Auto-Initialized Cascaded Level Set (AI-CALS) Segmentation of Bladder Lesions on Multidetector Row CT Urography

Lubomir Hadjiiski, PhD, Heang-Ping Chan, PhD, Elaine M. Caoili, MD, Richard H. Cohan, MD, Jun Wei, PhD, Chuan Zhou, PhD

Rationale and Objectives: To develop a computerized system for segmentation of bladder lesions on computed tomography urography (CTU) scans for detection and characterization of bladder cancer.

Materials and Methods: We have developed an auto-initialized cascaded level set method to perform bladder lesion segmentation. The segmentation performance was evaluated on a preliminary dataset including 28 CTU scans from 28 patients collected retrospectively with institutional review board approval. The bladders were partially filled with intravenous contrast material. The lesions were located fully or partially within the contrast-enhanced area or in the non–contrast-enhanced area of the bladder. An experienced abdominal radiologist marked 28 lesions (14 malignant and 14 benign) with bounding boxes that served as input to the automated segmentation system and assigned a difficulty rating on a scale of 1 to 5 (5 = most subtle) to each lesion. The contours from automated segmentation were compared to three-dimensional contours manually drawn by the radiologist. Three performance metric measures were used for comparison. In addition, the automated segmentation quality was assessed by an expert panel of two experienced radiologists, who provided quality ratings of the contours on a scale from 1 to 10 (10 = excellent).

Results: The average volume intersection ratio, the average absolute volume error, and the average distance measure were $67.2 \pm 16.9\%$, $27.3 \pm 26.9\%$, and 2.89 ± 1.69 mm, respectively. Of the 28 segmentations, 18 were given quality ratings of 8 or above. The average rating was 7.9 ± 1.5. The average quality ratings for lesions with difficulty ratings of 1, 2, 3, and 4 were 8.8 ± 0.9, 7.9 ± 1.8, 7.4 ± 0.9, and 6.6 ± 1.5, respectively.

Conclusion: Our preliminary study demonstrates the feasibility of using the three-dimensional level set method for segmenting bladder lesions in CTU scans.

Key Words: Bladder cancer; CT urography; level sets; 3D segmentation.

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INTRODUCTION

Bladder cancer is a common type of cancer that can cause substantial morbidity and mortality among both men and women. Bladder cancer causes 14,880 deaths per year in the United States (1). Early detection of bladder cancers is very important. The survival rate for patients whose cancers were detected and treated early is high (1). Early diagnosis and treatment of these lesions can improve the morbidity, mortality, and their attendant costs compared to diagnosis at a later stage when muscularis mucosa invasion and/or regional or distant metastases have developed. However, at the present time, only 75% of cancers are detected in the early localized stage.

Multidetector row computed tomography (MDCT) urography is a very promising new imaging modality for evaluation of patients with known or suspected urothelial neoplasms (2–5). It offers the distinct advantage of providing essentially complete imaging of the urinary tract and of the remainder of the abdomen and pelvis in a single study. With MDCT urography, it is expected that the need for other imaging studies (such as intravenous urography, ultrasonography, or magnetic resonance imaging) will be substantially reduced. Computed tomography urography (CTU), therefore, may spare the patient the considerable effort of undergoing a potentially large number of alternative imaging studies and also reduce health care costs.

Preliminary studies (6) have suggested that CTU may have superior sensitivity in detecting urinary tract lesions compared with all available alternative imaging studies. Recent research

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Department of Radiology, The University of Michigan, MIB C476, 1500 East Medical Center Drive, Ann Arbor, MI 48109-5842 (L.H., H.-P.C., E.M.C., R.H.C., J.W., C.Z.). Received May 10, 2012; accepted August 21, 2012. This work was supported by USPHS Grant R01CA134688. **Address correspondence to:** L.H. e-mail: lhadjisk@umich.edu

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has demonstrated that CTU can detect urothelial neoplasms that are very small (measuring as small as 2–3 mm in maximum diameter). It has also been reported that CTU can occasionally identify bladder lesions missed by cystoscopy, a procedure that has been traditionally considered to be the “gold-standard” for nonsurgical diagnosis of bladder abnormalities.

Despite these potential benefits, there are a number of technical difficulties related to CTU. Each CT scan for urinary tract produces, on average, about 300 slices at a slice interval of 1.25 mm with a range of 200 to 600 slices. Reformatted images (in the coronal with or without sagittal planes) must also be reviewed. As a result, interpretation of a CTU study demands extensive reading time from a radiologist who has to visually track the upper and lower urinary tracts and look for abnormal lesions usually small in size. The interpreting radiologists frequently need to adjust window settings and may use zooming on a display workstation to improve visualization. The possibility of multiple lesions demands that radiologists pay close attention throughout the urinary tract. In addition, reported results in the literature (7,8) show that substantial interobserver variability exists among radiologists in detection of bladder cancer on MDCT urography with reported sensitivity ranging from 59% to 92%.

With the increase in radiologists’ workloads, the chance for oversight of subtle lesions is not negligible. Computer-aided detection (CAD) might therefore play an important role in the reading of CTU. We are developing a CAD system for detection of bladder cancer in CTU.

Lesion segmentation is a crucial step in CAD systems for detection and characterization of bladder cancer. It also has potential applications in tracking changes of bladder lesion volume. Li et al (9) and Duan et al (10,11) analyzed the automatically segmented bladder wall for suspected lesions on magnetic resonance (MR) cystography. In a different study Duan et al (12) proposed an adaptive window-setting scheme for segmentation of bladder tumor surface on MR images. Hadjiiski et al (13) reported preliminary results for segmentation of bladder lesions on CTU scans using level sets. The segmentation of bladder lesions on CTU is challenging. Some lesions are located fully or partially within the contrast-enhanced area and some are located entirely in the non–contrast-enhanced area of the bladder. The boundaries between the lesions and the adjacent normal tissues have very low contrast. The bladder lesions often are small in size, subtle in contrast, and have irregular boundaries. The main goal of this study is to develop a computerized system for segmentation of different type of bladder lesions on CTU scans and to evaluate its segmentation accuracy in comparison with an experienced radiologist’s manual segmentation.

MATERIALS AND METHODS

With institutional review board approval, we retrospectively collected a preliminary dataset of CTU scans from patient files at the University of Michigan Health System. We developed a level set–based method and performed a pilot study for segmentation of lesions within the bladder. Figure 1 shows a CTU slice of a bladder. The bladder is partially filled with intravenous contrast material and a lesion is located in the non–contrast-enhanced area.

Level Set Segmentation

We have developed an auto-initialized cascaded level set (AI-CALS) method for bladder lesion segmentation. The system consists of three stages: preprocessing, initial segmentation, and three-dimensional (3D) level set segmentation. The system was an adaptation of our previously developed method for segmentation of head and neck lesions (14). A brief description of the AI-CALS method is presented here and the details can be found in a previous report (14).

Level set segmentation generally starts with an initial contour, which is then evolved iteratively to search for the true lesion boundary. A block diagram of the AI-CALS is shown in Figure 2. The first and second stages of AI-CALS were designed to automatically generate an initial 3D contour (14), which autoinitializes the 3D cascaded level set in the third stage. In the first stage, preprocessing techniques are applied to a predefined volume of interest (VOI) in the original 3D volume. The VOI can be marked by an automated lesion detection program or by a user, and approximately encloses the lesion to be segmented. In this study, the VOI was marked by an experienced abdominal radiologist. Smoothing, anisotropic diffusion, gradient filters, and the rank transform of the gradient magnitude are applied in 3D to the VOI and are used to obtain a set of smoothed images, a set of gradient magnitude images, and a set of gradient vector images for the slices within the VOI. The smoothed set is used in the second stage, whereas the latter two sets are used during level set propagation in the third stage.

In the second stage, the AI-CALS system automatically labels a subset of voxels in the VOI for analysis of lesion statistics based on the attenuation, gradient, and location of the voxels. First, the maximal ellipsoid W inscribed in the lesion VOI is defined. The ellipsoid is centered at the VOI and has axis lengths the same as the dimensions of the VOI box. Then, the lesion center is approximated by the ellipsoid $1/2W$ with radii one half of the inscribed ellipsoid W, forming a binary mask. Then the regions of high gradient are removed from $1/2W$ by removing all the voxels x for which the percentile value of $|\nabla I(x)|$ is in the top 50%. Finally, the voxels which have intensity in the smoothed image below -400 HU are also removed. Additional details can be found in a previous report (14). After these procedures, a subset S of voxels that belong to smooth (low gradient) areas and are relatively close to the center of the lesion is identified. S is then used as a statistical sample of the full population of voxels in the object of interest and the mean μ and standard deviation σ of the voxel values from the smoothed image within S are computed. The

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