A Supplemental Technique for Preoperative Evaluation of Giant Intracranial Aneurysm

Hua-wei Wang1,* Chen Wu1,* Zhe Xue1,* Xu-jun Shu1 Zheng-hui Sun1

1 Chinese PLA General Hospital, Neurosurgery, Beijing, China

Address for correspondence Zhenghui Sun, MD, Chinese PLA General Hospital, Neurosurgery, Beijing, China (e-mail: szh_301@126.com).

Introduction

Giant intracranial aneurysms (GIAs) are defined as aneurysms of >25 mm in diameter and constitute 2.5 to 5.0% of all intracranial aneurysms.1–3 GIAs are more tumor-like than small aneurysms. The most common clinical presentation of a GIA is a local mass effect resulting in cranial nerve palsy, visual field defects, or limb weakness.2,4 Endovascular treatment for GIAs is limited due to its failure to relieve such mass effects, high cost for more coils, and high complication rate.5

Thus, in certain cases, open surgery may be the best choice. However, GIAs have always been one of the most difficult cerebrovascular lesions to surgically manage. Despite the advances in microsurgical techniques, the corresponding surgical morbidity and mortality rates have remained as high as 20%.5,6 Therefore, meticulous imaging studies and individualized planning are required before surgery.

In the clinical setting, preoperative planning mainly involves digital subtraction angiography (DSA) and computed tomography angiography (CTA), which can always provide precise information about the circulating parts of GIAs and their patent arteries. However, neither examination technique can reveal the noncirculating parts of GIAs, such as thrombi. Spontaneous

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thrombotic aneurysms can constitute up to 60% of all GIs3,7; thus, the diameters and real morphology of GIs are often likely to be underestimated by DSA or CTA.8 Additionally, because they behave like tumors, GIs can compress the surrounding parenchyma and shift the brain structures from their normal locations. These changes also cannot be recognized only by DSA or CTA; therefore, other techniques are required to provide more information about GIs for preoperative planning.

The utility of magnetic resonance imaging (MRI), a useful noninvasive examination technique, has been increasing in the evaluation of GIs.8 The time-of-flight (TOF) sequence, mainly referred to as magnetic resonance angiography (MRA), has an ability to visualize circulating parts of aneurysms similar to the abilities of DSA and CTA.9,10 Motion-sensitized driven equilibrium (MSDE) is another established sequence that can distinguish GIA thrombi from artifacts,11,12 many of which are caused by turbulent blood flow.8,13 3D Slicer (http://www.slicer.org; ▶ Fig. 1) is a free software for medical image visualization and analysis. This software supports image segmentation, registration, and multimodal visualization. In the present study, we reconstructed the circulating and noncirculating parts of GIs with TOF and MSDE sequences by 3D Slicer (Version 4.6.2 for Mac OS X) to reveal an integrated presentation of GIs and validate its usefulness for preoperative planning.

**Material and Methods**

**Patients**

After being approved by the institutional ethics committee of Chinese PLA general hospital, we retrospectively reviewed patients with GIs who were treated surgically in our department between July 2015 and July 2018. Only the patients with preoperative TOF and MSDE MRI sequence and DSA imaging were included. Thrombi were also counted as parts of GIs when measuring diameters. The maximum diameters were determined by both DSA and MRI. The exclusion criteria were (1) ruptured aneurysms, regardless of whether the GIs were responsible for the hemorrhage and (2) previous treatment of the GIs by microsurgery or endovascular intervention. At last, 31 consecutive patients with 31 GIs were included in the study.

**Segmentation and Measurement**

Both the TOF and MSDE sequence data for every case were loaded into 3D Slicer, which was installed in a personal computer (MacBook Pro, 2.6 GHz Intel Core i5; Apple Inc., Cupertino, California, United States). GIA reconstructions were independently performed by two neurosurgeons who received the same guided training on the reconstruction procedure until they attained adequate proficiency. The reconstructions were

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**Fig. 1** The (a) time of flight (TOF) and (b) motion-sensitized driven-equilibrium (MSDE) sequence data were imported into 3D Slicer in Digital Imaging and Communications in Medicine (DICOM) format. Three compositions were identified after comparison at the same anatomical slides between the two sequences: blood flow, thrombi (purple arrows), and artifacts (black arrow). (c) The giant intracranial aneurysm (GIA) was first automatically marked with the Threshold Effect tool. (d) Next, the Paint Effect tool was used to manually prune and modify the structures. Finally, (e) the segmentation was converted to a 3D model and (f) this was similar to digital subtraction angiography (DSA) at the same angle. Integration of the thrombotic and circulatory parts together produced a whole model of the GIA and allowed for extraction of its (g) diameter and (h) volume. The reconstructed GIA was integrated (i) with slide images and (j) into a head model to obtain more information. (k) The GIA model could be rotated at any angle, and two arteries (black and white arrows) could be verified in the surgical view angle. (I) The arteries (black and white arrows) could be confirmed during surgery in the same view.
mainly based on TOF sequences. Three compositions were identified in the TOF sequences: blood flow, thrombi, and artifacts. The MSDE sequences were used as a reference for distinguishing thrombi from artifacts in the TOF sequences.

The Threshold Effect tool was applied to automatically mark the circulatory parts of the GIAs and the cerebrovascular circulation (∼Figs. 1 and 2). Manual drawing was then performed with the Paint Effect tool to prune or modify the colored structures slice by slice. All of the manual procedures covered ~25 to 50 slices according to the range of thrombi or artifacts in the GIAs. Finally, the resulting segmentation was converted to a 3D model with a smooth contour. The morphology on 2D digital subtraction angiography (DSA) also confirmed the nonthrombotic GIA. We then integrated the model into the reconstructed skull with semitransparency and rotated it to the neurosurgeon’s view. The view could be adjusted to any angle with the computer mouse. Both the reconstructed model and intraoperative fluorescence contrast image confirmed a surrounding perforator artery (arrows), proving the accuracy and usefulness of the reconstruction by 3D Slicer for preoperative planning.

**Statistical Analysis**

After confirmation of the data distribution, the diameters of the GIAs were determined (median or mean ± standard deviation), and a paired t-test was used for comparison between DSA and 3D reconstruction. To test for interobserver agreement, the intraclass correlation coefficient (ICC) for DSA and 3D reconstruction was calculated using a one- and two-way random-effects model, respectively, and was used as evidence of reconstructive stability. The coincidence rate for a thrombus verified between the preoperative and postoperative periods was expressed as a percentage. All statistical analyses were performed with SPSS Statistics 22 (IBM Corp., Armonk, New York, United States). A value of \( p < 0.05 \) was considered statistically significant.

**Results**

The patients comprised 17 women (55%) and 14 men (45%), with a mean age of 46.7 years (range, 23–67 years). Among all GIAs, 15 (48.4%) were identified as thrombotic aneurysms. The mean diameter of all GIAs was 28.7 ± 1.5 mm (range, 25.9–31.9 mm). Most GIAs (93.5%) were located in the anterior circulation; only two were located in the posterior circulation. In general, most clinical presentations of GIAs were attributed to a mass effect. Among all patients, 12

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**Fig. 2** Magnetic resonance imaging (MRI) examination of (a) time of flight (TOF) and (b) motion-sensitized driven-equilibrium (MSDE) sequences confirmed a nonthrombotic giant intracranial aneurysm (GIA) affected by artifacts (arrows). (c) First, the GIA was automatically marked with the Threshold Effect tool. (d) We then manually pruned and painted the whole aneurysm with Structure 17 using the Paint Effect tool. (e) Finally, the segmentation was converted to a 3D model with a smooth contour. (f) The morphology on 2D digital subtraction angiography (DSA) also confirmed the nonthrombotic GIA. (g) We then integrated the model into the reconstructed skull with semitransparency and rotated it to the neurosurgeon’s view. The view could be adjusted to any angle with the computer mouse. Both the (g) reconstructed model and (h) intraoperative fluorescence contrast image confirmed a surrounding perforator artery (arrows), proving the accuracy and usefulness of the reconstruction by 3D Slicer for preoperative planning.
presented with a vision defect, 8 with headache, 2 with ptosis, 2 with limb weakness, 2 with epilepsy, and 1 with hypomnesia. The remaining four patients had no obvious symptoms, and their GIAs were incidentally found. The patient and aneurysm characteristics are summarized in Table 1.

The interobserver agreement was excellent for aneurysmal diameter and volume measurement by DSA or 3D Slicer reconstruction. The ICC for diameter by DSA, diameter by 3D Slicer was 28.67 \pm 1.48 \text{ mm}, respectively (\textit{p} < 0.001). When only nonthrombotic GIAs were included, the mean diameter measured by DSA and 3D Slicer was 28.69 \pm 2.03 and 28.97 \pm 1.79 mm, respectively (t = 1.023, \textit{p} = 0.323; Table 2). The mean aneurysmal volume was 8,292.6 \pm 1,175.1 mm\(^3\). For thrombotic GIAs, the thrombus volume constituted 46.89 \pm 14.58\% of the total aneurysm volume. The average time for all reconstruction procedures was \textasciitilde 30 minutes.

Discussion

Because they are tumorlike, GIAs often present with paroxysmal neurologic symptoms that are associated with a mass effect, and this may limit the ability to treat GIAs with endovascular intervention. In certain cases, open surgery may be the best choice. However, GIAs are always challenging to manage microsurgically. Therefore, meticulous imaging studies and individualized planning are required before surgery. Therapeutic planning for GIAs requires comprehensive images. DSA and CTA, both standard techniques, cannot reveal a thrombus in a GIA, which influences the accuracy of preoperative planning. The aneurysmal reconstruction with TOF and MSDE sequences by 3D Slicer in our series is a supplemental technique for surgical planning.

3D Slicer is a free open-source, extensible software application for medical image computing and segmentation. It can be used for quantitative assessment of the aneurysmal and thrombotic volume, which may be an independent risk factor for a poor outcome. The software allows us to not only measure the whole volume of the GIA but also split the volume into thrombotic and nonthrombotic portions. The TOF MRA imaging is often affected by artifacts resulting from slow and swirling blood flow in GIAs, which in turn may cause blood signal suppression and is mostly used for vessel

Table 1 Patient and aneurysm characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Number of GIAs</th>
<th>Patient sex, F/M</th>
<th>Patient age (y), mean (min, max)</th>
<th>GIA location, number (%)</th>
<th>Aneurysmal character, number (%)</th>
<th>GIA diameter, mean (\pm) SD (mm)</th>
<th>Volume, mean (\pm) SD (mm(^3))</th>
<th>Clinical presentation, number (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>DSA</td>
<td>3D Slicer reconstruction</td>
<td>Vision defect 12 (38.7%)</td>
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<td></td>
<td></td>
<td>DSA</td>
<td>24.46 \pm 5.25</td>
<td>Headache 8 (25.8%)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>3D Slicer reconstruction</td>
<td>28.67 \pm 1.48</td>
<td>Ptosis 2 (6.5%)</td>
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<td>Limb weakness 2 (6.5%)</td>
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<td>Epilepsy 2 (6.5%)</td>
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<td>Hypomnesia 1 (3.2%)</td>
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<td>Negative 4 (12.9%)</td>
</tr>
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</table>

Table 1: Patient and aneurysm characteristics

Table 2 The estimation of ICC between measurer

<table>
<thead>
<tr>
<th>Type</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
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<tr>
<td>DSA One-way random</td>
<td>0.98</td>
</tr>
<tr>
<td>3D Slicer reconstruction</td>
<td>0.87</td>
</tr>
<tr>
<td>Aneurysmal volume Two-way random</td>
<td>0.98</td>
</tr>
</tbody>
</table>

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Table 3 Paired t-test between two methods for diameter measurement

<table>
<thead>
<tr>
<th>Type</th>
<th>DSA (mm)</th>
<th>3D Slicer (mm)</th>
<th>t</th>
<th>(p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All GIAs</td>
<td>24.46 \pm 5.25</td>
<td>28.66 \pm 1.48</td>
<td>4.948</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>GIAs without thrombus</td>
<td>28.69 \pm 2.03</td>
<td>28.97 \pm 1.79</td>
<td>1.023</td>
<td>0.323</td>
</tr>
</tbody>
</table>

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wall imaging at the carotid bifurcation,\textsuperscript{12,21} where swirling flow is also present. Several reports have demonstrated the ability to use MSDE techniques for imaging of vessels in the intracranial region.\textsuperscript{22} In the present study, we could have reconstructed the thrombus with the MSDE sequence and integrated the data together with the circulatory portion reconstruction using the TOF sequence. However, the different parameters for the layer thickness between the two sequences could result in an inconsistent volume measurement; therefore, we only used the MSDE sequence as a reference for identification during the reconstructions in this series.

As a free open-source software accessible from the internet, 3D Slicer can run on a personal computer and does not require specialized equipment. Thus, it is easy to access at home or in the operating room. This feature is very important for neurosurgeons. Medical imaging, especially the MRI, is performed by radiologists. Although radiologists can offer neurosurgeons the best images with which to diagnose GIAs, they cannot consider the imaging findings from the neurosurgeon’s intraoperative viewpoint. Additionally, traditional 2D images may be adequate for very experienced neurosurgeons, but a less experienced neurosurgeon may have difficulty extracting useful information. Therefore, 3D Slicer helps us to seize the initiative of processing image data to some extent.

The process of reconstruction is also a method with which to learn the anatomical relationship between GIAs and peripheral tissue before surgery, and the reconstructed model can be infused into a brain model and rotated at any angle (\textsuperscript{\textit{Figs. 1, 2}}). From this aspect, 3D Slicer reconstruction can serve as a teaching tool for less experienced neurosurgeons. On the other hand, combined with the popular augmented reality (AR) technology,\textsuperscript{23} the reconstructed 3D images may optimize the workflow for surgical procedures by providing essential anatomical information that is entirely integrated into the surgical field. This is really worthy of a further exploration.

This study has some limitations. First, it may have been relatively time-consuming: the average time required for all reconstruction procedures was \textasciitilde30 minutes. However, this time decreased as the learning curve progressed. Moreover, the time was dependent on the desired quality of the model. A coarser but adequately usable model for preoperative evaluation could be reconstructed even more rapidly. Second, the 3D Slicer is not approved by the Food and Drug Administration for certain clinical tasks and could only be used as a reference. However, this limitation is double-sided; the packages provide users with plenty of useful tools without any restrictions, as in commercial software. Third, no aneurysms of \textless25 mm in diameter were included in our series, and the sample size (31 GIAs) was small.

\section*{Conclusion}

In conclusion, GIAs are challenging to manage microsurgically, and meticulous imaging studies and individualized surgical planning are required before surgery. The MSDE sequence brings diagnostic benefit as comparison to other MRI sequences. GIA reconstruction with 3D Slicer is a low-cost, dependable, and useful supplemental technique for surgical planning.

\section*{Conflict of Interest}

None declared.

\section*{References}


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