Volumetry of subdural hematomas in computed tomography images: ABC methods versus an intelligent computational technique

Volumetría de hematomas subdurales en imágenes de tomografía computarizada: métodos abc versus una técnica computacional inteligente

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Abstract

This work evaluates the performance of some methods oriented towards the generation of the volume of four subdural hematomas (SDH), present in multi-layer computed tomography images. To do this, firstly, a reference volume is specified: the volume obtained by a neurosurgeon using the manual planimetric method (MPM); which allows the generation of manual segmentations of space-occupying lesions. In this case, these volumes are matched with the SDH. In parallel, the volumetry of the 4 SDHs 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 the calculation of the volume of the hematoma under the assumption that the SDH has an ellipsoidal shape. In third place, SDH's are studied through an intelligent automatic technique (SAT) that generates the three-dimensional segmentation of each SDH. Finally, the percentage relative error is calculated as a metric to evaluate the methodologies considered. The results show that the SAT method exhibits the best performance generating an average percentage error of less than 5%.

Keywords*:* ABC Methods, Automatic Intelligent Technique, Segmentation, Volumetry of subdural hematomas.

Resumen

Este trabajo evalúa el rendimiento de algunos métodos orientados a la generación del volumen de cuatro hematomas subdurales (SDH), presentes en imágenes de tomografía computarizada multicapa. Para hacer esto, en primer lugar, se especifica un volumen de referencia: el volumen obtenido por un neurocirujano utilizando el método planimétrico manual (MPM); que permite la generación de segmentaciones manuales de lesiones ocupantes de espacio. En este caso, estos volúmenes se comparan con el SDH. Paralelamente, se obtiene la volumetría de los 4 SDH, considerando tanto la versión original del método ABC / 2 como dos de sus variantes, identificadas en este documento como el método ABC / 3 y el método 2ABC / 3. Los métodos ABC permiten el cálculo del volumen del hematoma bajo el supuesto de que el SDH tiene una forma elipsoidal. En tercer lugar, los SDH se estudian a través de una técnica automática inteligente (SAT) que genera la segmentación tridimensional de cada SDH. Finalmente, el error relativo porcentual se calcula como una métrica para evaluar las metodologías consideradas. Los resultados muestran que el método SAT exhibe el mejor rendimiento generando un porcentaje de error promedio de menos del 5%.

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

Introduction

Among the different types of hematomas or intracranial and extracerebral hemorrhages, one type are subdural hematomas (SDH). Normally, SDH are pathologies caused by traumatic brain injuries or craneoencephalic traumas (CET) that cause the laceration of brain tissue or its vessels[1] and are located below the dura mater membrane that surrounds the brain[1]. According to the time of evolution, from the moment of the CET, they are classified as: acute (up to 3 days), subacute (up to 2 weeks) and chronic (more than 2 weeks)[2].

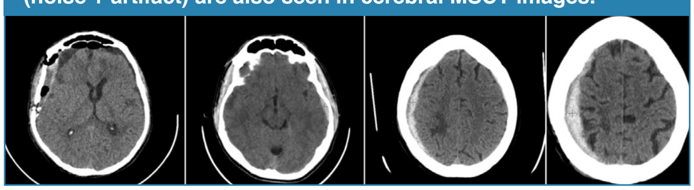
Multilayered computed tomography (MSCT)[3] is the most used diagnostic test to identify chronic SDH which are common in digital brain neuroimaging (DCNI), especially in patients with a high rate of postoperative recurrence[4]. In addition, the sizes of chronic pre- and post-operative subdural hematomas have been used in clinical trials to predict the risk of postoperative recurrence[5].

Additionally, the increasing incidence of this type of pathology has also increased the use of automatic computational techniques aimed at the accurate and efficient definition of the volume of these hematomas, since that volume is the main parameter considered by medical specialists, when addressing and monitoring SDH[6].

Also, it is important to point out that the DCNI are accompanied by various imperfections such as noise[3,7] and artifacts[8]. These imperfections become real challenges when computational segmentation strategies are implemented oriented towards the generation of the morphology (normal or abnormal) of both the cerebral anatomical structures and space-occupying lesions, such as, for example, subdural hematomas.

Figure 1, generated based on multilayered computed tomography (MSCT) images, presents axial views of the 4 SDH considered in this work. Notice that the main problems typical of this type of image, noise (Poisson) and the stair artifact are seen.

Figure 1. Localization, by means of a red cross, of the SDH in each of the databases considered, in which imperfections (noise + artifact) are also seen in cerebral MSCT images.



The most relevant attribute or predictor of an SDH is its volume. The reason why this attribute is so important is that its numerical value is crucial for defining both the prognosis of the patient and the conduct to follow in addressing this condition[7]. Accordingly, some methodologies oriented towards the estimation of said predictor have been reported in literature. Some of those methodologies are described forthwith.

Stanišić et al.[4,5], perform a comparative study between techniques that use linear measurements, to estimate the volume of the SDH, and a computational method that calculates the volume directly analyzing the 3D morphology of 107 SDH, present in corresponding MSCT images to 107 patients. They establish the limitations that linear methods have when estimating the volumes of SDH in patients evaluated after the surgical intervention.

On their part, Wang et al.[6], evaluate classic ABC methods to estimate the volume of SDH and validate them against a variant of these methods they put forward in their paper. A primary result they obtain is that their variant exhibits a performance that surpasses the classic ABC methods.

Sucu et al.[9], evaluated 28 computerized tomographies in which they determine the volume of SDH using the ABC/2 method. They emphasize the importance of determining whether this method yields comparable results when estimating the volume of both acute and chronic SDH. They state that the mentioned method generates valid results for both types of bruises. In the ABC methods, parameter A is the axial view of the layer or cut where the SDH exhibits its largest diameter; in similar fashion, B is made to coincide with the diameter of the SDH perpendicular to the diameter of A; while C is the product of the thickness of the image by the number of cuts in which the SDH is present[10].

Our contribution, this article, constitutes an extension of the work presented in[11]. The main contributions of the present work are:

a) Use an intelligent automatic technique (SAT) to calculate the volume of the ICH, present in 4 databases formed by three-dimensional brain images of MSCT. This technique considers three stages: pre-processing, segmentation and post-processing. These stages are subject to a validation process that uses the Dice coefficient to compare SDH segmentations obtained automatically and manually[11].

b) 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 SDH (Av). For comparison, the volume obtained by the manual planimetric 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.

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

Materials and methods

Description of the Data Bases used

The databases (DB) used were supplied by the Central Hospital of San Cristóbal-Táchira-Venezuela. They were acquired through the MSCT modality and consist of three-dimensional images (3D), corresponding to the anatomical structures present in the head of 4 male patients. Their numerical characteristics are presented in table 1.

Table 1. General characteristics of the databases considered in the present work.

DB Label	Voxels Number	Voxel Dimensions (mm^3)	Scanner Type	Age (years)
DB1	512x512x60	0.4551 x 0.4551 x 2.8096	*Siemens Spirit CT84299*	37
DB2	512x512x27	0.4882 x 0.4882 x 5.0521	**GE Hi Speed **DUAL** CT*	21
DB3	512x512x40	0.4023 x 0.4023 x 3.2780	**GE Light Speed VCT IRIS*	81
DB4	512x512x20	0.4589 x 0.4589 x 6.2784	**GE Light Speed VCT IRIS*	38

**GE= General Electric*

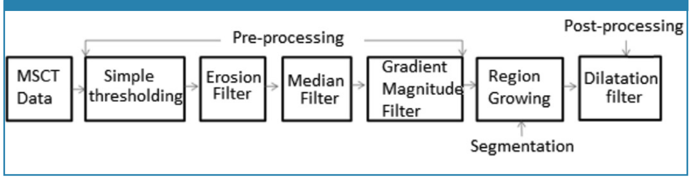
Table 1 shows there is high variability in the size of the voxel in a group of 4 patients with age range between 21 and 81 years. In addition, the identification of the scanners allows the inference about the robustness of the proposed technique in view of inter-scanners variability.

In order to round up and validate the study, manual segmentations are available, generated by a neurosurgeon, corresponding to the hematomas present in the four DBs. These segmentations represent the ground truth that will serve as a reference to validate the results linked to the segmentation.

Smart Automatic Technique (SAT) for the segmentation of SDHs.

By means of figure 2, presents a schematic diagram synthesizing the computational algorithms that make up the SAT. For a detailed description of the SAT, reference[11] should be reviewed, since, as indicated above, this article is an extension of that work.

Figure 2. Block diagram of the intelligent automatic technique proposed in[6].



It is also necessary to point out that the Dice coefficient (Dc)[3] is a metric used to compare segmentations of the same 2D or 3D image, obtained by different methodologies. In the medical context, usually, the Dc is examined to establish how similar, spatially, manual segmentation (RD) and automatic segmentation (RP) are, and that generates the morphology of any anatomical structure. Additionally, the Dc is at a maximum when a perfect overlap between RD and RP is reached and it 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). The mathematical model that defines the Dc, is given by Equation 2.

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

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 on the therapeutic conduct to be followed. In this sense, patients whose lesions meet any of the following criteria must be subject to surgery [10].

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 areas of the brain (mass effect).

4- Location of the hematoma in the cortical zone.

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

Quantification of the hematomas considering the determination of the respective volume

Measuring the volume of bruises is important to define the final conduct for the patient's treatment. The volume and behavior of the lesion define parameters called surgical criteria which are fundamental at this point.

Obtaining the volumes related to the automatic segmentations

The proposed technique generates the automatic segmentation of the SDH present in each of the 4 databases described. From such segmentations, the volume of the hematoma to be characterized, is calculated by multiplying the voxel dimensions by the number of voxels that make up the automatically segmented SDH.

Results

Quantitative results

During the segmentation process, the criterion employed was that the optimal parameters for 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 0.8876 was obtained, indicating a 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 SDH segmentation, using the SAT method, is comparable to that reported in references[12,13].

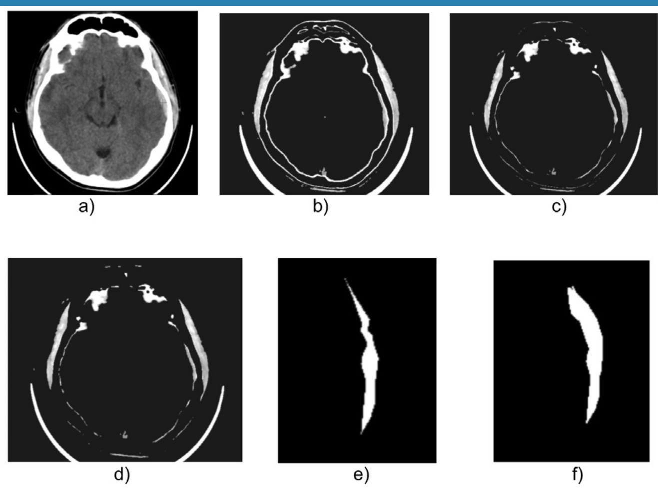
Table 2. Comparison of the average Dc generated both by the SAT and by other techniques, reported in the literature, for 3D segmentation of the SDH.

Authors	Technique	Modality	Average Dc
Kamnitsas *et al (2017)*[12]	Neural network Convolutions	MSCT	0.9032
Prakash *et al (2012)*[13]	Regularized level sets	MSCT	0.8971
Vera *et al.* (Technique proposed in the current work)	SAT	MSCT	0.8765

Qualitative results

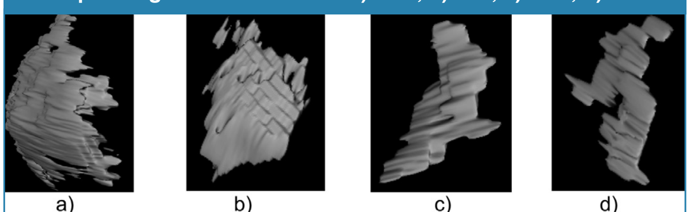
Figure 3, shows a 2-D view of both the original SDH and the processed versions after applying the SAT technique to one of the DB considered.

Figure 3. Cross-sectional view of images belonging to the database identified as DB1: a) Original, b) Thresholdized, c) Erode, d) Median, e) Segmented, f) Postprocessed with the binary morphological dilation filter.



As complementary evidence, figure 4 shows an excellent three-dimensional representation of the 4 segmented subdural hematomas.

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



In figure 4, it can be seen 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 volumes of the SDH is not always valid. Additionally, Table 3 shows the values for the volumes calculated for the SDHs using both the SAT method and the ABC methods considered.

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

	Volume (cm^3)				
Database	MPM	SAT	ABC/2	ABC/3	2ABC/3
DB1	15.17	15.69	15.81	10.54	21.08
DB2	8.95	9.32	11.07	7.38	14.76
DB3	3.51	3.63	4.49	2.99	5.98
DB4	2.09	2.26	2.46	1.64	3.30

It can be inferred from table 3 that SAT, ABC/2 and 2ABC/3 methods estimate the value of the volume; while the ABC/3 method underestimates it. According to Huttner et al.[14], the ABC/3 method has not been validated clinically and, indeed, can exhibit excellent behavior in cases in which the patient consumes anticoagulants or has undergone radio and/or chemotherapy.

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 linked with each of the methods considered to obtain the volume of the 4 SDHs present in the selected databases.

	Percentage relative error (%)			
	SAT	**ABC/2**	**ABC/3**	**2ABC/3**
DB1	3.43	4.22	30.52	38.96
DB2	4.13	23.69	17.54	64.92
DB3	3.42	27.92	14.81	70.37
DB4	8.13	17.70	21.53	57.89
Average Percentage Relative error (%)	4.78	13.38	21.1	58.03

Table 4, supports the conclusion that the SAT method generates the best average percentage relative error (Erp). In addition, the ABC methods exhibit the best performance in ABC/2, although in small volume hematomas it tends to produce bigger errors. This may be due to the fact that this method is based on the hypothesis that the SDH has an ellipsoidal shape and according to[14], this presumption is not always fulfilled (see, additionally, figure 4).

In this section it is important to remember that the main surgical usefulness of the determination of SDH volumes is that they weigh heavily on the behavior to be followed regarding the patient. In this sense, if only volume is considered, hematomas that exceed the threshold of 30 cm^3 are susceptible to surgery. Following this criterion, and considering the results of the volume obtained by the MPM and those derived from the SAT method, which yielded the lowest *PrE*, none of the four patients is a candidate for 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, is not always fully satisfactory. In this sense, the fulfillment of the geometric hypothesis that an SDH has an ellipsoidal shape represents the main limitation of these methods, especially when it comes to patients who have SDH with no definite shape, relatively small and/or large volume. However, when the SDH 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 do not yet have that condition. Additionally, in several investigations it has been verified that these methods have as an additional disadvantage: they are 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 SDH, present in computed tomography images. This statement is based on the fact that the Dc obtained is comparable with that reported in the literature. The segmentations generated, automatically, by the SAT allows for the calculation of the volume of each SDH in a precise and efficient manner. This volume figure is vital to address the hematoma that affects the health status of a patient and decide whether or not it is surgically treated.

Because the SAT method generated the lowest average percentage error, which did not exceed 5%, it can be said that the performance of the SAT method outperforms 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.

The technique developed in the present work allowed the successful segmentation of all four hematomas present in the 4 databases considered, regardless of the type of scanner with which the images of cerebral tomography were acquired, This is an indication that the aforementioned computational technique, based on intelligent operators, is trustworthy even in case of inter-subject and inter-tomographic variability.

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