Presurgical Planning for Supratentorial Lesions with Free Slicer Software and Sina App

Ji-gang Chen, Kai-wei Han, Dan-feng Zhang, Zhen-xing Li, Yi-ming Li, Li-jun Hou

BACKGROUND: Neuronavigation systems are used widely in the localization of intracranial lesions with satisfactory accuracy. However, they are expensive and difficult to learn. Therefore, a simple and practical augmented reality (AR) system using mobile devices might be an alternative technique.

OBJECTIVE: We introduce a mobile AR system for the localization of supratentorial lesions. Its practicability and accuracy were examined by clinical application in patients and comparison with a standard neuronavigation system.

METHODS: A 3-dimensional (3D) model including lesions was created with 3D Slicer. A 2-dimensional image of this 3D model was obtained and overlapped on the patient’s head with the Sina app. Registration was conducted with the assistance of anatomical landmarks and fiducial markers. The center of lesion projected on scalp was identified with our mobile AR system and standard neuronavigation system, respectively. The difference in distance between the centers identified by these 2 systems was measured.

RESULTS: Our mobile AR system was simple and accurate in the localization of supratentorial lesions with a mean distance difference of $4.4 \pm 1.1$ mm. Registration added on an average of $141.7 \pm 39$ seconds to operation time. There was no statistically significant difference for the required time among 3 registrations ($P = 0.646$).

CONCLUSIONS: The mobile AR system presents an alternative technology for image-guided neurosurgery and proves to be practical and reliable. The technique contributes to optimal presurgical planning for supratentorial lesions, especially in the absence of a neuronavigation system.

INTRODUCTION

In neurosurgical operations, precise presurgical planning of surgical approach and craniotomy is of great importance, which depends much on the detailed preoperative localization of intracranial lesions. Experienced neurosurgeons learn to correlate patient’s anatomy with presurgical 2-dimensional (2D) images and localize the intracranial lesions. However, the accuracy of such methods is sometimes not satisfactory because it is subjective and closely related to clinical experience. Neuronavigation systems for intraoperative image guidance improve surgical accuracy and surgeons’ orientation, reducing iatrogenic injury to patients. As an established technology, neuronavigation has been used widely in neurosurgery. However, the neuronavigational systems are expensive and relatively difficult to learn because they require hand–eye coordination on the part of the neurosurgeon to operate according to images in the monitor. Therefore, it is necessary to develop simple and practical techniques for the fusion of virtual images and the real-time surgical field.

Augmented reality (AR) is a fast-developing technology that combines reality and virtual images, allowing the presentation of virtual images in a real-time environment. Aside from implementation of AR using expensive image guidance systems and surgical microscopes, some authors have described alternative low-cost solutions that use mobile devices in neurosurgical...
settings, which are referred as mobile AR. This technology renders AR as much more convenient, affordable, and popular. In current study, we report a simple and practical mobile AR system for presurgical planning of scalp flap and localization of supratentorial lesions, which works mainly with a free Slicer software and a smartphone app.

METHODS

Patients

From October 2015 to October 2016, a group of 16 patients with supratentorial lesions were admitted prospectively into our department. This study was approved by the ethics committee of the Changzheng Hospital, and signed informed consent for each patient was available.

Three-Dimensional (3D) Modeling and Segmentation with Free Slicer Software

All patients, independent of their sex, had their hair fully shaved. Before magnetic resonance imaging (MRI) scanning, 5 vitamin E soft capsules (100 mg; Xinchang Pharmaceutical Factory, Zhejiang, China) were pasted around the lesions with self-adhesive films according to preoperative head computed tomography (CT) presentations. All MRI scans were performed with a 1.5-Tesla magnetic resonance scanner (Signa Excite; GE Medical Systems, Milwaukee, Wisconsin, USA), and the data of plain and enhanced MRI TI phases were exported as Digital Imaging and Communications in Medicine (DICOM) medical images (Figure 1A-C). We used sequence parameters as follows: repetition time, 9.6 milliseconds; echo time, 4.3 milliseconds; flip angle, 15°; matrix, 256 × 256; slice thickness, 0.8 mm; field of view, 160 × 160 mm; sequence, gadolinium-enhanced 3D fast spoiled gradient-echo.

Segmentation and 3D modeling were performed with a 3D Slicer (3D Slicer 4.0; Surgical Planning Laboratory, Harvard University, Boston, Massachusetts, USA) on the basis of DICOM images of included patients. Models of the superior sagittal sinus with cortical veins, markers of vitamin E soft capsules, and the lesion were segmented out and built, respectively (Figure 1D).

A small sphere model with a diameter of 2 mm was constructed and marked with blue. It was located at the center of the scalp projection area of lesion. This sphere model could be localized by the neuronavigation system later and used as a reference point to check the accuracy of our AR system. All the models were exported in stereolithography format. After the 3D model was rotated to a proper view angel (superior view for the frontal lesions and lateral view for the parietal lesions), a 2D image of this view angle was then saved and exported. Two neuroradiologists (J.G.C. and K.W.H.) reviewed the MRI data and conducted reconstruction independently.

Importing the Image Into the Sina App

Sina is an Android app available in Google Play Store. The primary aim is to assist in intraoperative neurosurgical planning. After the 2D image of the reconstructed model was imported into the smartphone (HUAWEI honor 6 plus, Android 4.4.2), we launched the Sina app and loaded the 2D image from image gallery. Then, this image showed up on the phone screen as hemitransparent and overlapped on the live feed from the camera. Because images in Sina cannot be modified, we superimposed the image on the patient’s head manually by adjusting the distance between the device and the patient’s head.

Registration

Patients were positioned supine after being administered anesthesia. The midline of head was used as an anatomical landmark and signed with a marker pen preoperatively. Five vitamin E capsules on the head were taken as fiducial markers. Sina was launched, and a 2D image of the reconstructed model was loaded as the first step. Via the use of the fiducial markers and midline as guides, the 2D image was overlapped on the head. The operator held the smartphone manually and adjusted the distance between device and head to make sure that the fiducial markers and midline could match with the corresponding markers and superior sagittal sinus on the image.

To reduce error in the procedure, the registration process was repeated 3 times for each patient by 3 authors (D.F.Z., Y.M.L., L.J.H.) independently. Registration time was recorded and defined as time needed from starting the Sina app to the 2D image matching with patient’s head. After each registration, the center of lesion projected on scalp was marked as a dot directly by an assistant for the first 2 times and the contour as well as center of lesion was drawn on patients’ head simultaneously the third time (Figure 1E-G).

Comparing the Accuracy of Sina with a Standard Neuronavigation System

Standard neuronavigation was conducted for every patient with a neuronavigation system (Brainlab Kick 1.0; Brainlab AG, Feldkirchen, Germany). The DICOM images and all the models constructed in Slicer previously were imported into the neuronavigation software. Standard registration of the neuronavigation system was performed according to the system’s protocol. The blue small sphere model was first located with the precalibrated pointer in the neuronavigation system and acquired as a reference point, which was automatically set as the “view center” in the neuronavigation system. Then, the “Freeze” function of neuronavigation system was used, which enabled the measurement of distance between the reference point and the tip of the precalibrated pointer. Here, we used this method to measure distance between the reference point localized by neuronavigation system and the point marked by AR system. The accuracy of the Brainlab system in measuring distance was 0.1 mm. The distance difference was then averaged from 3 available values (Video 1).

Statistical Analysis

Continuous data were expressed as the mean and standard deviation. The Friedman test was used to compare the distance differences and required times of 3 registrations. Statistical analyses were conducted with SPSS version 22.0 (IBM, Inc., Armonk, New York, USA). The significance level was defined as 0.05.
RESULTS
The mean age of our patients was 57.4 ± 8.7 years (range, 43–74 years), and 8 were male. A total of 93.75% (15/16) of the patients were diagnosed with meningioma, with only 1 patient having a glioma. Seven lesions were in the frontal lobe, 6 in the parietal lobe, 2 in both of the frontal and parietal lobe, and 1 in the temporal lobe (Table 1).

The mean total registration time was 141.7 ± 39.4 seconds with a range of 89–224 seconds. The mean time for the first registration was 48.6 ± 15.0 seconds (range, 30–79), for the second registration was 45.8 ± 12.9 seconds (range 30–75), and for the third was 47.3 ± 12.9 seconds (range 30–70). There was no statistically significant difference for the 3 registration times ($P = 0.646$). Compared with standard neuronavigation system, our mobile AR system was accurate with a mean $\pm$ standard deviation of 4.4 ± 1.1 mm and range of 2.3–6.3 mm (Table 1). No statistically significant result was detected in distance difference of 3 registrations ($P = 0.153$).

DISCUSSION
The beginning of AR can be traced back as early as 1960s. As a great interest in health care, AR has been used in surgery for several decades, especially in neurosurgery, where a combination of CT data and the operating microscope was used in stereotaxic operation to allow accurate and safe neuronavigation. Nowadays, AR increasingly is attractive as a popular technology because of the proliferation of smartphones. It’s being used widely with imaging technologies to superimpose MRI or CT data on patients during operation, offering surgeons navigational information.

Various AR methods for scalp localization have been reported using the anatomic structures, stereotactic frames, or frameless surgical navigators. However, scalp localization should be accurate and simple. In this study, we presented a reliable and simple AR technique that could be useful for presurgical planning and image-guided neurosurgery.

Our method was a typical example of mobile AR implementation and potentially carried the discussed advantages of these techniques by using Sina app combined with Slicer software to assist in locating supratentorial lesions. In the present study, we used fiducial markers to increase the navigation accuracy. It has been applied commonly in clinical practice and had been reported to err by 1.5–4 mm by various authors. On the basis of data from this study, the mean distance difference was 4.4 ± 1.1 mm, with a maximum deviation of 6.5 mm. A previous study of the Sina app that used anatomic structures such as the coronal suture and midline as the natural markers showed a deviation of 10.2 ± 2 mm. However, artificial markers were not used in this study. Our findings confirmed that AR would have a greater accuracy level if used with other registration models, such as adhesive or bone-implanted fiducials. This conclusion was consistent with several other studies.

<p>| Table 1. Data of Patients Undergoing Operations |</p>
<table>
<thead>
<tr>
<th>Age, Years/Sex</th>
<th>Site</th>
<th>Size, mm</th>
<th>Pathology</th>
<th>Time Required for Registration, seconds</th>
<th>Distance Difference, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>First</td>
<td>Second</td>
</tr>
<tr>
<td>47/M</td>
<td>Left parietal</td>
<td>63</td>
<td>Meningioma</td>
<td>79 75 70 224</td>
<td>6.5 6.3 6.2 6.3</td>
</tr>
<tr>
<td>65/F</td>
<td>Right frontal</td>
<td>27</td>
<td>Meningioma</td>
<td>71 61 66 198</td>
<td>3.1 3.4 3.3 3.3</td>
</tr>
<tr>
<td>54/M</td>
<td>Right parietal</td>
<td>54</td>
<td>Meningioma</td>
<td>69 58 56 183</td>
<td>4.5 4.8 4.8 4.7</td>
</tr>
<tr>
<td>61/M</td>
<td>Right frontal and parietal</td>
<td>23</td>
<td>Meningioma</td>
<td>58 54 63 175</td>
<td>4.4 4.2 4.4 4.3</td>
</tr>
<tr>
<td>43/F</td>
<td>Right parietal</td>
<td>15</td>
<td>Meningioma</td>
<td>55 61 52 168</td>
<td>4.6 4.8 4.8 4.7</td>
</tr>
<tr>
<td>74/M</td>
<td>Left parietal</td>
<td>54</td>
<td>Meningioma</td>
<td>49 43 55 147</td>
<td>3.6 3.6 3.9 3.7</td>
</tr>
<tr>
<td>68/M</td>
<td>Right frontal</td>
<td>42</td>
<td>Meningioma</td>
<td>54 42 59 155</td>
<td>2.2 2.3 2.5 2.3</td>
</tr>
<tr>
<td>48/M</td>
<td>Right parietal</td>
<td>51</td>
<td>Meningioma</td>
<td>49 45 39 133</td>
<td>4.1 4.3 4.4 4.3</td>
</tr>
<tr>
<td>63/F</td>
<td>Left frontal</td>
<td>68</td>
<td>Meningioma</td>
<td>44 42 40 126</td>
<td>5.2 5.4 5.3 5.3</td>
</tr>
<tr>
<td>62/M</td>
<td>Left temporal</td>
<td>35</td>
<td>Meningioma</td>
<td>39 43 40 122</td>
<td>6 6.2 5.9 6.0</td>
</tr>
<tr>
<td>51/M</td>
<td>Left frontal</td>
<td>44</td>
<td>Meningioma</td>
<td>39 35 43 117</td>
<td>2.5 2.6 2.9 2.7</td>
</tr>
<tr>
<td>53/F</td>
<td>Right parietal</td>
<td>24</td>
<td>Meningioma</td>
<td>43 47 41 131</td>
<td>5.9 5.5 5.8 5.7</td>
</tr>
<tr>
<td>58/F</td>
<td>Left frontal and parietal</td>
<td>28</td>
<td>Meningioma</td>
<td>37 33 38 108</td>
<td>5.5 5.3 5.2 5.3</td>
</tr>
<tr>
<td>52/F</td>
<td>Left frontal</td>
<td>20</td>
<td>Meningioma</td>
<td>36 31 30 97</td>
<td>3.8 3.9 3.5 3.7</td>
</tr>
<tr>
<td>53/F</td>
<td>Left frontal</td>
<td>27</td>
<td>Meningioma</td>
<td>29 33 32 94</td>
<td>3.9 4.1 4.1 4.0</td>
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<tr>
<td>67/F</td>
<td>Left frontal</td>
<td>25</td>
<td>Meningioma</td>
<td>27 30 32 89</td>
<td>4.5 4.8 4.8 4.7</td>
</tr>
</tbody>
</table>

Distance difference indicates the distance between the 2 methods of localization.
M, male; F, female.
Another important factor contributing to the accuracy of our method was the use of the 3D Slicer software for reconstruction. The reconstructed 3D image could be rotated to any view angle, and we could get a precise 2D image of proper view angle from the 3D reconstructed model without any tilt. According to a similar mobile AR study that used the Sina app without 3D reconstruction, $1/14$ of tilt could cause about 2 mm of targeting deviation. What's more, the angle of MRI scanning was determined manually by radiographer, and axial MRI might not be exactly vertical to the floor. In this way, the deviation would increase evidently if the head position was not in the right way during the MRI scanning. This deviation could be eliminated completely by 3D reconstruction of MRI data.

In our study, we reconstructed the cortical veins together with supratentorial lesions. Thus, the relationship between 2 of them was clearly visualized after registration. The basic craniotomy and skin flap planning could then be decided according to the localization of lesions and veins. Moreover, these cortical veins could be used as landmarks to seek lesions after dural opening. This also would be helpful for venous protection in surgical process, especially for lesions closely related to veins, such as the cerebral parafalk lesions.

Theoretically, we can reconstruct a model that contains the sulci, gyri, and cortical vessels with Slicer at the same time. After dural opening, we can coregister the model with surgical field of the cortex surface. It would likely be a useful neuronavigational tool.

Figure 1. (A) Axial, (B) coronal, and (C) sagittal magnetic resonance imaging demonstrated a superficial supratentorial meningioma. (D) The superior view of the reconstructed model revealed the relationship among the following structures: the lesion (yellow), marker (red), center of the lesion (dark blue), and sagittal sinus with cortical vein (light blue). (E) Superior view of the patient’s head with marker (vitamin E capsule) before surgery. (F) Screen capture of the Sina during registration. (G) A U-shaped skin incision was marked according to the location of lesion. (H) Intraoperative photography verified the location of lesion, and (I) the lesion was removed.
aid during operations of small lesions, especially for those shallow subcortical ones. However, considering the brain shift after dural opening, the second registration would not be accurate enough. Because of this, some authors have proposed methods such as intraoperative image updating to compensate for brain shift.21

Simplicity and availability of the device and software are evident advantages as well. Compared with other AR solutions, our method achieved similar effects with simplified MRI processing, registration procedure, and AR image generation. It does not require additional costs or technical complexity other than few markers, an Android phone, and a free App. Sina neurosurgical assist has been used in several studies for AR and proved to be effective with acceptable deviation.22,23 Moreover, 3D Slicer is a free open-source software popular for 3D modeling and has been applied for reconstruction in some AR studies.9-11 Because our method is inexpensive and convenient with satisfactory accuracy, it could be used in the developing areas in which neuronavigation system is inaccessible.

There are some limitations to this study that should be discussed. Although our method is reliable for supratentorial lesions, this does not apply exactly to infratentorial lesions. The success of our mobile AR system depends greatly on the definition obtained in the MRI scan reconstruction. The posterior fossa anatomy varies from supratentorial anatomy in a way that shallow sulci of cerebellar folia is difficult to identify in reconstructed model. It also has an almost parallel orientation, which makes registration unreliable. Moreover, cortical veins of the posterior fossa are of small diameter and difficult to reconstruct on 3D Slicer. All of these variables might explain why we are unable to perform our AR system in the infratentorial region.

Our method was only tested by a limited number of cases in a single center. Multicenter studies with larger sample sizes are required to assess the feasibility and clinical application of this new method. A study on a large population by different users with various background might produce different results.

In addition, manual image overlaying and lack of feedback about the precision of overlap should be considered as the disadvantages of our method. Incomplete overlapping of the images with head may be the major source of deviation in this setting. The performers do not need much training in overlaiding. However, the potential effect of user’s experience in using this app has not been addressed either.

REFERENCES


