Automated Infarction Core Delineation

Comparison between using Cerebral Blood Volume and Perfusion Blood Volume Maps

Petr Maule, Jana Klečková
Department of Computer Science and Engineering
University of West Bohemia
Pilsen, Czech Republic
e-mail: pmaule@kiv.zcu.cz, kleckova@kiv.zcu.cz

Vladimír Rohan, Radek Tupý
Department of Neurology
The University Hospital in Pilsen
Pilsen, Czech Republic
e-mail: rohan@fnplzen.cz, tupyr@fnplzen.cz

***Abstract* — This article is focused on development of a tool supporting physicians with an appropriate treatment decisions at patients with acute ischemic stroke. The automated tools for infarction core area delineation could provide important information about the volume of the infarction core. This article describes such automated method results used on both cerebral and perfusion blood volume computed tomography maps compared with manual infarction core delineations made by two physicians.**

Keywords - ischemic stroke; infarction core delineation; perfusion blood volume maps; computed tomography

I. Introduction

This paper deals with acute ischemic strokes, which are the third leading cause of death and the first leading cause of disability in population over 60 years old. Patients undergo several types of computed tomography (CT) examinations and based on the results appropriate treatment follows. Possible treatment is a thrombolytical treatment, which can not be indicated if the patient exceeds certain level of the volume of the infarction core. Studies like [1] and [2] deal with finding of the best threshold value for the infarction core. The largest study [1] at 130 patients found threshold at 2 ml/100g using cerebral blood volume maps (CBV) provided by Perfusion Computed Tomography (CTP) examination. The threshold can vary from patient to patient and the threshold is also dependent on the used method.

Thrombolytical treatment infarction core volume level limitation must be evaluated from the whole brain but the CTP examination is often limited in the covered area. Different methods are to be used for the whole brain infarction core volume evaluation.

Several studies described process of construction of so called perfusion blood volume maps (PBV) [3], which are constructed from non contrast computed tomography examination (NCCT) and computed tomography angiography (CTA) [4]. It expresses also the blood volume level as CBV but the provided information is not the same. CBV maps are computed from a series of images observing spreading of the contrast material while the PBV maps are constructed by adjusted subtraction of two values – densities with and without contrast material, which is also depended on the quantity of the contrast material in the time of the CTA data acquisition [3]. Another difference can be seen also in the slice thickness of the used CTA and NCCT examinations. The NCCT slice thickenss is often about 5 mm while the CTA slice thickness can be 1 mm. This difference increases partial volume impact in the final PBV maps.

This article shows comparision of automated infarction core delineation method using CBV maps and PBV maps. First, we describe the used material and its adjusting for our use. Next, the method itself is introduced and results are presented. Discussion summarizes our findings and proposes future steps.

II. Material

In cooperation with the University Hospital in Pilsen we had an access to 24 anonymized examinations from 12 patients with a supratentorial stroke. 12 examinations were CBV maps and 12 PBV maps. Both examination types are with the whole brain coverage acquired on dual-source CT (Somatom Definition, Siemens Healthcare, Forchheim, Germany) and PBV maps were constructed using commercial software Siemens syngo Neuro PBV. We also had available manually delineated best opinion prediction of infarction core provided by one radiologist and one neurologist experienced in CT evaluation. CBV and PBV maps including the manual delineations were mutually registered. PBV and CBV maps were available in DICOM format and after the mutual registration they had dimensions 512x512 with 44 images per examination with used units *ml/l*.

We can refer the two physicians as Ph1 and Ph2. Ph2 in one patient's examination did not mark any area meaning the opinion that there is no infarction core at all. The average mutual correspondence between the findings of the two physicians expressed by Matthews correlation coefficient is 62.09% for CBV maps and 56.90% for PBV maps.

III. Segmentation Adjustement

The CBV examinations were already segmented by the instrument and the bones and cerebral ventricles were removed. The PBV examinations have already segmented bones and cerebral ventricles but probably because of the partial volume effect the steep values changes persist on the two different tissue types borders. Both examination types contain a rests from non-ideal segmentation at the bottom part under the skull base, which would significantly

Copyright (c) IARIA, 2012. ISBN: 978-1-61208-202-8

influence the following methods' results. Because of this reason we performed segmentation adjustement step, which selects one image as a divider and for further processing are used only images from the top to the divider image. All images below are ignored. We used following technique for finding the divider image.

A. Divider Image Detection

If we refer one examination image as Im_i where $i=0$ corresponds to the top of the examination (in the sense of the top of the head) and i_{max} to the last image (in the sense of the bottom of the head), then, for every image, we can calculate following equation:

$$C_i = C_i^{IN} / C_i^{OUT}. \quad (1)$$

C_i^{IN} means count of voxels of the image i, which values are above zero, C_i^{OUT} means count of voxels of the image i, which values are below or equal to zero (except voxels with value -1024 representing the outer space).

One of the image becomes the divider image according to the C_i value. For this purposes, we start comparing C_i values from the bottom image with $i=max$ towards the upper image with index $i=0$. The first image with index i, which satisfies condition $C_i<Th$ becomes the divider image. We found optimal Th value for CBV examination 2.0 and for the PBV examination 1.0.

This segmentation adjustment step (example in Fig. 1) is just auxiliary for following method comparison to remove posterior fossa from further processing. We evaluated that this segmentation adjustment step is successful in 95.8% (23) cases from all 24 examinations in the sense of providing enough area by the segmentation adjustment step to be possible to delineate enough area to cover 100% of manual infarction core tracking. The only one unsuccessful case reduces the area but it is still possible to find 96.3% of the manually marked infarction core volume.

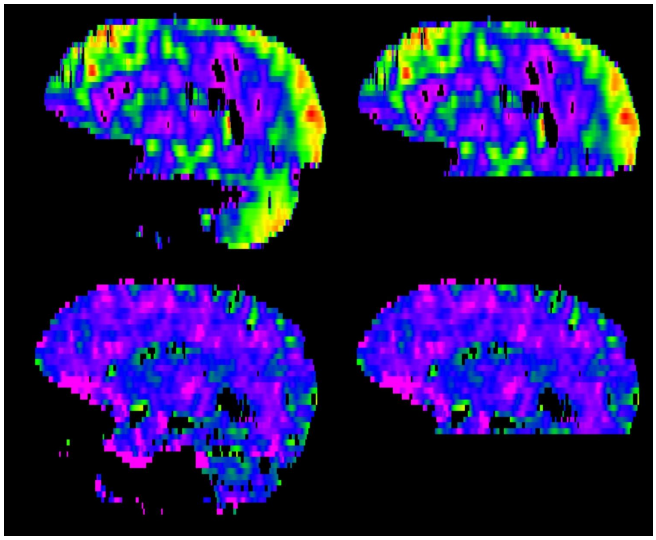

Figure 1. CBV (upper row) and PBV (bottom row) segmentation adjustment step, original examination on the left and adjusted examination on the right using sagittal views. Displayed values range is from 0 ml/l to 150 ml/l using a common color-scale.

IV. Automated Delineation Method

Details of the image processing method used in study [1] are not presented enough to reproduce it by own prototype software. PBV and CBV maps, which we have available, are also provided by commercial software and so that we tried to use simple thresholding for processing it. We found a need for the examination preprocessing and a need for focusing to area of the infarction core to avoid false-positive voxels, which would be included into the whole volume of the infarction core.

We developed a prototype software, which processes CBV and PBV examinations. The automated infarction core delineation is based on examination's preprocessing, and following thresholding and it is focused to delineate only the infarction core area and thus to reach higher specificity.

A. Image Preprocessing

We used preprocessing examination in a form of edge preserving smoothing as mentioned in [1]. We used Curvature Anisotropic Diffusion smoothing with the usually used parameters defined by [5]:

Time step: *0.0625*
Conductance: *3.0*
Iterations: *5*

B. Thresholding

After the preprocessing step we tried to find the best threshold corresponding to the highest specificity. We used thresholds from *0 ml/l* to *21 ml/l*. The value *21 ml/l* corresponds to the found threshold value from [1], which is *2 ml/100g*. The used increment was *1 ml/l*. The thresholding process is simple in CBV examinations - all values from 0 to threshold are marked as infarction core but in PBV examinations we faced to high amount of negative values, which belongs to the imperfect bone and cerebral ventricles segmentation but also to supposed infarction core areas. In order to avoid marking such voxels we reduced them by lower limitation of thresholding to arbitrarily used value *-50*.

C. Infarction Core Area Selection

We faced to too many false-positives voxels and thus we grouped all adjacent voxels, after the thresholding step, into groups and we discarded all groups instead of the largest one, which we believe to be the one corresponding to the infarction core. The disadvantage of this step is a possibility that the largest group does not correspond to the infarction core while the correct group was discarded since it is smaller than the largest group.

D. Match Evaluation

We have two patterns of how the automated findings should ideally look like. We compare our automated findings according to the patterns separately. Firstly, for the CBV examinations, and secondly, for the PBV examinations. Let

Copyright (c) IARIA, 2012. ISBN: 978-1-61208-202-8

us call the match between CBV automated findings and findings of Ph1 as CBV-Ph1, similarly CBV-Ph2 and also PBV-Ph1 and PBV-Ph2.

For each match we can evaluate 4 voxel counts. TP (true positive) - increased when both voxels were marked as infarction core, by physician and also by automated method, TN (true negative)– both voxels were marked as non-infarction core, FP (false positive) – the automated method marked voxel as infarction core while the physician marked the same voxel as non-infarction core and FN (false negative) – automated method marked voxel as non-infarction while physician as infarction core.

Tables I and II present sensitivities and specificities as an average values from all 12 patients excluding those with incorrect match, which count is presented in IM column.

E. Incorrect Match

We call incorrect match the case when the automated method findings and the physician's findings have marked no common infarction core voxel, it means TP = 0 while FP > 0.

V. Results

Results of the described method are presented in Table I for CBV examinations and in Table II for PBV examinations. Fig. 2 demonstrates using of different threshold values on PBV examination. The specificities seem to be high but lets consider that all examinations have 512x512x44=11534336 voxels and for example the average infarction core area from manual marking of the Ph1 contains 28603 voxels. If the automated method would find all voxels marked by physician but it would mark the 3 times larger area, the specificity would be 99.5%.

We can see that for CBV examinations we can obtain very high specificity, almost 100% (thresholds from *0* to *7 ml/l*) but for the PBV examinations the maximum specificity was found only 99.24378%, which is not satisfying.

VI. Discussion

We believe that the low specificity in PBV images is caused mostly by partial volume effect, which is caused by

TABLE I. CBV Results

Threshold [ml/l]	Sensit. Ph1 [%]	Specif. Ph1 [%]	IM[a] Ph1	Sensit. Ph2 [%]	Specif. Ph2 [%]	IM[a] Ph2
0	2.79	99.98695	8	2.10	99.98542	8
1	21.77	99.97208	6	19.39	99.97134	6
2	19.52	99.99688	4	17.38	99.99704	4
3	26.08	99.99348	3	23.28	99.99424	3
4	35.12	99.98405	3	30.11	99.98456	3
5	41.86	99.97453	3	37.67	99.97327	4
6	43.51	99.96923	2	38.91	99.96935	3
7	52.46	99.94637	3	46.45	99.94888	4
8	57.97	99.90980	3	51.71	99.91527	4
9	61.95	99.88400	3	55.85	99.89189	4
10	65.77	99.85239	3	60.28	99.86398	4
11	75.79	99.33449	3	67.38	99.35707	3
12	73.22	99.11246	2	65.10	99.13822	2
13	78.39	98.82117	1	70.50	98.84521	2
14	83.34	98.42550	1	75.58	98.43674	2
15	86.17	98.03474	1	79.07	98.02557	2
16	88.78	97.58111	1	81.92	97.55204	2
17	91.13	97.03577	0	83.22	96.99077	1
18	92.57	96.54330	0	85.66	96.48031	1
19	93.74	96.03487	0	87.75	95.95049	1
20	94.72	95.51506	0	89.48	95.41960	1
21	95.54	94.93930	0	90.92	94.81682	1

a. Count of incorrect matches from total 12 patients

TABLE II. PBV Results

Threshold [ml/l]	Sensit. Ph1 [%]	Specif. Ph1 [%]	IM[a] Ph1	Sensit. Ph2 [%]	Specif. Ph2 [%]	IM[a] Ph2
0	62.28	99.20641	4	58.97	99.24378	4
1	67.33	99.07244	4	63.35	99.11330	4
2	69.19	98.96140	3	64.01	99.00619	3
3	72.12	98.82390	3	66.53	98.87054	3
4	74.46	98.70119	3	69.10	98.75185	3
5	76.84	98.55058	3	71.73	98.60509	3
6	78.93	98.38614	3	74.08	98.44412	3
7	75.47	98.40800	2	72.15	98.46359	2
8	77.62	98.31482	1	74.71	98.32093	2
9	79.42	98.16158	1	76.89	98.16444	2
10	81.41	97.99354	1	79.36	97.99234	2
11	82.98	97.81751	1	81.37	97.81185	2
12	78.36	97.68276	0	77.15	97.67533	1
13	80.55	97.50674	0	80.08	97.49548	1
14	81.90	97.33071	0	82.00	97.31522	1
15	83.17	97.13386	0	83.70	97.11169	1
16	84.39	96.94731	0	85.24	96.92112	1
17	85.68	96.76089	0	87.12	96.72960	1
18	86.87	96.56792	0	88.41	96.52946	1
19	87.84	96.36111	0	89.65	96.31516	1
20	89.63	95.80393	1	90.92	95.71346	2
21	90.38	95.58968	1	91.79	95.49068	2

a. Count of incorrect matches from total 12 patients

Copyright (c) IARIA, 2012. ISBN: 978-1-61208-202-8

different slice thickness of source images and also by the imperfect segmentation of the bones and cerebral ventricles. Because of this reason the PBV examinations contain steeper changes of values and also high amount of negative values especially at two different environment borders including the infarction core. The edge preserving smoothing at least with the used settings is not strong enough to make the infarction core distinguishable by used thresholding.

We also believe that the use of different kind of filters like meaning can be useful for the PBV examinations despite of the loss of details and in combination with a local neighborhood features better results could be obtained.

VII. Conclusion

We presented simple combination of edge preserving smoothing with selecting the largest continuous area, which is considered to be infarction core. Using the thresholding technique we evaluated correspondence between automated method and manual infarction core delineations provided by 2 physicians. We can see that while the same method can in the case of CBV maps provide almost 100% specificity, it is almost unusable in the same form using the PBV maps. In discussion we mentioned our opinion of the low PBV specificity and we proposed our ideas how to improve results on PBV maps.

Acknowledgment

The work presented in this paper is supported by The Czech Science Foundation project 106/09/0740.

References

[1] Wintermark M., et al., “Perfusion-CT Assessment of Infarct Core and Penumbra: Receiver Operating Characteristic Curve Analysis in 130 Patients Suspected of Acute Hemispheric Stroke”, Stroke 2006;37;979-985.

[2] Murphy B.D., et al., "Identification of penumbra and infarct in acute ischemic stroke using computed tomography perfusion-derived blood flow and blood volume measurements". Stroke 2006;37:1771–77.

[3] Srinivasan A., Goyal M., Azri F. A., Cheemum L., "State-of-the-Art Imaging of Acute Stroke", RadioGraphics 2006; 26:S75-S95.

[4] Hamberg L.M., Hunter G.J., Kierstead D, Lo E.H., Gilberto González R, Wolf G.L., "Measurement of cerebral blood volume with subtraction three-dimensional functional CT", AJNR Am J Neuroradiol. 1996; 17: 1861–1869.

[5] Ibanez L., Schroeder W., Ng L., Cates J., “The ITK Software Guide”, Kitware, Inc. ISBN 1-930934-10-6, 2003. http://www.itk.org/ItkSoftwareGuide.pdf [retrieved: April, 2012]

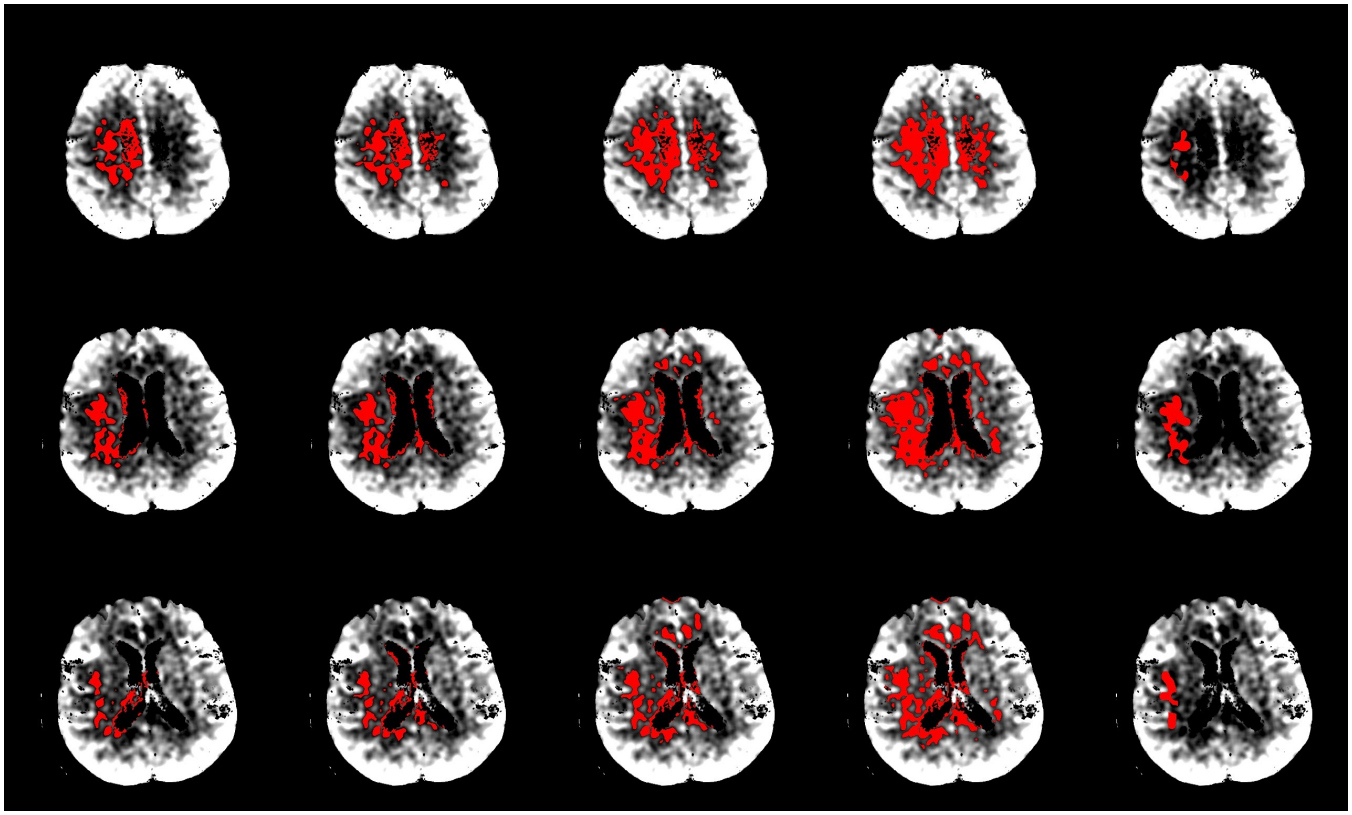

Figure 2. Example of infarction core detections (red color) on PBV examination using edge preserving smoothing. Columns from left correspond to thresholds 0, 2, 7, 12 ml/l and the last column expresses manual tracking by Physician 1. Rows correspond to different locations in the examination. The used lower limit for infarction core -50 ml/l was used.

Copyright (c) IARIA, 2012. ISBN: 978-1-61208-202-8