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A novel technique for fence-post tube placement in glioma using the robot-guided frameless neuronavigation technique under exoscope surgery: patient series

Shinichiro Koizumi, MD, PhD, Yuki Shiraishi, MD, Ippei Makita, MD, Makoto Kadowaki, MD, Tetsuro Sameshima, MD, PhD, and Kazuhiko Kurozumi, MD, PhD

Department of Neurosurgery, Hamamatsu University School of Medicine, Hamamatsu, Shizuoka, Japan

BACKGROUND Robotic technology is increasingly used in neurosurgery. The authors reported a new technique for fence-post tube placement using robot-guided frameless stereotaxic technology with neuronavigation in patients with glioma.

OBSERVATIONS Surgery was performed using the StealthStation S8 linked to the Stealth Autoguide cranial robotic guidance platform and a high-resolution three-dimensional (3D) surgical microscope. A surgical plan was created to determine the removal area using fence-post tube placement at the tumor and normal brain tissue boundary. Using this surgical plan, the robotic system allowed quick and accurate fence-post tube positioning, automatic alignment of the needle insertion and measurement positions in the brain, and quick and accurate puncture needle insertion into the brain tumor. Use of a ventricular drainage tube for the outer needle cylinder allowed placement of the puncture needle in a single operation. Furthermore, use of a high-resolution 3D exoscope allowed the surgeon to simultaneously view the surgical field image and the navigation screen with minimal line-of-sight movement, which improved operative safety. The position memory function of the 3D exoscope allowed easy switching between the exoscope and the microscope and optimal field of view adjustment.

LESSONS Fence-post tube placement using robot-guided frameless stereotaxic technology, neuronavigation, and an exoscope allows precise glioma resection.

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KEYWORDS navigation-guided fence-post tube technique; robot-guided frameless stereotactic technique; exoscope

Gliomas are some of the most malignant tumors, with glioblastoma multiforme having the worst prognosis. Although immunotherapy, viral and gene therapy, and other molecular therapeutics have been developed for clinical use,[1] excision of as much of the tumor as possible remains the most effective treatment, as indicated by increasing survival with increasing extent of resection.[2–4]

The navigation-guided fence-post tube technique is used to improve the tumor resection rate in glioma surgery.[5] To determine the resection plane, several tubes are inserted around the tumor under the guidance of a neuronavigation system before or after dural incision.[6] With this technique, it is possible to prevent deviations in neuronavigational positioning related to cerebrospinal fluid leakage and brain movement associated with progressive tumor removal.[7,8] As such, the navigation-guided fence-post tube technique can improve the tumor resection rate by allowing precise tumor resection. This technique is also useful for preserving the eloquent area.[9] Nevertheless, the manual insertion of the fence-post tube normally requires adjustment of the trajectory line in two or three directions on the multiplanar image while viewing the neuronavigation screen, which requires technical experience.

Recently, robotic devices have been used for stereotactic neurosurgery.[10] For example, rather than frame-based techniques, robot-guided frameless stereotactic techniques are increasingly used for brain tumor biopsies[11–14] and stereo-electroencephalography depth electrode placement.[15,16] The feasibility, safety, accuracy, and diagnostic yield of the robot-guided frameless stereotactic technique are also widely accepted.[17,18] Thus, the aim of the present study was to describe our new technique for fence-post tube placement using the robot-guided frameless stereotactic technique with neuronavigation in patients with glioma who receive exoscopic surgery.

ABBREVIATIONS 3D = three dimensional; CT = computed tomography; MRI = magnetic resonance imaging.

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Study Description

Patients

Three patients who underwent tumor resection in May 2021 were included in this study. The first patient was a 52-year-old woman with anaplastic oligodendroglioma who had three fence-post tubes inserted after a dural incision. The second patient was a 26-year-old woman with diffuse astrocytoma recurrence. The third patient was a 48-year-old man with anaplastic oligodendroglioma recurrence. The second and third patients had two fence-post tubes inserted before the dural incision. The study protocol was approved by the Ethics Committee at Hamamatsu University School of Medicine (Protocol No. 20-279).

Stealth Autoguide

All procedures were performed using a multiapplication robotic guidance device (Stealth Autoguide cranial robotic guidance platform, Medtronic). This system includes a control panel and a four-axial lightweight robot positioning unit. The control panel interfaces with a neuronavigation system (StealthStation S8, Medtronic). The system receives spatial data on the predefined trajectory and provides real-time information on the accuracy of the robot's alignment to the planned trajectory. The robot positioning unit comprises two flat modules connected to two guide extensions, which attach to a guidance sheath. The flat modules are capable of submillimetric rotational and sliding movements, allowing precise alignment to the planned trajectory. After the instrument positioning is completed, the robot's guidance sheath is locked to prevent further motion. The robot positioning unit is also rigidly connected to a Mayfield head holder or the surgical bed via a hand-lockable, three-jointed arm to provide further stability (Fig. 1).

Image Acquisition

Magnetic resonance imaging (MRI) was performed in all patients using a 3T MRI scanner (Discovery MR 750W, GE Healthcare) with a 12-channel phased array neurovascular array coil. The MRI set included contrast-enhanced T1-weighted and fluid-attenuated inversion recovery sequences. A brain three-dimensional (3D) computed tomography (CT) scan was obtained in all patients (0.625-mm sequential axial images). 3D preoperative CT was used as the reference imaging modality because it provides a better quality of facial anatomy reconstruction during registration.[19]

FIG. 1. A: Enlarged view of the operative setup. KINEVO 900 (Zeiss). **B:** 3D compatible 4K liquid crystal display monitor (Sony). **C:** StealthStation S8 (Medtronic). **D:** Flat modules of the robot positioning unit (Stealth Autoguide, Medtronic). **E:** Hand-lockable, three-jointed arm for the robotic device. **F:** Reference star and arm.

Surgical Planning

Patient-to-image registration in neuronavigation was performed on preoperative 3D CT data using optic tracking and surface matching and cross-checked on anatomical landmarks as a reference. Planning and selection of the entry point and the target point were performed on a Stealth workstation (Fig. 2A). Trajectories were selected starting from the entry points set on the interface between the tumor and the normal brain to the target points set in the deepest parts of the tumor, with adjustment to avoid eloquent areas, vessels, sulci, or ventricles (Fig. 2B). The surgeon was in full manual control of advancement of the fence-post tube to the target point. An exoscope overlayed the tumor area onto the navigation screen with a virtual line to confirm the boundary between the tumor and normal tissues, which allowed final confirmation of the insertion site of the fence-post tubes (Fig. 2C).

Surgical Techniques

All procedures were performed with patients under general anesthesia. The Mayfield head holder was positioned to avoid any interference with robot movements. The hand-lockable, three-jointed arm of the robotic device was fastened to the surgical bedside rail ipsilateral to the lesion, whereas the neuronavigation reference star arm was attached to the head holder contralaterally. After registering the neuronavigation system using a facial surface registration, sterile preparation and draping were performed in standard fashion. After performing the skin incision and craniotomy, the robot positioning unit was manually prepositioned next to the planned entry point by the surgeon under image guidance using the high-resolution 3D exoscope (KINEVO 900, Carl Zeiss Meditec AG) (Fig. 3A). This manual prepositioning is necessary because the robot positioning unit workspace is limited (4×4 cm), and its modules only provide a small angular (± 20°) and translational (± 30 mm) movement of the guidance sheath.[15]

We confirmed that the fence-post tube insertion sites were not in the eloquent area by using extracranial stimulation or direct stimulation of the motor cortex. After making the cruciform dural opening or opening of the dura in the excision area of the tumor, the robot positioning unit was automatically positioned and locked into a position accurately aligned to the planned trajectory (Fig. 3B). For actual insertion of the fence-post tube, we used the ventricular drainage tube (Phycon ventricular drainage tube, Large size, outer diameter = 3.8 mm, Fuji Systems) as the outer cylinder with a 2.2-mm Nashold biopsy needle as a stylet (Fig. 3C). The fence-post tube was manually advanced through the guidance sheath to the target position under continuous depth guidance using its two passive markers displayed on the neuronavigation screen (Fig. 3D). The depth of the fence-post tube was set manually as the position at which the tube stopped when inserting. The exact depth was automatically calculated by the neuronavigational system as soon as the robot positioning unit was aligned to its trajectory. Next, the dura was incised and the tumor was removed as planned using the high-resolution 3D exoscope or the microscope. To remove the tumor in the boundary area, we used both the fence-post tubes and

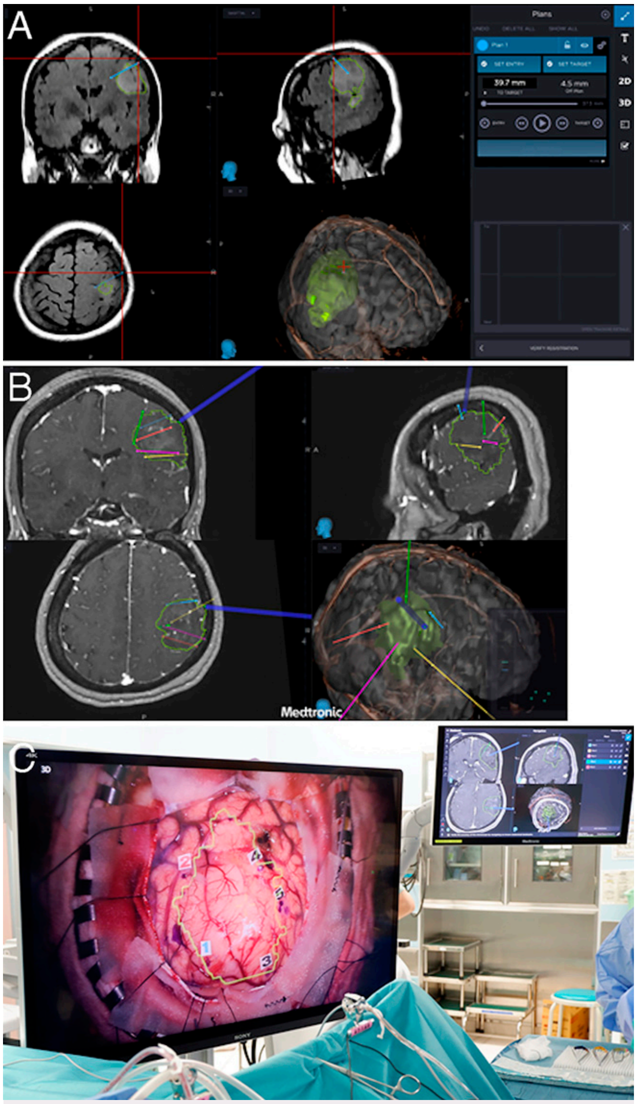

FIG. 2. **A:** Planning and selection of the entry point and target point were performed on a Stealth workstation. **B:** Trajectories were selected starting from the entry points set on the interface between the tumor and normal brain tissues to the target points on the deepest parts of the tumor. **C:** The exoscopic image was overlayed onto the tumor area on the neuronavigation screen with a virtual line to confirm the boundary between the tumor and normal brain tissues.

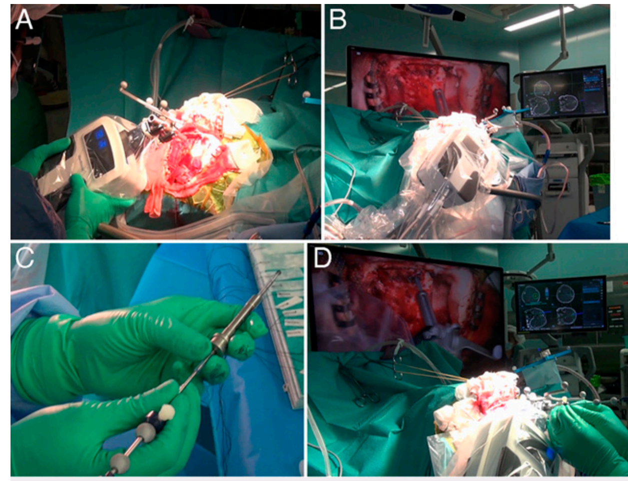

FIG. 3. **A:** The robot positioning unit was manually prepositioned next to the planned entry point by the surgeon under image guidance. The robot positioning unit was automatically positioned and locked in a position accurately aligned to the planned trajectory. **B:** The neuronavigation system confirmed that the robot positioning unit was in the correct position while viewing the surgical field with the exoscope. **C:** For actual insertion of the fence-post tube, we used the ventricular drainage tube (Phycon; Large size, outer diameter = 3.8 mm) as the outer cylinder with a 2.2-mm Nashold biopsy needle as a stylet. **D:** The fence-post tube was manually advanced through the guidance sheath to the target position under continuous depth guidance using its two passive markers displayed on the neuronavigation screen.

the virtual line of the tumor boundaries indicated by the neuronavigation system at the lesion where the fence-post tubes were not placed together. The position memory function of the KINEVO 900 allowed easy switching between the exoscope and the microscope, with adjustment of their optimal fields of view.

Feasibility

Placing the fence-post tubes using the robot-guided frameless stereotactic technique was feasible in all three patients (i.e., conversion to the manual navigation-guided fence-post tube technique was not required). One patient had three fence-post tubes inserted after the dural incision, whereas two patients had two fence-post tubes inserted before the dural incision.

Accuracy Assessment

The target alignment performed by the robotic system was automatically calculated, with highly accurate positioning performed in all three patients. In all patients, the fence-post tubes (i.e., the ventricular drainage tube as the outer cylinder with a 2.2-mm Nashold biopsy needle as a stylet) were inserted at the planned position in a single operation, and the tumor resection was successful. Additionally, no adverse events (e.g., vascular injury) associated with fence-post tube placement were observed.

Clinical Outcomes

Using a high-resolution 3D exoscope, the surgeon could simultaneously view the surgical field image and the navigation screen with minimal movement of the line of sight, allowing the operation to proceed safely. The position memory function of the KINEVO 900 also allowed the surgeon to easily switch between the exoscope and the microscope, with adjustment of their optimal fields of view. Additionally, the combination of the KINEVO 900 and the neuronavigation system allowed the surgeon to trace the tumor boundaries in three dimensions, which enabled accurate removal of even irregularly shaped tumors.

During the tumor removal procedure, no hemorrhage was detected along the trajectory or tip of the fence-post tubes in any patients. Furthermore, no patients developed permanent new neurological symptoms or signs, no robotic device-related adverse effects were noted, and no infections developed in any patients.

Illustrative Case

A 48-year-old man was transferred to our hospital with tonic-clonic seizures involving his upper and lower limbs. MRI of the head showed a 42-mm tumor in the left frontal lobe (Fig. 4A). The tumor showed no enhancement after contrast agent administration. A gross total resection of the tumor was performed, and the pathological diagnosis was oligodendroglioma. No radiotherapy or chemotherapy was administered. However, after 2 years, the tumor recurred in front of the extraction cavity (Fig. 4B). We planned a surgery to insert two fence-post tubes, one at the anterior end of the recurrent tumor and one at the deepest part from the center of the tumor (Fig. 4C). A craniotomy was performed in the same area as the prior surgery, and the fence-post tubes were inserted using the robot-guided frameless stereotactic system before the dural incision (Fig. 4D). The dura was then incised and the tumor was removed as planned. Postoperative MRI showed gross total resection (Fig. 4E), and the patient was neurologically intact with no morbidity. The pathological diagnosis was anaplastic oligodendroglioma, and the patient received a standard course of radiotherapy and chemotherapy.

Discussion

Observations

With rapid advancements in surgical-assistive robots, there is increasing use of robotic technology in neurosurgery, including for stereotactic procedures such as deep brain stimulation electrode placement,[20–22] stereo-electroencephalography for refractory epilepsy,[20,23] catheter placement,[15] stereotactic biopsy of intracranial lesions,[15,20,24,25] and radiosurgery.[26] These studies have verified the safety and accuracy of robotic stereotactic technology. In the present study, we used these stereotactic procedures to establish a new frameless stereotactic technique for fence-post tube placement under robot guidance.

Insertion of a fence-post tube typically requires adjustment of the trajectory line in two or three directions on the multiplanar image while viewing the neuronavigation screen, which is a procedure that requires technical experience. In the present study, we found that use of the Stealth Autoguide allowed highly accurate placement of the fence-post tube by quickly selecting a location around the target region based on the surgical plan. Additionally, when using the exoscope, the surgeon was able to simultaneously view the surgical field image and the neuronavigation screen without gaze movement, which made the operation safer. Using the position memory function of the KINEVO 900, it was also easy to switch between the exoscope and the microscope and to adjust their optimal fields of view. Use of the ventricular drainage tube (Large size, outer diameter = 3.8 mm) as the outer cylinder of a 2.2-mm Nashold biopsy needle with water as a lubricant allowed smooth insertion and removal of the needle. Additionally, because insertion of ventricular drainage tubes into the brain is common practice, we considered that it would be safe for use as a fence-post.

The Stealth Autoguide allowed quick and accurate movement of the fence-post tubes from their position around the target tumor to the position based on the surgical plan; this level of precision cannot be achieved manually. We used the fence-post tubes and the tumor boundary indicated by the neuronavigation system to improve the tumor removal rate. The fence-post tubes were placed into the deep medial, deep apical, and lateral posterior areas, whereas the areas without fence-post tubes were removed by referring to the neuronavigation contour. In our patients, combined use of the KINEVO 900 and the neuronavigation system allowed us to follow the tumor boundaries in three dimensions, handle irregular tumor shapes, and resect the tumor more accurately.

The fence-post tubes were placed after using the neuronavigation system to confirm that the virtual insertion line did not contain any vascular structures, fiber tracts, or eloquent areas. To further help avoid the eloquent areas, we also used motor evoked potential monitoring with extracranial stimulation and direct motor cortex stimulation in patients in whom the motor cortex was exposed within the surgical field. No bleeding or adverse symptoms caused by fence-post tube placement were observed in any patients. Our results suggest that this procedure is safe and feasible and improves targeting accuracy. Note that fluorescence-guided surgery is also performed at our facility. Administration of 5-aminolevulinic acid was performed in all three patients, although no tumor fluorescence was obtained. Because low-grade gliomas often show no 5-aminolevulinic acid fluorescence, we believe that the fence-post tube technique is particularly useful.

There are some limitations to our study. First, the study was designed to evaluate the feasibility of a novel frameless stereotactic technique of fence-post tube placement under robotic guidance. Thus, the study lacks a comparison with the standard manual method. Furthermore, although our frameless stereotactic technique was safe and accurate, we only examined three patients. Thus, future studies with more patients are required. Finally, although there was no deviation of the neuronavigation system due to brain shifting, swelling, or bleeding in the present study, further studies should consider the capacity of this system to respond flexibly when such deviation occurs.

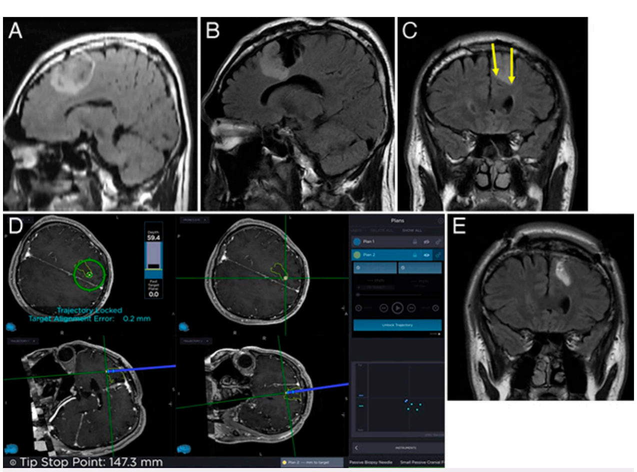

FIG. 4. MRI revealed an intraaxial tumor in the left frontal lobe. **A:** The lesion presented as high-intensity signal on fluid-attenuated inversion recovery (FLAIR) imaging. **B:** After 2 years, the tumor recurred in front of the extraction cavity (FLAIR imaging). **C:** Fence-post tube placement was planned for the anterior end of the recurrent tumor and the deepest part from the center of the tumor (*arrows*). **D:** The fence-post tubes were inserted using the robot-guided frameless stereotactic technique followed by neuronavigation before the dural incision. **E:** Postoperative MRI showed gross total resection (FLAIR imaging).

Lessons

Fence-post tube placement using our robot-guided frameless stereotactic technique with neuronavigation and an exoscope was highly accurate and allowed more precise glioma resection. This method is a useful application of recent developments in robotics technology.

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Disclosures

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

Author Contributions

Conception and design: Koizumi, Sameshima, Kurozumi. Acquisition of data: all authors. Analysis and interpretation of data: Koizumi, Sameshima, Kurozumi. Drafting the article: Koizumi, Sameshima. Critically revising the article: Koizumi, Sameshima. Reviewed submitted version of manuscript: Sameshima, Kurozumi. Approved the final version of the manuscript on behalf of all authors: Koizumi. Statistical analysis: Sameshima. Administrative/technical/material support: Koizumi, Sameshima. Study supervision: Koizumi, Sameshima, Kurozumi.

Correspondence

Shinichiro Koizumi: Hamamatsu University School of Medicine, Shizuoka, Japan. coizmmd@hama-med.ac.jp.