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Semiautomatic segmentation for prostate brachytherapy: Dosimetric evaluation

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ABSTRACT

PURPOSE: To demonstrate that manual prostate segmentation in transrectal ultrasound images can be replaced with semiautomatic segmentation.

METHODS AND MATERIALS: Semiautomatic segmentation using a tapered ellipsoid model was applied to transrectal ultrasound images. Region-based volumetric evaluation was performed between original and physician-reviewed semiautomatic contours. For dosimetric assessment, treatment plans generated on semiautomatic contours were overlaid on physician-reviewed semiautomatic contours and dose parameters were computed. To establish a threshold for the acceptable amount of dosimetric degradation below which the adoption of semiautomatic planning is unacceptable, the range of variability in dosimetric quality attributed to manual variability was obtained and compared with that of semiautomatic contours.

RESULTS: An average volume error (1—Dice similarity coefficient) of less than 7% between semiautomatic and manual volumes (140 cases) was obtained. The difference between the mean V_{100} of plans created for semiautomatic contours then overlaid on physician-reviewed semiautomatic contours and the original V_{100} values, that is, before overlaying on the physician-reviewed contours (41 cases) was lower than 5%. An average total duration of 2–4 min, which includes algorithm initialization, 11.67 ± 3.57 s algorithm time, and contour modification is required per case. This algorithm is being used at the British Columbia Cancer Agency and to this date has been applied for the treatment of more than 600 patients.

CONCLUSIONS: In terms of volumetric and dosimetric accuracy, the proposed algorithm is a suitable replacement for manual segmentation in the context of our planning technique. The benefits are shorter segmentation times; greater consistency; less reliance on user experience; and smooth, symmetric contours.

Keywords: Prostate segmentation; Dosimetric evaluation; Prostate brachytherapy

Introduction

Accurate, consistent delineation of the prostate boundary is important for effective treatment of prostate cancer with radiation therapy and applies to both external beam therapy and brachytherapy. For transperineal brachytherapy, this is usually done by manual segmentation of transverse B-mode images derived from transrectal ultrasound (TRUS) imaging.

Although it is a safe and real-time system, TRUS does not provide an unambiguous image of the gland, thus affecting the manual delineation of the prostate. Various attempts have been made to improve prostate visibility. Daanen *et al.* (1) attempted to fuse MRI data with TRUS data for more reliable image processing and prostate volume identification. However, MRI is not part of the standard of care for prostate radiation treatment and would add expense and time to the treatment. Furthermore, because TRUS and MRI are carried out under different conditions (different rectum deformation by endorectal coils or TRUS and different leg and pelvis

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position), complex deformable registration techniques must be used. In previous reports by Sahba *et al.* (2) and Pathak *et al.* (3), image processing techniques have been used for ultrasound image enhancement.

Different imaging modalities lead to different segmentation results. For example, Smith *et al.* (4) have evaluated the reproducibility and modality differences of prostate contouring, after brachytherapy implants, using three-dimensional (3D) TRUS and T2-weighted MR and CT imaging. Prostates from 10 patients with early-stage prostate cancer (T2b or less) were segmented twice by seven observers. Their results showed high contouring variability of the anterior base and apex in 3DTRUS, whereas the prostate–rectum interface had the smallest variability. In TRUS imaging, the interobserver variability of prostate contouring is high. A study by Choi *et al.* (5) showed that prostate volume measurement by TRUS may vary among observers when patients have large prostates ($\geq 30\ cm^3$). The average volume difference between 101 prostates measured by two experienced observers was reported as $6.00\ cm^3$ for prostates with a mean measured volume of $30\ cm^3$ or more and $1.51\ cm^3$ for prostates with a mean measured volume of $30\ cm^3$ or less. These numbers increased to $6.84\ cm^3$ and $3.99\ cm^3$, respectively, when measurements were performed by one experienced and one less experienced observer (110 prostate volumes measured in this case).

In low-dose rate (LDR) permanent implant brachytherapy, for ease of planning and more robust seed implantation, some centers prefer contours that are smooth and symmetric with respect to the medial line (6) in the transverse plane. These two requirements are difficult to satisfy manually, whereas an automatic segmentation method, in addition to producing a smooth and symmetric volume, can reduce the variability of the contours related to the observer bias and random factors. Additionally, the time required for performing segmentation can be greatly reduced, and thus can be adapted for subsequent intraoperative planning.

Various ultrasound-based segmentation methods have been proposed in the literature. Methods using higher-level knowledge, such as using 3D geometric shapes, in addition to lower-level image information, such as texture and edges, have been more successful compared with pure image-based segmentation methods. Deformable models (such as active contour models or snakes) are surfaces or curves that deform based on various parameters, such as the amount of curvature and image intensity gradients. Examples and different variations of these methods are presented in the literature (7, 8). These models create continuous contours, which may get trapped by false edges. Statistical shape models (9, 10) or active shape models incorporate statistically extracted variations in the shape. Their deformation toward the boundary of an object is constrained by the characteristics of the object they represent.

The anatomy of the prostate suggests fitting ellipses, ellipsoids, superellipses, and similar geometries. In deformable superellipses (11), ellipses with additional squareness, tapering, and bending parameters are used. Their automatic segmentation results on 125 prostate ultrasound images showed a mean error of less than 2 mm between computer-generated and manual contours. However, their method generated 2D segmentation of the prostate, which may suffer from the inability to segment low quality images, especially at the base and apex. By comparison, a 3D segmentation algorithm can produce contours even for the poor images at the prostate's superior (anterior base) and inferior (apical) zones by using the higher quality midgland images. Furthermore, in 3D segmentation, axial continuity is easily maintained. This is achieved during manual segmentation by visually comparing contours of various image depths. The 3D segmentation method provided in the literature (12) requires 90 s to create the prostate surface model and generate the solid models necessary for high-intensity focused ultrasound therapy planning. Manual tracing of approximately five transverse and three sagittal images of the prostate is needed to initialize this algorithm. This adds to the total segmentation duration and introduces an observer variability that has not been quantified. Other 3D methods have been proposed in the literature (9, 10, 13). These methods either require extensive user interaction (e.g., manual delineation of several images for initialization of the algorithm) or require a long processing time or modifications to the conventional imaging system. Moreover, rarely has the intra- and interobserver variability of the resulting contours been evaluated and compared with that of manual contouring (12, 13).

The ellipsoid fitting method in the report by Badiei *et al.* (14) is fast and produces symmetric and smooth 3D volumes. This method assumes an ellipsoidal shape of the prostate anatomy, whereas tapering is usually observed in both the transverse plane and along the main axis of the prostate. We have gradually resolved this problem in our earlier work (15, 16) to produce a 3D semiautomatic segmentation method. Compared with the above-mentioned methods, this algorithm is fast and has been shown to generate reliable and repeatable clinical target volumes (CTVs), making it a suitable candidate for real-time use in brachytherapy treatment planning and dosimetric evaluation.

In this article, we provide an extensive clinical validation of the segmentation method from our earlier work (17), which is being used as a part of the LDR prostate brachytherapy procedure at the Vancouver Cancer Center and BC Cancer Agency (BCCA). Currently, the semiautomatic contour is first approved and modified, if required, before treatment planning. The results from our earlier work (17) suggested that such modifications are so minor that they may not be necessary in many cases. Indeed, a volumetric study showed that the semiautomatic segmentation error is within the range of inter- and intraobserver variability of