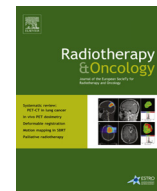




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Original article

A longitudinal evaluation of improvements in radiotherapy treatment plan quality for head and neck cancer patients

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ABSTRACT

Purpose: To investigate changes in head-and-neck cancer (HNC) plan quality following the introduction of new technologies and planning techniques in the last decade.**Methods and materials:** Thirty plans were selected from each of four successive periods (P). P1: 7-field static intensity-modulated radiotherapy (IMRT) with parotid gland sparing; P2: dual-arc volumetric-modulated arc therapy (VMAT, similar to P3–P4), including submandibular gland sparing; P3: inclusion of individual swallowing muscles and attempts to further reduce parotid and oral cavity doses through manual interactive optimization; P4: containing the same organs-at-risk (OARs) as P3, but automatically interactively optimized. Plan benchmarking included mean salivary gland/swallowing muscle/oral cavity ($D_{sal}/D_{swal}/D_{oc}$) doses. Differences in mean doses between the periods were analyzed by an ANCOVA, taking geometric differences across periods into account.**Results:** Compared to P1, P2 plans improved D_{sal} by 3.4 Gy on average. P3 improved $D_{sal}/D_{swal}/D_{oc}$ by 6.9/11.5/7.2 Gy over P2, showing that D_{swal} and D_{sal} could be improved simultaneously. In P4, D_{oc}/D_{swal} slightly improved over P3 by 1.7/3.8 Gy. Improved OAR sparing in P3/P4 did not come at the cost of increased dose deposition elsewhere and planning target volume (PTV) dose homogeneity was similar.**Conclusions:** New technologies and planning techniques were successfully implemented into routine clinical care and resulting in improved HNC plan quality.

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Radiotherapy treatment planning for locally advanced head-and-neck cancer (HNC) evolved over the years from only attempting spinal cord sparing [1], to sparing multiple additional organs-at-risk (OARs), including the parotid and submandibular glands, individual swallowing muscles and the oral cavity [2]. Minimizing salivary gland and oral cavity doses is important for reducing the severity and incidence of xerostomia and oral mucositis, respectively [3–5], while recent investigations highlight the importance of swallowing muscle sparing to prevent dysphagia [2,6–8]. Increased treatment plan complexity has been facilitated by advances in dose delivery techniques such as intensity-modulated radiotherapy (IMRT) and volumetric-modulated arc therapy (VMAT) which allow for the shaping of more complicated dose distributions [9]. However, IMRT and VMAT plan quality can vary substantially between planners and radiotherapy centers [10–13], partly due to the learning curve for advanced planning and partly because the amount of achievable OAR sparing is unknown before starting the planning process. Automated solu-

tions to generating consistent, high-quality treatment plans are therefore attracting interest [14–19].

Treatment planning improvements are often based on traditional planning studies, that compare plans created by different delivery or planning techniques on the same patient cohort, frequently leading to the adoption of the better technique for future patients. However, once new techniques are introduced in routine clinical practice, the realized gains in plan quality and dosimetry are rarely investigated.

Over the last decade, treatment planning for HNC at the VU University Medical Center evolved from static gantry IMRT plans solely attempting parotid gland, spinal cord and brainstem sparing, to automatically optimized dual-arc VMAT plans sparing the parotid and submandibular glands, up to seven individual swallowing muscles, and the oral cavity. Moving from controlled planning studies to routine clinical practice creates the risk that increasing plan complexity might lead to unexpected negative consequences. For example, sparing new OARs might degrade sparing of previously included OARs, dose deposition in normal tissue might increase, or dose conformity might be compromised. To investigate the impact of the successive introduction of new technologies and planning techniques, combined with sparing of more OARs, on

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routine plan quality, we performed an analysis of longitudinal dosimetric trends by comparing four periods from 2005 to 2015. Endpoints included sparing of new and prior OARs, dose conformity, planning target volume (PTV) dose coverage and homogeneity, and dose deposition in the body.

Materials and methods

Patient selection

Treatment plans of 120 locally advanced HNC patients were selected from four different time periods (30 patients per time period). Each period is characterized by the introduction of a new technology or planning approach. Geometric variability was minimized by only including patients with primary tumors located in the tonsillar region or lateral pharyngeal wall of the oropharynx.

Period 1 (P1, May 2005 to October 2008) patients were typically treated using seven equidistant coplanar IMRT fields with emphasis on PTV dose coverage and parotid gland, spinal cord and brainstem sparing.

P2 plans (July 2008 to May 2010) cover the introduction of VMAT (RapidArc™, Varian Medical Systems, Palo Alto, USA) for HNC patients in July 2008 [20,21]. Contralateral submandibular gland sparing was introduced in 2009 [22].

In P3 (August 2012 to October 2013) individual swallowing muscles were included for sparing [23] and the spinal cord maximum dose constraint was placed <40 Gy. Further dose reductions to the salivary glands were also attempted, facilitated by additional instructions and planner training in performing interactive optimization, and improved planning protocols. Additionally, while the oral cavity was occasionally included in P1–P2, routine sparing of this structure commenced halfway through P3. A “continue previous optimization” (CPO) was introduced after the first RapidArc optimization and subsequent dose calculation. The CPO is designed to compensate for differences between the fast dose calculation algorithm used during optimization, and the final, high resolution dose calculation, and generally improves PTV dose homogeneity [24].

In P1–P3, manual interactive optimization was performed using 3 to 5 optimization objectives for each parallel OAR, attempting to

Table 1
For all considered periods, the approach to planning, tumor stages and fractionation. Thirty patients were included per period and all included patients that received bilateral irradiation.

Period	1 Parotid gland sparing, 6/7-field IMRT	2 Submandibular gland sparing, dual arc VMAT	3 Swallowing muscle sparing, dual arc VMAT	4 Automatically optimized, dual arc VMAT
<i>Tumor staging</i>				
T4	12 (N0 = 4/N1 = 3/N2 = 4)	12 (N0 = 2/N1 = 3/N2 = 5/N3 = 1)	3 (N0 = 2/N1 = 1)	8 (N0 = 1/N1 = 4/N2 = 3)
T3	10 (N0 = 2/N1 = 2/N2 = 6)	6 (N0 = 1/N1 = 1/N2 = 4)	3 (N2 = 2/N1 = 1)	10 (N0 = 2/N1 = 6/N2 = 2)
T2	7 (N0 = 1/N1 = 2/N2 = 4)	11 (N0 = 3/N1 = 2/N2 = 6)	19 (N0 = 1/N1 = 3/N2 = 15)	9 (N0 = 3/N1 = 2/N2 = 4)
T1	1 (N1 = 1)	1 (N0 = 1)	4 (N1 = 1/N2 = 3)	2 (N2 = 2)
Tx	–	–	1 (N2 = 1)	1 (N2 = 1)
<i>Prescribed doses/fractionation</i>				
Boost PTV	70 Gy/35 × 2 Gy	70 Gy/35 × 2 Gy	70 Gy/35 × 2 Gy	70 Gy/35 × 2 Gy
Elective PTV	54.25 Gy/35 × 1.55 Gy (n = 23)	54.25 Gy/35 × 1.55 Gy (n = 11)	54.25 Gy/35 × 1.55 Gy (n = 30)	54.25 Gy/35 × 1.55 Gy (n = 30)
	57.75 Gy/35 × 1.65 Gy (n = 7)	57.75 Gy/35 × 1.65 Gy (n = 19)		

Abbreviations: *, † and #: statistically significant differences ($p < 0.05$) with respect to period 1, period 2 and period 3, respectively. Evaluated using independent sample t -tests.

Table 2
For all considered periods, the size of planning target volumes (PTVs) and organs-at-risk (OARs), and the OAR-PTV overlap volumes, averaged over all 30 patients. Data are presented by mean ± standard deviations (range).

Period	1	2	3	4
<i>PTV volumes (cm³)</i>				
Boost	220.5 ± 102.1 (68.2 to 513.1)	233.7 ± 167.7 (39.8 to 801.8)	184.3 ± 55.2 (94.5 to 315.0)	192.9 ± 104.1 (36.8 to 420.8)
Elective	368.2 ± 120.0 (160.6 to 668.1)	370.0 ± 105.9 (229.9 to 676.4)	387.7 ± 85.1 (238.9 to 592.6)	333.5 ± 58.3 (240.1 to 484.1)#
Transition	36.5 ± 20.6 (6.8 to 101.0)	44.5 ± 35.5 (3.7 to 169.5)	75.5 ± 27.0 (22.8 to 144.3)†*	70.1 ± 37.2 (18.6 to 167.3)†*
Elective + transition	404.7 ± 133.1 (194.9 to 743.6)	414.5 ± 118.5 (268.3 to 719.1)	463.2 ± 98.0 (284.0 to 697.2)	403.7 ± 60.8 (282.0 to 571.2)#
Combined PTV	625.2 ± 221.0 (263.1 to 1237.8)	648.2 ± 212.8 (372.6 to 1143.5)	647.4 ± 129.2 (378.5 to 878.5)	596.6 ± 133.0 (336 to 882.6)
<i>OAR volumes (cm³)</i>				
Composite salivary glands	76.2 ± 20.8 (49.3 to 123.5)	69.4 ± 18.7 (36.2 to 112.8)	82.3 ± 25.3 (31.4 to 130.5)†	75.0 ± 16.1 (38.9 to 107.6)†
Composite swallowing muscles	31.1 ± 7.9 (18.5 to 50.8)	31.7 ± 9.1 (17.8 to 51.6)	37.4 ± 9.5 (21.1 to 54.6)†*	34.9 ± 11.1 (23.1 to 71.7)†*
Oral cavity	122.3 ± 47.0 (43.5 to 270.3)	92.4 ± 29.1 (39.8 to 150.1)*	102.5 ± 25.0 (21.2 to 137.2)*	104.7 ± 51.5 (21.1 to 261.3)*
<i>OAR-PTV overlap volumes (%)</i>				
Composite salivary glands	28.6 ± 11.5 (8.4 to 52.4)	27.4 ± 13.2 (6.5 to 62.5)	23.9 ± 8.6 (9.3 to 42.5)	22.4 ± 9.8 (7.7 to 50.0)†
Composite swallowing muscles	26.9 ± 20.6 (7.6 to 86.2)	32.8 ± 23.4 (8.5 to 91.6)	21.1 ± 11.5 (5.1 to 50.1)†	21.9 ± 13.6 (0.7 to 61.5)†

Abbreviations: *, † and #: statistically significant differences ($p < 0.05$) with respect to period 1, period 2 and period 3, respectively. Evaluated using independent sample t -tests.

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