The ABCs of Accurate Volumetric Measurement of Cerebral Hematoma

Afshin A. Divani, PhD; Shahram Majidi, MD; Xianghua Luo, PhD; Fotis G. Souslian, MD; Jie Zhang, PhD; Aviva Abosch, MD, PhD; Ramachandra P. Tummala, MD

Background and Purpose—Both initial hematoma volume and hematoma growth are independent predictors of clinical outcomes and mortality among intracerebral hemorrhage patients. The purpose of this study was to evaluate the accuracy of different computed tomography image acquisition protocols and hematoma volume measurement techniques.

Methods—We used plastic and cadaveric phantoms to determine the accuracy of different volumetric measurement techniques. We performed both axial and spiral computed tomography scans with 0.75-, 1.5-, 3.0-, and 4.5-mm-thick transverse sections (with no gap). Different measurement techniques (planimetry, ABC/2, and 3D rendering) and different window width/level settings (I, 150/50 versus II, 587/−321) were used to assess generated errors in volumetric calculations.

Results—Both axial and spiral computed tomography scans yielded similar percent errors for different slice thicknesses and different measurement techniques. Comparison of different measurement techniques revealed a significant difference in measurement error only from the ABC/2 method as compared with 3D-rendering measurements (P<0.0001). The overall measurement error according to the ABC/2 method was further increased by ≈8% for irregularly shaped hematomas (P=0.0004). A significant percent difference in measurement error was observed between window width/levels I and II for both planimetry (mean difference across all thicknesses, 1.91±3.78, P=0.004) and Analyze software (mean difference across all thicknesses, 6.92±7.29, P<0.0001) methods.

Conclusions—A better understanding of the limitations that may affect measurement of hematoma volume is crucial in the assessment of hematoma volume, which is considered an independent marker of clinical outcome. (Stroke. 2011;42:1569-1574.)

Key Words: hematoma volume ■ volumetric measurements ■ intracerebral hemorrhage

Mortality resulting from intracerebral hemorrhage (ICH) is reported to be ≈40% in the first month, 50% in the first year, and 75% in 11 years. Both initial hematoma volume and hematoma growth are independent predictors of clinical outcomes and mortality among ICH patients. Therefore, rapid and accurate measurement of hematoma volume is an important component of clinical management. There are a variety of methods used to measure the volume of a hematoma. The use of an empirical equation of an ellipsoid volume was first suggested by Ericson and Hakonsson. Later on, a simplified version of the ellipsoid equation, known as ABC/2 or XYZ/2, has been used. Even though other methods for hematoma volume calculations have been proposed after the ABC/2 method, published studies have been limited regarding the role of image acquisition protocols, such as slice thickness, in the accuracy of volumetric measurements of hematoma. The purpose of this study was to evaluate the accuracy of different computed tomography (CT) protocols and hematoma volume measurement techniques. We used silicone and cadaveric phantoms to determine the accuracy of commonly used imaging techniques in measuring predetermined volumes.

Materials and Methods

Silicone Phantom
We scanned 6 arbitrarily shaped solid-silicone phantoms of different volumes (ranging from 9.47 to 68.42 mL) by using a multichannel/multidetector CT scanner (Sensation 64, Siemens Healthcare, Erlangen, Germany). The volumes of silicone objects were determined by measuring the volume of water displaced by the phantoms in a filter flask.

Image acquisition was performed for axial and spiral CT protocols with a 0.75-mm (with no gap) slice thickness. The scanned objects were also reconstructed in 1.5-, 3.0-, and 4.5-mm-thick transverse sections. For volume estimation, we used different methods, including planimetry, 3D volume rendering, ABC/2, and ABC/2 with adjusted C values. The ABC/2 method is based on the volume of an ellipsoid that is approximately equal to ABC/2 (when the value of π is approximated to 3). In this formula, A represents maximum length measured on the slice with the largest area, B represents maximum...
width perpendicular to A on the same slice, and C represents the number of slices in which the hematoma is visualized multiplied by the slice thickness. In the ABC/2 adjusted method, C values were calculated as described previously by Kothari et al.\textsuperscript{7}

We used Medical Image Processing, Analysis, and Visualization (Center for Information Technology, National Institutes of Health, Bethesda, MD) software for performing planimetry measurements. Image segmentation and volume rendering were performed by using 2 commercially available packages (Analyze 10; Analyze Direct, Inc, Overland Park, KS, and Voxar 3D, Barco NV, Kortrijk, Belgium). For calculating volumes with Analyze software, the region of interest (ROI) was segmented from surrounding regions automatically by setting up threshold levels. Then the segmented regions were visually checked and manually adjusted to ensure that the regions inside the ROI were completely included. Finally, the volume of the ROI was calculated by sampling all of the slices that included the ROI. In calculating the volumes with Voxar 3D, window level and width (WL) were adjusted until the volume of the ROI was not changed visually. Next, the ROI was manually segmented from surrounding regions by sculpting the region outside the ROI. This procedure was repeated in different directions by rotating the 3D image until all regions outside the ROI were totally sculpted. Then all visible regions were chosen to calculate the ROI volume. All measurements were performed in a blinded fashion.

**Cadaver Phantom**

The study was approved by the Anatomy Bequest Program at the University of Minnesota. We used 9 male cadaver heads within 24 hours after death. To simulate a hematoma mass, we used an ultrasound gel mixture (99 mL gel and 1 mL iodinated contrast). The gel mixture was put under vacuum at 30 psi to remove air bubbles to reduce artifacts on CT images. We used frame-based stereotaxy (StealthStation navigation system; Treon, Medtronic, Minneapolis, MN) to deliver the gel mixture into the brain parenchyma. Postmortem changes and lack of intracranial pressure invariably lead to extra-axial and intra-axial air. Penetration of the skull and dura can increase this pneumocephalus and reduce the accuracy of the stereotactic coordinates. To overcome this problem, we drilled 2 random holes in the skull, followed by durotomies, before obtaining the preoperative stereotaxy planning CT scan. Consequently, the resulting epidural and subdural spaces would already be incorporated into the calculation of the coordinates. Next, a stereotactic head frame (Integra CRW System, Integra LifeSciences, Plainsboro, NJ) was affixed to the skull to obtain stereotaxy planning CT scans. The images were then transferred to the stereotactic navigation system that was used to calculate the coordinates where the gel mixture would be injected (Figure 1).

After attaching the arc system to the CRW frame, we used the coordinates that were obtained from the StealthStation to create burr holes. Next, a predetermined volume of gel mixture (ranging from 9
to 74 mL) was delivered to the location of interest through a 20-gauge needle (12 in. long) connected to the upright arc on the CRW frame. The gel was injected at a rate of 0.5 mL/min by using a syringe pump (PHD, Harvard Apparatus, Holliston, MA). After completion of each injection, the needle was removed and the burr hole was sealed with bone wax. The data were collected from 9 cadaver-head phantoms and 14 injections. CT scanning was performed on each head on completion of all gel mixture injections. Image acquisition was performed for axial (with tilted gantry) sequences with 1.5-mm (no gap) collimation. The scanned objects were also reconstructed in 3.0- and 4.5-mm-thick transverse sections. Figure 2 is representative of a CT scan showing simulated, regular and irregular shapes, with cerebral hematoma on the left frontal region.

To assess the effect of WL settings on volumetric measurements, we altered image contrast by arbitrarily changing the values for WL to those that provided the best visual representation of the hematoma mass (I, 150/50 versus II, 587/321). For each set of WL values, the measurements were repeated for both silicone and cadaver phantom studies by using Analyze software and the planimetry technique.

Statistical Analysis
The absolute percent error was calculated for each measurement. Values are presented as mean ± SD, unless otherwise noted. The Wilcoxon signed-rank test was used for all within-object comparisons, such as the comparison of axial and spiral scans, the comparison of 2 different measurement techniques, and the comparison of 2 different WL settings, for the same set of objects, and other measurement parameters. The Wilcoxon rank-sum test was used for between-object comparisons, including the comparison between regular and irregular shapes. Comparisons across multiple thickness levels were conducted with a multivariate linear mixed model. The absolute percent error was calculated for each measurement. Planimetry, ABC/2, ABC/2 adjusted, Analyze, and Voxar 3D measurements, respectively, but none of the differences was statistically significant. Comparison of different measurement techniques versus measurements obtained from Analyze software for different slice thicknesses revealed a significant difference for ABC/2 and ABC/2 adjusted (P<0.0001). Both ABC/2 and ABC/2 adjusted techniques resulted in an overall underestimation of volume (ABC/2, −7.82%, P=0.06; ABC/2 adjusted, −38.56%, P<0.0001).

We observed a significant linear association between slice thickness and absolute percent error for both the planimetry and ABC/2 methods. For each millimeter increase in slice thickness, the planimetry method produced 0.98% and 1.13% increases in error for the axial scan and the spiral scan, respectively, whereas the ABC/2 method had 0.73% and 1.57% increases, respectively (Figure 3). However, neither measurement obtained from Analyze or Voxar 3D showed a significant linear association. Even though the 0.75-mm slice thickness almost consistently produced the least amount of error, we did not observe a statistically significant difference between the values obtained from 0.75-mm and 1.5-mm scans.

A significant percent difference in measurement error was observed between WL I and II settings for both planimetry (mean difference across all thicknesses, 7.68±2.67, P<0.0001) and 3D rendering by Analyze (mean difference across all thicknesses, 3.44±2.58, P=0.0005) methods. Table 1 shows the difference in mean ± SD absolute percent error of measurements calculated by planimetry and 3D volume rendering by Analyze for 2 different WL settings.

Results
Silicone Phantoms
Absolute percent errors in volume measurements for silicone phantoms, for different slice thickness, and for measurement methods, for both axial and spiral CT scans, are shown in Figure 3. The ABC/2 adjusted measurements on axial scans resulted in a percent error ranging from 32.44±22.07 to 41.41±4.36 for different slice thicknesses. Therefore, owing to a high error yield, we eliminated the use of ABC/2 adjusted measurements for the rest of the study. The absolute percent error in spiral CT scans was larger than in axial scans by 5.10%, 0.23%, 0.20%, and 0.15% for the planimetry, ABC/2, Analyze, and Voxar 3D measurements, respectively, but none of the differences was statistically significant. Comparison of different measurement techniques versus measurements obtained from Analyze software for different slice thicknesses revealed a significant difference for ABC/2 and ABC/2 adjusted (P<0.0001). Both ABC/2 and ABC/2 adjusted techniques resulted in an overall underestimation of volume (ABC/2, −7.82%, P=0.06; ABC/2 adjusted, −38.56%, P<0.0001).

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Table 1. Absolute Percent Error Difference in Hematoma Volume Measurements for Different Window Width/Level Settings

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean ± SD Percent Error Difference, P Value</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>0.75 mm</td>
</tr>
<tr>
<td>Planimetry</td>
<td></td>
</tr>
<tr>
<td>Silicone phantom</td>
<td>6.42±1.54, 0.03</td>
</tr>
<tr>
<td>Cadaveric phantom</td>
<td>NA</td>
</tr>
<tr>
<td>3D rendering</td>
<td></td>
</tr>
<tr>
<td>Silicone phantom</td>
<td>2.99±3.25, 0.09</td>
</tr>
<tr>
<td>Cadaveric phantom</td>
<td>NA</td>
</tr>
</tbody>
</table>

NA indicates not applicable.

Cadaver Phantoms

Absolute percent error in volume measurements for cadaveric phantoms, of different slice thicknesses and measurement methods, is shown in Figure 4. We classified each simulated hematoma on the basis of its observed shape on CT scans as regular or irregular. For the cadaveric phantom measurements, we only used planimetry, ABC/2, and 3D rendering by Analyze software techniques. When comparing the difference in volume measurements between regular and irregularly shaped hematomas, we observed only a statistically significant difference for measurements obtained from the ABC/2 method (mean percent error was 7.72% smaller for regular compared with irregularly shaped hematomas, P=0.0004, for measurements across all thickness levels). In a comparison of different measurement methods for hematoma shapes and different slice thicknesses, the ABC/2 method yielded a significantly higher percent error compared with planimetry or 3D rendering by Analyze (both methods P<0.001 for regular and irregular shapes across all thickness levels).

The differences in absolute percent error of hematoma volume measurements calculated by planimetry and 3D volume rendering by Analyze for 2 different WL settings for cadaveric phantom measurements are shown in Table 1. Significant differences in measurement error were observed between WLs I and II for both planimetry (mean difference across all thicknesses, 1.91±3.78, P=0.004) and Analyze (mean difference across all thicknesses, 6.92±7.29, P<0.0001).

The intraclass correlation between the 2 raters (S.M. and F.G.S.) for measurements of volume, obtained from cadaveric data by planimetry and the ABC/2 methods, is shown in Table 2. The intraclass correlation ranged between 0.91 and 1.00 for different methods, hematoma shapes, and thickness levels, indicating a high reproducibility between the 2 raters.

Discussion

Recent clinical trials, such as INTERACT8 and ATACH9 studies, have focused on the aggressive reduction of blood pressure and its impact on hematoma volume and clinical outcomes. Hematoma volume has been considered an important predictor of clinical outcomes in ICH. Thus, accurate knowledge of hematoma volume at presentation and its progression is important for determining clinical prognosis. In the present study, we determined the accuracy of commonly used measurement techniques for predetermined hematoma volumes.

Several studies have compared different measurement techniques.7,10–15 However, little attention has been paid to the role of image acquisition protocols such as slice thickness and imaging contrast on the accuracy of volumetric measurements. Moreover, the comparisons for measurement techniques are rarely evaluated vis-a-vis true volumetric values. Therefore, reckoning of volume may not necessarily shed light on the accuracy of the technique in the absence of knowledge of accurate hematoma volume. Pronas et al16 studied the accuracy of volume measurement in tumors on CT by using acrylic spheres of diameters between 1.6 and 25.4 mm. They concluded that a smaller slice thickness and larger-diameter spheres produced more accurate measurements. However, the percent errors for different slice thicknesses (0.625, 1.25, 2.5, and 5.0 mm) were higher (18%, 22%, 29%, and 39%, respectively) than those we obtained in our study.

Since the original ABC/2 method was suggested, other investigators have attempted to use variations of it. However, the underlying shortcomings of such techniques remain the same. Application of the ABC/2 method and its variations may be particularly inaccurate for volume calculations of irregular and discontinuous hematomas. Hüttner et al12 reported an overestimation of 32.1% in hematoma volume calculations for irregular and dichotomized shapes of hema-
tomomas among ICH patients with a history of warfarin use. However, CT image acquisition for the study was performed with an 8-mm transverse section thickness (with equal gap thickness) that would introduce significant error regardless of the measurement method used. Wang et al\textsuperscript{15} also reported error estimations (for 5-mm CT slices with no gap) of 9.9%, 16.7%, and 37.1% by the ABC/2 method versus a computer-assisted volumetric analysis for patients with ICH volumes of <20 mL, 20 to 40 mL, and >40 mL, respectively. In our study, the ABC/2 method produced a larger percent error compared with the other measurement techniques, particularly among irregularly shaped objects. Needless to say, the impact of such an error on clinical decision making needs further thorough investigation if every milliliter of hematoma volume counts in relation to clinical outcome.\textsuperscript{3}

The planimetry volume calculation method uses simple volume summation by calculating the volume of hematoma in each CT slice as a disk, with an area equal to the one outlined by the operator, multiplied by the slice thickness. The linear sum of individual volumes constitutes the volume of the hematoma. However, volume-rendering software packages, such as those used in this study, use different nonlinear interpolation methods to reconstruct the overall 3D shape and subsequently calculate the volume. In the presence of high spatial resolution (smaller slice thickness), linear and nonlinear summation of the volumes obtained from each slice would not result in a statistically significant difference. Both 3D-rendering software packages (Analyze and Voxar 3D) produced the least amount of error in volumetric calculations. In both cases, interpolation methods effectively compensated for larger slice thicknesses. However, image segmentation and 3D-rendering methods require postprocessing and are currently unavailable as a measurement option at the bedside. The ABC/2 measurement techniques exhibited less sensitivity to an increase in slice thickness compared with planimetry, possibly owing to a larger embedded error in measurement.

Window WL setting can also affect the accuracy of volumetric measurements of hematomas. We tested 2 WL settings in our study, wherein the advantage/disadvantage of the 2 settings was not obvious to the naked eye. However, we obtained as much as an 8% difference in mean volumetric measurement error between the 2 settings. In addition, the use of CT scanners by different manufacturers (that is, GE, Siemens, Philips, and so forth) may slightly affect volume measurements, mainly owing to their different image reconstruction algorithms.\textsuperscript{17}

It is important to point out that none of the measurement methods mentioned herein addresses the problem of the heterogeneity of CT attenuation within the hematoma mass, which has been reported to be associated with hematoma volume expansion. Barras et al\textsuperscript{10} studied the effect of hematoma shape (regular/irregular) and density (homogenous/heterogeneous) on hematoma growth and concluded that density heterogeneity was an independent predictor of ICH growth. The conditions considered in our study represent a “best-case scenario.” The amount of error related to each factor considered (that is, slice thickness, measurement method, and WL setting) may increase in a “real-case scenario,” where the signal intensity of the hematoma with respect to brain tissue may not be as optimum as the ones generated in this study.

### Conclusions

In this study, we have presented a detailed investigation of the factors that may affect the accuracy of volumetric measurement of hematoma volume in ICH patients. A better understanding of these limitations is crucial, since hematoma volume is considered an independent predictor of clinical outcome. Measurement techniques such as ABC/2 may introduce significant measurement errors, and 3D volumetric measurement techniques entail postprocessing of the imaging data, which requires expertise in using an imaging software package. Therefore, a bedside measurement technique with a high level of accuracy is warranted for rapid assessment of hematoma volume. Protocols for accurate assessment of hematoma volume and its characteristics (for example, shape and density) should be incorporated into the CT scanner consoles, which would allow the operator to obtain such information accurately in a timely manner.

### Acknowledgments

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### Disclosures

None.

### References


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**Table 2. Intraclass Correlation Between the 2 Raters for Measurements of Volume Obtained From Cadaveric Data by Planimetry and ABC/2 Methods**

<table>
<thead>
<tr>
<th>Intraclass Correlation (95% CI)</th>
<th>Regular Shape</th>
<th></th>
<th></th>
<th></th>
<th>Irregular Shape</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 mm</td>
<td>3.0 mm</td>
<td>4.5 mm</td>
<td>1.5 mm</td>
<td>3.0 mm</td>
<td>4.5 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planimetry</td>
<td>1.00 (1.00, 1.00)</td>
<td>1.00 (1.00, 1.00)</td>
<td>1.00 (1.00, 1.00)</td>
<td>1.00 (1.00, 1.00)</td>
<td>0.97 (0.85, 0.99)</td>
<td>1.00 (1.00, 1.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABC/2</td>
<td>0.99 (0.96, 1.00)</td>
<td>0.98 (0.93, 0.99)</td>
<td>0.98 (0.93, 0.99)</td>
<td>0.93 (0.67, 0.99)</td>
<td>0.91 (0.60, 0.98)</td>
<td>0.97 (0.85, 0.99)</td>
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</table>
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探讨颅内血肿体积的精确测量方法

The ABCs of Accurate Volumetric Measurement of Cerebral Hematoma

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背景与目的：无论是初始血肿体积还是血肿扩大都是脑出血患者临床预后和死亡的独立预测因素。本研究的目的是评价不同CT成像参数及血肿体积测量方法的准确性。

方法：分别采用硅树脂塑形模型和尸体模型来评价不同血肿体积测量方法的准确性。采用轴位扫描和螺旋扫描的方式分别以0.75、1.5、3.0、4.5 mm的层厚(无缝隙)进行CT扫描。研究中对不同的体积测量方法(面积求和法、ABC/2法和三维[3D]重建法)和不同的窗宽窗位设置(I,150/50和II,587/-321)进行比较，评价其误差大小。

结果：对于不同的层厚和不同的测量方法来说，分别采用轴位和螺旋扫描会产生相同比例的误差。不同测量方法进行比较，只有ABC/2法和3D重建法间比较具有统计学意义(P<0.0001)。ABC/2法对于不规则形状的血肿体积的测量误差会增加约8%(P=0.0004)。在用面积求和法计算血肿体积时，不同的窗宽窗位设置I和II之问的测量误差相比较具有统计学意义(所有层厚的平均差，1.91±3.78，P=0.004)；在用Analyze软件分析方法计算血肿体积时，I和II之间的测量误差相比较同样具有统计学意义(所有层厚的平均差，6.92±7.29，P<0.0001)。

结论：血肿体积是临床预后的独立预测因素，因而更好的了解影响血肿体积测量准确性的限制性因素就显得至关重要。

关键词：血肿体积，体积测量，脑出血

From the Departments of Neurology (A.A.D., S.M., F.G.S., A.A., R.P.T.), Neurosurgery (A.A.D., F.G.S., A.A., R.P.T.), and Radiology (A.A.D., J.Z., R.P.T.), and the Division of Biostatistics (X.L.), School of Public Health, University of Minnesota, Minneapolis, MN.

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Voxar 3D，Barco NV 公司，Kortrijk，比利时。用 Analyze 计算体积时，通过自动设置阈值，将感兴趣区域 (the region of interest, ROI) 与周围组织区分开来。然后划分出来的区域再经过调整以确保 ROI 被全部包含进来。最后 ROI 的体积由包含 ROI 的所有层面相加得到。应用 Voxar 3D 时，首先调整窗宽窗位直至 ROI 不会因视觉而改变，然后人工将 ROI 与周围组织间的轮廓画出来。这个过程需要不断变换旋转 3D 图形的角度以确保所有 ROI 区域以外的图形都被去除。最后计算所选取的 ROI 的体积。所有操作都采用盲法。

尸体模型

本研究通过了明尼苏达大学遗体捐赠程序。共完成 9 例 24 小时内死亡的男性尸体的头颅模型。利用超声膏混合物 (99 mL 膏和 1 mL 碘对比剂) 来制造血肿模型。膏混合物被置于 30 psi 的真空环境中去除气泡，以避免在 CT 上造成伪影。我们用立体定向仪 (StealthStation navigation 系统，Treon, 美敦力，明尼阿波利斯，明尼苏达) 将膏混合物注入脑组织。死后脑组织的改变及颅内压缺失不可避免的会导致气体的进入，颅骨和硬膜的穿刺会导致颅内气体的增加进而影响立体定向的准确性。为解决这个问题，立体定向术前，在颅骨上随即钻取两孔，然后切开硬膜。这样注射前硬膜下及硬膜外腔隙基本平衡。接下来，头颅模型被固定于立体定向头架 (Integra CRW System, Integra LifeSciences, Plainsboro, NJ) 中进行 CT 扫描。影像信息被传送至立体导航系统进而确定注射部位 (图 1)。

将弧装置连接到 CRW 架后，首先钻孔，然后用 20 gauge 注射器 (12 英寸长) 将一定体积 (9 mL 到 47 mL) 的膏混合物注入目标区域。注射泵 (PHD, Harvard Apparatus, Holliston, MA) 的注射速度为 0.5 mL/ 分。每进行完一次注射，拔出注射针并用骨蜡

图 1 StealthStation 的快照，显示了制作血肿模型的手术过程。手术入路为图片上从颅盖延伸至大脑的白色线条。同样显示了硬膜下和颅内的散在气体，右上方图示为注射辅助装置。CRW 表示为完整的 CRW 系统。
封闭穿刺孔。最后共完成 9 个模型，14 个穿刺部位。每个模型穿刺完毕后进行 CT 扫描。轴位扫描以 1.5 mm 层厚平行扫描（倾斜头架）。扫描后图像分别以 3.0 和 4.5 mm 层厚重建。图 2 显示了两组图像，分别为左侧额叶的规则和不规则的血肿。

为评价不同窗宽窗位对血肿体积测量的影响，我们选取具有视觉效果较好的血肿，分别调整窗宽窗位（I, 150/50 和 II, 587/-321）进行比较。每一组窗宽窗位值均分别用硅树脂塑形模型和尸体模型及 Analyze 软件和面积求和工具重复进行试验。

统计学分析

每次测量结果均计算了绝对百分误。数据除非额外说明，均以平均数 ± 标准差表示。对象内比较，如轴位扫描和螺旋扫描的比较、两种不同测量方法的比较及两组窗宽窗位值间的比较均采用 Wilcoxon 单因子秩检验。不同样本间包括规则形状和不规则形状血肿间的比较采用 Wilcoxon 秩和检验。比较包含不同层厚的测量效果采用多因素线性回归模型。P<0.05 具有统计学意义。

结果

硅树脂塑形模型

采用不同层厚，不同测量方法以及轴位或螺旋扫描方法，硅树脂塑形模型中血肿体积测量的绝对百分误在图 3 中显示。在轴位扫描中，不同层厚间采用校正的 ABC/2 法测量的百分误大小从 32.44±22.07 到 41.41±4.36。由于较高的误差，我们在剩余的研究中舍去了校正的 ABC/2 法。在螺旋扫描图像下，分别用面积求和法、ABC/2 法、Analyze 和 Voxar 3D 测量法的绝对百分误分别为 5.10%、0.23%、0.20% 和 0.15%，但是差别无统计学意义。在不同层厚的扫描中，无论是 ABC/2 法还是校正的 ABC/2 法和 Analyze 软件分析结果的差别均有统计学意义 (P<0.0001)。ABC/2 法和校正的 ABC/2 法都会低估血肿体积 (ABC/2, -7.82%, P=0.06；校正 ABC/2, -38.56%, P<0.0001)。

我们还观察到在面积求和法和 ABC/2 法中，层厚和绝对百分误之间存在线性相关关系。层厚每增加 1 mm，面积求和法中，轴位和螺旋扫描的误差分别增加 0.98% 和 1.13%；而在 ABC/2 法中误差分别增加 0.73% 和 1.57%（如图 3）。然而，无论 Analyze 还是 Voxar 3D 测量均未显示上述线性相关关系。即使是在 0.75 mm 层厚时，误差仍然很小。在 0.75 至 1.5 mm 层厚间误差差别无统计学意义。

用面积求和法测得体积，I 和 II 两组窗宽窗位设置间的测量误差差别具有统计学意义（所有层厚的平均差，7.68±2.67, P<0.0001）。用 Analyze 进行 3D 重建后测量误差差别亦具有统计学意义（所有层厚的平均差，3.44±2.58, P=0.0005）。表 1 以平均值 ± 标准差的格式显示分别用面积求和法和 Analyze 进行 3D 重建后，两组窗宽窗位设置间的测量误差的差别。

尸体模型

图 4 展示了尸体模型中不同方法、不同层厚测量的绝对百分误。所有 CT 扫描下血肿的形态分为规则和不规则两类。在尸体模型中，只选用了面积求和法、ABC/2 法和 Analyze 3D 重建法三种方法。发现只有在使用 ABC/2 法时，规则和不规则血肿
体积的测量误差的差别具有统计学意义（规则血肿的平均百分误较不规则血肿的低 7.72%，测量包括所有层面）。比较不同方法间测量误差的不同发现，
ABC/2 法的误差明显高于面积求和法和 Analyze 3D 重建法（无论对于规则还是不规则血肿，和两种方法比较均 P<0.001，测量包含所有层面）。

表 1 中数据为分别用面积求和法和 Analyze 3D 重建法比较在 I 和 II 两组窗宽窗位设置间的测量误差的差别。用面积求和法，I 和 II 间差别具有统计学意义（所有层厚的平均差，1.91±3.78，P=0.004）。用 Analyze 3D 重建法分析时差别同样具有统计学意义（所有层厚的平均差，6.92±7.29，P<0.0001）。

表 2 中显示不同操作者（S.M 和 F.G.S）间的一致性分析。在运用不同方法、测量不同血肿形状、不同层厚时，操作者间的相关性为 0.91 至 1.00 之间，显示了较高的可重复性。

讨论


有数个研究已经对不同测量方法进行过比较[7,10-15]。然而，上述研究均忽略了成像技术，如层厚、图像对比度对血肿体积估测的影响。更重要的是，既往的研究很少将估计体积与实际体积一一对应比较。所以，在不知道实际体积的情况下，就无法评价影像学技术对血肿体积估测过程的影响。

Prionas 等[16] 的研究利用直径在 1.6-25.4 mm 间的亚克力球来评价 CT 在估测肿瘤体积时的准确性。得出了层厚越薄，肿瘤体积越大，估测结果越准确。然而该研究中，不同层厚（0.625、1.25、2.5 和 5.0 mm）的百分误（18%、22%、29% 和 39%）均较本研究大。

鉴于 ABC/2 法的广泛应用，一些研究者试图对其进行改良。然而，无论如何改良，其固有的缺点依然存在。ABC/2 法及其改良版在测量不规则和不连续血肿时更加显示出其不准确性。

Huttner 等[12] 研究得出在估测不规则和“葫芦”型血肿体积时，会产生 32.1% 的高估。然而，在用 8 mm 均匀层厚进行 CT 扫描时，不论采用什么方法均会产生明显误差。

Wang 等[15] 的研究得出对于脑出血体积分别在 <20 mL, 20 到 40 mL 和 >40 mL 时，ABC/2 法较计算机辅助分析法误差更高。在本研究中，ABC/2 法较之其他方法产生更大百分误，尤其是在测量不规则血肿时。当然每一毫升血肿体积的增加均会导致临床结果的改变，这样的误差对临床决策的影响则需要更进一步深入的研究[3]。

面积求和法是通过将血肿分割成一个个平面，将连续的每一个层面血肿涉及的面积相加得到总的血肿体积。然而，本研究中应用的体积重建软件采用非连续性的插值方法重建整个 3D 图形，然后计算体积。在较高空间分辨率（很厚的层厚）下，连续和非连续的面积相加结果无明显差别。两种 3D 重建软件

图 4 以轴位扫描，在尸体模型中不同方法、不同层厚测量的绝对百分误。A、规则形状的血肿，B、不规则形状血肿，不同方法的回归系数 (P 值) 亦分别标识。
分析了可能影响脑出血患者血肿体积估测准确性的各种因素。由于血肿体积是临床预
则及密度均一或不均一对血肿扩大有明显影响，考虑到血肿内部信号不均匀的问题，有报道这和血肿
后的独立预测因素，所以更好的理解影响血肿体积
造模型这样的理想。

窗宽设置同样可以影响体积测量的准确性。我们评估了两种窗宽窗位设置对测量准确性的影响，
不过两者的区别在肉眼观察下并不明显。然而，两
者的平均测量误差间大约有8%的差别。不同厂家 (如
GE、Siemens) 生产的 CT 对体积的测量也稍有影响，可能是由于成像重建技术不同而导致的 [13]。

需要指出的是，在本研究中所有方法均未考
虑到血肿内部信号不均匀的问题，有报道这和血肿
扩大有关。Barras 等 [10] 的研究显示血肿规则或不规则及密度均一或不均一对血肿扩大有明显影响，最
后得出结论：密度均一是脑出血血肿的独立预测因素。本研究中情况代表了
最理想的情况”。其中每一个影响因素 (如：层厚、测量方法、窗
宽窗位设置) 均会导致 “现实世界” 中误差的增加，因为真实脑组织中的血肿信号并不会如本研究中所
选模型这样的理想。

结论
本研究深入探讨了可能影响脑出血患者血肿体积
估测准确性的各种因素。由于血肿体积是临床预
则的独立预测因素，所以更好的理解影响血肿体积
测量准确性的限制性因素就显得至关重要。ABC/2 法
会产生明显的测量误差，3D 重建法需要大量的后
处理工作，且这些工作需要图像分析系统的专业知识。
所以，开发床旁的高准确性的测量方法是血肿
快速估测的保证。将来如果可以把快速测定血肿体
积和特点 (如形状和密度) 的模块融入常规 CT 扫描，
则操作者就可以快速地获取相关信息。

参考文献
1. Ronning P, Sorteberg W, Nakstad P, Russell D, Helseth E. Aspects of in-