FULLY COMPUTERIZED ABC/2 BRAIN HEMORRHAGE VOLUME APPROXIMATION

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Abstract

A hemorrhage volume is one of an essential information for a neurosurgeon to assess a severity level in the brain of a patient. The processes of approximation and evaluation can be very time consuming as there are up to 256 slices per patient to be evaluated and the shapes and sizes of the hemorrhages can be difficult to detect or evaluate the volume. Surprisingly, there are not much software that can automatically and fully computerize the processes. In this paper, we computerized steps in the conventional brain hemorrhage volume approximation ABC/2. We achieved an average of 2.33 cm^3 absolute error of the volume or 8.8% average relative error compared to the ground truths' volumes.

Keywords: **Brain hemorrhage, CT scan slice, Ellipse Fitting**

Introduction

A brain hemorrhage is a serious sign of stroke which needs an urgent examination and proper treatments from a doctor. A hemorrhage occurs due to many reasons such as accident and diseases. When there is a bleeding inside a brain, so called an Intracerebral Hemorrhage (ICH), brain tissues with high pressure reduce blood flow and thus kill brain cells resulting brain swelling. This is known as cerebral edema. When the pooled blood is collected into a mass, it is called a hematoma (WebMD).

Unfortunately, according to the numbers revealed by the official website of the college of neurological surgeons of Thailand (Royal College of Neurosurgeons of Thailand, 2018), throughout the nation there are only 496 neurosurgeons totally while there are approximately seventy thousand patients

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(Tepsitha, 2012). With a rough ratio of 1 neurosurgeon per 140 patients, clearly it is impossible for a neurosurgeon to handle all cases efficiently and promptly. To avoid the worst outcomes for the patients, the computer assisted software can play an important role in helping neurosurgeons obtain patient's conditions in a timely manner. The disability and the mortality rates of patients with stroke can be greatly reduced if a hemorrhage is detected at the early stage and an appropriate treatment is given to a patient promptly.

In this work we have developed software that computerizes all procedures of a neurosurgeon for approximating the volume of the hemorrhage starting from detecting the hemorrhage in a sequence of CT scan slices until lastly calculating the volume of the hemorrhage. This last step is crucial for a neurosurgeon to assess the severity of a patient.

To approximate a hemorrhage's volume, the following procedures are practically done by a neurosurgeon. Firstly, CT scan slices with hemorrhage are selected from all given slices. This process are time consuming because the number of slices can be up to 256 per patient, a hemorrhage often has similar intensity as other components in the brain, and the size and the shape of a hemorrhage vary from one patient to another. Then a slice containing the largest hemorrhage is selected, and assessed using a widely used and well-accepted hemorrhage volume approximation formula ABC/2. A patient who has a high volume of hemorrhage and other abnormal symptoms such as nausea and inability to communicate or move normally will be looked after closely.

In the past there are not much computer aided software that had been used for hemorrhage volume approximation. Maeda *et al*. (2013) had compared two ways of computing an Intracerebral hemorrhage volume using a conventional ABC/2 formula computed manually and by a tool aided named DicomViewer. In their method, distances A and B were measured semi-automatically (Ariani *et al*., 2014). They discovered that the volumes of ICH using the ellipse (ABC/2) method assessed by humans yielded volumes smaller by 15% than those measured using the software aided tool. Sheth *et al*. (2009) detected the shape and calculated a hemorrhage volume using ALICE software (NIH, 2011). The user manually draws the region of the hemorrhage on each tomographic slice and the software approximates the volume of the patient using the ABC/2 formula. Dowlatshahi *et al*. (2012) used the segmentation algorithms provided by Quantomo software to quantify the volume on CT scan. The software that they had used can work on both a CT scan and MRI scan. They measured the volume of the hemorrhage by manually drawn the boundary of the hemorrhage shape and size. Zimmerman et al. (2006) used a biomedical software named Analyze (Robb, 1991), a tool kit with an interactive display for neurosurgeons to test on the image data obtained by CT scan to evaluate the volume of hemorrhage using the Radiologic Estimation. Scherer *et al*. (2016) had developed the hemorrhage segmentation for ICH volume. They used the random-forest approach in the segmentation of a hemorrhage. The method worked automatically only in the segmentation process; however, the process of selecting the largest slice of hemorrhage, and calculating A, B, and C were done manually with a measurement tool namely MITK (Wolf *et al*., 2005).

The computer aided tools and software were brought to help into the work only some part of the tasks and they were done semi-automatic way. In this work, we developed fully automatic programs that integrate many techniques together to compute a volume of a hemorrhage with an ICH type approximated by a conventional formula ABC/2 (Tress *et al*., 2014). This proposed work can help a doctor quickly prescreen patients who need urgent attention so that the treatments can be given and/or proper actions could be done in a timely manner.

The paper is organized as follows. The coming section materials and methods provides into sub-sections: background, methods, and experimental setup. Then the results and discussions are presented. The conclusion is provided in the last section.

Materials and Methods

Background

CT Scan Slice Images of Brain

A computed tomography scan (RSNA, 2018) widely short known as a CT scan, is a diagnostic imaging test that produces cross-sectional images of specific areas of a scanned object. Without cutting the object, the detailed of the internal structures such as shape, size, density and texture can be observed using computer-processed combinations of many X-ray measurements taken from different angles. This detailed information can be used to determine if there is a medical problem as well as the extent and exact location of the problem, and other important details. Depending on the manufacturer, each CT scan machine usually produces a number of slices in a multiple of 64 such as 64, 128, and 256 (Fornell, 2010). The CT scan is still used widely even though there are many more newer technologies of scanning such as Magnetic Resonance (MRI) (Chalela *et al*., 2007) because a CT scanning machine is cheaper, produces the output slices faster, and can view a larger portion of the body.

Because it fast produces slices with decent details for the components, CT is frequently selected to scan the brain to find any signs of abnormalities such as a distance of midline shift and hemorrhage. In the CT scan slice of a normal patient, inside of the skull there are only brain tissues so called gray and white mater and a cavities filled with cerebrospinal fluid (CSF) so called ventricles. In comparison, a slice of a patient with stroke, the hemorrhage is often present. In the CT scan slice, ventricles appears dark color and the white and gray matter are pale gray whereas the hemorrhage shown in the whitish gray. Figure 1 shows components in the brain and a comparison of normal and abnormal cases.

Mathematical Morphology

Mathematical morphology (MM), a branch of image processing, is the analysis of spatial structure (Bloch *et al*., 2007). Mathematical morphology is used as a tool for extracting the components in the image which will be useful for description or representation. MM can be used in grayscale, and binary image in the pre or post processing. Most morphological operation is basically based on the expanding (dilation) and shrinking (erosion) operation.

Erosion is an operation that shrinks an object's shape or edge to be smaller or thinner (Chen and Haralick, 1995). It erodes away the foreground and results in the thinner of the object. To use erosion, two types of data is considered: image and structuring element. The structuring element is very important since it will be used for determining how much the element is going to get eroded (Tambe *et al*., 2013). The following formula illustrates how the erosion method is done:

$$A \ominus B = \{z \mid (B)_z \subseteq A\},$$

where A is the set of input image, B is the set of structuring elements and $(B)_z$ is a translation of B that has origin z, i.e., $(B)_z = \{b + z \mid b \in B\}$. Therefore, erosion A of by B is considered as the set of all points z such that $(B)_z$ is included in A. In this respect, it is a shrinking operation.

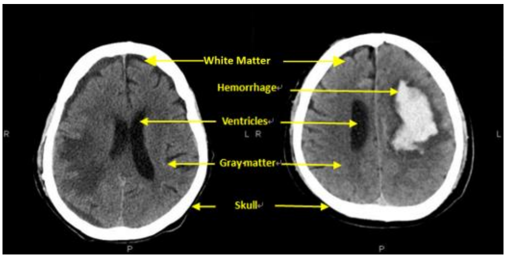

Figure 1. Examples of CT scan slices with haemorrhage (Right) and without hemorrhage (Left)

Dilation is an operation that expands or thickens objects in an image (Rodrigo, 2009). In this context, the dilation makes the image to grow in size. To dilate the image, two parts of data is considered: image and structuring element. The following formula shows how dilation method is done:

$$A \oplus B = \{z \mid (\hat{B})_z \cap A \neq \emptyset\},$$

where A is set of input image, B is the set of structuring elements and $(\hat{B})_Z$ denotes the symmetric of B, i.e., $(\hat{B})_Z = \{b| - b \in B\}$. As a result, the dilation of A by B is considered as the set of all points z such that intersection of $(\hat{B})_Z$ with A is not null. In this respect, it is known as an expanding operation.

Projection Profile Analysis

Projection profile technique is known as the construction of data which performed by collapsing data from a multidimensional into a smaller one. For instance, it is a one dimension representation of a two dimension image (Mamatha and Srikantamurthy, 2012). Projection can be done both horizontal and vertical direction. Most of the projection profile techniques have been done on the text segmentation, layout segmentation, skew estimation and a segmentation of an image for further analysis (Javed *et al*., 2013). Projection profile also enables programmer to obtain different types of information to apply in a classification techniques for the analysis. For example, intensity statistics of pixels in a 2-D picture is projected within the vertical and horizontal directions to obtain different information to be used within the classification. The projection profile can be done as the following mathematical formula:

$$HPP(x) = \sum_{1 \le y \le c} f(x,y)$$
$$VPP(y) = \sum_{1 \le x \le r} f(x,y),$$

where $HPP(x)$ is known as the horizontal projection profile, $VPP(y)$ is the vertical projection profile, and r is the row and c is the number of columns of the image.

Conventional Intracerebral Haemorrhage Volume Approximation

A fast and simple formula ABC/2 for volume approximation of an Intracerebral haemorrhage (ICH) has been widely used since 1980s. It is derived from the ellipsoid volume formula. The approximated formula is simply defined as

$$V = \frac{ABC}{2},$$

where A is the widest distance across the hemorrhage (cm), B is the longest distance (cm) in the direction perpendicular to A, and C is the height (cm) of the hemorrhage which can be calculated easily using the thickness of the slice cutting and the number of slices contains hemorrhage. Due to the fact that the formula is calculated based on the ellipsoid shape, its accuracy with respect to the real volume of the hemorrhage depends primarily on the shape. It can be totally different when the shape of the hemorrhage is multi-lobulated or very irregular. This formula has long been used by the doctors and the cutoff of the hemorrhage volume based on this formula has widely accepted and standardized.

Ellipse Fitting

Ellipse fitting with the least square fitting (Stojmenovic and Nayak, 2007) is known as a technique which uses to best fit the ellipse in the points of interest. This ellipse fitting method can be done and calculated quickly, and remain unchanged to the rotation, and scaling. The ellipse equation in the general conic form is described as follow:

$$F(x,y) = ax^2 + bxy + cy^2 + dx + ey + f = 0,$$

where a, b, c, d, e, f are coefficients of the ellipse and (x, y) are coordinates of points lying on it. The polynomial $F(x, y)$ is called an algebraic distance of the point (x, y) to the given conic. The fitting of a general conic is approached by minimizing the sum of squared algebraic distances.

Methodology

As the objective of this work is to automatically approximate the volume of the ICH from the CT scan slice based on a conventional brain hemorrhage volume ABC/2 formula, we utilize several algorithms to solve subtasks in the procedures. The flowchart shown in Figure 2 describes the overall process of this work. The detail of each step is described in more details in the following subsections.

Getting Region of Interest

As we focus on only a hemorrhage of type ICH which occurs within the brain issues inside of the skull, we first remove the background, skull, and parts of attached issues outside the skull region to maintain only the inside region. The removal of skull and all components out-side skull was done using a mathematical morphology (MM) technique with the disk structuring element and the erosion operator (Tambe *et al.*, 2013). The mathematical morphology is a well-known technique for the analysis and processing of geometrical structures. It probes an image with a simple pre-defined shape and draws conclusions on how this shape fits in the image. This probing process is so called the structuring element. In our case, as the skull shape is round, the structuring element we used is a disk shape. We smoothen the edge of the internal region of the skull by using the erosion operator. More information about mathematical morphology (MM) technique can be found in the background subsection of this section.

Figure 3 shows images of slices before and after getting region of interest.

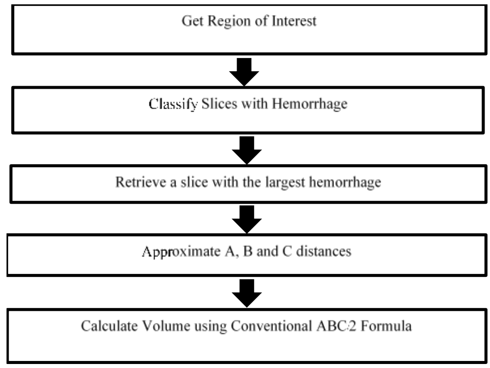

Figure 2. The flowchart of the processes

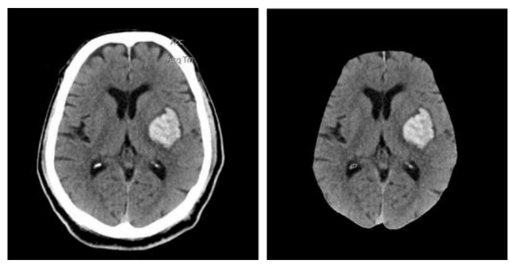

Figure 3. Examples of slices before (left) and after (right) removing the skull and attached components

Detection of Slices with Hemorrhage

We use a projection profile based decision tree to classify slices in which a hemorrhage is present from those that have no hemorrhage. As the shapes and sizes of the hemorrhages vary from case to case, the only information that we rely on is intensity. Inside the skull, the hemorrhages normally have the lightest color compared with the other components. We take this observation as a main clue for selecting features used in the classification process.

For each slice, we use features which are collected from intensity data of the line profile in vertical and horizontal directions. In each direction, the summation, the average, the standard deviation (*SD*) of intensity are used. For each brain CT scanned image input dimension w by h, we construct a 2-D intensity matrix *I*. Let $L_x(i)$ be the i^{th} column vector of *I* and $L_y(j)$ is the j^{th} row vector of *I*. We define

$$Sum_x(i) = \Sigma_{j=0}^{w-1} L_x^j(i)$$
$$Avg_x(i) = Sum_x(i)/nz(L_x(i))$$
$$SD_x(i) = stdev(Lx(i))$$
$$Sum_y(i) = \Sigma_{j=0}^{h-1} L_y^j(i)$$
$$Avg_y(i) = Sum_y(i)/nz(L_y(i))$$
$$SD_y(i) = stdev(L_y(i)),$$

where *i* is the index, *stdev*(*v*) is the standard deviation of v, and *nz*(*v*) is the number of nonzero numbers of v. The maximum of Sum_x, maximum of Avg_x, maximum of SD_x, maximum of Sum_y, maximum of Avg_y, maximum of SD_y from the projection profile together with the number of pixels of which its intensity is in a hemorrhage range are used as features. A decision tree based on these features are constructed for hemorrhage-slice classification. It is worth noting that the information of intensity in the range of hemorrhages which are used in our experiment is collected from a sample of 70 images in the test collection manually. Table 1 shows the ranges of intensity of components inside of the skull.

Retrieve a Slice with a Largest Hemorrhage

We used the thresholding method (Senthilkumaran and Vaithegi, 2016) to get a region of a hemorrhage for each slice image containing hemorrhage obtained from the previous step. The intensity range of hemorrhage shown in Table 1 is used in the thresholding method to segment the hemorrhage region from the background. Then we use the image hole filling (Somasundaram and Kalaiselvi, 2010) to binarize the image to get a clear edge of a hemorrhage. Figure 4 show the hemorrhage region after using the thresholding and image hole filling method. The numerical area of the hemorrhage is represented by the number of pixels within the haemorrhage area of which their intensity are in the range of haemorrhage. The slice that has the largest area is selected to be used to calculate the distances A and B in the next step.

Calculate A, B, and C Distances

As the ABC/2 hemorrhage volume approximation is originally derived from an ellipsoid volume formula, we approximate the shape of the 2D hemorrhage region with an ellipse. It is worth noting that as an ellipse needs not lie in the normal x-y Cartesian coordinate, so we need first find the orientation of the ellipse.

To get the orientation of the ellipse, the ellipse fitting method (Stojmenovic and Nayak, 2007) is used. To get the distances of A and B, we extend the major and minor axes of the fitted ellipse to find the cutting points on the boundary detected from the previous step. A is the distance between the two cutting points along the major axis and B is the distance between the cutting points along the minor axis. Figure 5 shows an ellipse fit on to an edge of a hemorrhage and the distances A and B. For the C distance, it can be easily calculated as a product of the distance between two slices (thickness) and the number of slices known to have hemorrhages.

Calculate a Volume of the Hemorrhage

To calculate the volume of the hemorrhage, we have followed the ABC/2 formula which has been widely used by the neurosurgeons in the hospital. After we get the distance of A and B from the major and minor axes and C from the thickness of the slices with

Table 1. Intensity Ranges of different regions in the skull

Region	Intensity range
Gray matter	65-115
White matter	95-140
Ventricles	5-50
Hemorrhage	157-211

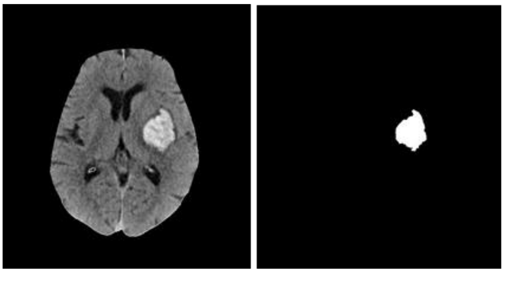

Figure 4. Images of a region of interest (left) and after applying thresholding method and image hole filling

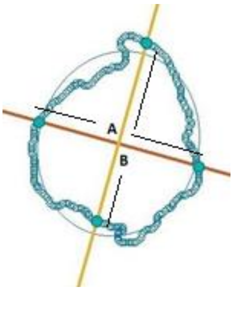

Figure 5. An ellipse fit on to an edge of a hemorrhage and the distances A and B

the number of slices having hemorrhage, we then calculate the hemorrhage using the ABC/2.

Image Collection, Ground truths, and Running Environment

We have collected the CT scan slices from 30 patients from Thammasat Hospital in our experiment. There are totally 989 slices in the collection. Throughout the collection, 481 slices covering the brain were examined. Out of this number, there are 236 slices that have no hemorrhage and the other 245 slices have hemorrhage. The entire collection has been provided and approved ethically used by Thammasat Hospital in Thailand. To evaluate the goodness of with our results, the following ground truth data from two doctors are provided: the indices of slices with hemorrhages, types of hemorrhage, boundaries of the hemorrhages, midline shift distances, manually measured A, B, and, C distances. All images are of dimension 512×512. The horizontal and vertical resolution is 96 dpi and bit depth is 24. The proposed methods are implemented in Matlab 2015a and run on a computer with Intel® Core™ i5-3317U CPU @ 1.70GHz (4 CPUs).

Table2. Results of hemorrhage slice classification

Evaluation	Percentage
Accuracy	98.54
Sensitivity	98.78
Specificity	98.31
Precision	98.37

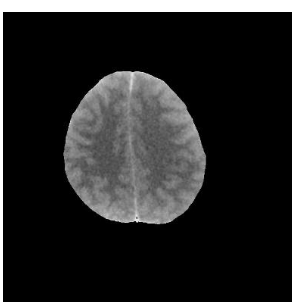

Figure 6. White center line in a range of hemorrhage pixel

Results and Discussion

Detection of Slices with Hemorrhage

Table 2 depicts the percentage of hemorrhage classification using the projection profiles based decision tree. The algorithm can differentiate slices with hemorrhages from those that have no hemorrhages excellently. There are only a few cases of misclassification. Figure 6 shows the misclassified case. This image gives the false classification of having hemorrhage due to the fact that the white matter and the mid-line, the line in the middle of the left and right of the brain, are closed to the range of the hemorrhage.

Retrieval of a slice with the largest hemorrhage

For each patient, we compare the index of the slice returned automatically by our program with those selected manually from the two doctors (D1 and D2) and find the difference between them. Figure 7 reveals the difference of indices of hemorrhage slices selected by our algorithm compared with the two doctors for 30 patients. There are twenty two cases out of thirty (73.33%) that our indices from the program match exactly with at least one of the doctors. The overall average index difference is less than one.

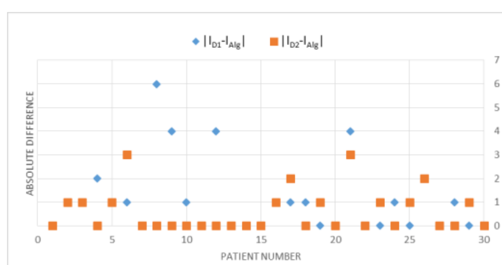

Figure 7. Absolute differences of indices (I) of Hemorrhage Slices between of our algorithm(Alg) and those of the doctors (D1 and D2)

Automatic A, B and C approximation Hemorrhage Segmentation

Table 3 shows the average evaluations of recall and precision of regions obtained from our algorithm that uses the thresholding algorithm (T) in comparison with the ground truth regions provided by the two doctors (D1 and D2) for 30 patients. We obtain over 81% on precision and 93% on recall. The numerical results clearly show that our hemorrhage segmentation algorithm is very accurate.

A and B Approximation

Figure 8 depicts A and B distances from our algorithm in comparison with the hand draw ground truths from two doctors. The numerical results of the difference of distances between the algorithm and the ground truth are shown in Table 4. The results showed that the ellipse fitting method provides fairly close distances to the ground truth. The absolute distances are 0.26 and 0.09 cm to the ground truths on average for A and B, respectively. It is worth pointing that the inter-observer reliability of ground truths has the average differences of the distances for A and B are 0.07 and 0.17 cm, respectively. The magnitude of the differences of distances from ours in comparison with those of the ground truths are relatively close to the difference between the ground truths themselves. We believe a large inter-observer reliability can be because of the level of expertise of a doctor, irregularity of the shape of a hemorrhage, and the human errors from hand drawing. Figure 9 shows an example of a case that the ground truths are significantly different.

Table 3. Average evaluation of the recall and precision of the hemorrhage pixel region between the thresholding method (T) and the ground truths (D1, D2)

Evaluation	T against D1	T against D2
Recall	93%	95%
Precision	82%	81%

Table 4. The average differences of A and B distances in cm between those of Ellipse fitting Method (E) and those of the ground truths (D1 and D2)

Method	Average distances	cm
Ellipse fitting (E)	A	4.58
	B	3.01
D1	A	4.29
	B	2.95
D2	A	4.36
	B	3.12
Absolute differences	$\lvert A_E - A_{D1} \rvert$	0.29
	$\lvert A_E - A_{D2} \rvert$	0.22
	$\lvert B_E - B_{D1} \rvert$	0.06
	$\lvert B_E - B_{D2} \rvert$	0.11

C Approximation

Table 5 shows the average C values approximated by our program in comparison

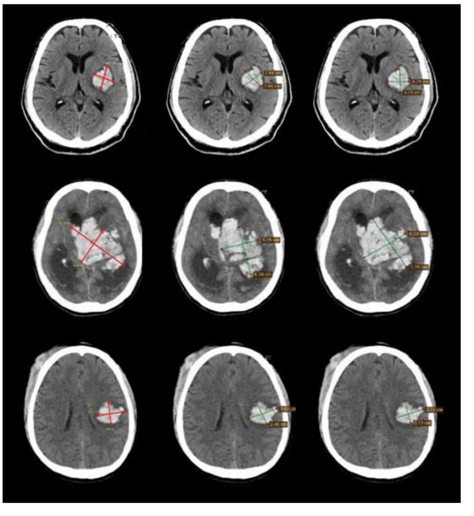

Figure 8. Examples of A and B distances from our program (left) and the ground truths from the doctors (middle and right) of three patients shown at different rows

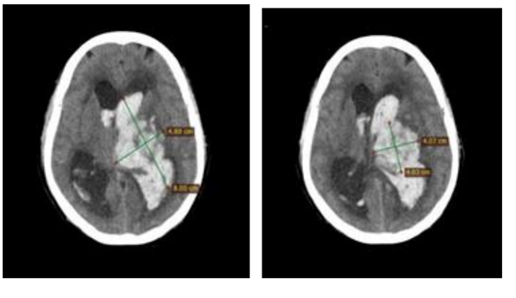

Figure 9. Great disagreement between the ground truths

with those of the ground truths (D1 and D2). Due to a simple calculation for C, our approximation is comparatively close to the ground truths.

Calculate Volume

Table 6 shows that the average volumes obtained from our program and from the ground truths. The results of overall volume of ours and the doctors show slight absolute differences between them. Our work is usable and benefit for the doctors who are in need with the hemorrhage volume analysis. The process in the running time for calculating the volume from start until end is 0.13 sec per image.

Table 5. C approximation from our program and ground truths (D1 and D2)

	C_{prog}	C_{D1}	C_{D2}
Average distances (cm)	4.03	4.05	4.02

Table 6. Average volumes (V) from our program and the ground truth

V_{prog}	**27.76**
V_{D1}	**25.59**
V_{D2}	**27.28**
$\lvert V_{our} - V_{D1}\rvert$	**2.17**
$\lvert V_{our} - V_{D2}\rvert$	**0.48**

Conclusions

This work is proposed to help doctors to quickly analysis the patients' hemorrhage volume. It integrates many image processing techniques to automatically and fully computerized ABC/2 hemorrhage volume approximation from a sequence of CT scan slices. The developed program performed excellently and experimentally proven to have very high accuracy with low running time.

Thus, this work can be used to efficiently assist the doctors to analyze the patients' hemorrhage volume.

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