# Assessment of methods for volumetric quantification of intracerebral hematomas in computerized tomography images

Evaluación de métodos para la cuantificación volumétrica de hematomas intracerebrales en imágenes de tomografía computarizada

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## Abstract

This work evaluates the performance of computational methods aimed at volume generation of five intracerebral hematomas (ICH), present in multi-layer computed tomography images, by means of three complementary steps. First. A ground truth volume or reference volume (RV) is considered. This RV is obtained, by a neurosurgeon, using the manual planimetric method (MPM). In a second step, the volumetry of the 5 ICH's is obtained considering both the original version of the ABC/2 method and two of its variants, identified in this paper as ABC/3 method and 2ABC/3 method. The ABC methods allow for calculating hematoma volume under the geometric assumption that the ICH has an ellipsoidal shape. In a third step, a smart automatic technique (SAT) is implemented to generate the three-dimensional segmentation of each ICH. In the context of the present work, the expression SAT method is used to refer to the new methodology proposed to calculate the volume of the ICH. In order to evaluate the performance of the SAT, the Dice coefficient (Dc) is used to compare the dilated segmentations of the ICH with the ICH segmentations generated, manually, by a neurosurgeon. Finally, the percentage relative error is calculated as a measure to evaluate the methodologies considered. The results show that the SAT method exhibits the best performance, generating an average percentage error of less than 3%.

**Keywords:** ABC Methods, Intelligent Automatic Technique, Segmentation, Intracerebral Hematoma Volumetry.

## Resumen

Este trabajo evalúa el rendimiento de los métodos computacionales dirigidos a la generación de volumen de cinco hematomas intracerebrales (HIC), presentes en imágenes de tomografía computarizada de múltiples capas, por medio de tres pasos complementarios. Primero. Se considera un volumen básico o volumen de referencia (RV). Este RV es obtenido, por un neurocirujano, usando el método planimétrico manual (MPM). En un segundo paso, la volumetría de los 5 ICH se obtiene considerando tanto la versión original del método ABC / 2 como dos de sus variantes, identificadas en este trabajo como el método ABC / 3 y el método 2ABC / 3. Los métodos ABC permiten calcular el volumen del hematoma bajo la suposición geométrica de que el ICH tiene una forma elipsoidal. En un tercer paso, se implementa una técnica automática inteligente (SAT) para generar la segmentación tridimensional de cada ICH. En el contexto del presente trabajo, la expresión método SAT se utiliza para referirse a la nueva metodología propuesta para calcular el volumen del ICH. Para evaluar el rendimiento del SAT, el coeficiente de Dice (Dc) se usa para comparar las segmentaciones dilatadas de la ICH con las segmentaciones ICH generadas, manualmente, por un neurocirujano. Finalmente, el error relativo porcentual se calcula como una medida para evaluar las metodologías consideradas. Los resultados muestran que el método SAT muestra el mejor rendimiento, generando un porcentaje de error promedio de menos del 3%.

**Palabras clave**: Métodos ABC, Técnica automática inteligente, Segmentación, Volumetría de hematomas intracerebrales.

## Introduction

In the clinical context, the use of digital brain neuroimaging allows the diagnosis, approach and monitoring of diseases that affect the anatomy and/or physiology of the human brain. Of special interest for the present work, is the pathology called intracerebral hematoma (ICH) that is characterized by the rupture of intracerebral blood vessels with extravasation of blood into the cerebral parenchyma[1]. The ICH forms a mass, usually oval, which can compress the adjacent brain tissue[2]. Particularly, spontaneous non-aneurysmal ICHs are usually located in the ganglia at the base of the brain and are primarily due to inadequately controlled arterial hypertension[1].

Additionally, it is important to note that digital brain neuro-images are accompanied by various imperfections such as noise[3,4] and artifacts[5]. These imperfections become real challenges, when implementing computational segmentation strategies oriented towards the generation of the morphology (normal or abnormal) of both the anatomical structures of the brain and of space-occupying lesions, such as, for example, hematomas[6]. Figure 1, generated on multilayered computed tomography (MSCT) images, presents axial views of the 5 ICH considered in this work. Notice the presence of the main typical problems of this type of image: noise (Poisson) and artifacts (Staircase and Partial Volume).



**Figure 1. Brain MSCT images, Location, (red cross), of the ICH in each of the databases considered. Imperfections (noise + artifacts) are also present.**

Besides, the most relevant attribute or predictor of an ICH is its volume. The reason why this attribute is so important is that its numerical value weighs heavily in both the prognosis for the patient and the therapeutic conduct to follow[7]. Due to this, some methodologies oriented towards the estimation of volume have been reported in the literature. Two such methodologies are described forthwith.

Yildiz et al.[8], estimate the volume of 193 ICH present in brain MSCT images and use it as a fundamental predictor to establish the average number of deaths that occur in hospitalized patients suffering from this pathology. These researchers use the ABC/2 method. In this method, parameter A is the axial view of that layer where the ICH exhibits its largest diameter. Likewise, B is made to coincide with the diameter of the ICH perpendicular to A; while C is the product of the thickness of the image by the number of cuts in which the ICH is present[9].

Rodríguez et al.[10], study the inter-subject variability that occurs when estimating the volume of 40 ICH using the computer-assisted planimetric method. The time spent by the five specialists to segment the 40 databases exceeded 5 hours, a feature reflecting the cumbersome nature of the manual method.

On our part, this article constitutes an extension of the work presented in reference[6]. The main contributions of the present work are:

a) To Use an intelligent automatic technique (SAT) to calculate the volume of the ICH, present in five databases formed by three-dimensional brain images of MSCT. This technique considers the stages of pre-processing, segmentation and post-processing. These stages are subject to a validation process that uses the Dice coefficient to compare ICH segmentations obtained automatically and manually[6].

b) To Consider the percentage relative error (*PrE*) to perform a comparative study between the ABC methods and the SAT method, in such a way that their performance can be established when they yield the volume of the ICH (Av). For such comparison, the one obtained by the planimetric manual method (MPM), applied by a neurosurgeon, is taken as the reference volume (Rv). The percentage relative error is calculated using the mathematical model given by equation 1.

$$PrE = \frac{100*|Rv - Av|}{Rv} \qquad (1)$$

## Materials and methods

**Description of the databases**

The databases (DB) used were provided by the Central Hospital of San Cristóbal-Táchira-Venezuela, were acquired through the modality of MSCT and are constituted by three-dimensional images (3D), corresponding to the anatomical structures present in the head of 5 male patients. Their numerical characteristics are shown in table 1.

**Table 1. General characteristics of the databases used in the present work.**

| DB label | Voxels number | Voxel dimensions (mm³) | Age (years) |
|---|---|---|---|
| DB1 | 512x512x50 | 0.4883 x 0.4883 x 2.7483 | 65 |
| DB2 | 512x512x24 | 0.6211 x 0.6211 x 3.1139 | 69 |
| DB3 | 512x512x30 | 0.4453 x 0.4453 x 4.8300 | 17 |
| DB4 | 512x512x40 | 0.4766 x 0.4766 x 3.2985 | 75 |
| DB5 | 512x512x40 | 0.3964 x 0.3964 x 3.6785 | 54 |

As Table 1 reveals, high variability in voxel size is observed in a group of five patients in an age range between 17 and 75 years. As complementary data, manual segmentations are available, generated by a neurosurgeon, corresponding to the hematomas present in the DB considered. These segmentations represent the ground truth that will serve as reference to validate the results obtained with the segmentation technique used.

**Smart automatic technique (SAT) for ICH segmentation.**

In figure 2, a schematic diagram synthesizes the computational algorithms that make up the SAT. For a detailed description of the SAT, reference[6] should be revised, since, as indicated above, this article is an extension of that reference.

**Figure 2. Block diagram of the smart automatic technique (SAT) proposed in[6].**
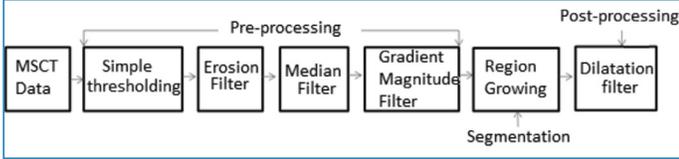


It must be pointed out that the Dice coefficient (Dc)[3] is a metric used to compare segmentations of 2D or 3D image, obtained by different methodologies. In the medical context, usually, the Dc is considered a measure to establish how similar, spatially, manual segmentation (RD) and automatic segmentation (RP) are, when generating the morphology of any anatomical structure. Thus, the Dc is at its maximum value when there is a perfect overlap between RD and RP and is minimal when RD and RP do not overlap at all. In addition, the values expected for the Dc are real numbers between 0 (minimum) and 1 (maximum). Equation 2 gives the mathematical model that defines the Dc.

$$Dc = \frac{2|RD \cap RP|}{|RD| + |RP|} \qquad (2)$$

**Clinical utility of the volumes occupied by the hematomas**
The main clinical utility of the characterization of hematomas by obtaining the volume lies in the decision-making to establish the conduct to be followed. In this regard, surgery is mandatory for patients whose lesions meet any of the following criteria[9,11]:

1- Lesion located in the anterior or middle cranial fossa with volume greater than 30 cm$^3$.

2- Displacement of the midline (imaginary line between occipital eminence and crista gally) greater than one cm, from its original position.

3- Compression, displacement or occupation of specific brain areas (mass effect).

4- Lesion located in the posterior fossa (cerebellum, stem) with a volume between 10 cm$^3$ and 15 cm$^3$ depending on the clinical patient situation.

**Quantification of hematoma considering the determination of its volume**
Measuring the volume of bruises is important to define the handling of the case. The volume of the lesion and clinical data define parameters called surgical criteria, which are fundamental during treatment.

**Obtaining volumes related to automatic segmentations**
The proposed technique generated the automatic segmentation of the ICH present in each of the five dat-abases described. From such segmentations, the volume of the hematoma is calculated by multiplying the voxel dimensions by the number of voxels that make up the automatically segmented ICH.

## Results

### Quantitative Results
During the segmentation process, the criterion applied was that the optimal parameters of the algorithms that make up the SAT are those that produce the highest Dc. At the end of the tuning process, a maximum Dc of 0.8659 was obtained; this means good correlation between the manual segmentations and those obtained by the SAT. Additionally, table 2 shows that the average value of the Dc obtained for the segmentation of the ICH, using the SAT method, is comparable to that reported in references[12,13].

**Table 2. Comparison of the average Dc generated both by the SAT and by other techniques, reported in the literature, for the 3D segmentation of the ICH.**

| Authors | Technique | Modality | Average Dc |
|---|---|---|---|
| Kamnitsas *et al* (2017)[12] | Convoluting neural networks | MSCT | 0.8917 |
| Prakash *et al* (2012)[13] | Regularized level sets | MSCT | 0.8432 |
| Vera *et al*. (Proposed technique in the current article) | SAT | MSCT | 0.8654 |

### Qualitative Results
Figure 3, shows a 2-D view of both the original ICH and the processed versions after applying the SAT technique to one of the DB considered.

**Figure 3. Axial image view: a) Original, b) Thresholdized, c) Eroded, d) Median, e) Gradient magnitude, f) Segmented, g) Postprocessed with the binary morphological dilation filter.**
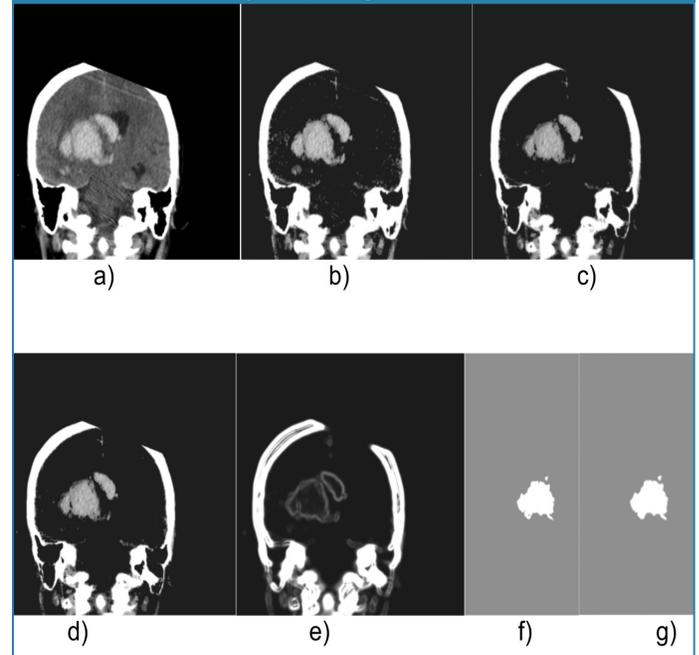


Figure 4 shows an excellent three-dimensional representation of the segmented ICHs, corresponding to all five of the databases used in the present investigation.

**Figure 4. 3-D representation of the segmented ICHs, corresponding to the databases: a) DB1, b) DB2, c) DB3, d) DB4, d) DB5.**
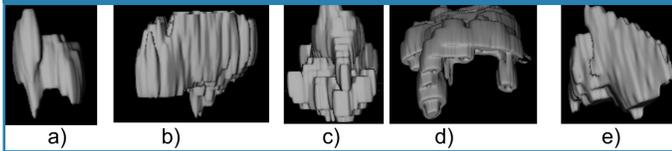
a)   b)   c)   d)   e)

Figure 4, also shows that this type of hematoma does not have a defined shape and therefore, in general, it can be said that the geometric hypothesis considered by the ABC methods to estimate the ICH volumes is not always valid. In addition, in a study with 83 patients conducted by Huttner et al.[14], only 44% had housings with ellipsoidal shape in the parenchymal tissue, that is, 66% of the patients, considered in this study, had ICH's with a non-ellipsoidal shape.

Further on this point, table 3 shows the values for the volume of the ICH, calculated using MPM and both the SAT method and the ABC methods.

**Table 3. Values obtained for the volume occupied by each of the segmented hematomas.**

| Database | Volume (cm³) | | | | |
|---|---|---|---|---|---|
| | MPM | SAT | ABC/2 | ABC/3 | 2ABC/3 |
| DB1 | 2.01 | 2.53 | 2.45 | 1.63 | 3.27 |
| DB2 | 39.77 | 40.52 | 42.84 | 28.56 | 57.12 |
| DB3 | 26.49 | 26.87 | 27.92 | 18.61 | 37.23 |
| DB4 | 6.91 | 7.56 | 8.07 | 5.38 | 10.76 |
| DB5 | 27.89 | 28.09 | 29.47 | 19.65 | 39.29 |

Table 3 showx that SAT, ABC/2 and 2ABC/3 methods yield larger values for the volume; while the ABC/3 method possibly underestimates it. According to Huttner et al.[14], the ABC/3 method has not been validated clinically and, indeed, it can exhibit excellent behavior in cases in which the patient consumes anticoagulants or has undergone radio and/or chemotherapy. In addition, these authors assert, that in such cases the ABC/2 method presents a significant decrease in the accuracy of the estimation of the ICH volume.

Table 4 presents the values corresponding to the relative percentage errors related to each of the methods considered.

**Table 4. Values obtained for the percentage relative error related to each of the methods considered to obtain the volume of the 5 five ICH present in the selected databases.**

| | Percentage Relative Error (%) | | | |
|---|---|---|---|---|
| | SAT | ABC/2 | ABC/3 | 2ABC/3 |
| DB1 | 4.98 | 21.89 | 18.74 | 62.52 |
| DB2 | 1.89 | 7.72 | 28.19 | 43.63 |
| DB3 | 1.43 | 5.40 | 29.73 | 40.53 |
| DB4 | 3.76 | 16.79 | 22.14 | 55.72 |
| DB5 | 0.72 | 5.67 | 29.56 | 40.89 |
| Average percentage relative Error (%) | 2.56 | 11.49 | 25.67 | 48.66 |

From data on table 4, it can be stated that the SAT method generates the best average percentage relative error

(*PrE*). As for the ABC methods, the best performance is that of ABC/2, although in small volume hematomas it tends to produce bigger errors. This may be a consequence of this method assumption that the ICH has an ellipsoidal shape; a condition which is not always the case, according to[14] (see, additionally, figure 4).

In this section, it is important to remember that the main surgical utility of the determination of the ICH volumes is that they carry much weight on the conduct regarding the patient. In this sense, if only volume is considered, hematomas that exceed the threshold of 30 cm³ are susceptible to surgery. Following this criterion, and considering the results of the volume obtained from the MPM and the the SAT method, those that yield the lowest *PrE*, only the patient corresponding to the DB2 is a candidate to surgery.

## Conclusions

In general, it can be said that the main characteristic of ABC methods is their simplicity and efficiency, although their performance, in many concrete situations, point to the fact that they may not always be the best option. In this sense, the assumption that an ICH has an ellipsoidal shape represents the main limitation of these methods, especially when it comes to patients who have ICH with no defined shape, relatively small and/or large volume. However, when the ICH complies with the aforementioned hypothesis, these methods have an acceptable performance and, in particular, the ABC/2 method deserves its prestige since it has been clinically validated, while its variants have not. Additionally, in several investigations, it has been verified that these methods have the additional disadvantage of being operator-dependent.

In the context of the present work, we have used an intelligent automatic technique (SAT) whose tuning allows the precise segmentation of the ICH, present in computed tomography images. This statement is based on the fact that the Dc obtained is comparable with those reported in the literature. The segmentations generated, automatically, by the SAT allow us to calculate the volume of each ICH in a precise and efficient manner. This volume is vital to decide whether or not the hematoma is surgically treated.

Because the SAT method generated the lowest average percentage error, which did not exceed 3%, it can be affirmed that the performance of the SAT method outstrips the ABC methods considered. In part, this is due to the fact that the SAT does not assume any geometric consideration when it generates the volume of an intracerebral hematoma.

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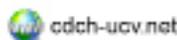
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