Application of Multimodal Image Fusion to Precisely Localize Small Intramedullary Spinal Cord Tumors

Peihai Zhang[1], Guihuai Wang[1], Zhenxing Sun[1], Xianli Lv[1], Yi Guo[1], James Wang[1], Youtu Wu[1], Wei Shi[1], Huifang Zhang[1], Huiting Liu[2], Yang Lu[1]

■ OBJECTIVE: **We sought to study the application of precise intraoperative localization of small intramedullary spinal cord tumors.**

■ METHODS: **From November 2015 to August 2017, 5 patients with small intramedullary spinal cord tumors were arranged in this group. By using the O-arm image system, we acquired the intraoperative computed tomography images of all patients and sent them to the Stealth navigation system. Medtronic Synergy Cranial software was used to complete the image fusion with preoperative magnetic resonance images, and the fused images were used to localize the intramedullary spinal cord tumors by the navigation system. The navigation errors were evaluated by measuring the maximum distance between the end of the tumor in sagittal magnetic resonance imaging and its real position.**

■ RESULTS: **Five patients accomplished the multimodal image fusion, and we successfully completed the image-guided surgeries. The mean diameter of tumors was 12.2 ± 3.1 mm in sagittal magnetic resonance imaging, and the mean incision length was 12.7 ± 3.3 mm. The time of image processing was between 13 minutes and 17 minutes, and the mean value was 15 ± 1.6 minutes. The navigation error was between 0.9 mm and 1.5 mm, and the mean value was 1.2 ± 0.2 mm.**

■ CONCLUSIONS: **The application of the multimodal image fusion combined with intraoperative O-arm image navigation system can be used to localize small intramedullary tumors.**

INTRODUCTION

Primary spinal cord tumors account for 2%–4% of all primary central nervous system (CNS) tumors, one third of which are intramedullary. In most cases, surgery is the preferred treatment.[1,2] During traditional procedures, surgeons localize spinal segments aided by radiographs and localize tumors by their clinical experience. It is reported that the probability of performing an operation on the wrong spinal segments is 0.032%–15%.[3-8] Blind myelotomy may cause neurologic deficits and go against the concept of precise neurosurgery.

By simulating the multimodal image fusion technology used in intracranial tumors, we acquired the intraoperative computed tomography images of patients by O-arm system and sent them to the StealthStation navigation system (Medtronic). Medtronic's Synergy Cranial software (Minneapolis, Minnesota, USA) was used to complete the fusion with preoperative magnetic resonance imaging (MRI). Finally, we localized the intramedullary spinal cord tumors guided by fused images. Preliminary results are as follows.

METHODS

We retrospectively studied 5 patients of intramedullary spinal cord tumors who accepted operations between November 2015 and August 2017 in Beijing Tsinghua Changgung Hospital. There were 2 males and 3 females, 2 of whom suffered from cervical segment intramedullary tumors and the other 3 had thoracic level tumors. The main symptoms of these patients included weakness (2 cases), dysesthesia (3 cases), and paraplegia and incontinence (1 case). The preoperative McCormick score was class IV in 1 case and class II in the other 4 cases.

All patients underwent preoperative enhanced MRI scans (3.0T GE, Boston, Massachusetts, USA). Images were saved

Key words
- Multimodal image fusion
- Navigation
- Spinal cord tumors

Abbreviations and Acronyms
CNS: Central nervous system
CT: Computed tomography
IDEAL: Iterative decomposition of water and fat with echo asymmetric and further squares estimation
MRI: Magnetic resonance imaging

From the [1]Department of Neurosurgery, Beijing Tsinghua Changgung Hospital, Tsinghua University, Beijing; and [2]Peking Union Medical University Hospital, Beijing, China

To whom correspondence should be addressed: Guihuai Wang, M.D.
[E-mail: youngneurosurgeon@163.com]

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and transferred to the StealthStation 7 Navigation Workstation (Medtronic) in digital imaging and communications in medicine format before operations. The diameter of all tumors was measured on sagittal MRI. Specific parameters of enhanced MRI scanning were as follows: iterative decomposition of water and fat with echo asymmetric and further squares estimation sequence (IDEAL sequence). Layer thickness was 3 mm with 1-mm intervals layered. The contrast agent was gadolinium diethylenetetramine pentaacetic acid.

During operations, we obtained intraoperative computed tomography (CT) images through an O-arm image system (Medtronic) and completed the fusion of intraoperative CT and preoperative MRI by Synergy Cranial software in the navigation workstation. In order to distinguish the fused images, the MRI was switched to rainbow style. Image fusion was confirmed by 2 senior neurosurgeons. The time for setting up an O-arm and acquiring an image has already been counted into the image processing time. Three-dimensional models were built in the Synergy Cranial software, which included bone, vessels, and tumors, optionally in size and transparency, and the surgical approaches were simulated on the workstation.

The localization of tumors was confirmed by multimodal fusion images of CT and MRI. Considering the displacement of the spinal cord after cerebrospinal fluid loss and excision of tumors, the navigation errors were evaluated by measuring the maximum distance between the end of the tumor in sagittal images and its real position. During operations, the navigation probe was replaced by the focus of the microscope and we projected the outline of the tumor onto the operative field. The diameter of tumors and incision length of spinal cords were measured in sagittal planes.

Descriptive statistics were used to obtain mean and standard deviation. SPSS (version 12.0; SPSS Inc., Chicago, Illinois, USA) was used for analysis.

RESULTS

Five cases of intramedullary spinal tumors were localized precisely and resected completely. The postoperative pathology diagnosis confirmed 3 cavernous hemangiomas and 2 ependymomas. One month after surgery, the McCormick score of patients was class IV in 1 case and class II in 4 cases. The clinical symptoms of patients have been improved, and all the patients have no cerebrospinal fluid leakage or central nervous system complications such as infection. The mean time of image processing was 15 $\pm$ 1.6 min. The mean diameter of tumors was 12.2 $\pm$ 3.1 mm, and the mean incision length was 12.7 $\pm$ 3.3 mm. Detailed information is shown in **Table 1**.

The mean value of navigation errors was 1.2 $\pm$ 0.2 mm, which met the demands of precise localization of tumors. One case of C4-5 level intramedullary ependymoma (**Figure 1**) and 1 case of T2 level intramedullary cavernous hemangioma (**Figure 2**) looked like the normal tissues after exposure of the spinal cord. Combined with the intraoperative microscopic navigation technology, virtual microscope navigation cross replaced the tip of the navigation pointer and projected an outline of the tumor in operative fields. We could significantly reduce the unnecessary damages of exploratory operations by the multimodal image fusion technology.

DISCUSSION

Although the incidence rate is not high, incorrect localization of myelotomy will not only prolong the hospital stay but also increase the trauma and costs of patients, so the intraoperative localization of intramedullary spinal cord tumors is a problem of significant importance for spinal surgeries. Sometimes it even left the doctor in legal disputes. In recent years, the application of O-arm image navigation systems has been reported increasingly year by year in spinal surgeries.[9-13] In 2015 Jang, Sang Hoon et al[9] reported 31 patients underwent anterior cervical surgeries intraoperatively with the O-arm image navigation system. The results of navigation showed that the horizontal deviation was 0.49 $\pm$ 0.71 mm, vertical deviation was 0.88 $\pm$ 0.93 mm, and the sagittal alignment deviation angle was 0.59 $\pm$ 0.55. The accuracy of the O-arm image navigation system fully satisfied the clinical needs of spinal cord tumors localization without radiation risks for the operators.[11] However, it is impossible to display spinal cord tumors in CT images and the O-arm could not directly be used for the tumors localization.

The multimodal image fusion technology, based on 2 or more image sources, is helpful to get more accurate, comprehensive, and reliable images on the same situation.[14-16] In recent 10 years, multimodal image fusion technology has always been used with the neural navigation system in intracranial tumors, especially for gliomas.[17-22] It is reported that this technique could significantly improve the resection rate of tumors and reduce the postoperative complications with the help of intraoperative MRI. However, it needs special operation rooms, specific instruments, and expensive costs, which most medical centers could not afford.[23-25]

After the laminectomy, intraoperative ultrasound could be used to localize spinal cord tumors. The cost of ultrasound is much

Table 1. Information of 5 Patients with Intramedullary Spinal Cord Tumors

Location	Pathology	Tumor Size	Image Processing Time	Navigation Error	Incision Length
C3-4	Ependymoma	16.2 mm	15 minutes	1.1 mm	16.5 mm
C4-5		15.4 mm	16 minutes	0.9 mm	15.8 mm
T2		9.4 mm	15 minutes	1.2 mm	10.1 mm
T4	Cavernous hemangioma	8.5 mm	17 minutes	1.4 mm	9.2 mm
T7-8		11.5 mm	17 minutes	1.5 mm	12.0 mm