Medical Dosimetry ▮ (2016) ▮▮▮–▮▮▮

Medical Dosimetry

journal homepage: www.meddos.org

Research article

The dilemma of parotid gland and pharyngeal constrictor muscles preservation—Is daily online image guidance required? A dosimetric analysis

Olivia Duffy, B.Sc., Elizabeth Forde, M.Sc., and Michelle Leech, M.Sc.

Applied Radiation Therapy Trinity (ARTT), Discipline of Radiation Therapy, Trinity College, Dublin, Ireland

ARTICLE INFO

Article history:
Received 17 February 2016
Received in revised form
19 October 2016
Accepted 26 October 2016

Keywords:
Head and neck cancer
Daily image guidance
Pharyngeal constrictor muscles
Parotid glands

ABSTRACT

With margin reduction common in head and neck radiotherapy, it is critical that the dosimetric effects of setup deviations are quantified. With past studies focusing on the quantification of positional and volumetric changes of organs at risk (OARs), this study aimed to measure the dose delivered to these the parotid gland (PG) and pharyngeal constrictor muscles (PCMs) using cone beam computed tomography (CBCT). Furthermore, this investigation sought to establish a potential time trend of change in dose delivered to target volumes secondary to ascertaining the need for daily image guidance (IG) to reduce the dose burden to these important OARs. Intensity modulated radiotherapy (IMRT) plans for 5 locally advanced head and neck patients' plans were created and mapped to weekly CBCTs. Each plan was recalculated without heterogeneity correction allowing for dosimetric comparison. Dosimetric endpoints recorded to assess the effect of positional variation were as per ICRU 83 and included D_{95} and D_{98} for the target volumes, mean dose (MD) and $V_{30\ Gy}$ for the PGs, and $V_{50\ Gy}$ and MD for the PCMs. Results were deemed statistically significant if $p < 0.05$. No significant time trends were established for these OARs. A significant decrease in $V_{50\ Gy}$ was observed for all PCMs ($p < 0.001$) on all CBCTs relative to the original plan. Regarding target volumes, a highly significant decrease in MD (MD = 20 Gy, CI: −20.310 to −19.820) in D_{98} of the high-dose planning target volume (PTV [70 Gy]; $PTVD_{98\%} = 70$ Gy) for case 3 was found ($p \leq 0.001$). A nonpredictable, yet significant dosimetric effect was found. A clinically acceptable balance must be achieved between OAR dosimetry and target coverage as can be achieved by frequent IG.

Introduction

The radiotherapeutic management of head and neck cancer (HNC) patients with intensity modulated radiation therapy (IMRT) still poses challenges, despite the advancements in the precision of treatment delivery.[1] The conformality and characteristic sharp dose fall off of IMRT rationalizes it as the standard of care in this patient cohort, as it allows the sparing of critical structures that have close anatomical relationships to the target volumes. More specifically, it can be appreciated that a target volume proximal to the pharynx may receive doses up to 70 Gy whereas the parotid gland (PG), can be spared to receive only 30 Gy.[2,3]

There exists an inherent detriment with the sharp dose fall off by which the effect of set up errors can amplify dosimetric consequences. Although tumor control and late toxicity remain the primary outcomes measured, they cannot be considered in the absence of volumetric dose metrics, which have been highlighted in relation to the late sequelae of xerostomia and aspiration.[4,5] A dual problem exists as first the IMRT plan is based on a snapshot of the patient's anatomy whereby deviations may occur on a daily basis from this and its intended dose delivery. Secondly, the target volumes and organs at risk (OARs) undergo independent morphological changes as treatment progresses. It has been documented that the PGs can undergo progressive shrinkage in volume of up to 4.9% weekly.[6,7] Despite ICRU 62 revising nomenclature by the introduction of a planning OAR volume to account for such internal deviations, it overlooks the potential perturbation in dose distribution that is based on the residual changes the OAR can undergo devoid of setup uncertainties.[8]

Reprint requests to: Michelle Leech, M.Sc., Applied Radiation Therapy Trinity (ARTT), Discipline of Radiation Therapy, Trinity College, Dublin, Ireland.
E-mail: leechm@tcd.ie

http://dx.doi.org/10.1016/j.meddos.2016.10.003
0958-3947/Copyright © 2016 American Association of Medical Dosimetrists

Although past investigations have quantified the positional deviations and volumetric changes of these OARs, they lacked a serial computed tomography (CT)-based quantification of actual dosimetric effects caused by residual and internal changes. This study used cone beam CT (CBCT)-based image guidance (IG) to capture the dosimetric effect of these deviations on a patient's treatment plan. CBCT-based planning is now a feasible method to establish whether more frequent IG should be implemented to capture these internal deviations.[9-14]

In the current epidemological climate with human papillomavirus-mediated HNC increasing and younger cohorts with greater expected survival presenting for radiotherapy; minimization of acute and late sequelae becomes paramount.[15,16]

Methods and Materials

Patient population

After ethical approval, 5 HNC subsite cases were selected for inclusion in this dosimetric investigation. Prescription doses ranged from 60 to 70 Gy delivered in 30 to 35 fractions of 2 Gy per fraction, once daily.

Contouring

The target volumes and OARs were delineated as per ICRU 83, RTOG, and QUANTEC organ-specific papers, respectively, based on a CT slice thickness of 2.5 mm. OARs and their respective dose constraints adhered to during the planning process are summarized in Table 1. The PCMs were contoured manually by the lead investigator on the planning scans, using methods detailed in consensus publications by AIRO,[17] Eisbruch *et al.*,[18] Levendag *et al.*,[19] and Bhide *et al.*[20]

Optimization and planning

IMRT treatment plans, using nonopposing 5 to 9 field arrangements were generated using Eclipse treatment planning system. Each prescription was planned using 6 MV photons at a dose rate of 400 MUs per minute. Plans were calculated using the anisotropic analytical algorithm with a grid size of $0.25 \times 0.25\ cm^2$.

Each plan ensured 99.9% to 100% of the target volume received 95% of the prescribed dose.[21]

Plan application to CBCTs

Owing to the limitations in scan length of half-fan CBCT image acquisition, each patient's corresponding CBCT datasets were interpolated and a new 3D image generated using a grid of 0.25 cm. The new 3D CBCT images were registered to the patients planning CT scan using 3D rigid automatic bony registration to replicate the image match performed on the treatment unit. This method of registration was performed to reflect routine daily clinical practice as the corrections applied at treatment were unknown to the authors. The limited scan length also precluded any recontouring of structures directly on the CBCT images. Yang *et al.*[22] have indicated that owing to the inferior image quality of CBCT, owing to the increased scatter caused by a limited field-of-view in the longitudinal direction and the limited gantry rotation speed, the ability to delineate structures directly on a CBCT is hindered.

The IMRT plan based on the planning CT scan was applied to a corresponding CBCT from each week of treatment. A plan ("$Plan_{HOM}$") was generated from the IMRT plans by switching off the heterogeneity correction factor and recalculating the dose. This plan was then copied to each CBCT and recalculated, to ensure similarity in dose comparison and to avoid any discrepancy in calculation owing to variation in Hounsfield units between the planning CT and the CBCT. This is supported by Ma *et al.*,[23] where dose calculation on CBCT has a high level of agreement with a planning CT in regions of homogeneity, but not in regions where heterogeneities exist, such as in head and neck cases. Dosimetric data from each CBCT were then compared with each $Plan_{HOM}$.

Dosimetric and statistical analysis

To assess the dosimetric effect of positional variations, based on CBCT, the mean dose (MD) to the PGs as well as the volume receiving 30 Gy (V_{30}) was recorded. The MD was also recorded for the PCMs as was the V_{50}. Secondary to this the dosimetric effect of positional variation was assessed in relation to the target volumes.

Statistical analysis was performed using statistical package for social sciences (SPSS) version 20 comparing results from each CBCT-based plan and with the original $Plan_{HOM}$.

The Kolmogorov-Smirnov test was used to test the dosimetric data for normality. As all data were normally distributed, parametric 1-sample t-tests were used for each case quantifying the MD for each specified variable and result of which are found in Table 2. The time trend was analyzed using scatter-plot analysis and using Pearson correlations. Results are also summarized in Table 2.

Results

Ipsilateral PG

A statistically significant decrease in MD (MD = −0.210 Gy, CI: −0.390 to −0.340, $p < 0.050$) was only found in 1 case. This decrease in dose occurred after the fourth week of treatment after an initial increasing trend in dose received by the ipsilateral PG during weeks 2 to 5 (Fig. 1). No statistically significant dosimetric changes were found for $V_{30} < 50\%$ of the ipsilateral PG; however, the greatest nonsignificant MD was 9.4%. (CI: −77.610 to −36.670). No definitive time trend in dose received by the PGs was observed as depicted in Fig. 1. There was a nonsignificant effect on dose to the ipsilateral PG ($p > 0.050$) as expected from the anatomical location of these structures relative to the target volume.

Contralateral PG

A sinonasal case had a lower MD (1.5 Gy ± 0.050) in comparison with $Plan_{HOM}$ (1.6 Gy). This decrease was statistically significant ($p < 0.050$).

No statistically significant changes in $V_{30} < 50\%$ were noted. Two cases did not reach the required dosimetric threshold of 30 Gy on the original plans and were, therefore, excluded from the analysis.

Pharyngeal constrictor muscles

A statistically significant decrease in the volume of the PCMs receiving 50 Gy was found in all cases. The greatest decrease in

Table 1
QUANTEC and RTOG dose constraints for OARs

OAR	Dose constraint
Spinal cord	$D_{max} \leq 50$ Gy (< 1% risk of myelopathy) (QUANTEC)
Brainstem	$D_{max} \leq 54$ Gy (QUANTEC)
	1-10 cc < 59 Gy (RTOG)
Optic chiasm	$D_{max} < 54$ Gy (QUANTEC)
Ipsilateral and contralateral optic nerves	$D_{max} < 54$ Gy (QUANTEC)
Ipsilateral and contralateral cochleae	Mean dose < 45 Gy (QUANTEC)
Ipsilateral and contralateral lenses	D_{max} < 6–10 Gy (QUANTEC)
Ipsilateral and contralateral parotid glands	Mean dose < 26 Gy
	$V_{30} < 50\%$
Pharyngeal constrictor muscles	Mean dose < 60 Gy
Ipsilateral and contralateral submandibular glands	Mean dose < 35 Gy

D_{max} = maximum dose received by the OAR; QUANTEC = quantitative analyses of normal tissue effects in the clinic; RTOG = radiation therapy oncology group.