Extracting the Inner and Outer Borders of Bladder Wall and Flattening the Extracted Wall for MR Cystography

Z. Liang[1], C. Duan[2], D. Gu[3], and H. Lu[4]

[1] Department of Radiology, Stony Brook University, Stony Brook, NY, USA
[2] Beijing Key Lab of Medical Physics and Engineering, Peking University, Beijing, China
[3] Department of Computer Science, Stony Brook University, Stony Brook, NY, USA
[4] Department of Biomedical Engineering, Fourth Military Medical University, Xi'an, China

Abstract—**This paper presents a magnetic resonance imaging (MRI)-based virtual cystoscopy system, which extracts the bladder wall from T_1-weighted MR images where the wall is enhanced while the urine and surrounding fat tissues are suppressed by a fully non-invasive imaging procedure. The system analyzes the extracted wall and detects abnormal features automatically. Test results are encouraging by FROC (free response receiver operating characteristic) merit.**

Keywords—**Virtual cystoscopy, bladder wall segmentation, T_1-weighted magnetic resonance imaging, non-invasive procedure, computer aided detection.**

I. Introduction

Bladder cancer 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) [1-5]. There were 50,000 bladder carcinoma and 11,000 deaths reported in 1995 [1, 2] and over 56,000 bladder carcinoma and more than 12,000 deaths reported in 2002 [3]. The estimated numbers of diagnosed new cases increased to over 68,500 and deaths increased to over 14,000 in 2008 [4, 5]. The lifetime probability of developing the cancer is over 3% and the probability of dying from the cancer is approximately or slightly less than 1% as estimated a decade ago [6, 7]. The probabilities would be higher now by the estimation [4, 5].

Approximately 75% of the cancers were localized disease, 19% were regional metastases, 3% distant metastases, and remaining were others [1-4, 8]. Pathologically, more than 90% of the bladder cancer cases occur as pure transitional cell carcinoma. The remaining less than 10% are divided between squamous cell carcinomas (5% to 7%), adenocarcinomas (1% to 2 %), and sarcomas (1% to 2%) [9, 10]. Approximately 70% of the transitional cell carcinomas are superficial or papillary tumors. The remaining 30% are invasive [6, 7].

Since most bladder cancers are originated in the epithelial cells (e.g., uroepithelial cells) and treatable if diagnosed prior to metastasis and managed appropriately, therefore early detection is crucial to prevent the disease and reduce the death rate.

In addition to the need of early detection, an appropriate follow-up procedure is also crucial to prevent the disease and reduce the death rate. This is due to the fact that bladder tumor is difficult to manage because of its high recurrence rate after resection (as high as 80%) [1-5]. Therefore, it is essential to detect bladder abnormalities in a non-invasive and convenience manner, especially for follow-ups of resection.

Early asymptomatic bladder cancer may be associated with occult bleeding (microscopic hematuria) or the presence of dysplastic cells in the urine. Urine dipsticks or standard urinalysis, which detect peroxidase activity of hemoglobin and can be performed at home, provide a quick, safe, and inexpensive test for hematuria with a high sensitivity of approximately 90%. However, it has a very poor specificity, as low as 65% [11-13], because other causes can lead microscopic hematuria, such as benign prostatic hypertrophy, exercise, renal cysts, urethral trauma, menstrual bleeding, bladder stones, dysplasia, and asymptomatic infection. Furthermore, it can not provide accurate location and information on the tumor staging [14]. Evaluation of asymptomatic microscopic hematuria is very complicated and costly [11].

Other highly sensitive methods for detection of high-grade urothelial malignancy, in addition to the urine dipsticks, include urine cytology [15, 16], fluorescence in situ hybridization (FISH) [17, 18], and bladder tumor antigen (BTA) [19]. However, they share the same limitations as urine dipsticks in providing the location and staging of the tumor.

Among the minimal or non-invasive tests with accurate location, such as ultrasound, X-ray angiography, computed tomography (CT), etc, intravenous pyelography (IVP) is the standard radiological test used in the evaluation of a patient with hematuria. During IVP, a dye called contrast material is injected into a vein in the arm. A series of X-ray pictures is then taken at timed intervals. An IVP can show the size, shape, and position of the urinary tract, and it can evaluate the collecting system inside the kidneys. However, IVP carries the risk of allergic reaction, nephrotoxicity, and radiation exposure. Despite its utility, IVP does not demonstrate small bladder tumors and fiberoptic cystoscopy must be performed to evaluate the urinary bladder.

O. Dössel and W.C. Schlegel (Eds.): WC 2009, IFMBE Proceedings 25/V, pp. 322–325, 2009.
www.springerlink.com

Fiberoptic cystoscopy, a mandatory part of the evaluation of a patient with hematuria for bladder abnormalities, is more accurate, because most tumors (more than 90%) appear as small growths arising from the inner surface of the bladder wall in forms of polypoid, sessile, or abnormal plaques. This method is performed, when the patient is placed in a lithotomy position, by inserting an endoscope through the urethra into the bladder. It was reported with a sensitivity of approximately 87% and specificity of around 95% [2, 7]. However, it is invasive, time-consuming, expensive, and uncomfortable, with a risk of 5% to 10% rate of urinary track infection (and a higher rate of bleeding) following the invasive procedure. Due to the low specificity of standard urinalysis/IVP and the difficulty of fiberoptic cystoscopy, the finding of bladder cancer is usually at a very late stage, resulting in a high morbidity and mortality, as well as a high cost of patient management.

Recent advances in medical imaging technologies make virtual cystoscopy (VCys) a potential alternative [20-23]. By constructing a three-dimensional (3D) virtual bladder model, the VCys mimics the navigation environment of fiberoptic cystoscopy and detects bladder lesion candidates for urologists' further inspection to decide if cystoscopic intervention is necessary.

Most previous VCys work [20-28] are based on computed tomography (CT) technology, due to its high spatial resolution, fast acquisition speed, and wide availability. However, the sensitivity of CT imaging to soft tissues (including the urine) prohibits itself from providing good contrast in bladder wall [25, 26]. This limitation is partly mitigated by the injection of contrast medium (e.g., the urine may be either tagged by intravenous injection or empted with replacement of air through a catheter) [24, 25, 27, 28]. Unfortunately, not only is this procedure invasive and uncomfortable, but also the CT imaging delivers excessive X-ray exposure to the patients, both of which considerably decrease the patients' compliance. To avoid these obstacles, magnetic resonance imaging (MRI) turns out to be an alternative, considering its structural, functional and pathological information for diagnosing and staging the tumor growth. Besides, it uses endogenous rather than exogenetic contrast medium to alter the image intensity of bladder wall against its surroundings (urine inside and fat outside) towards a fully non-invasive procedure [29, 30]. Since hydrogen in water (or urine) has longer transverse relaxation time leading to higher intensity value in the T_2-weighted MR images, many previous MRI-based VCys or MR cystography researches focused on T_2-weighted imaging [31-33], where urine is used as endogenous contrast medium to enhance the contrast between bladder lumen and wall. Preliminary results showed that there is no statistically significant difference between MR and CT cystography for detection of tumors (sensitivity of 88.9% for tumors less than 10 mm and 100% for tumors equal or greater than 10 mm) [31-33]. Therefore, MR cystography may be a better choice for bladder evaluation.

This work presents a MRI cystography system which extracts the bladder wall from a T_1-weighted volume image of the bladder, analyzes the image texture of the extracted wall, and detects the patches where abnormalities are highly likely present for reviewers' assessment, i.e., a computer-aided detection (CAD) of abnormalities.

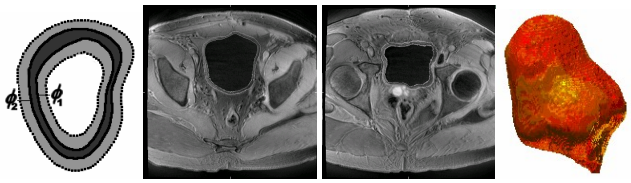
II. Methods

As reported [8-10], bladder carcinoma invades gradually from the mucosa into the wall muscles. Depending upon the degrees of penetration, bladder carcinoma is categorized into different stages. It is hoped that the transition at different stages can be reflected by image geometry and intensity features in the bladder wall [29, 30]. So far, geometrical analysis on the wall remains the primary tool (with some additional available intensity texture information) for locating bladder lesions by some irregular shape and contrast patterns at a late stage [24, 32, 33]. At early stages, flat and/or small tumors less than 5 mm are difficult to be detected and, therefore, deserved more attention [24, 32, 33]. Conventional quantitative measurements on the bladder wall, like curvedness and shape index, vary significantly from voxel to voxel [34]. In contrast, for a small bump protruding out of the bladder wall, the measurement of its thickness as the distance between the inner and outer borders tends to be a good indicator of the occurrence of abnormalities [24, 27-30]. Towards that end, the issue of accurately delineating the bladder wall inner and outer borders arises [34-36].

In order to minimize the partial volume effect (PVE) 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. Two T_1 scans were acquired after the patient voiding the bladder and taking a cup of water. One scan was at the middle stage of half-filled bladder and the other was at the final stage of fully-filled bladder.

Both T_1-weighted images were acquired by a Philips 1.5T Edge whole-body scanner with body coil as the transceiver includes. The image acquisition protocol includes, as an example, 3DFFE-SPIR CLEAR pulse sequence, 1.5mm slice thickness, 10^o flip angle, 448x448 image size with T_R =4.6666ms and T_E =2.2766ms. Other T_1-weighted pulse

sequences and scanning parameters can be explored to find an optimal protocol. Each of the T_1 volume image was segmented by a hybrid method which searches an inner border of the bladder by level-set strategy starting from a group of voxels with lowest intensity in the image. From the inner border, an enlarged version was obtained by the same level-set strategy with a different energy function [37]. Figure 1(a) is a 2D presentation. The obtained wall was then dilated for a sufficient large layer, which was further quantified by a PV segmentation algorithm [38]. Each voxel inside the dilated layer after the PV segmentation contains the percentages of three tissue types: urine, wall and mixture of fat/muscle (outside the wall). Those voxels with small wall percentages of less than 5% were ignored and the remaining voxels represent the bladder wall. Two examples of dilated layers are shown in Figs. 1(b) and 1(c). An example of extracted bladder is shown in Fig. 1(d).



(a) (b) (c) (d).

Fig. 1 Flowchart from image segmentation to 3D visualization

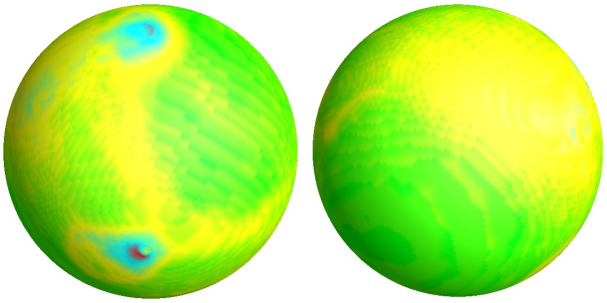


Fig. 2 Display of 3D object by 2D pictures

To facilitate clinical use, we applied a conformal flattening strategy [39] to deform the 3D object into 2D pictures. The 3D object was first deformed into a sphere. The deformation was based on the inner surface of the bladder. Then the sphere was flattened into two disks, each represents a half of the sphere. Figure 2 shows an example of two disks which were flattened from a sphere deformed from a patient bladder. The color map reflects the wall thickness distribution on the inner surface of the bladder. From green to red shows the thickness change from thin to thick. Two abnormalities are seen from the left picture. In addition to the color map of wall thickness, the geometry of the inner surface can also be displayed by shading and other computer graphics technologies.

III. Results

The presented MRI cystography system was tested on ten MR patient bladder scans with two tumors greater than 10 mm, one of 4 mm, and two less than 3 mm. The FROC (free response receiver operating characteristic) curve for the automatic CAD of the tumors is shown in Fig. 3. The false positive rate of detecting tumors equal or greater than 4 mm is acceptable. The detection sensitivity reaches 100 % with less than 35 false positives per patient scan.

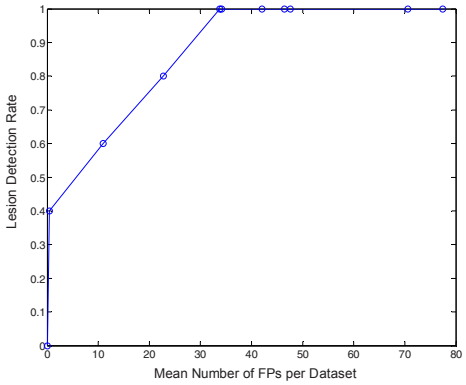


Fig. 3 FROC study of patient scans

IV. Conclusions

Although early detection of bladder cancer (tumor less than 3 mm) remains a challenging task by current clinical MRI scanners with 1.5 mm voxel resolution, the presented MRI-virtual cystoscopy system has demonstrated the potential for evaluation of tumor recurrence, which would otherwise require the patient to follow-up with fiberoptic cystoscopy every three to six months after tumor resection. Early detection would be feasible with improvement of MRI spatial resolution and contrast between the wall and its surrounding soft tissues.

Acknowledgment

This work was supported in part by NIH Grant #CA120917 of the National Cancer Institute.

References

1. P.A. Wingo, T. Tong, and S. Bolden: "Cancer statistics." *A Cancer Journal for Clinicians*, **45**: 8-30, 1995.
2. D.L. Lamm and F.M. Torti: "Bladder cancer." *A Cancer Journal for Clinicians*, **26**: 93-112, 1996.
3. A. Jemal, A. Thomas, T. Murray, and M. Thun: "Cancer statistics." *A Cancer Journal for Clinicians*, **52**: 23-47, 2002.

4. A. Jemal, R. Siegel, E. Ward, Y. Hao, J. Xu, T. Murray, and M.J. Thun: "Cancer statistics." *A Cancer Journal for Clinicians*, **58**: 71-96, 2008.
5. American Cancer Society: *Cancer Facts & Figures*, pp. 4-10, 2008.
6. S.M. Cohen and S.L. Johansson: "Epidemiology and etiology of bladder cancer." *Urologic Clinics of North America*, **19**: 421-428, 1992.
7. G.D. Steiner, D.L. Trump, and K.B. Cummings: "Metastatic bladder cancer: natural history, clinical course, and consideration for treatment." *Urologic Clinics of North America*, **19**: 735-746, 1992.
8. M. Donaldski, E.M. White, G.G. Ghahremani, and S.K. Patel: "Carcinoma arising in urinary bladder diverticula: imaging findings in six patients." *American Journal of Roentgenology*, **161**: 817-820, 1993.
9. N.R. Brettschneider and E. Oriheula: "Carcinoma of the bladder." *Urologic Nursing*, **10**: 14-19, 1990.
10. C.C. Rife, G.M. Farrow, and D.C. Utz: "Urine cytology of transitional cell neoplasms." *Urologic Clinics of North America*, **6**: 599-612, 1979.
11. G.D. Grossfeld and P.R. Carroll: "Evaluation of asymptomatic microscopic hematuria." *Urologic Clinics of North America*, **25**: 661-676, 1998.
12. S.T. Shaw, S.Y. Poon, and E.T. Wong: "Routine urinalysis: is the dipstick enough?" *Journal of the American Medical Association*, **253**: 1596-1600, 1985.
13. S. Woolhandler, R.J. Pels, D.H. Bor, D.U. Himmelstein, and R.S. Lawrence, "Dipstick urinalysis screening of asymptomatic adults for urinary tract disorders. I. hematuria and proteinuria." *Journal of the American Medical Association*, **262**: 1215-1219, 1989.
14. J.E. Husband: "Staging bladder cancer." *Clinical Radiology*, **46**: 153-159, 1992.
15. E.M. Messing and W. Catalona: "Urothelial tumors of the urinary tract." In: P. Walsh, A. Retik, E. Vaughan, & A. Wein (eds.), Campbell's Urology, 7th ed., pp.2327: W.B. Saunders Company, 1998.
16. . Flamm and S. Dona: "The significance of bladder quadrant biopsies in patients with primary superficial bladder carcinoma." *European Urology*, **16**: 81-5, 1989.
17. R.S. Cajulis, G.K. Haines, D. Frias-Hidvegi, K. McVary, and J.W. Bacus: "Cytology, flow cytometry, image analysis, and interphase cytogenetics by fluorescence in situ hybridization in the diagnosis of TCC in bladder washes: a comparative study." *Diagnostic Cytopathology*, **13**: 214-23, 1995.
18. M.F. Sarosdy, P. Schellhammer, G. Bokinsky, P. Kahn, R. Chao, L. Yore, J. Zadra, D. Burzon, G. Osher, J.A. Bridge, S. Anderson, S.L. Johansson, M.L. Lieber, and M. Soloway: "Clinical evaluation of a multi-target fluorescent in situ hybridization assay for detection of bladder cancer." *Journal of Urology*, 168: 1950 2002.
19. R. Kinders, T. Jones, R. Root, C. Bruce, H. Murchison, M. Corey, L. Williams, D. Enfield, and G.M. Hass: "Complement factor H or a related protein is a marker for transitional cell cancer of the bladder." *Clinical Cancer Research*, **4**: 2511-2520, 1998.
20. D.J. Vining, R.J. Zagoria, K. Liu, and D. Stelts: "CT cystoscopy: An innovation in bladder imaging." *American Journal of Roentgenology*, **166**: 409-410, 1996.
21. S. Hussain, J.A. Loeffler, R.K. Babayan, and H.M. Fenlon: "Thin-section helical computer tomography of the bladder: Initial clinical experience with virtual reality imaging." *Urology*, **50**(5), 685-689, 1997.
22. H.M. Fenlon, T. V. Bell, H.K. Ahari, and S. Hussain: "Virtual cystoscopy: Early clinical experience." *Radiology*, **205**(1), 272-275, 1997.
23. M. Merkle, A. Wunderlich, A.J. Aschoff, N. Rilinger, J. Gorich, R. Bachor, H.W. Gottfried, R. Sokiranski, T.R. Fleiter, and H.J. Brambs: "Virtual cystoscopy based on helical CT scan datasets: Perspectives and limitations." *The British Journal of Radiology*, **71**: 262-267, 1998.
24. .H. Song, I.R. Francis, J.F. Platt, R.H. Cohan, J. Mohsin, S.J. Kielb, M. Korobkin, and J.E. Montie: "Bladder tumor detection at virtual cystoscopy." *Radiology*, **218**: 95-100, 2001.
25. J.K. Kim, J.H. Ahn, T. Park, H.J. Ahn, C.S. Kim, and K.-S. Cho: "Virtual cystoscopy of the contrast material-filled bladder in patients with gross hematuria." *American Journal of Roentgenology*, **179**: 763-768, 2002.
26. M. Rousson, A. Khamene, M. Diallo, J.C. Celi, and F. Sauer: "Constrained surface evolutions for prostate and bladder segmentation in CT images." in *Lecture Notes in Computer Science*, **3765**:251-260, 2005.
27. S. Jaume, M. Ferrant, B. Macq, L. Hoyte, J.R. Fielding, A. Schreyer, R. Kikinis, and S.K. Warfield: "Tumor detection in the bladder wall with a measurement of abnormal thickness in CT scans." *IEEE Transactions on Biomedical Engineering*, **50**(3): 383-390, 2003.
28. R. Fielding, L. Hoyte, S.A. Okon, A. Schreyer, J. Lee, K.H. Zou, S. Warfield, J.P. Richie, K.R. Loughlin, M.P. O'Leary, C.J. Doyle, and R. Kikinis: "Tumor detection by virtual cystoscopy with color mapping of bladder wall thickness." *The Journal of Urology*, **167**: 559-562, 2002.
29. Z. Liang, D. Chen, T. Button, H. Li, and W. Huang: "Feasibility studies on extracting bladder wall from MR images for virtual cystoscopy." *Proc. International Society of Magnetic Resonance in Medicine*, **3**: 2204, 1999.
30. D. Chen, B. Li, W. Huang, and Z. Liang: "A multi-scan MRI-based virtual cystoscopy." *Proc. SPIE Medical Imaging*, **3978**: 146-152, 2000.
31. T.M. Bernhardt and U. Rapp-Bernhardt: "Virtual cystoscopy of the bladder based on CT and MRI data." *Abdominal Imaging*, **26**: 325-332, 2001.
32. T.M. Bernhardt, H. Schmidl, C. Philipp, E.P. Allhoff, and U. Rapp-Bernhardt: "Diagnostic potential of virtual cystoscopy of the bladder: MRI vs CT. Preliminary report." *European Radiology*, **13**: 305-312, 2003.
33. M. Lämmle, A. Beer, M. Settles, C. Hannig, H. Schwaibold, and C. Drews: "Reliability of MR imaging-based virtual cystoscopy in the diagnosis of cancer of the urinary bladder." *American Journal of Roentgenology*, **178**: 1483-1488, 2002.
34. L. Li, Z. Wang, D. Harrington, W. Huang, and Z. Liang: "A mixture-based computed aided detection system for virtual cystoscopy." *Proc. International Society of Magnetic Resonance in Medicine*, **1**: 146, 2003.
35. L. Li, Z. Wang, X. Li, X. Wei, H. Adler, W. Huang, S. Rizvi, H. Meng, D. Harrington, and Z. Liang: "A new partial volume segmentation approach to extract bladder wall for computer aided detection in virtual cystoscopy." *Proc. SPIE Medical Imaging*, **5369**: 199-206, 2004.
36. L. Li, Z. Liang, S. Wang, H. Lu, M. Wagshul, M. Zawin, E. Posniak, and C. Lee: "Segmentation of multi-spectral bladder MR images with inhomogeneity correction for virtual cystoscopy." *Proc. SPIE Medical Imaging*, in CD-ROM, 2008.
37. C. Duan, S. Bao, and Z. Liang: "A coupled level-set framework for bladder wall segmentation with application to MRI-based virtual cystoscopy." *Proc SPIE Medical Imaging*, in CD-ROM, 2009.
38. Z. Liang and S. Wang: "An EM approach to MAP solution of segmenting tissue mixtures: A numerical analysis." *IEEE Transactions on Medical Imaging*, **28**(2): 297-310, 2009.
39. X.D. Gu and S.T. Yao: "Global conformal surface parameterization." *ACM Symposium on Geometry Processing*, **1**: 127-137, 2003.

The corresponding author:

Author: Jerome Zhengrong Liang
Institute: Stony Brook University
Street: Department of Radiology
City: Stony Brook
Country: USA
Email: jzliang@mil.sunysb.edu