Application of Augmented Reality to Stereotactic Biopsy

Makoto SATOH,¹ Takeshi NAKAJIMA,¹ Takashi YAMAGUCHI,¹ Eiju WATANABE,¹ and Kensuke KAWAI¹

¹Department of Neurosurgery, Jichi Medical University, Shimotsuke, Tochigi, Japan

Abstract

Both frame-based stereotaxy and frameless stereotaxy are established surgical procedures. However, they each have their respective disadvantages when used in the biopsy of a deep-seated lesion. To overcome the drawbacks associated with these procedures, we evaluated the feasibility of applying augmented reality (AR) to stereotactic biopsy. We applied our trans-visible navigator (TVN) to frame-based stereotactic biopsy in five cases of deep-seated lesions. This navigation system uses the AR concept, allowing surgeons to view three-dimensional virtual models of anatomical structures superimposed over the surgical field on a tablet personal computer. Using TVN, we could easily confirm a clear trajectory avoiding the important structures as well as the target point's location in the lesion. Use of the stereotactic apparatus allowed the surgeon to easily advance the biopsy probe to the target point. Consequently, a satisfactory histopathological diagnosis without complication was achieved in all cases. In conclusion, applying AR to stereotactic biopsy is feasible and may improve the safety of the procedure.

Key words: neuronavigation, augmented reality, trans-visible navigator, stereotactic brain surgery

Introduction

Although frame-based stereotaxy is an established procedure used in the biopsy of deep-seated lesions,¹–³ errors due to inaccurate registration, incorrect targeting, incorrect coordinates, and the patient's head movement while in the frame may decrease the accuracy of the procedure. Frameless navigation using an optical or electromagnetic localization system is an alternative method for stereotactic biopsy,¹–³ but it requires an additional apparatus to advance the probe precisely to the target.²–⁵ Moreover, it requires surgeons to alternate their viewpoint from the operative field to the monitor. Augmented reality (AR) allows a real-time updated 3D virtual model of anatomical structures to be superimposed over the surgical field.⁶ It has been successfully used in neurosurgical procedures including aneurysmal clipping,⁷,⁸ brain tumor resection,⁷,⁹–¹¹ external drainage,¹² pedicle screw placement,¹³ and percutaneous vertebroplasty.¹⁴ We applied AR navigation to overcome the disadvantages of stereotactic biopsy.

Surgical Techniques

The application of AR navigation to stereotactic biopsy was performed as part of a project to develop a tablet personal computer (PC)-based AR navigation system.⁹ This project was approved by the Jichi Medical University Clinical Research Ethics Committee. All patients gave written informed consent for their participation in the research.

AR-based navigation

Trans-visible navigator (TVN) is AR-based navigation using a tablet PC (Surface Pro; Microsoft, Redmond, WA, USA; Fig. 1A). The development of our TVN system was previously described in detail.¹¹ Briefly, TVN allowed the superimposition of 3D virtual models over the surgical field and captured them using a back-facing camera on a tablet PC (Figs. 1B and 1C).

Augmented reality application was programmed using Unity Pro (Unity Technologies, San Francisco, CA, USA) and then installed into the tablet PC. Graphic resolution of the TVN system was 1920 × 1080 pixels.

A 3D position measurement was obtained using the motion capture system (VICON, Oxford, UK), and head registration was achieved using the anatomical landmark method. The 3D virtual models were created on the basis of preoperative computed tomography (CT)
and magnetic resonance images using an imaging software (Amira; FEI, Hillsboro, OR, USA). We created 3D virtual models of the skin, bone, tumor, vein, and venous sinus in all cases and the brain ventricles in one case.

**Surgical procedure**

Target coordinates were determined on contrast-enhanced CT images scanned in the stereotactic frame (Komai Stereotactic Frame; Mizuho Ltd., Tokyo, Japan). In the operating room, the patient’s head and stereotactic frame were fixed with a Mayfield Ultra Base Unit. The patient’s head was registered to the TVN using three anatomical landmarks: the nasion and bilateral preauricular points. Next, the surgeon determined the puncture trajectory and burr-hole position with the aid of TVN, which superimposed 3D virtual models over the surgical field to avoid important anatomical structures within the trajectory. After the burr hole was drilled, the stereotactic frame was attached and set with predetermined coordinates (Fig. 2A). Before puncturing, the surgeon reconfirmed the location of the trajectory within the lesion and the absence of structures in the trajectory path by manually aligning the camera axis of the tablet with the puncturing trajectory of the stereotactic frame. The biopsy probe was then advanced to the target point using the stereotactic apparatus (Fig. 2B).

**Case Presentations**

In five cases this surgical procedure was used (Table 1). In all cases, the CT images taken immediately after the procedure confirmed a trajectory and the biopsy point located in the lesion. Histopathological diagnosis of the five cases included glioblastoma in two, malignant lymphoma in two, and anaplastic astrocytoma in one.

**Illustrative case 1, patient no. 5**

This patient had a right thalamic tumor (Fig. 3A). This case required a puncture, avoiding the ventricle
and bridging vein. In addition, the hair line was located near the surgical field. Consequently, a burr hole was drilled behind the hair line for cosmetic reasons.

Trans-visible navigator showed a 3D virtual model of the bridging vein, ventricle, and tumor superimposed over the surgical field (Fig. 3B). Therefore, we were able to select the optimal puncture trajectory to avoid important structures with consideration of the hairline (Fig. 3C).

**Illustrative case 2, patient no. 4**

The patient had a right cerebellar tumor. Because the tumor was situated in the posterior fossa, special care must be taken due to the position of the sinuses. Therefore, the sinus, emissary vein, and the tumor were registered using TVN and viewed on the tablet PC during surgery. Following AR visualization, we obtained a good orientation, even after covering the head (Fig. 4A). Therefore, a safe trajectory and burr-hole position were possible using TVN guidance (Fig. 4B).

**Discussion**

Our TVN allows surgeons to reconfirm the accuracy of the target point and suitability of the trajectory by superimposing 3D virtual models over the surgical field, avoiding the drawbacks of frame-based stereotactic navigation. Our TVN also allows surgeons to advance the biopsy probe precisely along the trajectory without turning their viewpoints from the surgical field to the monitor, avoiding the drawbacks of frameless stereotactic navigation. The tablet does not interfere a surgeon’s view because real-time surgical field can be displayed on the tablet via its camera. In addition, there is sufficient space for surgical manipulation. Our study demonstrates that applying AR to stereotactic biopsy is feasible and may improve the safety of the procedure.

---

**Table 1  Series of trans-visible navigator guided stereotactic biopsy**

| Patient no. | Age (years) | Tumor location       | Diagnosis           | Complication | Registered models | Imaging modalities used to create the 3D models |
|-------------|-------------|----------------------|---------------------|--------------|-------------------|-----------------------------------------------|
| 1           | 79          | Right frontal lobe   | Glioblastoma        | None         | Tumor, vein, venous sinus | MRI, CT                                      |
| 2           | 78          | Left temporal lobe   | Glioblastoma        | None         | Tumor, vein, venous sinus | MRI, CT                                      |
| 3           | 60          | Right occipital lobe | Anaplastic astrocytoma | None       | Tumor, vein, venous sinus | MRI, CT                                      |
| 4           | 52          | Right cerebellum     | Malignant lymphoma  | None         | Tumor, vein, venous sinus | MRI, CT                                      |
| 5           | 76          | Right thalamus       | Malignant lymphoma  | None         | Tumor, vein, venous sinus, ventricle | MRI, CT                                      |

CT: computed tomography, MRI: magnetic resonance imaging, 3D: three-dimensional.
The limitations of our TVN for stereotactic biopsy are threefold. First, it is sensitive to the issue of brain shift, although it is common for all navigation methods and not limited to TVN. Second, although it is an easy procedure to perform, it requires an additional 30 min to create the 3D models and registration. Third, TVN did not show the real-time position of the needle tip in our surgical system. Therefore, TVN guided frameless biopsy has still not been achieved.

In conclusion, we tested the feasibility of applying AR navigation to stereotactic biopsy. The use of this navigational approach may improve the safety of the procedure.

Conflicts of Interest Disclosure

All authors who are members of the Japan Neurosurgical Society (JNS) have registered the Self-reported COI Disclosure Statement Forms on the website for JNS members. The authors have no conflicts of interest regarding the publication of this article.

References

1) Dhawan S, He Y, Bartek J, Alattar AA, Chen CC: Comparison of frame-based versus frameless intracranial stereotactic biopsy: systematic review and meta-analysis. World Neurosurg 127: 607.e4–616.e4, 2019
2) Woodworth GF, McGirt MJ, Samdani A, Garonzik I, Olivieri A, Weingart JD: Frameless image-guided stereotactic brain biopsy procedure: diagnostic yield, surgical morbidity, and comparison with the frame-based technique. J Neurosurg 104: 233–237, 2006
3) Dammers R, Haitsma IK, Schouten JW, Kros JM, Avezaat CJ, Vincent AJ: Safety and efficacy of frameless and frame-based intracranial biopsy techniques. Acta Neurochir (Wien) 150: 23–29, 2008
4) Paleologos TS, Dorward NL, Wadley JP, Thomas DG: Clinical validation of true frameless stereotactic biopsy: analysis of the first 125 consecutive cases. Neurosurgery 49: 830–835; discussion 835–837, 2001
5) Dorward NL, Alberti O, Palmer JD, Kitchen ND, Thomas DG: Accuracy of true frameless stereotaxy: in vivo measurement and laboratory phantom studies. Technical note. J Neurosurg 90: 160–168, 1999
6) Meola A, Cutolo F, Carbone M, Cagnazzo F, Ferrari M, Ferrari V: Augmented reality in neurosurgery: a systematic review. Neurosurg Rev 40: 537–548, 2017
7) Kockro RA, Tsai YT, Ng I, et al.: Dex-ray: augmented reality neurosurgical navigation with a handheld video probe. Neurosurgery 65: 795–807; discussion 807–808, 2009
8) Cabrilo I, Bijlenga P, Schaller K: Augmented reality in the surgery of cerebral aneurysms: a technical report. Neurosurgery 10 Suppl 2: 252–260; discussion 260–261, 2014
9) Watanabe E, Satoh M, Konno T, Hirai M, Yamaguchi T: The trans-visible navigator: a see-through neuro-navigation system using augmented reality. World Neurosurg 87: 399–405, 2016
10) Deng W, Li F, Wang M, Song Z: Easy-to-use augmented reality neuronavigation using a wireless tablet PC. Stereotact Funct Neurosurg 92: 17–24, 2014
11) Maruyama K, Watanabe E, Kin T, et al.: Smart glasses for neurosurgical navigation by augmented reality. Oper Neurosurg (Hagerstown) 15: 551–556, 2018
12) Eftekhar B: App-assisted external ventricular drain insertion. J Neurosurg 125: 754–758, 2016
13) Elmi-Terander A, Burström G, Nachabe R, et al.: Pedicle screw placement using augmented reality surgical navigation with intraoperative 3D imaging: a first in-human prospective cohort study. Spine (Phila Pa 1976) 44: 517–525, 2019
14) Abe Y, Sato S, Kato K, et al.: A novel 3D guidance system using augmented reality for percutaneous vertebroplasty: technical note. J Neurosurg Spine 19: 492–501, 2013
15) Nimsky C, Ganslandt O, Hastei R, Fahrbusch R: Intraoperative compensation for brain shift. Surg Neurol 56: 357–364; discussion 364–365, 2001

Address reprint requests to: Makoto Satoh, MD, Department of Neurosurgery, Jichi Medical University, 3311 Yakushiji, Shimotsuke, Tochigi 329-0498, Japan. e-mail: r1228sm@jichi.ac.jp