A Smartphone App to Assist Scalp Localization of Superficial Supratentorial Lesions—Technical Note

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■ BACKGROUND: **Neuronavigation is an established technology in neurosurgery. In parts of the world and certain circumstances in which neuronavigation is not easily available or affordable, alternative techniques may be considered.**

■ OBJECTIVE: **An app to assist scalp localization of superficial supratentorial lesions has been introduced, and its accuracy has been compared with established neuronavigation systems.**

■ METHODS: **Sina is a simple smartphone app that overlaps the transparent patients' computed tomography/magnetic resonance images on the background camera. How to use Sina intraoperatively is described. The app was used for scalp localization of the center of the lesions in 11 patients with supratentorial pathologies <3 cm in longest diameter and <2 cm from the cortex. After localization of the lesion using Sina, the center of the lesion was marked on the scalp using standard neuronavigation systems and the deviations were measured.**

■ RESULTS: **Implementation of Sina for intraoperative scalp localization is simple and practical. The center of the lesions localized by Sina was 10.2 ± 2 mm different from localization done by standard neuronavigation systems.**

■ CONCLUSION: **When neuronavigation is not easily available or affordable, Sina can be helpful for scalp localization and preoperative planning of the incision for selected supratentorial pathologies.**

INTRODUCTION

Neurosurgeons and neurosurgical trainees, over time, learn how to correlate image studies with patient anatomy and localize the lesions in the nervous system. However, that is not accurate enough and neuronavigation has become an established technology in neurosurgery. In certain circumstances and in parts of the world, neuronavigation is not easily available or affordable.

Popularity and availability of smart devices including smart phones make them a very good platform for augmented reality purposes and intraoperative localization. There are available apps that could be used for the same purposes; however, the need for certain features and potential for further development prompted the author to consider developing a simple app for scalp localization and intraoperative planning.

In this study the author introduces Sina Intraoperative Neurosurgical Assist (Sina) as a simple app to assist image-based scalp localization. It is an Android app written in Java available for download from Google Play Store.

In order to investigate the functionality of Sina in circumstances in which neuronavigation is not available, the accuracy of Sina has been compared with the established neuronavigation systems.

METHODS

App Instructions

Sina simply overlaps the transparent patients' computed tomography/magnetic resonance imaging (CT/MRI) on the background camera. The first screen of the app shows the instructions for use. There is a "SELECT IMAGE" button for selection and loading the images from gallery of the android device. After selection, the image will be transparent and

Key words
- Augmented reality
- Image-guided surgery
- Mobile applications
- Neuronavigation

Abbreviations and Acronyms
cm: Centimeter
CT: Computed tomography
MRI: Magnetic resonance imaging
Sina: Sina Intraoperative Neurosurgical Assist

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overlapped on the camera. While moving the device toward or away from the patient's head, the image can be overlapped properly. Magnification cannot be modified through Sina.

Because CT/MRI convention is as if one is viewing from below rather than above the head, the orientation of the loaded image is usually different from the patient's position. Therefore double tapping the image with Sina to flip the image is helpful.

Intraoperative Technique

Appropriate axial, coronal, and sagittal CT or MRI images best showing the lesion are taken by an Android device camera in portrait mode. These images could be taken by other cameras and transferred to the Android device with or without editing, before use by Sina.

After anesthesia and before positioning (while the patient is in neutral supine position), the coronal suture is localized on the skull and the midline of the head is marked using anatomic landmarks. Sina is launched, and the axial image is loaded as the first step. The side of the lesion is verified as a routine part of the time-out procedure. An assistant puts her or his finger on coronal suture so that the tip of the finger can be used as a reference point for contour of the skull. Using coronal suture and midline as anatomic guides, the axial image is overlapped on the head from the top of the patient so that the coronal suture of the head matches with its location on the image. Localizing the center of the lesion, a coronal line is drawn on the head by the assistant (**Figure 1**). Any other landmarks, like a skull dent, or radiodense markers that can be matched with its location on the images can also be used.

The coronal image is loaded as the next step. The assistant puts a finger on the coronal line that was drawn in the previous step so that the fingertip can be used as a reference point for contour of the skull at the coronal plane of the lesion. Using the midline and tip of the finger as guides, the coronal image is overlapped on the head. In more anterior lesions, the nose and orbital rim can also be used as guides to overlap the images over the head. After properly localizing the center of the lesion, an anteroposterior line is drawn by the assistant (**Figure 2**). The room lights may interfere with using the device and may need to be temporarily adjusted.

The crossing point between two drawn lines is considered the estimated center of the lesion (**Figure 3**). Optionally the sagittal cut can be loaded to check the accuracy of previous localization anteroposteriorly. Again, coronal suture should be used as the guide. For lesions close to the midline, using the sagittal image first and coronal image second works better.

Comparing the Accuracy of Sina with Standard Neuronavigation Systems

Because the accuracy of scalp incision matters more when the neurosurgeon deals with small lesions, the accuracy of Sina was compared with known neuronavigation systems for small superficial lesions. Lesions <3 cm in longest diameter were arbitrarily defined as small.

In 11 patients with supratentorial lesions <3 cm in longest diameter and <2 cm deep from the cortex, using the previously mentioned technique on Galaxy Note 3 5.7″, the lesions were localized by the author. After localization of the lesion using Sina, the center of the lesion was localized and marked (by an assisting registrar or fellow), using standard neuronavigation systems (one case StealthStation, Medtronic, Minneapolis, Minnesota, USA, and the rest Brainlab, Munich, Bavaria, Germany). A ruler was placed on the site for measurements.

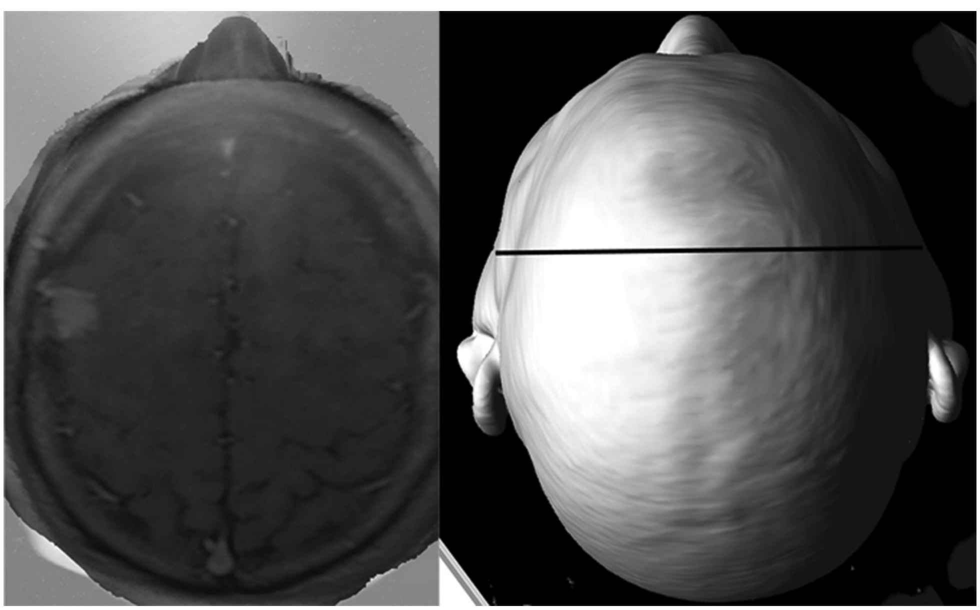

Figure 1. This is a reconstructed image (not taken intraoperatively) showing an example of overlapping of the axial image and drawing of the coronal line accordingly. On the right, localizing the center of the lesion, a coronal line is drawn on the head.

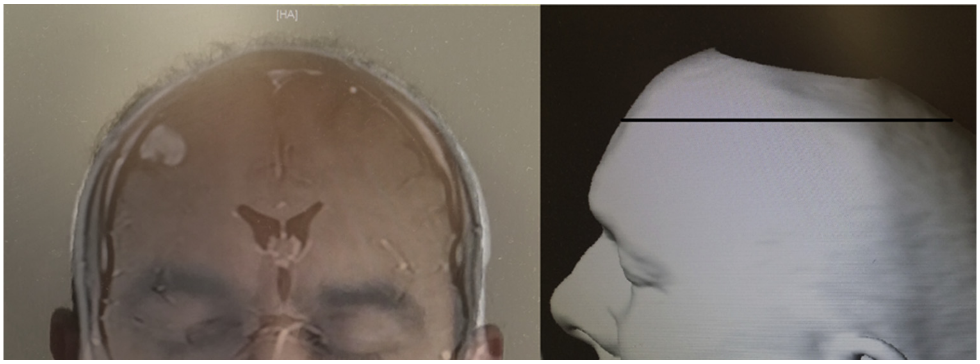

Figure 2. This is a reconstructed image (not taken intraoperatively) showing an example of overlapping the coronal image on the head, so that the contour of the head and midline match with the image. On the right, localizing the center of the lesion, an anteroposterior line is drawn on the head perpendicular to the scan.

The deviation of alignment (mm) was calculated by dividing the distance (pixels) between the localizations (A) by length (pixels) of 1 cm cut of ruler (CM) times 10 (10A/CM) (Figure 3). In order to reduce the error due to manual intervention, each measurement was done twice and then averaged. The deviations (mm) and other variables including age/sex, site, and size of the lesion and pathology were tabulated. All initial measurements were made in pixels using the computer software Paint (v6.2 Microsoft, Redmond, Washington, USA). The mean and standard deviation of the differences and durations were calculated using computer software Calc (LibreOffice 4.2.5.2, The Document Foundation, Paris, France).

RESULTS

Localization using Sina added on average 4 $\pm$ 1 minutes to the operating time. Taking photos of the patients' images were not included in the timing. Considering the fact that the prerelease versions of the app had been used by the author during app development, no comment could be made on the learning curve.

Table 1 shows the size of the lesions, pathology, and difference between neuronavigation and localization by Sina. The mean difference is 10.2 $\pm$ 2 mm with an 8- to 14-mm range.

Stealth was used for the second patient. Her lesion was 2 cm deep to the cortex. Brainlab was the neuronavigation system for the rest of the patients.

The directions of misalignments did not follow any specific pattern (was not predominantly craniocaudal or anteroposterior).

What Is the Likely Error If the Scan Has Not Been Acquired in Orbitomeatal Plane or Is Tilted?

Considering the fact that the rotation may happen around different axes and also that head shapes and location of the lesions are different, coming up with a generalized formula may

Table 1. Patient Characteristics, Size and Site of the Lesions, Pathology, and the Difference Between Neuronavigation and Localization by Sina Intraoperative Neurosurgical Assist

No	Age (years)/Sex	Site of the Lesion	Size of the Lesion (mm)	Pathology	Distance Between 2 Methods of Localization
1	32/F	Left frontal	19	Metastasis—breast	8
2	44/F	Right frontal	21	Metastasis—breast	9
3	67/M	Left frontal	25	Metastasis—lung	9
4	64/F	Midline occipital	26	Meningioma	10
5	47/F	Left frontal	25	Meningioma	12
6	59/M	Right parietal	20	Metastasis—renal	11
7	65/M	Left frontal	10	Metastasis—renal	8
8	55/F	Right parietal	28	Meningioma	14
9	49/M	Left parietal	22	Metastasis—lung	8
10	62/M	Left parietal	27	Metastasis—lung	13
11	66/M	Right parietal	20	Metastasis—lung	10

Figure 3. The image was taken intraoperatively after localizations done by Sina (*blue lines*) and neuronavigation systems (*black dot*). The deviation of alignment (A) and 1 cm length of the ruler (CM) are marked.

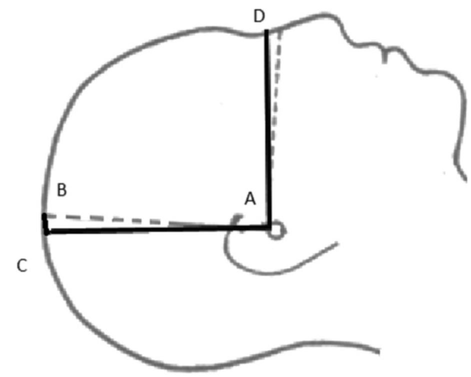

Figure 4. The scan should be acquired with AD as the orbitomeatal plane and AC as the auricular height. If we assume that the scan has been tilted for an angle (∠CAB in our special case), the center of the lesion is calculated as B instead of C (with CB as targeting error). The targeting anteroposterior error (CB) can be estimated by tangent of tilting angle (∠CAB) multiplied by the auricular height (AC). Due to the contour and shape of the head, the calculation is only an estimate for practical purposes and becomes less accurate as the angle increases. A smartphone app to assist scalp localization of cranial lesions is introduced.

not be practical. However, in order to estimate the error, the author has assumed rotation of the head around the line that joins 2 external auditory meatuses, in a special case of a lesion in the midline vertex. **Figure 4** shows that the targeting anteroposterior error (mm) is estimated by tangent of tilting angle multiplied by the auricular height. The auricular height varies in different races[1,2]; however, for a height of 120 mm, 1 degree of tilt can cause around 2 mm of targeting deviation. In practice, the majority of lesions are not in the midline and may be located at different heights from the orbitomeatal plane. Assuming the average height of the lesions from the orbitomeatal plane to be 60 mm (half of the auricular height), 1-mm targeting deviation for 1 degree of tilt seems to be a better estimate of the average error for practical purposes. It should be taken into consideration the presumption about the shape of the head and the fact that due to contour of the head, with increase of the tilting angle the estimated error using the abovementioned formula becomes less accurate.

DISCUSSION

In the preoperative phase, neurosurgeons have a mental image of where the target lesion is and plan the route of exposure. In the absence of neuronavigation systems, the distance of the lesion from the known anatomic structures or landmarks on radiographical images can be measured and used to localize the target. Various modification of this old technique has been published.[3] Sina is a simple app that leverages that old technique by overlapping imaging data with patient anatomy to localize an intracranial target. It simplifies and speeds up the process.

Using Sina for localization and intraoperative planning of the scalp incision is an example of clinical application of augmented reality techniques and potentially carries the discussed advantages of these techniques.[4]

Limitations and Sources of Error

The study has not compared the efficiency of Sina versus localization using only anatomic landmarks and measurements based on radiologic images. Theoretically the app cannot outperform localization by an experienced neurosurgeon based on perfect measurements, but using the app simplifies the task.

The potential significance of users' experience using the app has not been addressed either. The users do not require much training to be able to overlap the images; however, there is a learning curve for matching the radiology with anatomic landmarks, localizing the coronal suture, and having the imaging plane and photo plane coincide.

In order to be able to overlap the images over the head, the anatomic landmarks should be used as guides and contour of the head should be visible. In some cases, shaving of the head should be more extensive than it used to be.

Sina requires images in at least 2 planes for localization. In circumstances in which only axial images are available, Sina can only help showing the coronal plane of the lesion through the first step described earlier. Measurements based on the thickness of CT slices may be helpful for localization in these situations.

The need for overlaying and adjustment of the images manually, lack of feedback about the precision of the overlap, and the need for an assistant should be considered as disadvantages of the technique. Not overlapping the images properly is the major source of error. Coronal sutures may not be easily palpable or contour of the head may not be clear. However, the assistants can put their fingers on the scalp as reference points for contour of the skull. Additional markers on the scalp, like dents, previous incisions or staples, prominent curves, or palpable lesions can add to accuracy.

To increase accuracy, when practical, any available adhesive radiodense markers (e.g., electrocardiogram dots acting as neuronavigation fiducials) can be applied on both the axial and coronal (or sagittal) planes—roughly in the plane of the lesion. These could be localized on both the scan and intraoperative views. The user would then coregister the preoperative images with the intraoperative views through the app, using these reference points (as in formal neuronavigation systems).

The angle of CT (or MRI) scanning is determined manually by radiographer, which might be different from our assumption that the axial cuts are parallel to the floor or the coronal ones are perpendicular to them. Side-to-side tilting is also common. The estimated inaccuracy is roughly 1 mm for 1 degree of tilt. When practical, specifically asking the radiographers to consider that can reduce the inaccuracy. Using the scout image with the cuts overlaid on the lateral skull radiograph to estimate the angle and make the intraoperative smartphone view roughly perpendicular to the axial CT plane can also improve the accuracy, whenever it is practical.

Sina is not of significant help for posterior fossa lesions, and side of the lesions cannot be verified through the app. In more anterior pathologies, the rim and roof of the orbit are quite helpful. For lesions in the middle part of the cranium, the bony contour and midline are the main guides. Overlapping of coronal cuts is less accurate when the lesions are posteriorly located. In these cases starting with sagittal cuts and then coronal cuts works better.

The smart phones are held by hands, and that might have minimal contribution to the errors. Using the app on devices with a more stable position like smart glasses has potential to improve the accuracy.

Since the accuracy of scalp incision matters more with smaller lesions, it would be good if we could calculate and compare the ratio of accuracy over the volume of the lesions (or any surrogate variables). However, the fact that localization is based on 2-dimensional images and there is significant manual intervention, no sensible conclusions could be made out of those calculations.

The center of target for both neuronavigation and Sina was determined on the basis of visual judgment and marked with a marker that had on average 1-mm thickness. This could potentially contribute to the estimated differences in the study, and it also means that the author could not comment on the accuracy range below 1-mm precision.

Sina was tested by the developer on a limited number of cases (mainly located in frontal and parietal). Testing on a large population by different users with different background experience could reveal different results; however, these were considered acceptable considering the aim of the study, which was getting an estimate of the app performance and investigating its functionality in situations where standard neuronavigation systems are not available.

Advantages

Simplicity and availability of the device and software can be considered as the major advantages of the technique.

Sina is helpful not only in working on superficial solid lesions but also in optimizing the burr holes or minicraniotomies for liquefied subdural collections and catheterizing cystic lesions or ventricles. Application of Sina does not increase operative time significantly. In order to use Sina, the patient's head does not need to be fixed. The study shows that Sina has satisfactory accuracy for planning scalp incisions when standard neuronavigation is not available. The accuracy can improve through the suggestions made in the previous section and with larger images on bigger screens.

Using a smart device to assist in "coupling" imaging data (2-dimensional and 3-dimensional) with external patient landmarks in order to localize an intracranial lesion has significant potential for use and further development for smart and augmented reality glasses.

The cases that Sina was tested on, represent a small subset of the neurosurgical patients, particularly in developing countries. Although neuronavigation is effective in optimization of the craniotomy, the benefit of neuronavigation is still considered complementary for most patients in parts of the world with limited resources.[5] However, with the trend toward minimizing the incision and craniotomy size, the demand for better localization is increasing worldwide. In developing countries with limited financial resources, and in certain circumstances where neuronavigation is not easily available, Sina can be helpful for localization and preoperative planning of the scalp incision for selected supratentorial pathologies.

CONCLUSION

An app to assist scalp localization of superficial supratentorial lesions has been introduced, and the technique of localization and intraoperative planning of the scalp incision with assistance of the app has been described. The technique has potential for further development and application by other augmented reality devices.

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