Cortical vessel imaging and visualization for image guided depth electrode insertion

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INTRODUCTION: MR Imaging has been widely used in neurosurgery for guiding surgeons in performing more accurate and less invasive surgery. Stereo-electroencephalography (SEEG) is considered as gold standard for epileptogenic zone (EZ) locating with the depth electrode insertion procedure after craniotomy [1]. Recently, with the development of surgical navigation techniques, minimally invasive depth electrode insertion without craniotomy has been developed with many obvious advantages. The biggest challenge of the surgery is to avoid intracranial hemorrhage during the electrode insertion. Thus, accurate and fine imaging and 3D visualization of cortical vessels can help surgeons perform the surgical planning to avoid the hemorrhage.

PURPOSE: This study sought to develop an appropriate technique for cortical vessel imaging and visualization to minimize intracranial hemorrhage during the depth electrode insertion.

METHODS:

Cortical vessel imaging: For cortical vessel imaging, we used two imaging techniques: Phase Contrast Magnetic Resonance Angiography (PC-MRA) [2] and Contrast Enhanced Magnetic Resonance Angiography (CE-MRA). Time-of-flight was not recruited because of the majority of the cortical vessels are veins with slow blood flow. Images were acquired on a 3T scanner (Achieva, Philips Medical System) using an 8-channel head coil. The imaging parameters are: 3D acquisition, FOV=210x170mm, image matrix=348x285, slice thickness=0.6, slice number=316, SENSE=6(2 direction), TR/TE=20/9.8ms, flip angle=15^0, imaging time≈7mins.

Image segmentation: After MRI data acquisition, scalp vessels were removed for better cortical vessel visualization. Instead of directly identifying the vessel types from the vessel images, we chose to classify the structural image as extracranial part (including the scalp and skull) and intracranial part (brain tissue), and then we removed all the extracranial vessels by processing the underlying structure images. Fuzzy c-means clustering algorithm was implemented to achieve the intracranial and extracranial parts classification [3].

Vessel visualization: Volume rendering method was then implemented for vessel and cortex visualization [4]. This rendering method was selected because it is much more flexible for rendering the interest tissue by simply adjust the color and opacity transfer function and it looks more real than surface rendering for gyri and sulci visualization. Surgical planning trajectories, entry points and target points were also rendered and represented by lines and spheres.

Validation: Four epilepsy patients who needed depth electrode insertion under craniotomy were recruited and provided informed written consent. The surgeons planned insertion trajectories based on the vessel images by defining entry points while avoiding the cortical vessels. During craniotomies, cortical surface photos were taken. Then the surgeon matched the entry points on the cortex with the prior planned points to validate the accuracy of the surgical. CE-MRA as reference was also acquired from one patient.
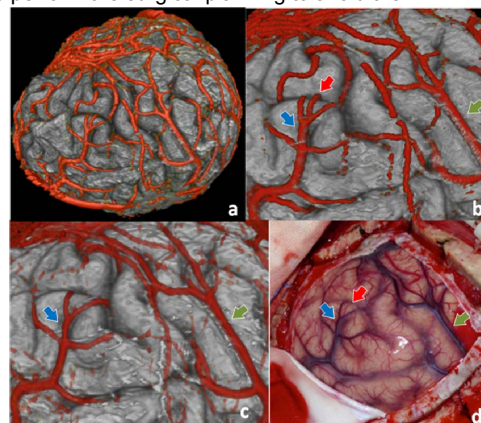

Figure 1 Comparison between visualization results for cortical vessel imaging and real picture for cortical vessels: (a) general view for cortex and vessel visualization; (b) local view in craniotomy area based on PC-MRA image; (c) local view in craniotomy area based on CE-MRA image; (d) real picture after craniotomy.

RESULTS:

Close agreement between imaged cortical vessels and real ones from photos was found. Green and blue arrows in Fig 1 emphasized the matched vessels between imaging results and real observation. The 2nd and 3rd level vein branches can be visualized well from both PC-MRA and CE-MRA. More arterioles were found from PC-MRA but not from CE-MRA (red arrow). We also observed blooming artifacts for arterioles.

Comparison between surgical planning and the real depth electrode insertion was shown in Figure 2. In this case, four trajectories were planned for depth electrodes insertion with the purpose to avoid vessels (Fig 2a), and then four depth electrodes were inserted based on the surgical planning (Fig 2b). After craniotomy, no significant vessels were observed on the planning entry position.

DISCUSSION AND CONCLUSION:

In this study, we found a good structural agreement between cortical vessel images and real situation. The MRA imaging technique and its visualization could provide sufficient cortical vessel structural information for surgical planning to avoid intracranial hemorrhage.

Comparing PC-MRA images and CE-MRA images, they could show almost the same results on cortical vessel visualization. Both of them could provide sufficient information to avoid important cortical vessels. But an obvious advantage of PC-MRA is non-invasive, which is risk-free for imaging and more comfortable for patients without the injection of contrast agent. So currently we only use PC-MRA technique for all the patients who need depth electrode insertion.
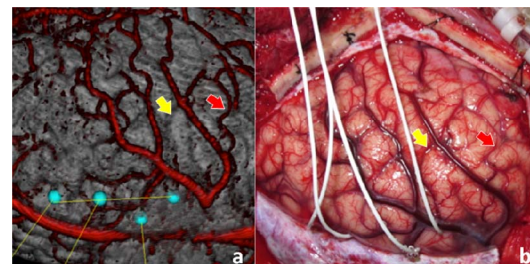

Figure 2 Preoperative surgical planning and real electrode insertion: (a) preoperative surgical planning, blue spheres represent entry points, yellow lines represent insertion path; (b) real electrode insertion, white wires are the depth electrodes.

One notable finding is that blooming artifacts were observed on the arterioles of PC-MRA images (Fig 1&2, red arrows). But that could not influent the risk of the surgical planning because the only affect of the blooming artifacts would be that the arterioles were shown thicker than the real situation. So planning the insertion paths based on the images with the thicker arterioles would not increase the risk.

The basic criteria for the surgical planning can also be defined based on the comparison between vessel visualization and real situation. Planning based on both vessel and cortex image was required. That is because venule missing was observed in the comparison (Fig 2, yellow arrows) because of the slow flow. But the corresponding position on cortex image showed dark area. That is because most venules are along the sulcus, which is shown darker in the cortex volume rendering according to its depth information. So the criteria for surgical planning should be to avoid the vessels on the vessel image and the dark area on the cortex image and the best choice is the brighter part without vessels on it. The case in Figure 2 is based on this criteria and it showed good result after craniotomy.

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