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Comparison the Accuracy of Fetal Brain Extraction from T2-Half-Fourier Acquisition Single-Shot Turbo Spin-Echo (HASTE) MR Image with T2-True Fast Imaging with Steady State Free Precession (TRUFI) MR Image by Level Set Algorithm

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Abstract

Background

Access to appropriate images of fetal brain can greatly assist to diagnose of probable abnormalities. The aim of this study was to compare the suitability of T2-True Fast Imaging with Steady State Free Precession (T2-TRUFI), and T2-Half-Fourier Acquisition Single-Shot Turbo Spin-Echo (T2-HASTE) magnetic resonance imaging (MRI) to extract the fetal brain using the level set algorithm.

Materials and Method: T2-TRUFI and T2-HASTE MRI of the uterus were performed. The fetal brain was cropped from the image manually, with an adequate margin of maternal tissues; and then the fetal brain was extracted using level set. The outcome was statistically analyzed to compare its success, error (Sensitivity and Specificity), and similarities (Dice and Jaccard), with those of images obtained by radiologist.

Results: The mean values of statistical tests to evaluate the similarity (Dice and Jaccard) and the success and error (Sensitivity and specificity) between two T2-TRUFI and T2-HASTE were calculated as 97.35%, 94.98%, 95.88%, 95.88%, 99.45%, 91.10%,83.82%, 86.44% and 99.11%, respectively. However, the results from two images showed high scores to extract the fetal brain, but images from the T2-HASTE technique resulted in better visually output.

Conclusion

Based on our results, the T2-HASTE MR images are preferred to fetal brain extraction by level set algorithm compared to the T2-TRUFI MR images.

Key Words: Level set algorithm, Fetal brain extraction, MR images, Sensitivity, Specificity.

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1- INTRODUCTION

Various methods including ultrasonography, maternal serum screening, amniocentesis and fetal sampling are applied to evaluate the fetal growth and development. Due to the potential risk of radiation-induced cancers, Fetography (radiography of the fetus in uteri), has avoided and has completely replaced by ultrasonography (1). Although, ultrasonography is the preferred method for fetal imaging and monitoring, the magnetic resonance imaging (MRI), is also recommended in the case of primarily detection of abnormalities by ultrasonography (2). The magnetic resonance (MR) image with the high contrast and resolution, especially for soft tissues, has improved the quality and accuracy of fetal brain study (3).

The first step to study the fetal brain is to extract the brain from the entire fetal image. The presence of maternal abdominal tissues surrounded to the fetal brain prevents application of adult brain extraction methods for the fetal images. Moreover, MR signals of fetal brain differ from signals of adult brain due to the incomplete cerebellar myelinations of the fetus (4, 5). Additionally, fetal movement in the amniotic sac causes motion artifact which can be reduced by fast MRI Protocols. However, this method decreases the spatial resolution or signal-to-noise ratio (SNR), of images, and may be caused a higher probability of partial volume artifact (6). The modern fetal MRI protocols require no sedatives to control fetal movement.

It is well known that the spin echo technique is more likely to have true T2 image and higher image quality compared to the gradient echo technique; in which could be considered as the gold standard to produce MR image (7). The T2-HASTE MRI protocol results a heavily T2-weighted image at a short time. The gradient echo pulse sequence cannot secure true T2 weighted image. Image property of true fast imaging with steady state (TRUFI), pulse sequence is much higher than those of a standard gradient echo pulse sequences. Different methods have been investigated to extract the fetal brain from the MR images, include atlas segmentation, high-order Markov fields, regional growth, topological models, etc. (4-6, 8-19). The ability of level set algorithm to extract fetal brain from T2-TRUFI and T2-HASTE MR images was investigated in this study. The active contours have potential to continuously extraction of tissue’s boundaries. The resultant approach could be used to process of cortex and reach to some valuable data such as sulci development and consequently fetal brain development during gestation.

Moreover, transformation and topological changes of active contour models facilitate the fetal brain extraction. Inhomogeneity correction of intensity and noise reduction could be done by segmentation in active contour models to access the more accuracy. Its ability to extend from two dimensions (2-D), to three dimensions (3-D), view is an added advantage when is required (20-22). The aim of this study was to compare the efficiency of MR images taken by T2-TRUFI and T2-HASTE MRI protocols for extracting the fetal brain using the level set algorithm.

2- MATERIALS AND METHODS

2-1. MR Imaging Technique

In this study a patient was examined with a 1.5 T scanner (Siemens-Avanto), on which three plane T1-weighted localizer sequence was obtained, followed to the two sagittal T2-weighted sequences (T2-HASTE and T2-TRUFI). The parameters of T2-HASTE were set as: time repetition (TR) = 1350 msec, time of echo (TE) = 92 msec, slice thickness = 6 mm, matrix size = 256 × 256, spacing between slices = 7.8 mm, echo train length (ETL) = 256, specific absorption rate (SAR) = 2.24. The parameters of T2-TRUFI were set as: repetition time (TR) = 4.4000, time of echo (TE) = 2.2000, slice thickness = 6 mm, matrix size = 208 × 256, spacing between slice = 7.8 mm, Echo train length (ETL) = 1, SAR = 1.8185. The orientation of fetal brain was in coronal plane. Eight slice of fetal brain from these two protocols were analyzed.

2-2. Fetal Brain Extraction

Following to obtain two sagittal T2-weighted sequence from patient, the fetal brain was cropped manually; associated with some maternal tissues due to decrease the number of background pixels and consequently to reduce the computation time. The recommended model by Li et al. (2011), was used to extract the fetal brain from MR images (23). In this model a different level-set formulation (Region based), was suggested in which minimizing of energy and estimating of intensity inhomogeneity were simultaneously corrected during segmentation process. The central point of fetal brain was considered to initialize level-set segmentation and then the resulted segmentation was implemented to extract the fetal brain.

One reference could not be used to compare the extracted fetal brain images between these two protocols (section 2.1), due to fetal movement. Hence, an independent reference was made for each image by Radiologist. Finally, each of these segmented images by radiologist was compared with level-set segmented images.

2-3. Implementation

The framework is implemented in a matrix laboratory (MATLAB), version R2016a (24), and windows 10 (64-bit Operating System), random access memory (RAM) = 4GB, Intel (R) Core (TM) i5-6300U, Central Processing Unit (CPU) @ 2.4GHz 2.5 GHz.

2-4. Data Analysis

2-4-1. Visual evaluation the accuracy of extracted fetal brain

To extract the fetal brain, the T2-HASTE and T2-TRUFI MR processed images by level set algorithm, were separately superimposed with those diagnosed by Radiologist. Consequently, three levels were considered to evaluate the consequences, visually: the white color pixels (correctly matched), the pink color pixels (incorrectly region extracted by level set), and the green color pixels (inability of level set to extract correctly).

2-4-2. Similarity indexes

In order to quantitatively evaluate the data, two similarity metrics were used: Dice coefficient (equation (Eq.) 1) (25), and Jaccard coefficient (Eq.2) (26). Using these metrics, the spatial overlap between two binary images could be found in which their values range between 0 (no match) and 1 (perfect match), as defined by the following equations:

$$D(T.S) = \frac{2|T \cap S|}{(|T| + |S|)} = \frac{2|TP|}{2|TP| + |FN| + |TN|} \quad (1)$$

$$J(T.S) = \frac{|T \cap S|}{|T \cup S|} = \frac{|TP|}{|TP| + |FP| + |FN|} \quad (2)$$

Where TP is true positive, FN is false negative, TN is true negative, and FP is false positive. The greater similarity index means more similarity between the extracted fetal brain and the reference image; hence, the overlapping level of these two binary images is higher. For example, Dice >0.7 is commonly acceptable level to successfully segmentation.

2-4-3. Success and Error rate

The ability to correctly identify appropriate tissue in the segmented mask as sensitivity (true positive fraction [TPF]), was calculated by Eq. 3. The ability of the proposed segmentation method to correctly remove non-desired pixels as specificity (true negative fraction [TNF]) was calculated by Eq.4 (27).

$$TPF = \frac{TP}{TP+FN} \quad (3)$$

$$TNF = \frac{TN}{TN+FP} \quad (4)$$

Sensitivity is defined as ratio of positive cases (overlapped pixels in binary images), in which correctly detected by algorithm. Specificity is defined as the ratio of negative cases (pixels did not diagnosed in the processed binary image by algorithm compared to the reference image). Sensitivity and specificity levels were used to determine the efficiency of our developed algorithm to correctly distinguish of overlapped and non-overlapped pixels. A level of 0 and 1 means none-success and completely-success to extract the fetal brain, respectively.

3- RESULTS

A set of segmented fetal brain images (one sample) include the manually segmentation (original image), corrected for intensity inhomogeneity (IIC), binary extracted image with level set and binary extracted image with radiologist from T2-HASTE and T2-TRUFI MR images are shown in **Figure.1**. The results indicate that the T2-HASTE MR image has more homogeneous intensity than the T2-TRUFI MR image for fetal brain extraction with level set algorithm.

As can be seen from **Figure.2**, using the MR images from the T2-HASTE protocol result in better agreement (white color), than the MR images from the T2-TURFI protocol to extract of fetal brain, followed to superposition of diagnosed region by radiologist with those extracted by level set algorithm. The quantitative results (Average score% ± standard deviation) for the segmented fetal brain images of T2-HASTE and T2-TRUFI protocols, were collected in **Table.1**. The estimated scores for the MR images produced by the T2-HASTE protocol were always higher than those from the T2-TURFI protocol.

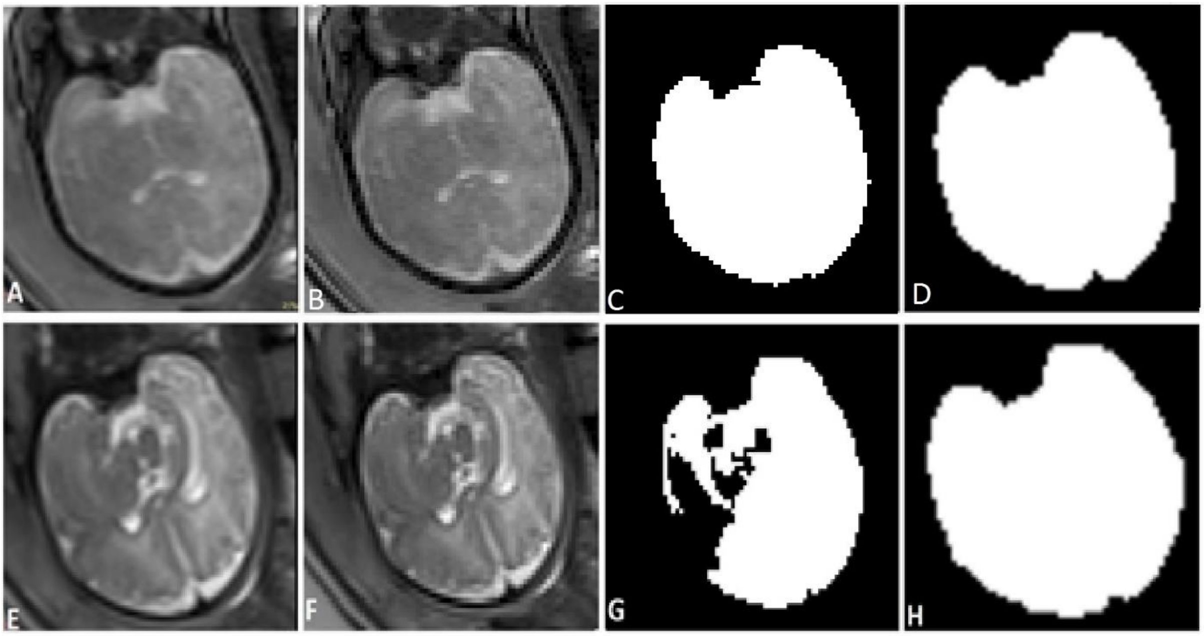

Fig.1: Illustration of T2-HASTE protocol: A) Manual segmented fetal brain (original image), B) IIC image, C) Brain extracted with level-set and D) Brain extracted with Radiologist; Illustration of T2-TRUFI protocol E) Manual segmented fetal brain (original image), F) IIC image, G) Brain extracted with level-set, H) Brain extracted with radiologist.

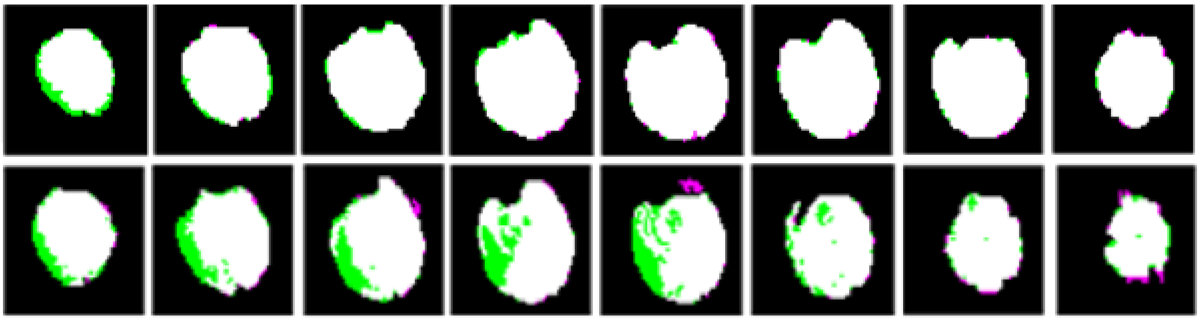

Fig.2: The brain extraction after superimposed manual segmentation with level set segmentation; **Upper row:** The T2-HASTE protocol; **Inferior row**: The T2-TRUFI protocol. Differences between Manual and level set segmentation showed: manually segmented (green), level set segmented (pink), and overlapped of manually and level set segmentations (white).

Table-1: Average score% ± standard deviation of the mean of different tests for the segmented images of T2-HASTE and T2-TRUFI protocols.

Variables	Dice (%) ± STD	Jaccard (%) ± SD	Sensitivity(%) ± SD	Specificity(%) ± SD
HASTE	97.35%±2.61	94.98%±4.65	95.88%±5.16	99.45%±0.35
TRUFI	91.10%±3.46	83.82%±5.88	86.44%±6.63	99.11%±0.47

SD: Standard deviation.

4- DISCUSSION

In this study fetal brain extracted from MR images (from the T2-HASTE and T2-TRUFI protocols), with level set algorithm. As can be found from Table.1, the similarity indexes (Dice and Jaccard), Success and Error rate (Sensitivity and Specificity), demonstrate that this algorithm successfully segment the fetal brain images from T2-Haste protocol (Table.1 and Figures 1 and 2). However, segmentation based on the T2-TRUFI protocol result acceptable statistical values (Table.1), but its visual inspection (Figure.1-G and Figure.2-inferior row), was not shown a good result. The probable reason for this fail may be caused by inability of algorithm to correct the intensity inhomogeneity of MR images. In clinical applications, respect to the diagnostic advantages of T2-TRUFI MR images (28), using of an added intensity inhomogeneity correction method is recommended before implementing of level set algorithm to extract fetal brain from T2-TRUFI MR images. To the best of our knowledge from literatures, our results to extract the fetal brain from MR images are in a good agreement with the reported data or even better than them. Ison et al. (2012), extracted fetal brain (in coronal direction) with a sensitivity and specificity of 88% and 85%, respectively (14). Taleb et al. (2013), extracted fetal brain and report the success level of 82% (correctly estimated by the mask); the failure label represented the whole brain was greater or smaller than mask and didn’t cover it completely (16).

Tourbier et al. (2015), extracted the fetal brain using the Multi-Atlas Fusion (MAF) strategy (18) that resulted in better extraction (improvement of 3.5%) with Dice index of 93% compared to extraction by Machine Leaning (ML) strategy with Dice index of 90%, reported by Kaniz et al. (2014) (17). Our data with Dice index of 97% on the T2-HASTE MR images improved extraction 3.5% and 6% compared to the data reported by Tourbier et al. (2015) (18), and Kaniz et al. (2014) (17), respectively. Our methodology based to the level set algorithm seems to be a successful manner to extraction fetal brain from MR images of a pregnant patient, produced by the T2-HASTE protocol.

5- CONCLUSION

Based on the results of this study, the level set algorithm could be used to accurately extract of fetal brain from MR images; the T2-HASTE MR images are preferred to fetal brain extraction by level set algorithm compared to the T2-TRUFI MR images.

6- CONFLICT OF INTEREST: None.

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