AUTOMATIC ORGAN DELINEATION OF COMPUTED TOMOGRAPHY IMAGES FOR RADIOTHERAPY PLANNING IN PROSTATE CANCER
An Overview

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Abstract: Prostate cancer is a common cancer worldwide and a leading cause of death. Radiotherapy is usually the first-line treatment for patients with slow-growing cancer that is confined to the prostate. In Radiation Therapy Planning (RTP), the recognition and outlining of clinical volumes in computed tomography (CT) images are one of the most time-consuming steps carried out by human experts. The aim of this review is to identify and summarize evidence of the use of automatic organ delineation of CT images for radiotherapy planning in prostate cancer. From the literature search, a total of seven studies, reported between 1994 and 2009, were selected. We associate the selected studies in order to compare results, in spite of their differences in methodology and outcome evaluators. Most of the studies conclude that the automatic approach is faster, while having equivalent accuracy to manual method. Concerning the observer's variability, automatic segmentation reaches significant gains in reproducibility. As future directions, it is recommended the improvement of the segmentation algorithms in the delineation of problematic soft tissues and future validation studies with large scale trials and possible studies of meta-analysis in the specific problems.

1 INTRODUCTION

Prostate cancer is a common cancer worldwide and a leading cause of death. According World Health Organization is accounting for about 250,000 new cases annually. Radiotherapy is usually the first-line treatment for patients with slow-growing cancer that is confined to the prostate. It represents a curative treatment option in these patients (Boehmer, D. et al., 2006) and the three-dimensional (3D) conformal radiotherapy is being increasingly applied since it may result in improved targeting of the prostate and significant sparing of normal tissues.

In the Radiation Therapy Planning (RTP), the recognition and outlining of clinical target volume and adjacent organs at risk, in Computed Tomography (CT) images, are one of the most time-consuming steps carried out routinely by human experts (Huyskens, D.P. et al., 2009, Haas, B. et al., 2008). It is only by displaying these that the dosimeters can devise an optimal plan to the prescribed dose while minimizing radiation of adjacent non-target tissues thereby maximizing the therapeutic gain of treatment (Neal, A.J. et al., 1994). Usually, they outline the boundaries of the structure by a process of continuous contour drawing on most (or all) slices of CT image set using a computerized Treatment Planning System (TPS). This is a laborious and subjective task ultimately dependent on the clinician´s expert eye, which is also prone to inconsistency and variability (Mcbain, C.A. et al., 2008, Pekar, V. et al., 2004).

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TPS for irradiation of malignant neoplasm requires CT images due to the similar physical behavior of the radiation used for imaging and for treatment. These images are limited of contrast for the structures of interest, ruling out many approaches to segmentation for this application (Quicken, M., 2000). The emergence of imaging and adaptive radiotherapy is producing amounts of image data whose manual delineation slice by slice has become infeasible (Boehmer, D. et al., 2006). The need of efficient and robust segmentation tools is even increasing (Li, T. et al., 2006). Segmentation is an image processing term literally implying the breaking down of an image into smaller parts. In the context of RTP this comprises the contouring of important volumes. At the present there is no universally accepted segmentation method that is proven to work on a large representative image database (Bueno, G. et al., 2001).

Despite all the advances in imaging for RTP, some anatomical regions remain indistinct and it is very difficult to delineate. This is usually because of an inability to differentiate the region of interest, from the adjacent structures of similar grey-scale signal density, for e.g. the base of the prostate gland at its interface with the base of the bladder (Mcbain, C.A. et al., 2008). Bladder, rectum and femoral heads should be delineated in the TPS to achieve a protection against high dosage of radiation trough a selection of the optimal beam orientations by visualizing 3D reconstruction (Mazonakis, M. et al., 2001).

For a better understanding of the automatic segmentation used in TPS see the authors (Freedman, D. et al., 2005, Quicken, M., 2000).

The aim of this article is to review, to identify and summarize evidence from scientific studies to obtain an overview about the use of automatic organ delineation of CT images for RTP in prostate cancer.

2 METHODOLOGY

The comprehensive literature search of this review was performed by using PubMed®. The final search was executed on December 31, 2009 using the query presented in Figure 1. The selection over the data collection was performed by one reviewer that examined the related articles.

This strategy was based on these following steps: apply the query (n=25), exclude the articles inadequate by reading the title and the abstract (n=21); review the chosen articles (n=4), add some relevant articles from related articles (n=2), and add some article adequate from the review references of the previous articles (n=1).

Search Query: A.8 not B.12

A [MeSH Terms]	B [MeSH Terms]
1-Human	1-Motion
2-Male	2-Movement
3-Radiotherapy Planning, Computer-Assisted/Methods	3-Magnetic Resonance Imaging
4-Image Processing, Computer-Assisted/Methods	4-Positron-Emission Tomography
5-Tomography, X-Ray Computed	5-Cone Beam Computer Tomography
6-Prostatic Neoplasms/Radiotherapy	6-Radiotherapy, Intensity-Modulated
7-Pelvis/Radiography	7-Ultrasonography
8- 1 and 2 and 3 and (4 or 5) and (6 or 7)	8-Brachytherapy
	9-Radiotherapy Dosage
	10-Radiation Dosage
	11-Portal System/Radiography
	12- 1 and ~and 11

Figure 1: *MeSH* terms and search query used in the methodology.

The inclusion criteria required that studies had a clinical evaluation of the automatic (semi-automatic) organ delineation and had used CT-based radiotherapy planning for prostate cancer patients. The exclusion criteria eliminate studies that had a clinical evaluation of the automatic organ delineation based only in Magnetic Resonance (MR) image, or ultrasound-guided brachytherapy, or multimodality images (combination of CT, positron emission tomography or MR). Articles that presented automatic localization of the prostate for image-guided radiotherapy on cone-beam CT scans or on megavoltage computed tomography images were not considered in this review.

3 FINDINGS

A total of seven studies were selected from the scientific literature. The studies were reported between 1994 and 2009. Three of them were published by *British Journal of Radiology.* Some of these studies were a result of a work between radiotherapy departments from different institutions or countries.

All of the studies are clinical validations that compare automatic segmentation with manual tracing of pelvic organs. Most of them, had presented quantitative and qualitative evaluations, and nearly all studies had as object of study the quality assessment of the automatic segmentation in terms of expert inter/intra variability. In the selected articles, it was identified the technique or algorithm or the software used in the automatic segmentation. To this evaluation, the observers that participated in the studies were clinical experts like Radiation Oncologist (n=5), Dosimeter (n=1), Physicist (n=4), Radiographer (n=1) and Oncologist (n=1). In the studies, the segmented pelvic organs were: the prostate (n=5), the seminal vesicles (n=3), the bladder (n=6), the rectum (n=7) and the femoral heads (n=4). Five studies used the same patients for both methods of segmentation (automatic and manual).

The table 1 shows a systematization of the outcomes resulting from the selected studies with different evaluators and respective metrics.

4 DISCUSSION

This review attempts to associate several studies in order to compare the outcomes, despite the differences in their methodologies, concerning segmentation techniques and statistical methods. In the segmentation approach, the studies evaluated the following techniques: region growing, deformable, morphological, automatic segmentation software and auto-segmentation algorithm. Regarding the samples, the studies differ in: CT data (number of sets and slices, slice thickness, image resolution) conditions of CT acquisition (administration of contrast, bowel gas, bladder filling), organs segmented, user's interaction, etc. The outcomes were measured trough different evaluators: efficiency (given by the respective segmentation times with mean volume/area and standard deviations of the organs segmented or distance

Table 1: Systematization of most outcomes, presenting metrics used to evaluate the manual tracing and the automatic segmentation (volume and time mean, overlapping ratio, Hausdorff distance) and metrics to compare directly the both segmentation methods (percentage of relative error, percentage of agreement, band area difference in terms of average maximum, median difference of volume and time, deviation mean, and overall rating in terms of percentage or levels).

Study	Manual tracing				Automatic Segmentation				Comparative Evaluators									
	V cm3	T s	O	HD mm	V cm3	T s	O	HD mm	RE %	AG %	BD cm2	VD cm3	TD s	D mm	Overall Rating (%) E	G	A	NA
Huyskens																		
Prostate	60				53				33	75					9	45	30	15
Bladder	250				242				9	91					36	42	12	9
Rectum	90				122				56	76					3	24	27	45
Femoral															12	27	6	54
Hass						53												
Prostate											0.81						✓	
Bladder											1.02						✓	
Rectum											2.64						✓	
Femoral											2.58					✓		
McBain																		
Prostate	61	480			54	120						3.1	360					
Vesicles	23	120			17	120						6	0					
Bladder	174	720			171	300						7.7	420					
Rectum	69	480			54	120						5.6	360					
Pekar																		
Bladder														1.5				
Rectum														1.6				
Right femur														0.9				
Bueno																		
Vesicles			9.1	1.1			0.9	1.5		72								
Bladder			0.9	1.5			0.9	1.2		92								
Rectum			1.0	0.8			0.7	1.7		90								
Mazonakis		738				504												
Prostate	46				47													
Bladder	305				302													
Rectum	118				110													
Neal																		
Prostate		194			219													
Vesicles		108			123													
Bladder		242			198													
Rectum		197			162													
Femur		1136			204													

V- Volume mean/ T- Time mean/ O- Overlapping ratio/ HD- Hausdorff Distance/ RE- Relative Error/ AG- Agreement/ BD- Band area Difference (average maximum)/ VD- median Volume Difference/ TD- median Time Difference/D-Deviation mean / E- excellent/ G- Good/ A- Acceptable/ NA- Not Acceptable measurement between the two methods), reproducibility (intra/inter variability given by the coefficient of variation values or relative percentage of agreement among the experts), accuracy (mean segmentation error), sensitivity (True Positive Rate), and specificity (True Negative Rate).

The most part of the studies, conclude that automatic segmentation closely reproduce manual contours with no significant volume difference and with a significant time difference. The automatic approach is faster with equivalent accuracy to manual method. In concern with the observer's variability, automatic segmentation reaches significant gains in reproducibility. This may be attributed to the reduced user interaction required for efficient segmentation of the organs.

In general, the studies used small samples, except the Hass *et al,* and one of the studies, Neal *et al*, contrary of the general outcomes, concluded that the time taken to segment automatically the prostate was superior compared with the manual tracing. This fact could be explained due to the algorithm limitations in the soft tissue segmentation.

In the automatic segmentation, the limitations found in the studies were: underestimation of prostate, distinguish the base of bladder from prostate, segment the real boundary of rectum and separation of the rectum from seminal vesicles.

All studies have emphasized the potential of the automatic approach to improve radiotherapy planning conditions. In contrast to manual slice delineation, organ segmentation can be done within a few minutes with no significant mean segmentation error. However, some problematic contours of soft tissues have to be corrected interactively.

In general, many published approaches in image segmentation are validated on a small set of test images and few methods in the domain of automated organ segmentation for RTP have been quantitatively validated so far.

As future directions, it is recommended the improvement of the segmentation algorithms in the delineation of problematic soft tissues and future validation studies with large scale trials.

Furthermore, a thorough systematic review aiming at a study of meta-analysis is required to critically access the differences between automatic and manual segmentation, especially for prostate cancer.

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