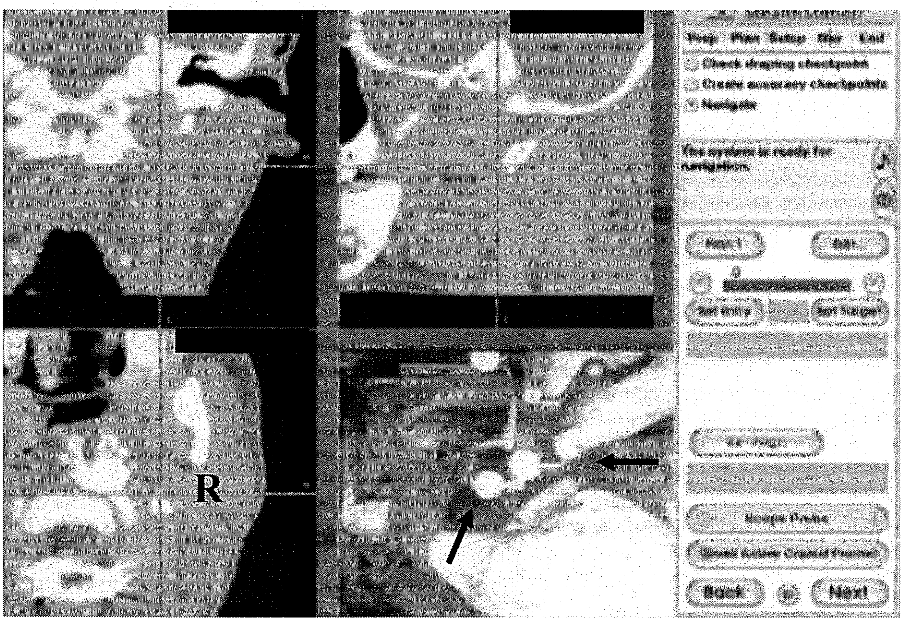
Pathologically, tumor cells were only exposed on the cross section between the main tumor mass and the resected anterior arch of C1. Postoperative radiation therapy (60 Gy) was administered.

Thereafter, the patient's course was uneventful. No recurrence or metastasis was observed 5 years after the operation. The patient had no complaints and has returned to his previous job as a manual laborer.

Case 2

A 72-year-old man was brought to hospital because of a sudden onset of severe neck pain and quadriplegia. At the hospital, he was diagnosed with a pathologic fracture of the axis (C2), and posterior decompression, biopsy and O-C5 fusion with transarticular screws were performed. The pathologic diagnosis was a chordoma. Fortunately, his paralysis recovered without sequelae. He was introduced to us several months after the above operation, with a large retropharyngeal tumor still invading the area posterior to the bilateral VAs in C2 (Figure 3).

Piecemeal resection was performed through a transmandibular approach using a navigation system. MRI data were useful in the resection of the prevertebral tumor, and



The system is ready for navigation.

Figure 2. Case 1: Navigation monitoring during blind dissection of the tumor. The tip of the pointer (indicated by the intersection point of the 2 green lines) was positioned near the right transverse process of C1 and the vertebral artery, which was invisible behind the large tumor mass (arrows) in the operation field.

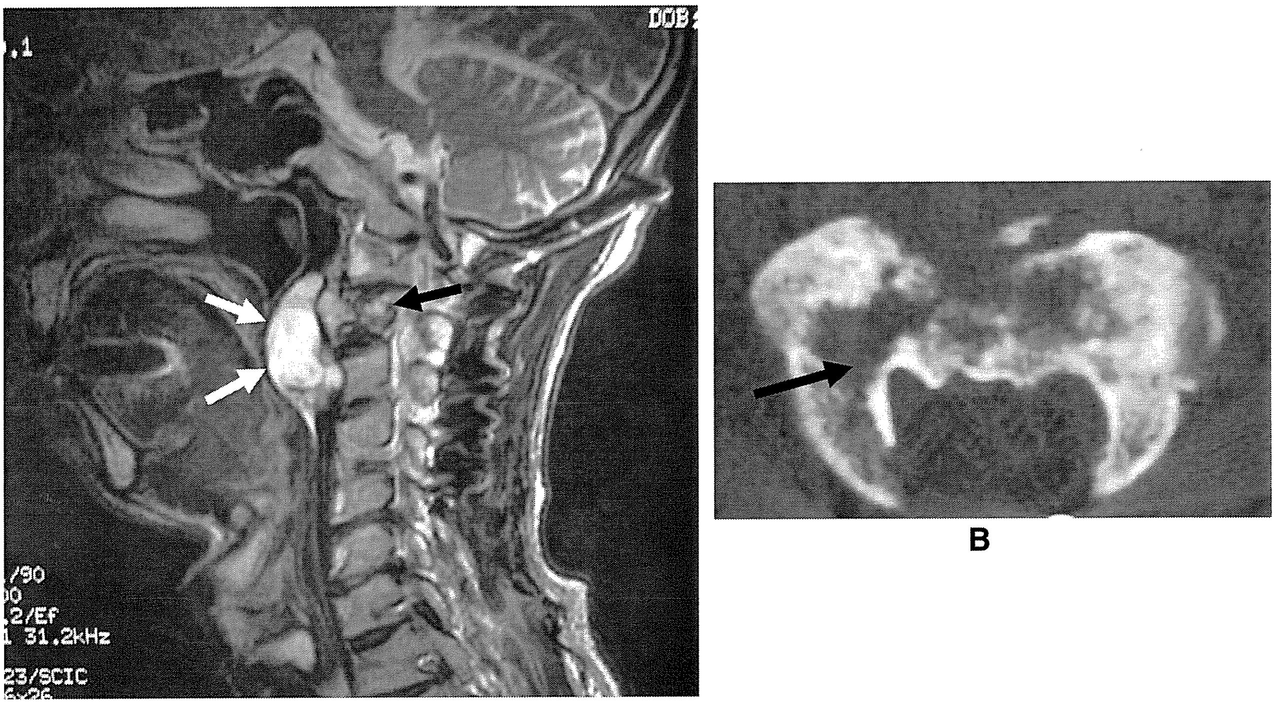


Figure 3. Case 2. Images taken when the patient was introduced to us. **A**, Sagittal T2-weighted MR image of the cervical spine. A retropharyngeal tumor (white arrows) and pathologic fracture of C2 (black arrow) were demonstrated. **B**, CT image of C2. In this section, the osteolytic lesion expanded posterior to the right vertebral artery (arrow).

CT data were helpful in the resection of the vertebral tumor. Supported by the navigation system, the VAs were exposed bilaterally and the tumor behind the VAs was resected. We were able to confirm on the navigation monitor that all the parts we had before surgery planned to remove were curetted (Figure 4). After resection of the tumor, an anterior cervical fusion was performed using vascularized radial forearm flap-fibula graft. The vascularized fibula was fixed between the C1 anterior arch and C3 with a buttress plate, and successfully united in 3 months.

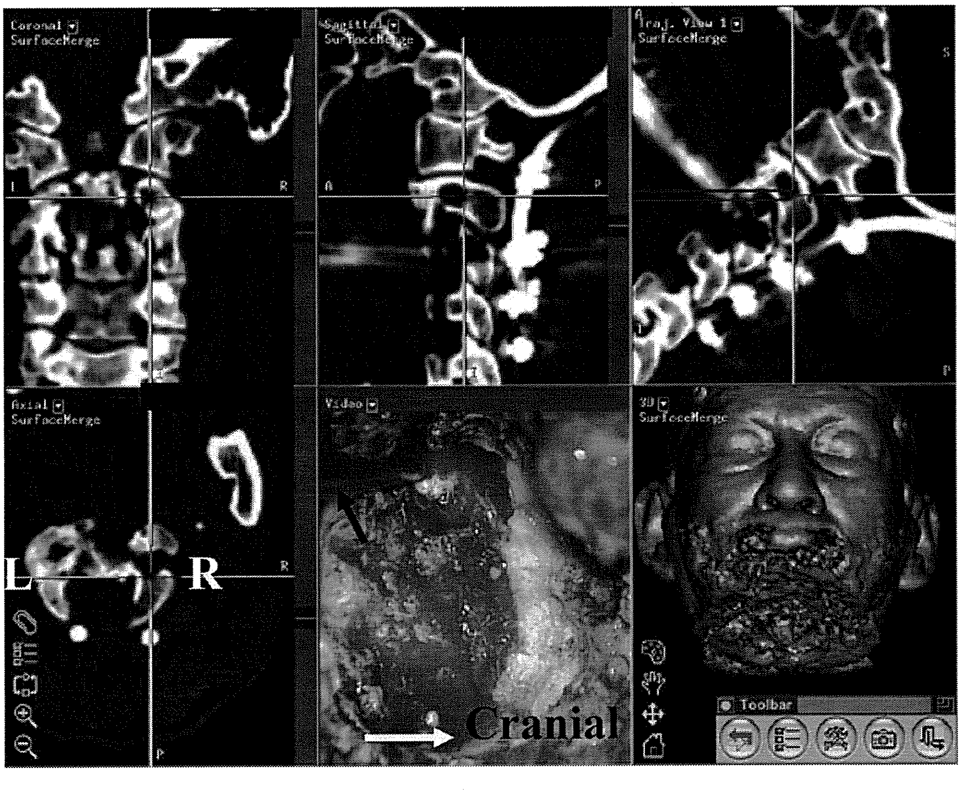


Figure 4. Case 2. Navigation monitoring after piecemeal resection of the tumor. The lower center image is a microscope view of the operative field. The intersection point of the 2 green lines indicates the tip of the pointer. It was confirmed that the most posterior part of the tumor, behind the right vertebral artery, was curetted as planned. The pointer is indicated by the arrow in the microscope view.

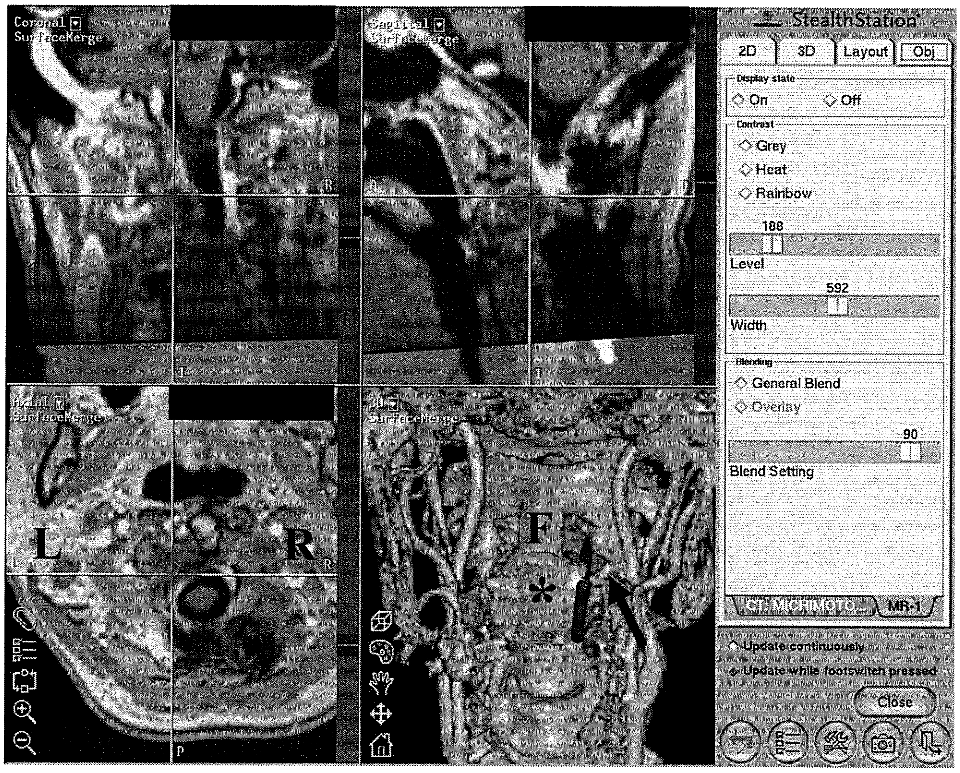


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Figure 5. Case 2. Navigation monitoring during the revision surgery. The right lower image is from 3-dimensional-constructed CT angiography, and the others are MR images. In the CT angiography image, the left vertebral artery involved in the recurrent tumor is apparent (black arrow). The blue arrow indicates the position of the pointer in the operation field. Its tip was positioned near the dura, which was also not visible, being covered by the scar tissue in the operative field. The asterisk indicates the buttress plate, which had been implanted to prevent dislodgement of the vascularized fibula (F).

Although the postoperative course was uneventful, follow-up MRI 2.5 years after the operation revealed that the tumor had recurred on the left side of C2. The patient elected to undergo revision surgery rather than heavy-particle radiotherapy, and the tumor was resected in the same way as in the previous operation. This time, CT angiography was used as a base image for the navigation to confirm the left VA position, which was involved in the recurrent tumor (Figure 5). The VA was successfully exposed beside the grafted fibula and the buttress plate, with guidance by the navigation system. MRI was useful to identify the tumor position, and to locate the dura covered by scar tissue (Figure 5). As in the previous surgery, we were able to confirm that we had curetted all the parts planned.

No recurrence has been observed to date, 11 months after the operation.

Case 3

The third case was a 58-year-old woman with rheumatoid arthritis (RA). Between 1995 and 2003, she underwent 7 surgeries because of spinal destruction by RA, resulting in C1–C2 and C6-sacrum fusion. During this period, she twice experienced Frankel C paralyzes because of spinal canal stenosis and instability adjacent to the previous spinal fusions. These paralyzes improved after emergency decompression and extension of the fixation, and she had managed to live independently.

She complained of deterioration consisting of bilateral numbness in her hands and weakness of all 4 extremities, resulting in becoming bedridden again in 2008. It was difficult to decide the responsible pathology, because her advanced RA status, with multiple joint destructions and muscle atrophy, and the sequelae of the previous paraplegia made neurologic diagnosis difficult. However, MRI revealed that central disc herniation at C2/3 combined with anterior listhesis of C2 compressed the spinal cord (Figure 6A). Anterior decompression and fusion was abandoned at first because the approach was difficult due to little neck motion and the location of the herniation behind the mandible, and obtaining bony fusion was considered difficult because of osteoporosis, instability at C2/3 and mechanical stress concentration on

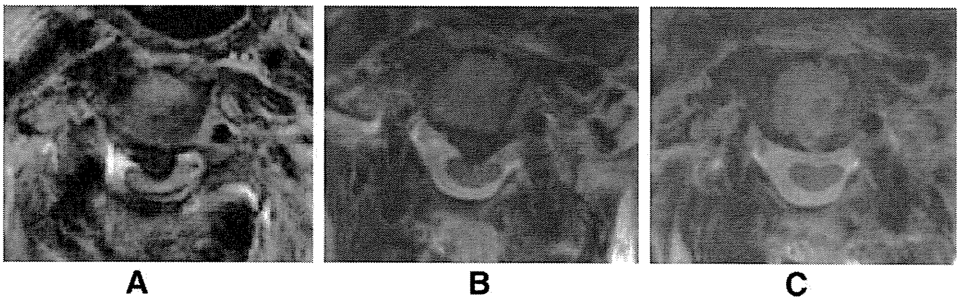

Figure 6. Case 3. Axial T2-weighted MR image at C2/3. **A**, Preoperative image. **B**, Image taken 6 weeks after posterior decompression. **C**, Image taken 1 week after anterior removal of the herniation.

C2–C6 after wide spinal fusion. Therefore, laminectomy from C2 to C3/4 and extension of the posterior fusion with instrumentation and local bone grafting was selected, which resulted in total spine fusion from the occiput to the sacrum. Although acceptable decompression of the cord was obtained (Figure 6B), the patient's symptoms did not change and she asked for removal of the herniated disc. Two months after the posterior surgery, an anterior approach to the cervical spine was performed using a navigation system for brain surgery. It was difficult to approach C2/3 in the totally fixed spine, but the multiple herniated fragments were removed through a corpectomy of the upper half of C3. The navigation system was helpful in locating the median line and clarifying the resection limits for the disc herniation. No anterior fusion was performed. After surgery, MRI demonstrated complete decompression of the spinal cord at C2/3 (Figure 6C). The finger motion of the patient improved slightly and she became able to transfer from the bed to a wheelchair by herself.

■ Discussion

Several articles have reported the successful application of navigation systems using software designed for brain surgery in the anterior approach to the upper cervical spine.[2,3] However, mobility in O-C and C1–C2 often decreases accuracy and makes this application unreliable.[4,5] However, in this study, rigid O-C fixation with metal implants had been performed in all patients, and therefore a navigation system for brain surgery was used successfully even in the upper cervical spine. Imaging artifacts from posterior metal implants did not disturb the navigation procedure.

As for the navigation system that we used (Stealth Station Tria), the software for spinal surgery has proved to be useful, especially in posterior implantation.[7,8] However, anterior applications pose problems in registration, and have therefore been seldom performed.[1] In the presented method using software for brain surgery, a reference arc was fixed to a Mayfield clamp allowing registration with head markers to be easily and quickly done with accuracy of less than 2 mm. Furthermore, our application has other merits compared with usual spine navigation. First, MRI images can be merged freely with CT images on the monitor, which is helpful in clarifying resection limits of soft tissue such as in tumors or disc herniation. In case 2, it was useful in locating the dura buried in postoperative scar and in case 3 for locating the disc herniation.

Second, CT angiography can be used as a base image, because the spine surface is not used for registration. With the software for spine surgery, contrast media would disturb the registration procedure. In case 2, CT angiography was helpful to locate a VA buried in recurrent tumor and postoperative scar.

Recent advances in technology have allowed the combination of intraoperative CT or MRI with a navigation system, and these techniques may overtake the application presented here as these systems can be used without O-C fusion because preoperative images and registration procedure are not necessary.[5,9,10] However, the image quality of intraoperative CT is not adequate and special equipments such as radio-transparent head clamps or operation tables are necessary. As for intraoperative MRI, it is very expensive and the surgical circumstances allowed are highly limited. Furthermore, it is impossible to use MR and CT images simultaneously, as in our application.

The application of our technique may not always be necessary, particularly with highly experienced surgeons. However, it greatly supports surgeons unfamiliar with the anterior approach to the upper cervical spine and surgeons performing revision surgery. They may be daunted by a narrow or deep corridor surrounded by important structures, or lost in the postoperative scar and abnormal anatomy. In such a situation, the navigation provides them with a less stressful and safer operation.

We do not know if this technique is applicable to the middle or lower cervical spine, even with a large enough range of posterior fusion, because the operative field is far from the registered skull, which may result in decreased accuracy.

Lastly, we emphasize that a reasonable surgical strategy should not be changed in order to use a navigation system. This application should be strictly limited to the cases, in which posterior fusion has already been done or initial posterior fusion is reasonably indicated.

In conclusion, this application is worthy of consideration as a tool for use in anterior upper cervical spine surgery in a few selected cases.

■ Key Points

- A frameless stereotactic image guidance system with software for brain surgery can be applied to the anterior approach to the upper cervical spine in patients who have previously undergone occipitocervical (O-C) fusion as the upper cervical spine can then be considered part of the skull.
- Chordomas of the upper cervical spine in 2 patients and disc herniation at C2/3 in 1 patient were successfully removed using an anterior approach using this technique.
- In this application, computed tomographic images can be freely merged with magnetic resonance images, which is helpful in clarifying soft tissues such as tumor, disc herniation, or the dural tube.
- Although an anterior approach to the upper cervical spine in the patient with O-C fusion may rarely be required, this application should be considered.

References

1. Seichi A, Takeshita K, Kawaguchi H, et al. Image-guided surgery for thoracic ossification of the posterior longitudinal ligament. Technical note. *J Neurosurg Spine* 2005;3:165–8.

2. Veres R, Bago A, Fedorcsak I. Early experiences with image-guided transoral surgery for the pathologies of the upper cervical spine. *Spine* 2001;26:1385–8.
3. Vougioukas VI, Hubbe U, Schipper J, et al. Navigated transoral approach to the cranial base and the craniocervical junction: technical note. *Neurosurgery* 2003;52:247–50.
4. Kaiser MG, McCormick PC. Comments. *Neurosurgery* 2003;52:251.
5. Wolinsky JP, Sciubba DM, Suk I, et al. Endoscopic image-guided odontoidectomy for decompression of basilar invagination via a standard anterior cervical approach. Technical note. *J Neurosurg Spine* 2007;6:184–91.
6. Neo M, Asato R, Honda K, et al. Transmaxillary and transmandibular approach to a C1 chordoma. *Spine* 2007;32:E236–9.
7. Ito H, Neo M, Yoshida M, et al. Efficacy of computer-assisted pedicle screw insertion for cervical instability in RA patients. *Rheumatol Int* 2007;27:567–74.
8. Kotani Y, Abumi K, Ito M, et al. Improved accuracy of computer-assisted cervical pedicle screw insertion. *J Neurosurg* 2003;99:257–63.
9. Kaibara T, Hurlbert RJ, Sutherland GR. Transoral resection of axial lesions augmented by intraoperative magnetic resonance imaging. Report of three cases. *J Neurosurg* 2001;95(suppl 2):239–42.
10. Takahashi S, Morikawa S, Egawa M, et al. Magnetic resonance imaging-guided percutaneous fenestration of a cervical intradural cyst. Case report. *J Neurosurg* 2003;99(suppl 3):313–5.