

# Precise volumetric quantification of blood (hematoma) in deformable solids/organs: preliminary results based on a proof-of-concept scheme

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**Abstract**—Excessive bleeding (hemorrhage) is a life-threatening condition and warrants emergency medical care depending on the severity. Although medical imaging can detect the severity of bleeding qualitatively, it is often challenging to quantify posthemorrhagic blood stored in the organ. This study aims to quantify blood volume based on an imaging dataset accurately. For the proof-of-concept (POC) phase, we procured the computed tomography (CT) scan images of liquid-filled containers having varying asymmetrical shapes and solid objects inside them, in the form of Digital Imaging and Communications in Medicine (DICOM) images. These containers contained different amounts of aqueous iodine solution, which provided us with contrast CT scans. Two algorithms based on minimal user input thresholding and slicing technique for volume quantification were conceptualized, and the estimated findings were compared to the measured liquid volume.

**Keywords**— hemorrhage, CT scan, voxel, slicing, volume quantification

## I. INTRODUCTION

Traumatic injuries may vary in their severity. However, excess bleeding through lacerations is a sign of an emergency and warrants immediate care and hospitalization. The blood volume in adults accounts for about 7% of body weight (70 ml/kg). For a 70 kg individual, the estimated blood volume (EBV) is around 5 litres. Typically, a patient requires emergency blood transfusion within an hour if the volume of blood loss is nearly a litre or more [1]. However, physicians can stabilize the patient with medication and saline solution if the hematoma volume is small. Situations like these are where the criticality of accurate blood hematoma quantification comes into play.

Hematoma quantification in the brain is relatively docile because it is small and regular in space. Also, the amount of bleeding in the brain is usually between 2 and 150 ml. On the other hand, blood loss in the abdomen can range from tens to thousands of millilitres. The abdominal cavity, for instance, is a highly irregular space with considerable subject-specific

variations. Traumatic abdominal blood loss involves a significant degree of clinical suspicion. Abdominal pain, hematemesis, haematuria, melena, and bruises are some of the symptoms. Severe bleeding may lead to haemorrhagic shock and even death [2]. As a result, critical evaluation of blood/hematoma in such irregular spaces is a challenging proposition. It is critical to emphasize that the nature of medical assistance, including the amount of blood that must be arranged, is determined by the amount of blood loss, which is in turn determined by a quantification process. Our current program is premised on this demand and aims to deliver a tool that can provide a clinically viable estimation of blood volume in a highly irregular space. As for hematoma volume measurement, the slicing approach has been established to yield better, more valid, and reliable results. It is unaffected by the shape of the hematoma, and the measurement results obtained with this method are not subject to significant errors due to the irregular shape of the hematoma [3]. Hence, we utilized this slicing concept to calculate the posthemorrhagic blood volume as the total of quantitative volume measurements in successive segments. Once the proof-of-concept (POC) scheme is validated, the same method and workflow can be replicated or extrapolated to similar scenarios involving subject-specific images of living organs or body parts.

The current proposal aims to develop software tool(s) that identify hemorrhage in patients and alert doctors, reducing the time it takes for patients in such dire situations to obtain care. Furthermore, once a patient has been diagnosed with haemorrhagic stroke, the physicians may employ the software tool to evaluate the size and location of the hematoma, allowing them to devise appropriate treatment alternatives and contemplate a successful intervention strategy.

## II. DATA

### A. Selection of data for POC phase

In the context of data acquisition, we considered five containers of entirely different shapes for the POC part of this research work. These containers contained different amounts of aqueous iodine solution, which provided us with contrast CT scans.

Table I shows the type of container used for the data collection part and the calculated amount of aqueous iodine solution present.

TABLE I: TYPE OF CONTAINER USED ALONG WITH ACTUAL MEASURED VOLUME.

Container name	Actual volume of contrast liquid (in ml)
I. Blue small	100
II. Blue small rugged	150
III. Green MD	250
IV. Blue large flora	350
V. Blue large BB	450

### B. Data description

For the POC component, there were two rounds/types of data collection:

- Containers containing only iodine aqueous solution of varying volumes.
- Containers with varying volumes of aqueous iodine solution and a variable quantity of solid objects acting as obstacles/hindrances inside each container.

With the help of an experienced radiologist, we acquired CT scans corresponding to the transverse and coronal planes. Fig. 1 shows samples of images in the transverse plane, whereas Fig. 2 shows examples of images in the coronal plane. A total of ten 3D CT scans were obtained, with each 3D CT scan containing

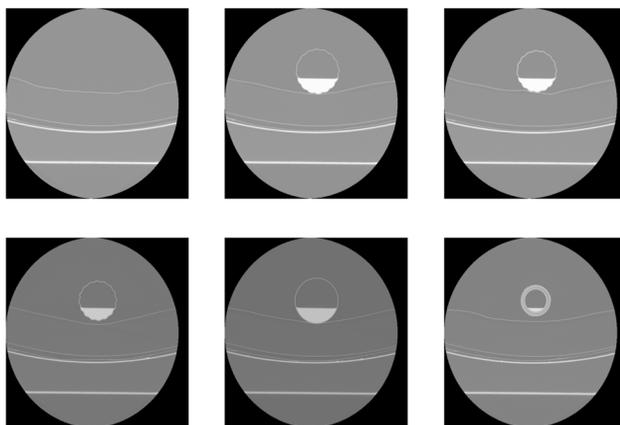


Fig. 1. Six slices of the “Blue small” container in the transverse plane

over 300 slices of its own (in the transverse plane). The first step of the POC section of the project has already begun.



Fig. 2. Six slices of the “Blue small” container in the coronal plane

## III. METHODOLOGY

For the initial viewing and investigation of the dataset, we used the MicroDicom viewer (version 3.9.5), which handles all DICOM medical image data, e.g., pixel data and slice meta-data. The overall procedure involved the following: thresholding segmentation for background subtraction, liquid area recognition [4], and as a result, the total fluid volume ( $V$ ) calculation formula for an entire 3D CT-scan is framed as:

$$V = \sum ((l*b*h) * (pix)) \quad (1)$$

where "pix" indicates the number of segmented pixels for an individual CT slice, and  $(l, b, h)$  denotes the sampling rate of the CT slice, where  $l$ ,  $b$ , and  $h$  stand for length, breadth, and width of a voxel, respectively.

### A. Algorithm-1

Algorithm-1 relied on the user providing a set of "lower" and "upper" pixel intensity thresholds (say,  $th1$  and  $th2$ ) based on the CT slices' visual examination. The algorithm used these thresholds to segment each slice of a 3D image, counting the number of foreground pixels. The volume of one voxel is determined by multiplying the sampling rate (physical space covered by each voxel which can vary along each dimension) of an element, i.e., each voxel's width ( $h$ ), length ( $l$ ), and breadth ( $b$ ). The volume of liquid in a single slice ( $vol_{S_i}$ ) is calculated by multiplying the number of foreground pixels ( $pix$ ) by the volume of a single voxel ( $l*b*h$ ). The total volume of the liquid in a single 3D CT scan image ( $V$ , or,  $vol_{S_{all}}$ ) is calculated by iterating the process and adding up the individual volume for each slice using (1). The flowchart for Algorithm-1 is shown in Fig. 3.

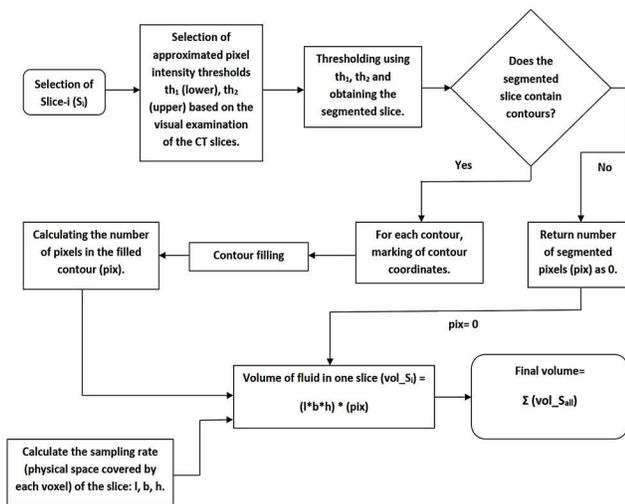


Fig. 3. Flowchart explaining Algorithm-1 for segmentation and volume quantification.

### B. Algorithm-2

Algorithm-2 was based on a single-pixel value input (say,  $th$ ) received from the user. We performed a visual inspection of each CT slice to approximate the most common pixel intensity value of the segment containing the liquid. The contours in each of these slices were determined and masked to create segments. The algorithm selected the contour(s) having the user-input pixel value ( $th$ ) for a slice with numerous segments. The process was repeated for each slice, and using (1), the total volume quantification process was accomplished as a result. Fig. 4 shows the flowchart for Algorithm-2.

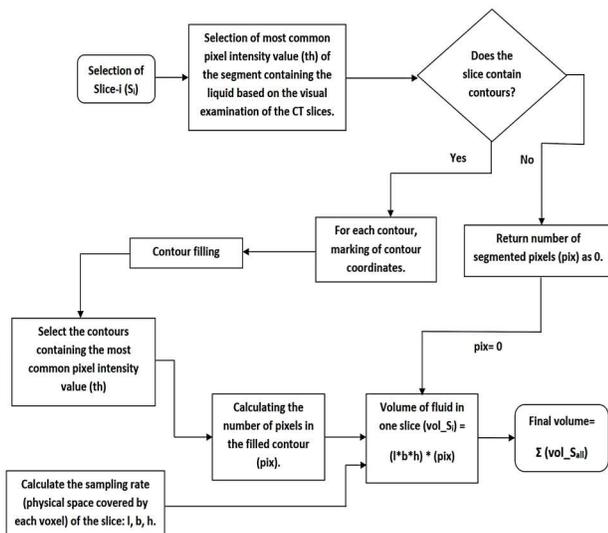


Fig. 4. Flowchart explaining Algorithm-2 for segmentation and volume quantification.

## IV. RESULTS

We studied five different containers carrying different volumes of liquid (aqueous iodine solution). The containers have diverse and asymmetrical shapes. Each algorithm took

approximately 1.35 secs per slice for the segmentation and quantification process in a system with AMD Ryzen 7 3750H 2.3 GHz processor and 16 GB of RAM running on Windows 10. Algorithm-1 underestimated the volume for the first three containers, i.e., Blue small, Blue small rugged, and Green MD. However, it approximated the volume of the final two containers (Blue large and Blue large BB) more accurately. Algorithm-2, on the other hand, overestimated the volume for the first three containers but produced significantly accurate results for the last two containers. The results pertaining to volume estimation by the two algorithms are shown in Table II.

TABLE II: VOLUMES CALCULATED USING ALGORITHM-1 AND ALGORITHM-2.

Container type	Actual volume of contrast liquid	Algorithm-1 Thresholds	Algorithm-1 calculated volume, with accuracy %.	Algorithm-2 Threshold	Algorithm-2 calculated volume, with accuracy %.
Blue small	100 ml	400-470	87.3 ml (87.3%)	400	108.8 ml (91.2%)
Blue small rugged	150 ml	400-470	129 ml (86.0%)	400	162.4 ml (91.73%)
Green MD	250 ml	385-470	214.1 ml (85.64%)	400	264.2 ml (94.32%)
Blue large flora	350 ml	450-700	334.9 ml (95.68%)	600	345.1 ml (98.6%)
Blue large BB	450 ml	450-700	419.6 ml (93.24%)	700	448.2 ml (99.6%)

Nevertheless, the average of the estimated volumes from algorithms 1 and 2 yielded significantly improved overall outcomes for each container, as shown in Table III.

TABLE III: VOLUMES IN BOLD DENOTE THE MOST CORRECTLY CALCULATED VALUE.

Container type	Actual volume of contrast liquid.	Algorithm-1 calculated volume, with accuracy %.	Algorithm-2 calculated volume, with accuracy %.	Average of algorithms 1 and 2, with accuracy %.
Blue small	100 ml	87.3 ml (87.3%)	108.8 ml (91.2%)	<b>98.05 ml</b> (98.05%)
Blue small rugged	150 ml	129 ml (86.0%)	162.4 ml (91.73%)	<b>145.7 ml</b> (97.13%)
Green MD	250 ml	214.1 ml (85.64%)	264.2 ml (94.32%)	<b>239.15 ml</b> (95.66%)
Blue large flora	350 ml	334.9 ml (95.68%)	<b>345.1 ml</b> (98.6%)	340.0 ml (97.14%)
Blue large BB	450 ml	419.6 ml (93.24%)	<b>448.2 ml</b> (99.6%)	433.9 ml (96.42%)

## V. DISCUSSION AND CONCLUSION

The volume of a hematoma can be measured in a variety of ways. Some of these are the Tada formula, the slicing method, the voxelization method [3], and even the statistical models [5, 6, 7]. Because of its inefficiency in calculating irregular hematoma, the Tada formula technique is considered a crude hematoma estimate [8]. Statistical models require an enormous amount of data for proper training and accurate classification results. Furthermore, statistical models need manual hematoma segmentation from chosen CT slices for model training, which is difficult owing to pixel-wise intensity fluctuations, irregular borders, high tissue contrast, and the presence of noise and artefacts. Several studies have shown that proper visual inspection and manual evaluation of CT-based hematomas is time-consuming, sensitive to intra- and inter-observer variability, and is susceptible to random errors and misinterpretations [9].

In this study, two novel algorithms based on minimal user input for thresholding and slicing method were developed for volume quantification to minimize the extra skill required for executing specific models and compensate for the accuracy of outputs. The application and results of these two algorithms on the contrast CT images of highly irregular-shaped objects containing aqueous iodine solution are achieved and briefly discussed. The early tasks of segmentation and volume quantification appear promising as part of the more significant problem. Even though the algorithms took a while to process the scans slice-by-slice and had some voxel misclassifications and quantification inaccuracies, both methods produced good results, albeit with certain room for improvement and customization.

## VI. FUTURE WORK

Based on the results of the POC scheme described above, the following future scope of work is being envisaged:

a) Application of the algorithms on the containers having varying volumes of aqueous iodine solution and a variable quantity of solid particles acting as obstacles/hindrances for each container.

b) Use of semi-supervised superpixel segmentation for attaining more meaningful regions and computational efficiency in the acquired data [10].

c) Using semi-supervised techniques for automatic image segmentation to construct masks, then using these masks to train neural networks to generate probability maps per slice for identifying target pixels (automatic voxel labelling) in test data for final fluid volume quantification [5].

d) Thresholding and segmentation of fluid from other body materials using a hierarchic genetic algorithm and volume quantification using the slicing method [11].

## VII. AUTHORS' CONTRIBUTIONS

The following are the authors' contributions to the paper: Suman Hazarika and Rahul Bhagawati conceived and designed the study; Suman Hazarika and Rahul Bhagawati collected the data; Rahul Bhagawati and Souptick Chanda analysed and interpreted the results, and Rahul Bhagawati, Souptick Chanda and Cota Navin Gupta drafted the manuscript. All authors reviewed the findings, and the final version of the manuscript was approved.

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