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PHYSICS CONTRIBUTION

ATLAS-BASED SEMIAUTOMATIC TARGET VOLUME DEFINITION (CTV) FOR HEAD-AND-NECK TUMORS

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Purpose: To develop a new semiautomatic method to improve target delineation in head-and-neck cancer.
Methods and Materials: We implemented an atlas-based software program using fourteen anatomic landmarks as well as the most superior and inferior computerd tomography slices for automatic target delineation, using an advanced laryngeal carcinoma as an example. Registration was made by an affine transformation. Evaluation was performed with manually drawn contours for comparison. Three physicians sampled and further applied a target volume atlas to ten other computer tomography data sets. In addition, a rapid three-dimensional (3D) correction program was developed.
Results: The mean time to the first semiautomatic target delineation proposal was 2.7 minutes. Manual contouring required 20.2 minutes per target, whereas semiautomatic target volume definition with the rapid 3D correction was completed in only 9.7 minutes. The net calculation time for image registration of the target volume atlas was negligible (approximately 0.6 seconds). Our method depicted a sufficient adaptation of the target volume atlas on the new data sets, with a mean similarity index of 77.2%. The similarity index increased up to 85% after 3D correction performed by the physicians.
Conclusions: We have developed a new, feasible method for semiautomatic contouring that saves a significant amount (51.8%) of target delineation time for head-and-neck cancer patients. This approach uses a target volume atlas and a landmark model. The software was evaluated by means of laryngeal cancer but has important implications for various tumor types whereby target volumes remain constant in form and do not move with respiration. © 2010 Elsevier Inc.

3D conformal radiotherapy, PTV, Target definition, Semiautomatic target definition, Anatomic landmarks, Affine transformation, Registration.

INTRODUCTION

The definition of clinical target volume (CTV) in intensity-modulated radiotherapy (IMRT) of head-and-neck tumors is a complex and important procedure (1, 2). The rapid dose falloff makes it possible to give higher doses to the gross tumor while sparing normal tissues and reducing the risk of side effects, as compared with conventional three-dimensional (3D) conformal radiotherapy (RT) (3–6). In general, head-and-neck tumor staging is done according to the TNM classification (7). In RT planning knowledge of the N stage and of the localization of pathologic lymph nodes is mandatory.

Accurate delineation of the CTV requires good anatomic knowledge of the complex lymphatic network of the head-and-neck region. Cervical lymph nodes have been grouped into levels I through VI, according to Robbins *et al.* (8, 9). This classification was further developed to standardize the nomenclature and terminology used in different operative techniques (neck dissection), as established in the field of cervical lymphatic surgery. However, this has led to the absence, from the TNM classification, of the retropharyngeal lymph nodes because they are very difficult to resect. However, detection and irradiation of the latter are necessary in RT of head-and-neck tumors. Som *et al.* (10) and Robbins (11) have used computer tomography (CT)–based delineation of lymph nodes by using a number of easily identifiable anatomic structures. Clinical target volume was defined based on lymphatic drainage and the N stage according to the 1997 classification of the American Joint

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Committee on Cancer, and consensus recommendations have been previously described by Gregoire *et al.* (12, 13).

In daily clinical practice defining the CTV changed from the formerly used two-dimensional slices to the modern 3D conformal RT and high intraobserver and interobserver variability in CTV delineation was observed, despite the existing consensus and guidelines (14–16). Because the forms of different target volumes in the head-and-neck region can partially resemble each other (Fig. 1), the development of a program that will define target volumes semiautomatically could be of clinical value.

In this study we present the evaluation of an atlas-based program that, by entering fourteen anatomic landmarks as well as the most superior and inferior CT slices, enables automatic contouring of the target volume for an advanced laryngeal carcinoma (N2b). The program is based on a target volume atlas and a landmark model. The software was optimized by the clinical operators and supplemented by adding a rapid 3D contouring module for the correction of the automatically generated proposal.

METHODS AND MATERIALS

For the functional framework of the program, two prerequisites were defined: (*1*) The time between data processing and the first semiautomatic target volume proposal should be less than 3 minutes, and (*2*) the target volume proposal should be in accordance with the pre-existing guidelines. In compliance with these requirements time-consuming image registration techniques were not applicable (17–19). Radiotherapy planning guidelines were taken into consideration by the corresponding atlas of the collected target volumes. Definition of target volume was performed by three radiation oncologists with experience in IMRT planning.

The functionality of the semiautomatic target contouring program is shown in Fig. 2. More than ten targets with their corresponding anatomic landmarks are required for atlas definition. From a given number of landmark data sets and their corresponding variable number of target volumes, an atlas will be constructed that consists of a landmark model, a target model, and an offset model (Fig. 3). The landmark model and the target model will be generated with the help of an affine transformation. The latter will be calculated based on the tensor products. The offset model will be estimated from the vector difference between the centers of gravity of the landmarks and those of the target volumes. By use of the offset model, the position of the proposed target volume will be adapted to the current CT data set.

To generate a current target volume using the atlas, the operator must transfer the corresponding landmarks of the atlas to the individual new data set. Because the automatic detection of the most superior and inferior slices of the target volume is technically very difficult, the program sets the entry of those slices in advance. Thereafter the landmark model of the atlas will be registered on the individual landmark's data set. The resulting transformation matrix will be applied on the target volume model. From the transformed target volume model the new target proposal is superimposed on the current CT scan by the same processing steps as with the atlas generation.

A special 3D module was developed to ensure rapid manual correction (Fig. 4). For the demonstration, the patient was selected with a similarity index (SI) of 72%. The SI is given by the following:

$$SI = A/(B + C - A)$$

where *A* is the collective number of target volume slices, *B* is the automatic target volume, and *C* is the manually contoured target volume.

By using the 3D functionality, the correction process, as performed by an experienced radiation oncologist, was completed in 5 minutes with an optimization of the SI up to 87%.

To evaluate the program for the landmark model, three radiation oncologists defined fourteen anatomic landmarks, as well as the level of the most superior and inferior slices of the target volume contour of an advanced laryngeal carcinoma (Fig. 5). For the landmark selection, well-reproducible anatomic level limits of the cervical region were preferentially selected, according to Gregoire *et al.* (12, 13).

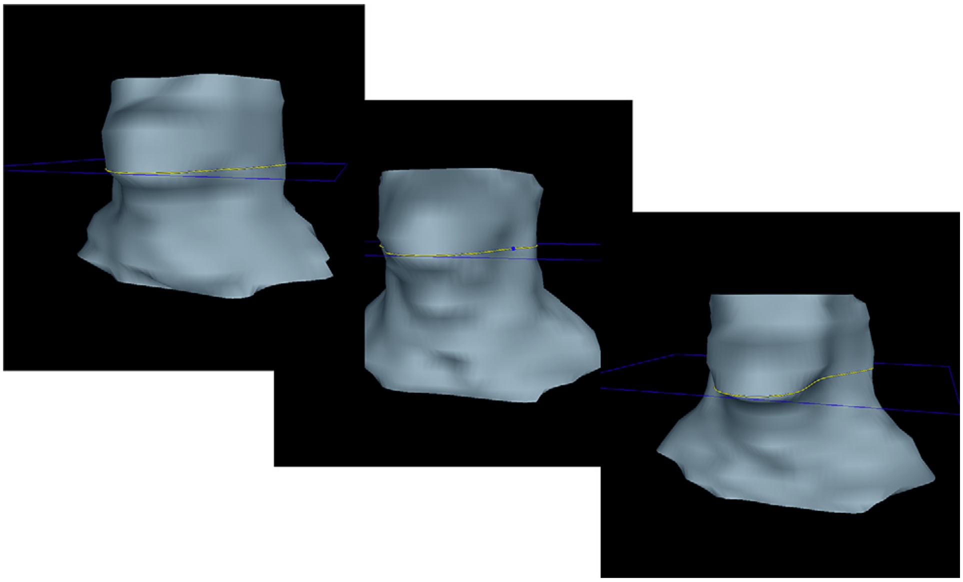

Fig. 1. Principal similarity of 2Nb-stage laryngeal cancer target volumes shown for three different head-and-neck tumor patients.