Introduction

Three dimensional visualization with virtual endoscopy of the bladder appears to be a promising tool for screening and follow up of cancer [1]. Fenlon et al. described excellent correlation between virtual and conventional cystoscopy, but the visualization of very small and sessile tumors remains problematic [2]. Vining reported a sensitivity of only 23% in detecting tumors smaller than 5mm using virtual cystoscopy [3]. To improve identification of these lesions we developed an algorithm for color mapping the thickness of the bladder wall. The purpose of this preliminary study was to demonstrate the feasibility of this algorithm in the bladder to detect small or sessile bladder cancer using virtual cystoscopy.

Materials and Methods

Five patients with a history of bladder cancer underwent a spiral CT scan of the pelvis. The study protocol was approved by our institutional review board, and written informed consent was obtained from all patients. Each patient underwent conventional cystoscopy to confirm diagnosis. No oral or intravenous contrast agent was administered. A 12 French Foley catheter was placed in the bladder, all urine drained, and the bladder insufflated with approximately 300cc room air or to tolerance. Three cc radiopaque contrast medium (Hypaque 60, diatrizoate meglumine, Nycomed, Princeton, NJ) were instilled through the Foley catheter to make urine produced during the scan discernible from the bladder wall. Using a Somatom Plus 4 scanner (Siemens, Iselin, NJ) applying 280mA with 120kVp and the smallest field of view to fit, the images were acquired with 3mm collimation and a pitch of 1. Reconstruction was performed at 3mm increments.
The data were transferred via Ethernet to a Sun-Workstation (Ultra 10, Sun Microsystems Inc., Mountain View, CA) in our Surgical Planning Laboratory. To improve the computation performance the slice resolution was reduced from 512 X 512 to a 256 X 256 pixel matrix. The next step was the segmentation of axial images, which is mandatory for surface reconstruction and thickness determination. Segmentation consists of outlining shapes on gray-scale images and assigning each voxel to the appropriate organ. We applied automatic segmentation algorithms based on the different threshold values for air and contrast enhanced urine to identify the inner surface of the bladder. Manual editing was used to assign the outer border of the bladder wall, ureters, and urethra. The latter served as landmarks for virtual cystoscopy. Using the segmented labels we generated three dimensional surface models applying a standard visualization pipeline consisting of marching cubes for triangle generation followed by triangle reduction and decimation [4].

We defined thickness as the shortest distance between a voxel on the inner wall to any voxel on the outer wall. To compute the wall thickness our algorithm first identifies the contour for each wall by traversing the boundary of the segmentation independently on each slice. These contours, including the spatial location of each normal on the contour, are stored in a file. Next the search space is restricted in three dimensions by excluding from the search those slices which are further away along the slice direction than the maximum thickness of the bladder wall. Finally, the search for the closest point on the opposite surface is carried out with the efficient nearest neighbor algorithm described by Friedman [5]. This algorithm can identify the closest point without computing the distance to every point on the opposite wall by first sorting the points on the opposite wall and then excluding those points which are, based on the sorting, further away than those first searched. Once the thickness has been identified for each voxel on the bladder walls, the thickness values are stored in the updated contour files.

The thickness values are assigned to triangle vertices in the surface model. The process of triangle decimation and smoothing shifts the triangle vertices away from the lattice coordinates of the data set. In order to correctly associate the triangle vertices with the thickness value closest to its final location, the efficient nearest neighbor search is again applied to map from triangle vertex coordinate to the contour locations. In this way, the thickness values are associated with each triangle vertex. These thickness values are used to color map the display of the triangles in the rendered representation.

Using this technique a quantitative thickness value for each matched set of contour points is calculated with minimal artifact formation. By setting a color scale for the thickness information we can visualize the surface model with different colors representing different wall thickness. We restricted the scale width from 0mm to 15mm thickness represented by colors from red to blue. The color mapped three dimensions model of the bladder including the urethra and ureters was imported into an experimental virtual endoscopy program (VESN, General Electric Corporate Research and Development Center, Schenectady, NY). In a reference window the camera position is represented by a pointer in the cross-sectional slice. A real time free flight through three dimensional reconstructed hollow organs is feasible using three different mouse buttons for rotating the virtual camera, moving forward and backward and moving the position of the object.

**Results**

It took approximately 20 minutes for transferal and preparation of the data including segmentation and three dimensional model generation. Computation of the wall thickness required an additional 5 minutes. At conventional cystoscopy three of the five patients had a diagnosis of bladder cancer. Each of the tumors measured more then 20mm in maximum diameter and could be easily detected on both axial
CT images and the three dimensional models (Figure 1). Virtual cystoscopy with color mapping showed the relationship of the tumors to the ureters and urethra. The other two patients were free of carcinoma. In one patient a subtle thickening of the left lateral bladder wall was identified using conventional and color mapped virtual cystoscopy (Figure 2). Biopsy revealed scar tissue with granuloma. One patient had no suspicious area on imaging which was confirmed at conventional cystoscopy. In our five cases a restricted color scale from red to blue representing 0mm to 15mm thickness proved to be very useful. Using this color range even subtle thickness changes appeared very clearly.

Discussion

The visibility of small structures in three dimensional reconstructions depends mainly on the resolution of cross sectional data, however, using sophisticated computer algorithms the diagnostic sensitivity of virtual endoscopy can be improved. Summers et al. reported an interesting approach to highlighting polypoid airway lesions by means of curvature classification in virtual bronchoscopy [6]. For the detection of small or flat and sessile lesions we believe color mapping contributes more comprehensive information, because it is not restricted to the surface and takes changes of the entire wall thickness into account. Other than in fibreoptic endoscopy it is not possible to see subtle color changes and flat tumors arising from mucosa. Virtual endoscopy can compensate for this lack of subtle high-resolution surface information by adding three dimensional depth information. This algorithm pursues the idea of higher integration of information content in voxel based images [7]. The relevance of this approach has to be proved in further clinical trials.

Figure Legends

Figure 1. 73 year old male with history of bladder cancer and hematuria.

A. Axial CT image shows polypoid mass arising from the anterior surface of bladder wall (arrows). Contrast enhanced urine (*) pools adjacent to the catheter.
B. Color mapped virtual endoscopy view of the same bladder. Superior-inferior view showing the catheter with balloon, the ureters (*) and the green to blue color mapped masses.

Figure 2. 52 year old male with history of bladder cancer
A. Axial CT image shows subtle thickening of the left bladder wall (arrow).
B. Color mapped virtual endoscopy. Inferior-superior view with catheter and left ureter as landmarks. Green color mapping of the left bladder wall indicating thickening.

References:


