Bladder Wall Extraction and Mapping for MR Cystography

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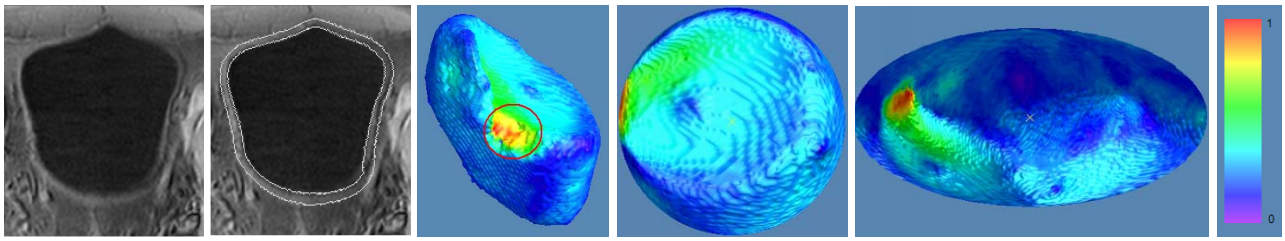
Introduction: Bladder carcinoma becomes the fifth leading cause of cancer-related deaths in the United States, primarily in older men with a 3:1 ratio of men to women, due to its rapid increase (as high as 36% within a decade) [1]. Over 68,500 cases of bladder carcinoma and more than 14,000 deaths were reported in 2008 [2]. Management of bladder tumor is difficult because of its high recurrence rate (as high as 80%) after resection [1]. Therefore it is crucial to detect bladder abnormalities by a non-invasive and convenience manner, especially for follow-ups of resection. A common test for bladder tumor is urine dipsticks of measuring the peroxidase activity of hemoglobin. It is sensitive but has a low specificity (approximately 70%). Computed tomography has been explored to detect bladder abnormal growths [3], where the urine has to be either tagged by intravenous injection or empted with replacement of air through a catheter. The invasive nature deems to be impractical in addition to the associated X-ray radiation. Because of the significant difference in T_1 and T_2 relaxations between urine and bladder wall, magnetic resonance imaging (MRI) has the potential to provide a non-invasive means for evaluation of the entire bladder [4]. This paper presents a novel approach to bladder wall extraction and mapping for MRI-based virtual cystocopy or MR cystography.

Methods: In order to minimize the partial volume effect (PVE) on the interface between the urine and bladder wall, T_1 weighted images were acquired as the primary information for the detection purpose, where the signal of urine is suppressed and the PVE goes from the wall into the lumen and has less impact on the wall as compared to T_2 weighted images, where the signal of urine is enhanced and the PVE goes from the lumen into the wall and would bury small pathological changes on the mucosa. T_1 scans were performed approximately 30 minutes after the patient voiding the bladder and taking a cup of water by the use of a Philips 3T Edge whole-body scanner with body coil as the transceiver. Scanning parameters included 3DFFE-SPIR CLEAR sequence, 1.5mm slice thickness, 10^o flip angle, 448*x*448 image size with T_R =4.6666ms and T_E =2.2766ms. The T_1 volume image was first interpolated for 1mm cubic voxel array, and then segmented by a minimization algorithm which utilizes two level-set functions to describe the inner and outer borders of the bladder wall, respectively, and a statistical cost function to describe the region between the borders. Picture (b) in the figure shows an example of the segmented inner and outer borders from T_1 weighted image (a). Taking the inner and outer borders as two iso-potential three-dimensional (3D) surfaces, the thickness of the bladder wall at any position on the inner border was determined without any ambiguity by calculating the length of the electric field line between the surfaces. Picture (c) shows the extracted bladder wall volume, where the colors reflect the normalized thickness distribution. For visualization purpose, the inner border was mapped into a sphere (d) and further flattened into an ellipse or earth-map (e) by conformal mapping method [5].



(a) (b) (c) (d) (e)

Results: The presented bladder-wall extraction strategy was tested on nine patient scans with comparison to the well-known Chan-Vese (C-V) method of extracting borders [6]. The extracted inner and outer borders (i.e., picture (b)) of the two methods were blindly scored by five experts. Statistical analysis on the scores showed that the presented strategy significantly outperformed ($p<0.0001$) the C-V method on the outer border segmentation and approached to statistically significant for the inner border detection ($p=0.066$). The presented ellipse maps of the extracted bladder walls show a noticeable difference on the wall thickness distribution between baseline reference and patients with abnormality growth. For example, a bladder tumor of 3cm size is so obvious on the flattened ellipse picture (e) such that it can be perceived only at the first sight. While the extracted wall volume (c) shows the abnormality and bladder morphology, the flattened ellipse picture (e) reveals the wall thickness distribution by a single display.

Discussion: Although early detection of bladder cancer (i.e., small tumor) remains a challenging task by current clinical MRI scanners with limited signal-to-noise ratio and spatial resolution, the presented MR cystograpy has the potential to evaluate tumor recurrence, which would otherwise require the patient to follow-up by fiberoptic cystoscopy every three to six months after resection. Early detection would be feasible with improved image quality by advanced MRI technology

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