Automated Analysis of Breast Tumour in the Breast DCE-MR Images Using Level Set Method and Selective Enhancement of Invasive Regions

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Abstract. Analysis of invasive regions using breast magnetic resonance (MR) images plays an important role in diagnosis and decision-making regarding the treatment method. However, many images are obtained by MR imaging (MRI); development of an automated analysis method for breast tumours is desired. The main purpose of this study was to develop a novel method for automated analysis of the tumour region in breast MR images. First, early and late-subtraction images were obtained by subtracting early- and late-contrast-enhanced MR images, respectively, from the pre-contrast ones. Then, tumours in the images were enhanced based on the signal values of the normal mammary regions. Subsequently, using the level set method, a type of dynamic contour extraction, the outline of the tumour in the tumour-enhanced images was obtained. In order to evaluate the usefulness of the analysis method, we compared the tumour size listed in the interpretation report by a physician and analyzed the results obtained from the proposed method using clinical images from 10 cases. The mean absolute error of the size of tumours in all cases was less than 3.0 mm. These results indicate that the proposed method may be useful for the automated analysis of invasive breast tumours using breast MR images.

Keywords: Breast tumour · Analysis · Magnetic resonance imaging · Level set

1 Introduction

Breast cancer is the most common cancer among women worldwide, with approximately 1.7 million new cases diagnosed in 2012 [1]. This is about 12 % of all new cancer cases and 25 % of all cancers in women. There are two main types of surgery for treating breast cancer – mastectomy and breast-conserving surgery. In the latter, only the part of the breast containing the cancer is removed. It has been adapted widely from the point of view of quality of life of patients with breast cancer.

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Currently, various modalities are used as diagnosis methods for breast cancer. These include mammography, breast ultrasound, and breast magnetic resonance imaging (MRI). Mammography and breast ultrasound are mainly used for screening, localization of tumour, and evaluation of malignancy. Breast MRI is often used to decide the appropriate form of surgery, and accurate analysis of the invasive region of tumours using breast MR images has become important in the diagnosis [2–4]. In this study, we focus on tumour analysis using breast MRI.

In breast MRI examinations, dynamic scans using contrast material are commonly used. Physicians identify the range of tumour by focusing on the time intensity curve obtained from multi-phase T1 weighted images. However, the burden of analysis with large amount of images should be released. Regarding the analysis of breast tumour, many automated analysis methods using time intensity curves have been developed for breast MR images [5–7].

Here, the increased pattern of signal value in the malignant region is not consistent. Furthermore, an increase in signal is also observed in normal tissue. Therefore, accurate identification of the range of tumour is often difficult; a method using the signal value of normal tissue is desirable.

In this study, we describe a novel automated analysis of the tumour region using the level-set method and selective enhancement of invasive regions in the dynamic contrast-enhanced breast MR images.

2 Materials and Methods

2.1 Materials

We collected breast MR images of 10 cases. They include T1-weighted MR images of precontrast, early-contrast (45 s after injection), and post-contrast (315 s after injection) enhanced breast MR images. These images were acquired using a 3-T unit (Signa HDXT 3.0T; GE Healthcare) at the East Nagoya Imaging Diagnosis Center (Nagoya, Japan). Fields of view ranged from 320–360 $\times$ 320–360 $\times$ 190 mm^3, and voxel size ranged from 0.625 $\times$ 0.625 $\times$ 1.8–0.703 $\times$ 0.703 $\times$ 1.8 mm^3. In all cases, the bounding boxes of invasive regions were determined by a physician. This study was approved by our institutional review board and patient agreement was based on the assumption that all data were anonymized.

2.2 Automated Analysis of Breast Tumours

The outline of the automated analysis is shown in Fig. 1. Proposed method consists of image alignment, subtraction, tumour enhancement, and tumour segmentation. Through these processing, the bounding box, which has x, y, and z coordinates, are obtained.

(1) Position alignment
During the dynamic scan in the breast MRI examination, position miss-alignment often occurs. Since this causes an error of automated analysis of invasive regions,

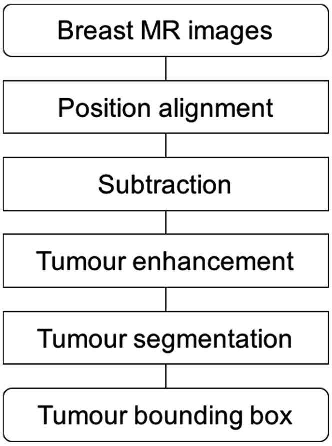

Fig. 1. Flow-chart of the analysis method

image alignment was conducted as pre-processing. We first defined the two kinds of images as $S(x, y, z)$ and $T(x, y, z)$, respectively. We then simply moved the $T(x, y, z)$ over each (x, y, z) point in the $S(x, y, z)$, and calculated the mean absolute error between $S(x, y, z)$ and the moved $T(x, y, z)$. Among all possible positions of $T(x, y, z)$, the position with the lowest error was determined as the best position.

(2) Subtraction
Thereafter, early- and late-subtraction images were obtained by subtracting early- and late-contrast–enhanced images, respectively, from the pre-contrast ones. Figure 2 shows the example of subtraction images.

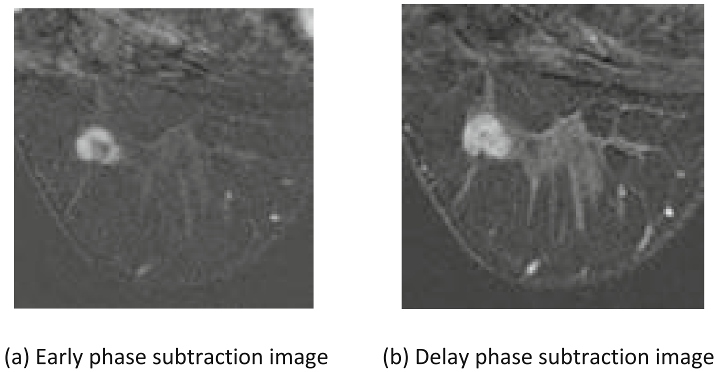

Fig. 2. Subtraction images

(3) Tumour enhancement
In the late-phase T1-weighted image, the signal value of the normal mammary gland was increased as well as that of the tumours. Therefore, regions in the late-subtraction images with a pixel value below a predetermined threshold were

excluded in order to eliminate the influence of the normal mammary glands. Higher pixel values were then output by comparing the pixel values of the early- and late-subtraction images. In this way, the exact region of tumour invasion was obtained.

(4) Tumour segmentation
Outline of the tumour in the tumour-enhanced image was obtained using the level set method, which is a type of dynamic contour extraction technique [8]. In this study, we introduced ITK SNAP for the processing of the level set method [9]. Finally, the bounding box of the tumour was calculated using the contour-extracted images; this was considered as the result of the automated analysis of tumour invasion.

3 Results

In order to evaluate the usefulness of the analysis method, we applied it to breast MR images from 10 cases. We compared the tumour size listed in the interpretation report by a physician and analyzed the results obtained from the proposed method.

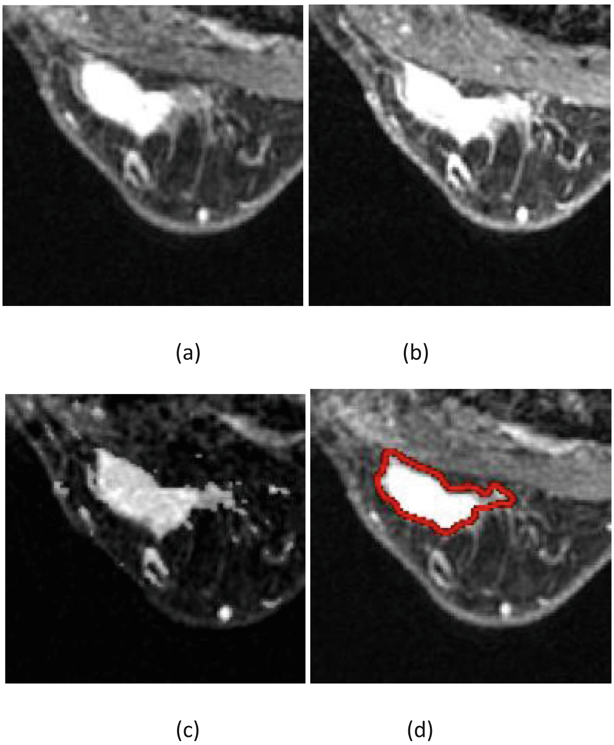

Fig. 3. Tumour segmentation result (Case 4). (a) Early contrasted enhanced image, (b) Delayed contrast enhanced image, (c) Tumour enhanced image, (d) Tumour segmented image (Red) (Color figure online)

Figures 3 and 4 show examples of tumour segmentation result where the tumour contour was traced correctly. The calculated tumour sizes for all cases are shown in Table 1. In eight out of 10 cases, measurement errors were less than 5 mm; the mean absolute error in the size of tumours was less than 3.0 mm.

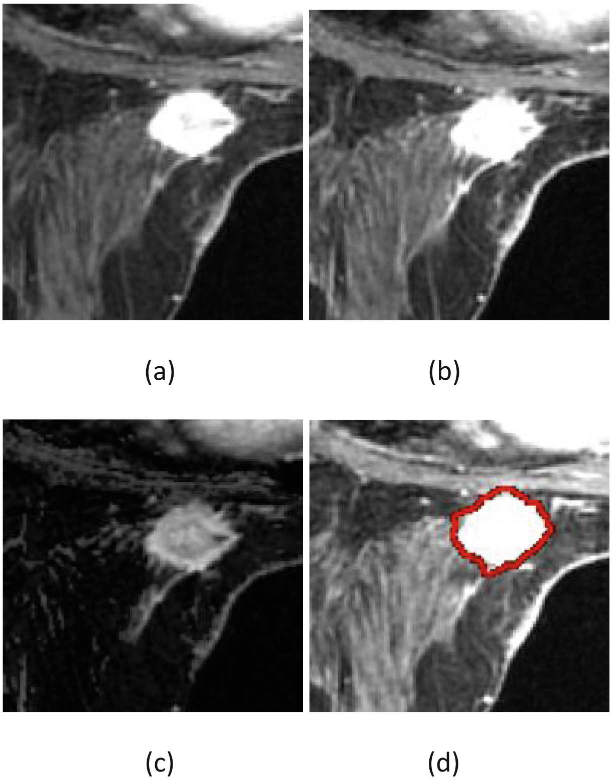

Fig. 4. Tumour segmentation result (Case 3). (a) Early contrasted enhanced image, (b) Delayed contrast enhanced image, (c) Tumour enhanced image, (d) Tumour segmented image (Red) (Color figure online)

4 Discussion

The mean absolute error of the measured size of invasive regions was less than 3.0 mm. However, there were two cases of overestimation (cases 2 and 9). In these cases, most of the normal mammary gland was recognized as a invasive region. Our method calculated the threshold based on the signal value on the normal mammary gland. However, the signal value on the normal mammary gland often fluctuates due to the influence of an abnormal lesion. Therefore, the threshold value was deviated from the appropriate value, resulting in the overestimation. We should improve the calculation method for the threshold from the normal mammary glands.

Table 1. Tumour measurement results

	X [mm]			Y [mm]			Z [mm]		
	Physician	Measured	Error	Physician	Measured	Error	Physician	Measured	Error
Case 1	11	10	−1	10	10	0	8	8	0
Case 2	10	16	+6	9	14	+5	7	10	+3
Case 3	20	18	−2	20	16	−4	15	15	0
Case 4	21	24	+3	17	16	−1	13	14	+1
Case 5	16	14	−2	13	14	+1	10	13	+3
Case 6	7	10	+3	6	7	+1	4	6	+2
Case 7	10	13	+3	10	10	0	9	9	0
Case 8	26	26	0	22	24	+2	21	21	0
Case 9	31	37	+6	21	29	+8	20	27	+7
Case 10	27	25	−2	18	22	+4	10	14	+4
MAE [mm]			2.8			2.6			2.0

MAE: mean absolute error

5 Conclusions

In this study, we proposed a novel method of automated analysis to quantify the tumour region using dynamic contrast-enhanced breast MR images. High accuracy was obtained in the evaluation using the clinical images. These results indicate that the proposed method may be useful for the automated analysis of invasive breast tumour using breast MR images.

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