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Physics Contribution

Deep Learning Algorithm for Auto-Delineation of High-Risk Oropharyngeal Clinical Target Volumes With Built-In Dice Similarity Coefficient Parameter Optimization Function

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Summary

Clinical target volume (CTV) delineation can vary among physicians and practices. In an effort to reduce this variability, we developed a deep learning auto-delineation algorithm for high-risk CTVs with a Dice similarity parameter optimization function. Most of our predicted volumes had high agreement with the physician ground-truth volumes. The predicted contours could be implemented clinically with only minor or no changes.

Purpose: Automating and standardizing the contouring of clinical target volumes (CTVs) can reduce interphysician variability, which is one of the largest sources of uncertainty in head and neck radiation therapy. In addition to using uniform margin expansions to auto-delineate high-risk CTVs, very little work has been performed to provide patient- and disease-specific high-risk CTVs. The aim of the present study was to develop a deep neural network for the auto-delineation of high-risk CTVs.

Methods and Materials: Fifty-two oropharyngeal cancer patients were selected for the present study. All patients were treated at The University of Texas MD Anderson Cancer Center from January 2006 to August 2010 and had previously contoured gross tumor volumes and CTVs. We developed a deep learning algorithm using deep auto-encoders to identify physician contouring patterns at our institution. These models use distance map information from surrounding anatomic structures and the gross tumor volume as input parameters and conduct voxel-based classification to identify voxels that are part of the high-risk CTV. In addition, we developed a novel probability threshold selection function, based on the Dice similarity coefficient (DSC), to improve the generalization of the predicted volumes. The DSC-based function is implemented during an inner cross-validation loop, and probability thresholds are selected a priori during model parameter optimization. We performed a volumetric comparison between the predicted and manually contoured volumes to assess our model.

Results: The predicted volumes had a median DSC value of 0.81 (range 0.62-0.90), median mean surface distance of 2.8 mm (range 1.6-5.5), and median 95th Hausdorff distance of 7.5 mm (range 4.7-17.9) when comparing our predicted high-risk CTVs with the physician manual contours.

Conclusions: These predicted high-risk CTVs provided close agreement to the ground-truth compared with current interobserver variability. The predicted contours could be implemented clinically, with only minor or no changes.

Introduction

Manual delineation of clinical target volumes (CTVs) remains a time-consuming task in radiation oncology. CTVs are tissue volumes that contain the demonstrable gross tumor volume (GTV) and provide coverage for any suspected microscopic disease and pathways of tumor spread such as regional lymph nodes (1). Because the radiation dose is prescribed to these volumes and adequate coverage is required to achieve cure, accurate CTV delineation is essential in radiation therapy. Although established guidelines are available to delineate site-specific CTVs, these volumes are still subject to high intra- and interobserver variability for most treatment sites (2-6). This variability in delineation and the heterogeneity in clinical practice have hindered our ability to systematically assess the quality of the radiation therapy plans and are considered major sources of uncertainty (7).

When treating head and neck (H&N) cancer, radiation therapy prevails as the principal nonsurgical treatment option. For this site in particular, the complexity of radiation treatment planning and the time required to delineate the target and normal tissue volumes are significantly increased (8) owing to the large number of organs at risk located near H&N tumors. To add to this complexity, H&N treatment plans typically require several CTVs, which are used to deliver different radiation dose levels, depending on the risk of recurrence for that region (ie, high-, intermediate-, and low-risk volumes). In particular, accurate delineation of the high-risk CTV is imperative, and failure to provide adequate coverage has the potential to reduce tumor control and increase the risk of locoregional recurrence (9, 10).

Although an abundance of work auto-delineating normal structures using atlas-based registration techniques is available (11-13), little work has been performed to auto-delineate H&N CTVs, especially to auto-delineate high-risk target volumes. Machine learning and deep learning normal tissue auto-segmentation approaches have increased in popularity during the past few years. Some improvements in normal tissue segmentation have been observed using these novel techniques; however, a need remains to investigate these approaches for auto-delineation of CTVs. To the best of our knowledge, no registration-based approaches are available to auto-delineate high-risk CTVs. This is not surprising owing to the lack of significant features on computed tomography (CT) images (limited by coverage of possible microscopic disease) and the high variability in GTV geometric shape, location, and subsite involvement. Although definition of the high-risk CTV is guided by the anatomic structures, the high-risk CTV is neither a distinct structure, such as the GTV, nor a specific anatomic structure, such as elective nodal chains. These limitations have hindered the development of auto-delineation algorithms for these volumes.