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Segmentation of MR-guided, high intensity, focused ultrasound treated lesions based on diffusion-weighted imaging and interactive information

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Abstract. As the gold standard of traditional ablation treatment area, DCE-MRI has the disadvantages of slow imaging speed and only single examination during surgery. DWI is gradually being adopted as a new alternative. Considering the complex lesion status of uterine fibroids DWI, the interaction-based image segmentation method has a wider range of applications. Our proposed segmentation algorithm can be applied to a variety of cases and achieves a good segmentation Dice of 0.85.

Keywords: MRgFUS; DWI; Interactive image segmentation; Threshold method.

1. Introduction

Magnetic resonance-guided high-intensity focused ultrasound (MRgFUS) has great advantages in the treatment of uterine fibroids [1]. The traditional dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) [2] postoperative evaluation method has a long imaging time, which is difficult to meet the needs of intraoperative examination of the ablation treatment field. Moreover, the contrast media used in DCE-MRI is toxic and cannot be used in patients with decreased renal function, and multiple injections in a short period of time may cause kidney and pancreatic diseases [3,4].

Diffusion-weighted imaging (DWI) is an emerging non-contrast-enhanced MRI imaging technology, which is the only non-invasive method that can detect the diffusion movement of water molecules in living tissue [5]. Under the action of the same gradient magnetic field, the attenuation of DWI signal intensity is related to the diffusion freedom of water molecules in the tissue, blood perfusion, and other physiological movements of water molecules in the direction of the diffusion-sensitive gradient magnetic field. The MRgFUS treatment domain shows uneven signal intensity enhancement on DWI. With the gradual increase of the diffusion sensitive gradient field parameters, the signal intensity also increases gradually [6]. The morphological consistency between the DWI signal-enhanced area and the non-perfused area of DCE has been confirmed by multiple studies [7].

In order to quickly calculate the non-perfusion volume of uterine fibroids during MRGFUS, manual segmentation is time-consuming, which is difficult to meet the real-time requirements in the operation process. To solve the problem of intraoperative real-time monitoring in the treatment of uterine fibroids with MRgFUS, a DWI image segmentation method based on two-stage dynamic interactive threshold method was proposed.

2. Method

2.1 Data sets and Data preprocessing

In this study, 4 adenomyoma patients treated with MRgFUS in Shanghai First People's Hospital from January 2020 to December 2021 were selected as the research objects. MRI was performed with GE Discovery MR750 3.0T system, including axial DWI and axial dynamic contrast-enhanced

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T1WI scan sequences. The B value for DWI application is 800 s/mm2. ITK-snap 3.4 was used to mark the treated area of uterine ablation on each slice of enhanced T1WI according to the imaging features, which was used as the gold standard for DWI segmentation.

The collected magnetic resonance data was read, and the pixel value range was (-4000,4000). The DWI image was converted from DICOM format to PNG format with pixel value range of (0,255) by normalization algorithm. Scale parameter SDWI was used as the normalization scale parameter. Take the value SDWI=500 to obtain a PNG image in which both the abdominal structure and the treatment area are clearly visible.

$$image=(image-min\_pixel)/SDWI \quad (1)$$

2.2 Two-stage interactive segmentation

The treatment domain of MRgFUS of uterine fibroids shows complete/incomplete hyperintensity rings or heterogeneous hyperintensity areas on DWI. The effusion filled uterine cavity, which also exhibits high-signal on DWI, interferes with the segmentation of the adjacent uterine fibroid treatment domain. The background of transverse abdomen DWI contains other organs that exhibit high signal, such as the rectum.

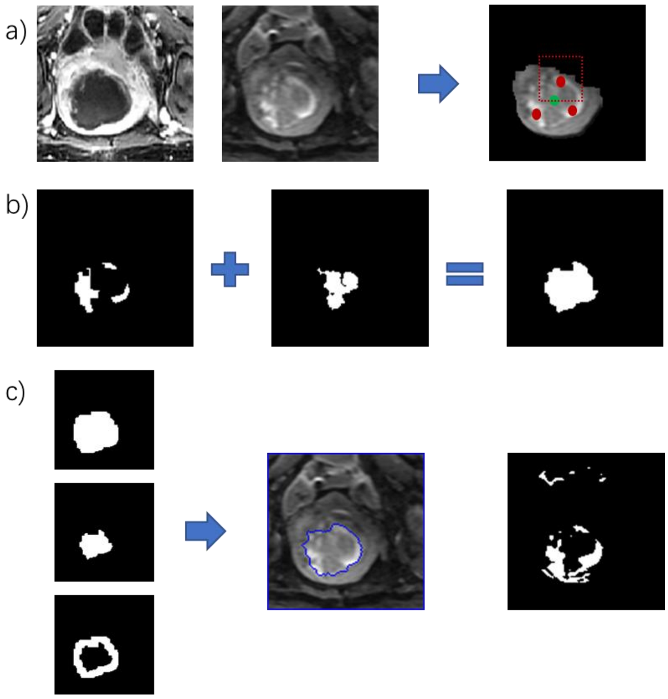

Figure 1. Representative examples of axial DCE and DWI segmentation. (a) Extract the uterine domain. The 32×32 image patch centered on the red interaction points was thresholded. Using the region growing algorithm with green interaction points as seed points. (b) The high signal area and low signal area are segmented based on the interaction points and superimposed. (c) The watershed algorithm optimizes the segmentation edge. Compared with the single threshold method, the integrity and accuracy of the segmentation results are significantly improved.

In the first stage, we use average pixel as the threshold to pre-segment the uterine region. In the second stage, the threshold method and region growth algorithm are used to segment the high signal area and central low signal area based on interaction points, which are introduced to avoid the influence of signal intensity differences in the treatment domain of the same uterine fibroid. These differences are caused by uneven degrees of vasogenic edema undergoing MRgFUS [8]. After collecting the above subregions, the hole noise is filled by the closed operation of morphology. The foreground and background are extracted by expansion and corrosion operations. The watershed algorithm is used for the coincident domains of foreground and background, thereby optimizing the edge segmentation effect.

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3. Results

Through clinical trials, we have demonstrated a variety of lesion states after MRGFUS treatment of uterine fibroids, including complete/incomplete hyperintensity rings, heterogeneous hyperintensity areas, and tissues near the region of interest that are easily confused by general algorithms. Compared with the Eigenimage filter segmentation method of DWI uterine fibroids treatment domain [9], we developed a segmentation algorithm suitable for more complex types of uterine fibroids.

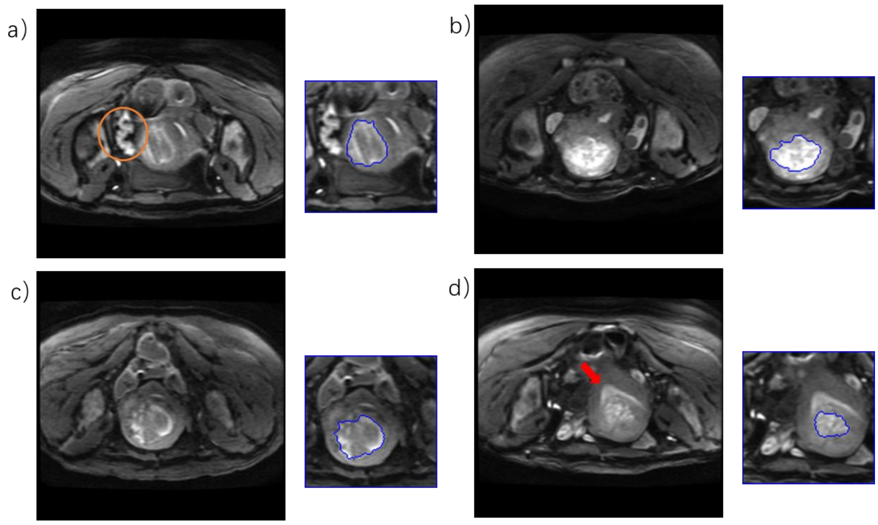

Figure 2. Segmentation results for different types of uterine fibroids. (a) There is a markedly high signal rectum on the left side of the uterus. (b) High signal area. (c) Incomplete high signal ring. (d) There is a uterine cavity containing fluid nearby, marked by a red arrow.

The similarity index of therapeutic region defined by DCE and DWI was evaluated by the Dice index and IOU index. There is a good agreement with the mean Dice index of 0.85. Through the introduction of interaction points, the segmentation accuracy of incomplete high signal ring significantly increased, even higher than the complete high signal ring examples with blurry edge. Interactive information acting on the boundary helps the therapeutic region and the adjacent uterine cavity to be completely separated.

Table 1. Three Scheme comparing.

Type	Hyperintensity area	Complete ring	Incomplete ring	Close to uterine cavity
Volume(cm3)	39.68	31.55	90.05	29.75
Dice	0.8616	0.8385	0.8543	0.8561
IOU	0.7593	0.7282	0.7461	0.7512

4. Conclusion

Based on the purpose of using DWI to calculate the non-perfusion area and monitor the ablation area in real time, we designed a two-stage interactive segmentation algorithm suitable for various types of uterine fibroids, which can assist doctors to adjust the treatment plan according to the ablation effect, avoid secondary treatment, and thus reduce the treatment burden of uterine fibroids patients.

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