A Deep Learning-Based Method for Predicting Volumes of Nasopharyngeal Carcinoma for Adaptive Radiation Therapy Treatment

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Abstract

This paper presents a new system for predicting the spatial change of Nasopharyngeal carcinoma(NPC) and organ-at-risks (OARs) volumes over the course of the radiation therapy (RT) treatment for facilitating the workflow of adaptive radiation therapy (ART).

Introduction

NPC is a malignant tumor occurring in the nasopharynx which lies behind the nose and above the level of the soft plate

During 33 days of RT treatment, the anatomical structures of the patient have changed. This cause an overdose to OARs, the risk of the exposure to healthy organs and a second chance for recurrent patients with less unrecoverable tissue damage.

ART is used to modify the initial planning in the pre-treatment according to the current patient condition such as the tumor response and anatomical changes of OARs.

The best timing for applying ART is still under debate. Therefore, we propose a system for predicting the future regions of NPC and OARs of *n-th* week in response to RT from previous weekly CT images from 1st to *(n-1)-th* week.

Materials

Our method is based on a weekly prediction of NPC and OARs shrinkage during the RT course. Therefore, a weekly axial CT images of 140 NPC patients during 6 weeks of RT course are constructed with size 512x512 [pixels].

From each weekly CT images, two radiation oncologists manually extract the regions of the NPC and 5 OARs (spinal cord, optic nerve, parotid gland, brainstem and lens) used as teaching labels.

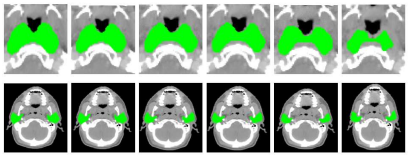

Figure 1. Examples of the shrinkage of NPC (Top row) and OARs (button row) during, (a)week 1, (b)week 2, (c)week 3, (d)week 4, (e)week 5 and (f)week 6, in response to RT.

Methods

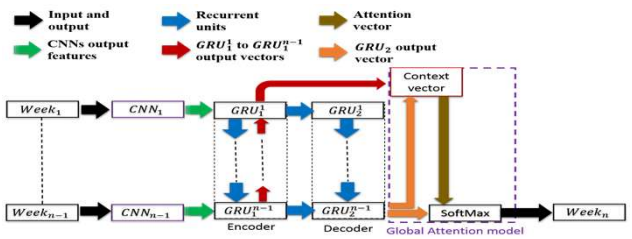

Figure 1. Architecture of TEP-Net.

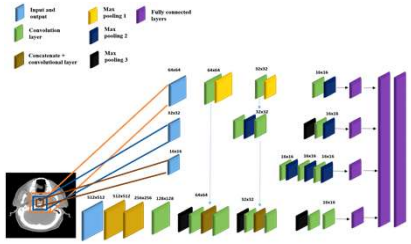

Figure 1. CNN construction.

- ❑ The system, called Tumor Evolution Prediction(TEP)-Net, consists of :
  - CNN to extract the features of CT images from week 1 to week *n-1*
  - Two GRUs to store and analyze the weekly trajectories of the NPC and OARs' shrinkage in response to RT treatment
  - Global attention model to predict the NPC and OARs at week n
- ❑ TEP-Net predicts NPC and OARs from axial, coronal and sagittal images
- ❑ 3D prediction of NPC and OARs by using:
  - Weighted voting method (TEP-NET-WV)
  - Fully connected networks (TEP-NET-FC)

Experimental Results

- NPC and OARs regions are predicted in week 4, 5 and 6 from CT images in week 1 to 3, week 1 to 4 and week 1 to 6, respectively.
- Four measurements: precision, recall, dice similarity coefficient (DSC) and root mean square symmetric surface distance (RMSSD) are used to evaluate the results

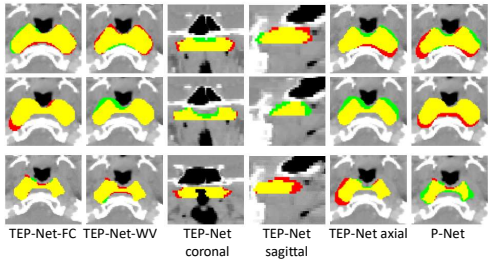

Figure 4. NPC predicted results in week 4 (Top row), week 5 (middle row) and week 6 (button row).(Green and red) ground truth and predicted region, respectively; (yellow) overlapping between the predicted region and the ground truth.

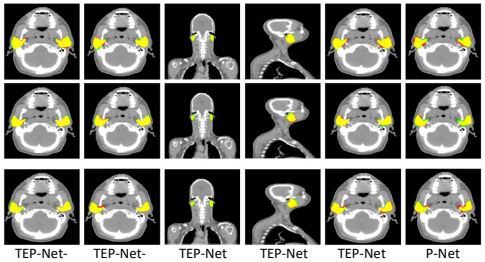

Figure 4. OARs predicted results in week 4 (Top row), week 5 (middle row) and week 6 (button row).(Green and red) ground truth and predicted region, respectively; (yellow) overlapping between the predicted region and the ground truth.

Table 1. Average and standard deviation of the accuracy of predicting NPC in (a) week 4. (b) week 5 and (c) week 6 by our five methods and P-Net.

Method	Precision	Recall	DSC		RMSSD	
			Values	*p*-value	Values	*p*-value
(a)Week 4						
TEP-Net-FC	**0.87 ± 0.31**	**0.85 ± 0.12**	**0.86 ± 0.51**	-	**1.4 ± 0.7**	-
TEP-Net-WV	0.86 ± 0.22	0.82 ± 0.18	0.84 ± 0.07	N.S.	1.5 ± 1.1	N.S.
TEP-Net sagittal	0.84 ± 0.091	0.84 ± 0.10	0.84 ± 0.09	< 0.05	1.4 ± 0.7	< 0.05
TEP-Net axial	0.82 ± 0.17	0.81 ± 0.15	0.81 ± 0.22	< 0.05	1.6 ± 0.4	< 0.05
TEP-Net coronal	0.80 ± 0.18	0.80 ± 0.23	0.80 ± 0.17	< 0.05	1.8 ± 0.9	< 0.05
P-net	0.78 ± 0.14	0.76 ± 0.21	0.77 ± 0.14	< 0.05	2.6 ± 1.1	< 0.05
(b)Week 5						
TEP-Net-FC	**0.88 ± 0.23**	**0.86 ± 0.25**	**0.87 ± 0.15**	-	**1.3 ± 0.7**	-
TEP-Net-WV	0.85 ± 0.15	0.86 ± 0.16	0.85 ± 0.41	N.S.	1.4 ± 0.8	N.S.
TEP-Net sagittal	0.83 ± 0.34	0.83 ± 0.16	0.83 ± 0.12	< 0.05	1.6 ± 1.4	< 0.05
TEP-Net axial	0.82 ± 0.09	0.83 ± 0.15	0.82 ± 0.31	< 0.05	1.7 ± 1.5	< 0.05
TEP-Net coronal	0.82 ± 0.12	0.82 ± 0.41	0.82 ± 0.17	< 0.05	1.7 ± 0.9	< 0.05
P-net	0.80 ± 0.12	0.80 ± 0.14	0.80 ± 0.17	< 0.05	1.8 ± 0.9	< 0.05
(c)Week 6						
TEP-Net-FC	**0.85 ± 0.08**	**0.81 ± 0.27**	**0.83 ± 0.13**	-	**1.4 ± 0.7**	-
TEP-Net-WV	0.82 ± 0.17	0.81 ± 0.24	0.81 ± 0.19	N.S.	1.8 ± 1.8	N.S.
TEP-Net sagittal	0.80 ± 0.32	0.80 ± 0.12	0.80 ± 0.13	< 0.05	1.8 ± 0.6	< 0.05
TEP-Net axial	0.78 ± 0.33	0.80 ± 0.01	0.79 ± 0.29	< 0.05	2.2 ± 1.4	< 0.05
TEP-Net coronal	0.78 ± 0.11	0.78 ± 0.09	0.78 ± 0.14	< 0.05	2.5 ± 0.2	< 0.05
P-net	0.76 ± 0.32	0.74 ± 0.21	0.75 ± 0.07	< 0.05	2.8 ± 1.2	< 0.05

Table 2. Average and standard deviation of the accuracy of predicting parotid gland in (a) week 4, (b) week 5 and (c) week 6 by our five methods and P-Net.

Method	Precision	Recall	DSC		RMSSD	
			Values	*p*-value	Values	*p*-value
(a)Week 4						
TEP-Net-FC	**0.87 ± 0.23**	**0.86 ± 0.07**	**0.86 ± 0.14**	-	**1.4 ± 0.9**	-
TEP-Net-WV	0.78 ± 0.28	0.78 ± 0.31	0.78 ± 0.22	N.S.	2.4 ± 0.7	N.S.
TEP-Net sagittal	0.84 ± 0.17	0.83 ± 0.32	0.83 ± 0.07	< 0.05	1.4 ± 0.5	< 0.05
TEP-Net axial	0.84 ± 0.12	0.82 ± 0.08	0.82 ± 0.13	< 0.05	1.5 ± 0.9	< 0.05
TEP-Net coronal	0.80 ± 0.23	0.80 ± 0.16	0.80 ± 0.11	< 0.05	1.8 ± 1.7	< 0.05
P-net	0.79 ± 0.44	0.79 ± 0.16	0.79 ± 0.17	< 0.05	2.2 ± 0.9	< 0.05
(b)Week 5						
TEP-Net-FC	**0.88 ± 0.21**	**0.87 ± 0.31**	**0.87 ± 0.12**	-	**1.3 ± 0.5**	-
TEP-Net-WV	0.85 ± 0.34	0.86 ± 0.22	0.85 ± 0.40	N.S.	1.4 ± 0.4	N.S.
TEP-Net sagittal	0.84 ± 0.04	0.83 ± 0.09	0.83 ± 0.19	< 0.05	1.6 ± 1.4	< 0.05
TEP-Net axial	0.83 ± 0.29	0.83 ± 0.45	0.83 ± 0.16	< 0.05	1.6 ± 0.8	< 0.05
TEP-Net coronal	0.83 ± 0.13	0.83 ± 0.51	0.83 ± 0.09	< 0.05	1.6 ± 0.5	< 0.05
P-net	0.81 ± 0.04	0.81 ± 0.08	0.81 ± 0.19	< 0.05	1.8 ± 0.8	< 0.05
(c)Week 6						
TEP-Net-FC	**0.86 ± 0.21**	**0.82 ± 0.47**	**0.84 ± 0.24**	-	**1.5 ± 1.4**	-
TEP-Net-WV	0.83 ± 0.18	0.82 ± 0.28	0.82 ± 0.19	N.S.	1.7 ± 0.5	N.S.
TEP-Net sagittal	0.81 ± 0.38	0.80 ± 0.14	0.80 ± 0.23	< 0.05	1.8 ± 1.1	< 0.05
TEP-Net axial	0.78 ± 0.35	0.80 ± 0.29	0.79 ± 0.15	< 0.05	2.1 ± 0.8	< 0.05
TEP-Net coronal	0.78 ± 0.17	0.77 ± 0.21	0.77 ± 0.19	< 0.05	2.6 ± 0.8	< 0.05
P-net	0.76 ± 0.17	0.74 ± 0.23	0.75 ± 0.25	< 0.05	2.8 ± 1.2	< 0.05

Discussion

TEP-Net-FC can predict the future shrinkage of NPC and OARs in response to RT robustly compared to the other five methods.

The paired t-test indicates that TEP-Net-FC is significantly different from all comparison method for DSC and RMSSD except TEP-Net-WV with no significant difference.

The obtained results prove that TEP-Net-FC can predict more robust the OARs with a large size compared with OARs with small size such as optic nerve and lens.

Despite the success of TEP-Net-FC, the predicted results obtained on week 6 are lower than those obtained on week 4 and week 5, where a 5 weekly CT images are used as input.

Conclusions

In this paper, we propose a new system for predicting the NPC and OARs response to RT treatment by using previous weekly changes of target region, week 1 to week *n-1*.

The proposed method predicts the target regions from weekly CT axial, coronal and sagittal images.

The final NPC and OARs prediction is obtained by integrating the obtained weights from the three sections.

From the experimental results, our proposed method using weighted fully connected layers as integration process, TEP-Net-FC, achieves a reliable prediction of NPC and OARs compared with other conventional prediction methods.

Future Directions

- We will introduce an integration by CNN with a conveniently loss function
- All OARs regions will be predicted and quantitative evaluations of each OAR accuracy will be reported.