Brain Volume Estimation Enhancement by Morphological Image Processing Tools

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ABSTRACT

Background: Volume estimation of brain is important for many neurological applications. It is necessary in measuring brain growth and changes in brain in normal/abnormal patients. Thus, accurate brain volume measurement is very important. Magnetic resonance imaging (MRI) is the method of choice for volume quantification due to excellent levels of image resolution and between-tissue contrast. Stereology method is a good method for estimating volume but it requires to segment enough MRI slices and have a good resolution. In this study, it is desired to enhance stereology method for volume estimation of brain using less MRI slices with less resolution.

Methods: In this study, a program for calculating volume using stereology method has been introduced. After morphologic method, dilation was applied and the stereology method enhanced. For the evaluation of this method, we used T1-wighted MR images from digital phantom in BrainWeb which had ground truth.

Results: The volume of 20 normal brain extracted from BrainWeb, was calculated. The volumes of white matter, gray matter and cerebrospinal fluid with given dimension were estimated correctly. Volume calculation from Stereology method in different cases was made. In three cases, Root Mean Square Error (RMSE) was measured. Case I with T=5, d=5, Case II with T=10, D=10 and Case III with T=20, d=20 (T=slice thickness, d=resolution as stereology parameters). By comparing these results of two methods, it is obvious that RMSE values for our proposed method are smaller than Stereology method.

Conclusion: Using morphological operation, dilation allows to enhance the estimation volume method, Stereology. In the case with less MRI slices and less test points, this method works much better compared to Stereology method.

Keywords

Brain Volumetry, Stereology Method, Dilation Operation, MRI, Gray Matter, White Matter, Cerebrospinal Fluid, Brainweb Database

Introduction

Nowadays, medical imaging has become a very important subject for a large number of medical applications such as diagnosis or treatment. Today, diagnosis of a patient is done by using imaging technology. In addition to the use of medical imaging devices in medicine, tissue recognition and classification play an important role in medical research and application [1].

Brain volume measurement is an important task in the studies of neurological and psychiatric disorders. Changes in the volume of Gray Matter (GM), White Matter (WM) and Cerebrospinal Fluid (CSF) can be used to specify physiological processes and disease entities or to specify

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disease severity [1,2]. Generally, brain volume measurement has some applications in neurological sciences; major application include diagnosis, disease monitoring and evaluation of potential treatments in neurodegenerative diseases like Alzheimer's disease (AD) and Multiple Sclerosis (MS)[1,3-5]. Thus, brain volume calculation is an indispensable process in most neuroimaging analyses. Magnetic resonance imaging (MRI) can be used as a precise method for volume measurement of internal structures or organs. MRI allows the noninvasive and in-vivo investigation of brain structure. Moreover, MRI can make differentiation between various tissues. These features make it suitable for the quantitative measurement of brain morphology, and it helps physicians diagnose and treat medical conditions [6-10]. Recent advances in magnetic resonance (MR) imaging sequences and in image analysis have made improvement in quantification of the size of anatomical structures within the human brain. Quantitative assessment of brain volume, achieved from volumetric MRI, has been applied for neurologic conditions [4,11]. The accuracy and precision in estimation of the brain volume and its structure is a necessary process for the evaluation of brain disorders and abnormalities [12].

Volume quantification on structural brain MR images is performed by using manual, semi-automated or automated methods. There are two methods for manual quantification of brain compartment volume from MRIs, namely stereology and manual tracing [13,14]. Stereological method using Cavalieri principle is a method for volume estimation of brain and internal brain compartments.

Researchers have employed these techniques to obtain volume estimations of various brain structures [15].

Stereology method is a manual method for estimating volume. In order to implement this method, the images should be segmented correctly; however, it is a time-consuming and user-dependent task. If we use small number of MR images with less resolution, the need for segmentation decreases and stereology method will be improved. In this study, we improved the stereology method for measuring GM, WM and CSF volumes within normal brain.

Material and Methods

In the first step, we calculated brain volume structures (GM, WM and CSF) by using stereology method. Stereological method is based on cavalieri principle [14-18].

In Cavalieri's principle, the volume of interest structures can be estimated from a series of parallel plane sections separated by a known distance provided by the set of sections beginning at a randomly chosen starting point.

For this work, the interest structure was cut into the series of parallel planes at distance T apart, the first plane starting randomly at the intervals 0 to T [14-18].

The cut surface area of each section was estimated with point counting grids. The point counting grids consist of sets of points on a transparent sheet, superimposed on sections randomly. Counting points that covered the region of interest provided an unbiased estimate of the areas of the object profile [15,19]. Finally, the volume of the object (V) was estimated with the following equation [19,17,7]:

$$V = T \times a(p) \times \sum p = T \times [d]^2 \times \sum p \qquad (1)$$

Where T is the section thickness, a(p) represents the area associated with each test point and $\sum p$ is the total number of test points, d is distance between test points.

For the evaluation of method in brain volumetry, we used digital phantom. The phantom data was obtained from BrainWeb database [20]. The resolution of the phantom was (1.0 mm)2 throughout. The exact volumetric ground truth is known a-priori and provided on the web site.

20 normal brain MR images were used from BrainWeb. The database was set of T1-weighted simulated data with these specific param-

eters: SFLASH (spoiled FLASH) sequence with TR=22ms, TE=9.2ms, flip angle=30 deg and 1 mm isotropic voxel size. The volume contains 362×434×362 voxels covering the brain completely. The volume of brain structures (GM, WM and CSF) was estimated in MATLAB software in 1mm slice thickness and 1mm distance between test points.

In this step, we decreased slice sections and increased distance between test points. For three cases according to equation (1), case I: T=5, d=5, case II: T=10, d=10 and case III: T=20 and d=20, the volume of brain structures was estimated. For enhancing stereology method in this way, dilation method with a definite structure element was applied. Dilation method is a morphology method in image processing that adds pixels to the boundaries of objects in an image. The number of pixels added to the objects in an image depends on the size and shape of the structuring element used to process the image. Dilation method for gray-scale images is defined in terms of minima of pixel neighborhoods used for the calculation of gradient of the filtered image [21]. Determining the structure element is an important task in dilation operation. Ellipse was the best structure element for this study. The radius of ellipse was selected for case I 3.5 mm, for case II 6.5 mm and for case III 13.1 mm. The stereological method was compared with our proposed method.

Results

According to equation (1); T, d are the variable parameters in Stereology method. Dilation method in MATLAB software optimizes Stereology method by changing these parameters. Thus, the brain volume measurement of 20 normal brain MRI is achieved by two methods. Table 1 shows the volume measurement of case I. In this case, Root Mean Square Error (RMSE) of Stereology method was calculated for GM 2.389136, WM 1.83619 and for CSF 1.530616, while RMSE for Dilation method was calculated 1.408555 for GM, 1.026126 for WM and 1.408379 for CSF.

In Table 2 for case II, the RMSE of Stereology method was 14.53527 for GM, 6.455868 for WM and 10.47331 for CSF, while this value for Dilation method was 4.813626 for GM, 1.856989 for WM and 2.870854 for CSF.

According to Table 3 for case III, RMSE in Stereology method was 32.04934 for GM, 19.08589 for WM and 31.21891 for CSF while this value in Dilation method was 4.207718 for GM, 6.093315 for WM and 8.492932 for CSF.

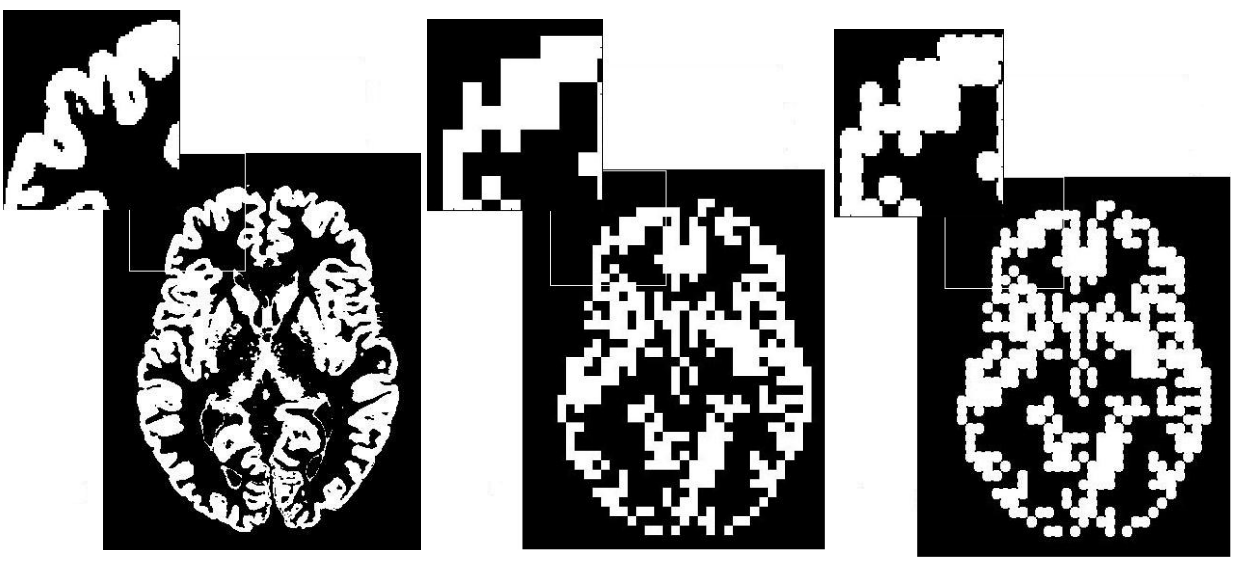
Figure 1 shows how dilation operation improves Stereology method in case II. Figures 2-10 compare the percentage error in volume estimation from Stereology method and our proposed method with dilation operation. Increasing the values T and d, would increase the percentage error but this percentage error for Dilation method is less than Stereology method.

Discussion

Although automated methods are fast for volume estimation, Stereology method with enough slice thickness can be used as a gold standard for measuring brain volume [15]. So, enhancement of this method can help investigators for volume estimation. Differences between brain volume of MRI using Stereology method and physical cut of post-mortem brain were not significant [12]. Thinner slices of MRI make volume brain estimation more accurate. 5-mm slice thickness and less is preferable [16]. In this study, Stereology method, a method for volume estimation was investigated. This method is a desirable method and the measurement achieved is almost correct. This method needs relatively high resolution images and enough MRI slices for calculating the brain volume correctly. Applying dilation operator on this method, made this method enhanced. In this method, the volume estimation was calculated more precise for less MRI slices and less resolution. The results obtained from the Dilation method with less MRI slices

Table 1: Volume estimation of GM, WM and CSF of the brain for two methods: Stereology and Dilation for case I, (the values are in cm)

subject	GM			WM			CSF		
	stereology	ground truth	dilation	stereology	ground truth	dilation	stereology	ground truth	dilation
4	961.45	963.65	964.17	648.38	646.86	644.68	362.59	361.73	361.55
5	1013.45	1011.08	1011.86	606.8	608.52	609.09	421.02	422.7	423.62
6	937.64	939.34	939.06	676.86	676.21	676.51	254.75	253.89	254.7
18	1050.05	1053.43	1050.02	571.66	572.8	572.29	382.77	381.17	381.57
20	994.64	997.07	996.82	602.91	604.58	605.03	375.31	374.09	375.12
38	1017.09	1019.19	1020.47	591.33	590.37	590.99	392.91	394.79	395.52
41	1013.63	1017.52	1015.77	606.69	605.19	604.77	388.08	386.53	388.07
42	1033.56	1031.55	1030.7	576.52	574.88	574.08	360.67	363.59	362.08
43	1107	1108.56	1110	663.95	662.37	663.04	339.7	338.08	339.51
44	1007.61	1009.78	1007.8	617.27	615.39	613.93	440.69	441.3	441.01
45	958.63	956.83	955.74	645.47	647.48	646.56	391.09	389.67	388.4
46	972.59	975.59	975.3	607.08	605.09	607.1	432.17	429.9	428.82
47	979.98	982.43	982.14	631.67	630.09	629.28	364	361.6	364.06
48	892.2	893.99	894.54	673.09	671.9	670.83	386.52	385.77	385.43
49	926.52	924.58	925.92	740.8	743.03	743.48	388.88	389.73	389.23
50	906.97	910.18	913.02	634.23	632.71	631.88	342.61	341.72	342.78
51	963.41	965.62	964.62	608.09	606.95	606.59	385.58	384.53	383.87
52	976.94	979.28	979.15	620.88	619.04	618.94	385.47	386.32	385.92
53	1041	1039.18	1038.8	575.77	571.19	573.1	298.34	299.38	299.61
54	984.72	986.61	984.9	576.61	575.66	575.13	432.25	434.02	432.79



A B C

Figure 1: Gray matter A) original image B) Stereology method for case II B) Dilation method for case II

Table 2: Volume estimation of GM, WM and CSF of the brain for two methods: Stereology and Dilation for case II, (the values are in cm)

subject	GM			WM			CSF		
	stereology	ground truth	dilation	stereology	ground truth	dilation	stereology	ground truth	dilation
4	953.38	963.65	966.96	641.13	646.86	645.66	371.5	361.73	364.74
5	1014.25	1011.08	1013.15	602.88	608.52	607.88	428.75	422.7	422.14
6	943.13	939.34	937.99	670.38	676.21	674.13	259.63	253.89	256.15
18	1040.88	1053.43	1044.58	576.25	572.8	574.31	395.38	381.17	384.64
20	978	997.07	989.18	609.88	604.58	606.49	389.13	374.09	379
38	1007.38	1019.19	1020.05	599.13	590.37	589.95	400.13	394.79	395.69
41	1001.75	1017.52	1012.42	597.38	605.19	605.28	398.88	386.53	389.8
42	1017.25	1031.55	1025.27	582.75	574.88	574.25	372	363.59	364.79
43	1136.25	1108.56	1106.13	653.88	662.37	658.7	348.88	338.08	341.04
44	999.88	1009.78	1008.57	619.63	615.39	616.16	450.38	441.3	442.86
45	946	956.83	954.64	652.5	647.48	649.83	400.63	389.67	391.27
46	959.88	975.59	972.94	612.88	605.09	602.87	439.5	429.9	430.28
47	961.88	982.43	979.93	635.25	630.09	629.08	376	361.6	364.41
48	887.88	893.99	897.1	669.25	671.9	671.22	392.25	385.77	383.42
49	918.13	924.58	926.7	738.13	743.03	741.73	396.5	389.73	388.77
50	890.13	910.18	906.19	641.38	632.71	635.63	354.88	341.72	347.29
51	949.63	965.62	960.88	618.88	606.95	604.97	394.13	384.53	387.68
52	957.88	979.28	968.04	623.25	619.04	622.61	402.38	386.32	391.66
53	1034.63	1039.18	1038.6	568.25	571.19	571.55	306.5	299.38	300.98
54	975.87	986.61	980.7	579.88	575.66	577.47	425.75	434.02	433.02

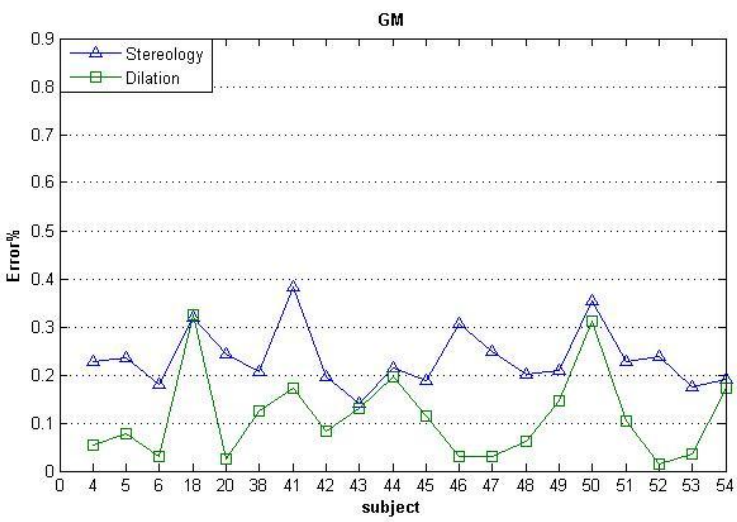


Figure 2: Percentage Error for GM volume estimation in two methods: Stereology and Dilation for case I

Table 3: Volume estimation of GM, WM and CSF of the brain for two methods: Stereology and Dilation for case III, (the values are in cm)

subject	GM			WM			CSF		
	stereology	ground truth	dilation	stereology	ground truth	dilation	stereology	ground truth	dilation
4	928	963.65	959.37	632	646.86	653.84	380	361.73	370.31
5	984	1011.08	1005.3	582	608.52	606.24	437	422.7	422.31
6	918	939.34	944.21	657	676.21	680.37	241	253.89	251.59
18	1023	1053.43	1052.56	552	572.8	582.12	425	381.17	392.14
20	965	997.07	995.79	618	604.58	613.76	404	374.09	383.92
38	1032	1019.19	1022.87	617	590.37	604.89	414	394.79	390.77
41	988	1017.52	1018.82	614	605.19	609.94	440	386.53	394.18
42	1000	1031.55	1032.27	560	574.88	582.25	400	363.59	373.68
43	1070	1108.56	1107.48	652	662.37	667.17	371	338.08	344.22
44	977	1009.78	1004.82	628	615.39	628	479	441.3	450.63
45	935	956.83	958.77	630	647.48	655.01	422	389.67	400.08
46	936	975.59	968.83	632	605.09	626.03	458	429.9	440.46
47	962	982.43	986.24	608	630.09	633.8	398	361.6	371.68
48	871	893.99	898.47	652	671.9	677.32	415	385.77	394.56
49	883	924.58	926.35	773	743.03	766.69	422	389.73	390.43
50	871	910.18	910.59	645	632.71	636.06	372	341.72	352.33
51	922	965.62	956.8	629	606.95	625.49	415	384.53	394.7
52	941	979.28	973.7	628	619.04	623.05	419	386.32	396.82
53	1010	1039.18	1043.51	557	571.19	583.69	325	299.38	309.65
54	954	986.61	982.17	595	575.66	585.65	451	434.02	437.81

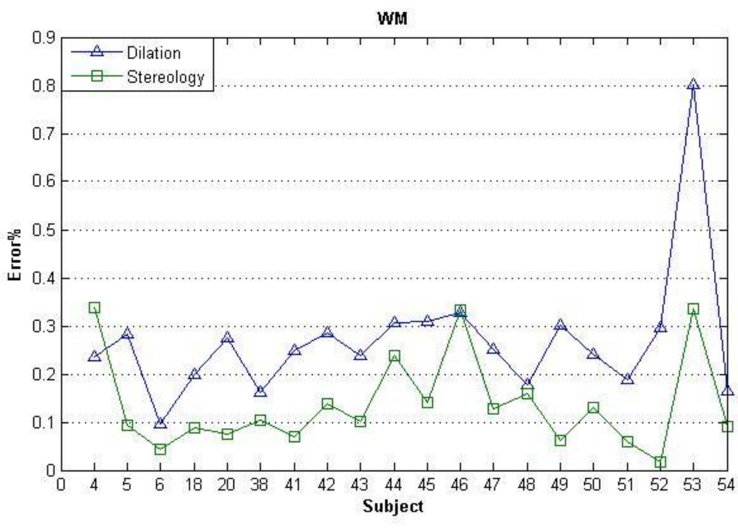


Figure 3: Percentage Error for WM volume estimation in two methods: Stereology and Dilation for case I

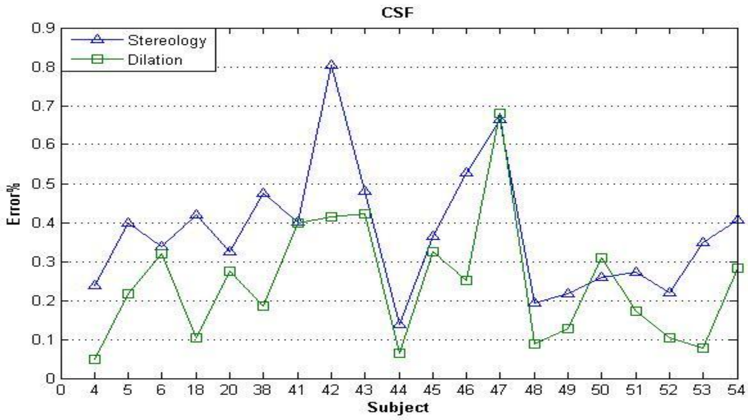


Figure 4: Percentage Error for CSF volume estimation in two methods: Stereology and Dilation for case I

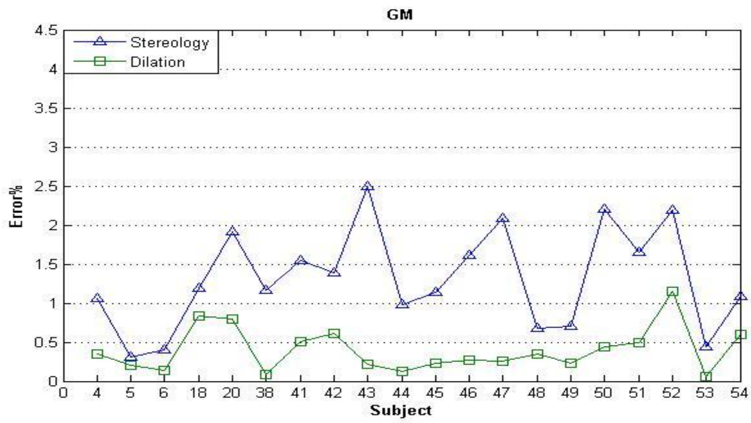


Figure 5: Percentage Error for GM volume estimation in two methods: Stereology and Dilation for case II

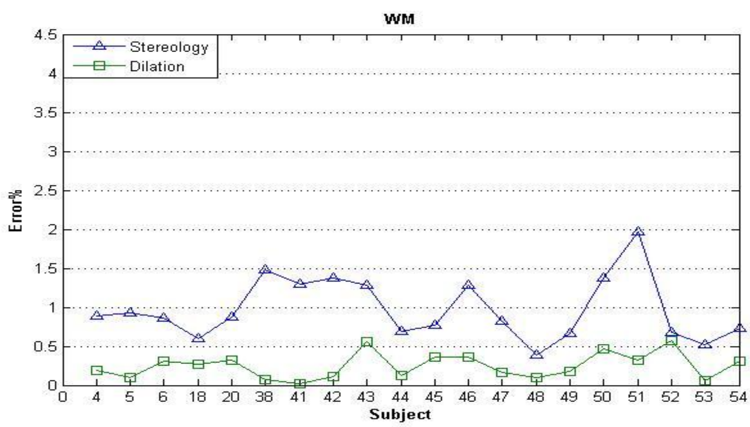


Figure 6: Percentage Error for WM volume estimation in two methods: Stereology and Dilation for case II

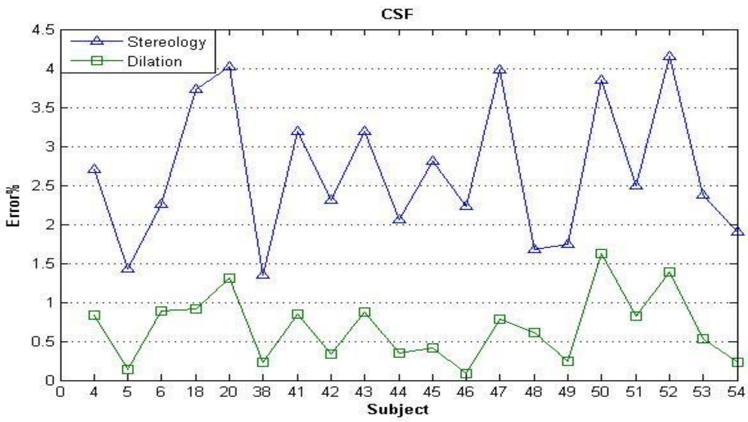


Figure 7: Percentage Error for CSF volume estimation in two methods: Stereology and Dilation for case II

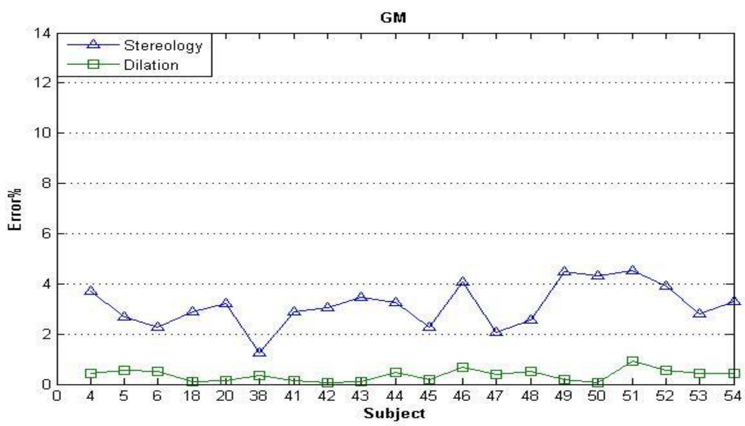


Figure 8: Percentage Error for GM volume estimation in two methods: Stereology and Dilation for case III

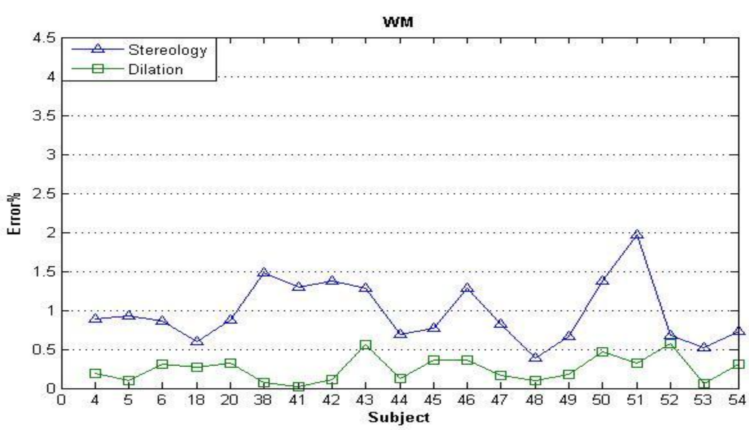


Figure 9: Percentage Error for WM volume estimation in two methods: Stereology and Dilation for case III

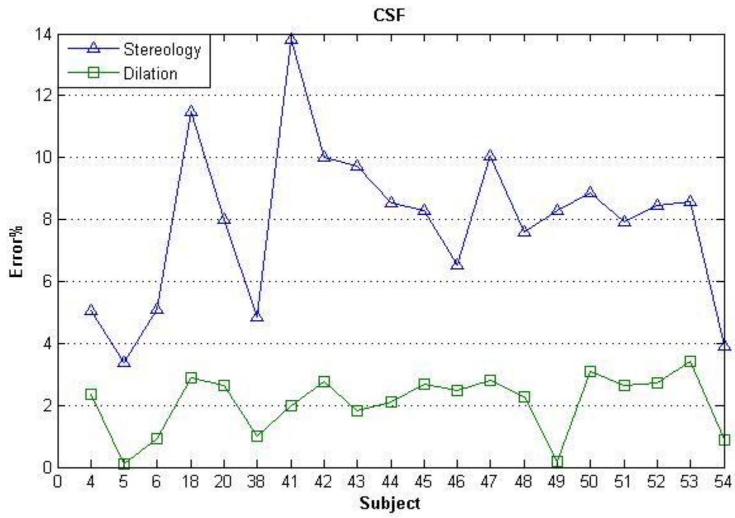


Figure 10: Percentage Error for CSF volume estimation in two methods: Stereology and Dilation for case III

and less resolution had less Root Mean Square Error (RMSE) compared to Stereology method. Thus, our proposed method calculated the volume more accurately than Stereology method, especially for larger amount parameters T and d.

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Conflict of Interest

None

References

1. Nair SSK, Revathy K, editors. Quantitative analysis of brain tissues from magnetic resonance images. Digital Image Processing, 2009 International Conference on; 2009: IEEE.
2. Geuze E, Vermetten E, Bremner JD. MR-based in vivo hippocampal volumetrics: 1. Review of methodologies currently employed. *Mol Psychiatry*. 2005;**10**:147-59. doi.org/10.1038/sj.mp.4001580. PubMed PMID: 15340353.
3. Hahn HK, Jolly B, Lee M, Krastel D, Rexilius J, Drexl J, et al., editors. How accurate is brain volumetry? International Conference on Medical Image Computing and Computer-Assisted Intervention; 2004: Springer.
4. Giorgio A, De Stefano N. Clinical use of brain volumetry. *Journal of Magnetic Resonance Imaging*. 2013;**37**:1-14. doi.org/10.1002/jmri.23671.
5. Karsch K, Grinstead B, He Q, Duan Y. Web based brain volume calculation for magnetic resonance images. *Conf Proc IEEE Eng Med Biol Soc*. 2008;2008:1210-3. doi.org/10.1109/iembs.2008.4649380. PubMed PMID: 19162883.
6. Galinsky VL, Frank LR. Automated segmentation and shape characterization of volumetric data. *Neuroimage*. 2014;**92**:156-68. doi.org/10.1016/j.neuroimage.2014.01.053. PubMed PMID: 24521852. PubMed PMCID: 4324567.
7. Scarpazza C, Tognin S, Frisciata S, Sartori G, Mechelli A. False positive rates in Voxel-based Morphometry studies of the human brain: should we be worried? *Neurosci Biobehav Rev*. 2015;**52**:49-55. doi.org/10.1016/j.neubiorev.2015.02.008. PubMed PMID: 25701614.
8. Mills KL, Tamnes CK. Methods and considerations for longitudinal structural brain imaging analysis across development. *Dev Cogn Neurosci*. 2014;**9**:172-90. doi.org/10.1016/j.dcn.2014.04.004. PubMed PMID: 24879112.
9. Keller SS, Roberts N. Measurement of brain volume using MRI: software, techniques, choices and prerequisites. *J Anthropol Sci*. 2009;**87**:127-51. PubMed PMID: 19663172.
10. Steen RG, Hamer RM, Lieberman JA. Measuring brain volume by MR imaging: impact of measurement precision and natural variation on sample size requirements. *AJNR Am J Neuroradiol*.

2007;28:1119-25. doi.org/10.3174/ajnr.A0537. PubMed PMID: 17569971.

11. Keihaninejad S, Heckemann RA, Fagiolo G, Symms MR, Hajnal JV, Hammers A. A robust method to estimate the intracranial volume across MRI field strengths (1.5T and 3T). *Neuroimage*. 2010;**50**:1427-37. doi.org/10.1016/j.neuroimage.2010.01.064. PubMed PMID: 20114082. PubMed PMCID: 2883144.
12. Ertekin T, Acer N, Icer S, Yildirim A. Estimation Of the Total Brain Volume Using Semi-Automatic Segmentation and Stereology of the Newborns' Brain MRI. *NeuroQuantology*. 2013;**11**(2). doi.org/10.14704/nq.2013.11.2.631.
13. Wang D, Doddrell DM. MR image-based measurement of rates of change in volumes of brain structures. Part I: method and validation. *Magnetic resonance imaging*. 2002;**20**:27-40. doi.org/10.1016/S0730-725X(02)00466-6.
14. Acer N, Turgut AT, Turgut M, Özsunar Y. Quantification of volumetric changes of brain in neurodegenerative diseases using magnetic resonance imaging and stereology: INTECH Open Access Publisher; 2011.
15. Acer N, Ilica AT, Turgut AT, Ozcelik O, Yildirim B, Turgut M. Comparison of three methods for the estimation of pineal gland volume using magnetic resonance imaging. *ScientificWorldJournal*. 2012;2012:123412. doi.org/10.1100/2012/123412. PubMed PMID: 22619577. PubMed PMCID: 3349090.
16. Tang Y, Whitman GT, Lopez I, Baloh RW. Brain volume changes on longitudinal magnetic resonance imaging in normal older people. *J Neuroimaging*. 2001;**11**:393-400. doi.org/10.1111/j.1552-6569.2001.tb00068.x. PubMed PMID: 11677879.
17. Furlong C, Garcia-Finana M, Puddephat M, Anderson A, Fabricius K, Eriksen N, et al. Application of stereological methods to estimate post-mortem brain surface area using 3T MRI. *Magn Reson Imaging*. 2013;**31**:456-65. doi.org/10.1016/j.mri.2012.09.001. PubMed PMID: 23238418.
18. Mayhew TM, Olsen DR. Magnetic resonance imaging (MRI) and model-free estimates of brain volume determined using the Cavalieri principle. *J Anat*. 1991;**178**:133-44. PubMed PMID: 1810922. PubMed PMCID: 1260542.
19. Sonmez OF, Odaci E, Bas O, Colakoglu S, Sahin B, Bilgic S, et al. A stereological study of MRI and the Cavalieri principle combined for diagnosis and monitoring of brain tumor volume. *J Clin Neurosci*. 2010;**17**:1499-502. doi.org/10.1016/j.jocn.2010.03.044. PubMed PMID: 20801042.
20. Collins DL, Zijdenbos AP, Kollokian V, Sled JG, Kabani NJ, Holmes CJ, et al. Design and construction of a realistic digital brain phantom. *IEEE Trans Med Imaging*. 1998;**17**:463-8. doi.org/10.1109/42.712135. PubMed PMID: 9735909.
21. Thapaliya K, Kwon G-R, editors. Extraction of brain tumor based on morphological operations. Computing Technology and Information Management (ICCM), 2012 8th International Conference on; 2012: IEEE.