Predicting dose-volume histograms for organ at risks using machine learning in head and neck Tomotherapy

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Introduction

- Radiation therapy plays an important and pivotal role in treating the patients with head and neck cancer.
- Patient specific dose prediction can contribute not only to improving treatment plan quality, but also to increasing efficacy of treatment planning work.
- In this study, dose prediction models for organ at risks (OARs) were developed and validated for head and neck (HN) tomotherapy using machine learning.

Materials and Methods

- ***Patient data***

Tomotherapy plans for 58 nasopharyngeal cancer (NPC) patients were employed. For each patient, three-dimensional the anatomical structures (the target and OARs) were characterized by using overlap volume histogram (OVH). Given target T and organ O, the OVH is a one-dimensional function giving the percent volume of O that is within a specific distance of r from T

$$OVH(r) = \frac{|\{p \in O | d(p,T) \leq r\}|}{|O|},$$

where $d(p,T)$ is the signed distance between point p and target's boundary, and the symbol | | represents the volume of an object. Dose volume histograms (DVHs) for brain stem, right and left parotid gland, right and left submandibular gland, right and left cochlea, esophagus, and spinal cord were included in training parameters.

- ***Principal component analysis of OVH and DVH***

Principal component analysis was applied to reduce dimension of OVHs and DVHs.

- ***Model training***

DVH prediction models for 9 OARs were trained and generated using 41 training data sets with the Ridge regression, Lasso regression, ElasticNet regression, and artificial neural network.

- ***Model validation***

The models were validated with 17 validation cases.

Results

- **Model training**

Table 1 The average mean square errors of the 10-fold cross validation with 10 repetition for OARs. Artificial neural network gave the best prediction performance for OARs.

OARs	Ridge regression	Lasso regression	ElasticNet regression	Artificial neural network
brain stem	0.1679±0.0146	0.1679±0.0146	0.1662±0.0123	0.1643±0.0051
RT parotid gland	0.1815±0.0166	0.1815±0.0166	0.1810±0.0160	0.1366±0.0150
LT parotid gland	0.1855±0.0297	0.1856±0.0297	0.1856±0.0297	0.1597±0.0101
RT submandibular gland	0.1767±0.0202	0.1768±0.0202	0.1760±0.0202	0.1608±0.0105
LT submandibular gland	0.1842±0.0230	0.1842±0.0231	0.1760±0.0164	0.1457±0.0105
RT cochlea	0.1885±0.0295	0.1882±0.0291	0.1883±0.0292	0.1785±0.0085
LT cochlea	0.1771±0.0146	0.1771±0.0146	0.1862±0.0267	0.1618±0.0092
esophagus	0.1666±0.0167	0.1667±0.0167	0.1688±0.0083	0.1471±0.0076
p_cord	0.1782±0.0130	0.1782±0.0130	0.1875±0.0466	0.1766±0.0076

RT : right; LT : left; p_cord : adding a 3mm margin to the actual spinal cord.

- **Model validation**

Table 2 The validation of predicted DVH for OARs on unseen data. Artificial neural network gave the lowest average mean square errors for OARs.

OARs	Ridge regression	Lasso regression	ElasticNet regression	Artificial neural network
brain stem	0.0831	0.0862	0.0802	0.0671
RT parotid gland	0.0663	0.0667	0.0651	0.0430
LT parotid gland	0.0723	0.0732	0.0723	0.0520
RT submandibular gland	0.0886	0.0886	0.0822	0.0671
LT submandibular gland	0.0850	0.0849	0.0845	0.0634
RT cochlea	0.0790	0.0792	0.0794	0.0596
LT cochlea	0.1006	0.1009	0.1001	0.0916
esophagus	0.0769	0.0772	0.0770	0.0612
p_cord	0.0733	0.0752	0.0724	0.0684

RT : right; LT : left; p_cord : adding a 3mm margin to the actual spinal cord.

- **Dosimetric characteristics**

Table 3 Comparison of original and predicted data by paired t-test. The predicted DVHs for OARs were in good agreement with the original data.

OARs	Parameter	Original data (Gy)	Predicted data (Gy)	*p*-value
brain stem	$D_{2\%}$	31.1±7.6	30.1±2.8	0.44
RT parotid gland	D_{mean}	23.0±3.8	23.5±2.8	0.24
LT parotid gland	D_{mean}	22.9±2.5	23.4±1.7	0.13
RT submandibular gland	D_{mean}	39.6±10.3	35.1±0.9	0.08
LT submandibular gland	D_{mean}	42.1±5.3	44.4±4.0	0.00
RT cochlea	D_{mean}	29.1±7.7	29.2±0.6	0.94
LT cochlea	D_{mean}	30.6±6.3	30.3±3.2	0.80
esophagus	D_{mean}	4.1±3.4	4.1±2.8	0.79
p_cord	$D_{2\%}$	26.9±3.5	25.8±0.7	0.18

RT : right; LT : left; p_cord : adding a 3 mm margin to the actual spinal cord;
$D_{2\%}$: dose received at least 2% of the volume; D_{mean}= mean dose.

- **Re-optimization of tomotherapy plan**

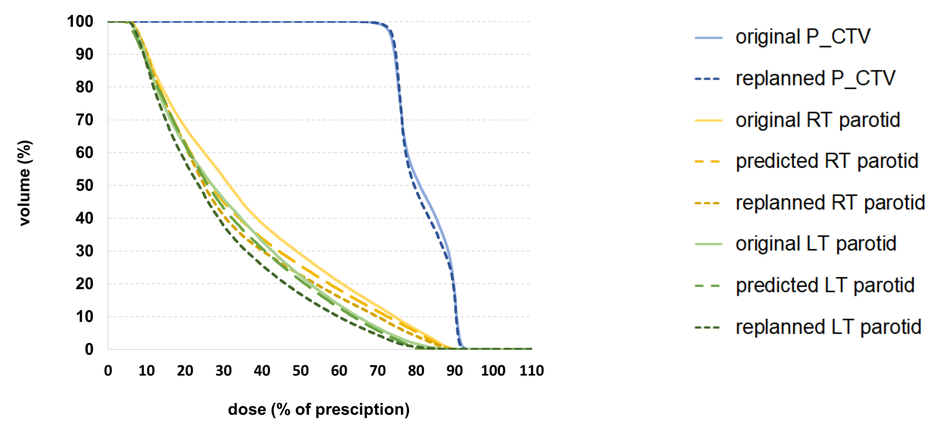

Figure 1 By re-optimization of tomotherapy plan with new dose constraints based on predicted dose value, a new DVH that matched the predicted DVH for parotid glands was obtained.

RT : right; LT : left; P_CTV : isotropic expansion of 3mm from clinical target volume.

Conclusion

The validation results of DVH prediction models for OARs matched well with the original plan in NPC tomotherapy. The patient specific DVH prediction from individual patient anatomic features could improve plan quality.