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Original article

Is accurate contouring of salivary and swallowing structures necessary to spare them in head and neck VMAT plans?

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ABSTRACT

Background and purpose: Current standards for organ-at-risk (OAR) contouring encourage anatomical accuracy which can be resource intensive. Certain OARs may be suitable for alternative delineation strategies. We investigated whether simplified salivary and swallowing structure contouring can still lead to good OAR sparing in automated head and neck cancer (HNC) plans.

Materials and methods: For 15 HNC patients, knowledge-based plans (KBPs) using RapidPlan™ were created using: (1) standard clinical contours for all OARs (benchmark-plans), (2) automated knowledge-based contours for the salivary glands, with standard contours for the remaining OARs (SS-plans) and (3) simplified contours (SC-plans) consisting of quick-to-draw tubular structures to account for the oral cavity, salivary glands and swallowing muscles. Individual clinical OAR contours in a RapidPlan™ model were combined to create composite salivary/swallowing structures. These were matched to tube-contours to create SC-plans. All plans were compared based on dose to anatomically accurate clinical OAR contours.

Results: Salivary gland delineation in SS-plans required on average 2 min, compared with 7 min for manual delineation of all tubular-contours. Automated atlas-based contours overlapped with, on average, 71% of clinical salivary gland contours while tube-contours overlapped with 95%/75%/93% of salivary gland/oral cavity/swallowing structure contours. On average, SC-plans were comparable to benchmark-plans and SS-plans, with average differences in composite salivary and swallowing structure dose ≤2 Gy and <1 Gy respectively.

Conclusions: Simplified-contours could be created quickly and resulted in clinically acceptable HNC VMAT plans. They can be combined with automated planning to facilitate the implementation of advanced radiotherapy, even when resources are limited.

Recent advances in radiotherapy have allowed increased sparing of organs-at-risk (OARs) in anatomically complex disease sites such as the head-and-neck. The clinical relevance of sparing OARs, such as the parotid glands and swallowing structures, has been demonstrated [1,2]. However, accurately contouring the many OARs necessary to conform to "state-of-the-art" guidelines is often time- and labor-intensive and is furthermore subject to considerable inter-observer variation, even for relatively simple OARs like the parotid glands [3]. While certain automated solutions have been proposed including atlas-based segmentation, these still require manual review/editing, limiting gains in time and efficiency [4–6]. These factors are barriers to the implementation of advanced radiotherapy in well-resourced environments and so are presumably even more relevant in low- and middle-income countries (LMICs) [7], where large numbers of HNC patients reside [8].

Contouring has become an increasingly evident rate-limiting step in the planning process as semi-automated knowledge-based planning can now quickly generate plans, even for complex regions such as the head-and-neck [9,10]. While certain critical structures, such as the spinal cord, necessitate accurate delineation in order to avoid partial omission of the organ from the contour and increased risks of unacceptable toxicity, other OARs may be tolerant of less conformal contours. This need not lead to worse overall OAR sparing as long as the majority of the OAR is within the contour. In addition, because patient anatomy may change during the course of radiotherapy, highly conformal delineation may be less robust [11,12]. We use the head-and-neck region as a paradigm to test whether accurate OAR delineation of salivary and swallowing structures is essential to create good treatment plans. In the process we evaluate whether an existing automated

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planning solution (RapidPlan™, Varian Medical Systems, Palo Alto, CA), containing a model library of previous treatment plans based on anatomically accurate contours, is versatile enough to also generate plans based on simplified-contours.

HNC plans, created using a simplified-contouring approach, were compared on the basis of OAR doses, to plans made with an automated atlas-based segmentation tool and plans made with manual clinical contours. If simplified contouring combined with automated planning can create good organ-sparing head and neck radiotherapy plans, this would provide a novel paradigm for helping to bring state-of-the-art radiotherapy to patients in limited resource environments.

Methods

Clinical plans

In our department, head-and-neck cancer (HNC) is treated using volumetric modulated arc therapy (VMAT; RapidArc™, Varian Medical Systems, Palo Alto USA), using 2 full arcs and 6-MV photons. Prescription doses of 70 Gy and 54.25 Gy are delivered to the boost (B) and elective (E) planning target volumes (PTV_B and PTV_E, respectively) in 35 fractions using a simultaneously integrated boost. Plans aim to deliver 95% of the prescribed doses to 99%/98% of PTV_B/PTV_E (using a virtual bolus for PTVs in close proximity to the body surface), while limiting the volume receiving >107% (V107) of the prescribed dose. A 5-mm transition region for dose fall-off is created between the PTVs and subtracted from PTV_E. Individual salivary and swallowing OARs are accurately delineated, with the pharyngeal constrictor muscle divided into 3 portions, based on the guidelines of Christianen et al. [13]. Clinical plans aimed to spare the oral cavity, salivary glands and swallowing structures (Table 1), however, it may have been decided not to spare certain structures due, for example, to excessive overlap with the PTV. RapidArc optimization for HNC was carried out using the progressive resolution optimizer v10.0.28 (Eclipse™ treatment planning system, Varian Medical Systems) combined with automated interactive optimization, as described previously [14,15]. Dose was calculated using Acuros™ 11.0.31 with a 2.5 mm calculation grid. A subsequent continue-previous-optimization (CPO) was performed to improve PTV dose homogeneity [16]. The brainstem, spinal cord and their planning-at-risk volumes (3-mm expansion) were assigned maximum point dose objectives placed below their respective dose tolerances. A 5–10 mm wide ring structure 5 mm from both PTVs, and a normal tissue objective, were used to stimulate dose fall-off.

Automated knowledge-based contouring

Smart Segmentation® (Varian Medical Systems) is a knowledge-based contouring tool [17]. A contouring-library comprising 94 HNC cases was created. This was ultimately only used to delineate the salivary glands as it did not perform well enough on the swallowing structures and oral cavity (Supplementary materials). Standard clinical contours were therefore used for the remaining non-salivary OARs in Table 1.

Table 1
Average volumes of clinical, smart-segmentation and simplified tube contours and average overlap percentage of clinical contours with smart-segmentation and simplified tube contours.

Clinical contours	Average Volume (cm^3)	Average overlap of clinical and smart segmentation contour (%)	Average overlap of clinical and simplified tube contour (%)
Salivary glands			
Contralateral parotid	32.8 ± 8.5	75.6 ± 12	95.2 ± 3.2
Ipsilateral parotid	32.4 ± 8.9	74 ± 10.7	94.5 ± 5.1
Contralateral submandibular	10.6 ± 2.2	69.6 ± 16.7	95.5 ± 2.4
Ipsilateral submandibular	10 ± 2.4	64.6 ± 22.9	96.3 ± 2.9
Oral cavity			
Oral cavity	217.9 ± 49.5		75.3 ± 9.6
Swallowing structures			
Cricopharyngeal muscle	3.5 ± 1.4		94 ± 3.5
Lower larynx	3.9 ± 2.1		92.6 ± 3.9
Upper larynx	12.4 ± 5.5		96 ± 3.3
Inferior pharyngeal constrictor	4 ± 1.8		93.4 ± 4.4
Medial pharyngeal constrictor	4.2 ± 2.2		91.1 ± 8.0
Superior pharyngeal constrictor	9.6 ± 1.9		92.4 ± 6.1
Upper esophageal sphincter	1.3 ± 0.4		95.3 ± 4.0
Trachea	30.3 ± 12.1		89.8 ± 9.7
Esophagus	7.8 ± 3.1		88 ± 11.6
Smart segmentation			
Salivary glands			
Contralateral parotid	27.4 ± 6.4		
Ipsilateral parotid	28.2 ± 7.5		
Contralateral submandibular	7.2 ± 2.8		
Ipsilateral submandibular	7.7 ± 1.3		
Simplified tube contours			
Salivary glands			
Contralateral parotid tube	87.2 ± 12.3		
Ipsilateral parotid tube	86.4 ± 10.4		
Contralateral submandibular tube	30.5 ± 3.5		
Ipsilateral submandibular tube	31.6 ± 3.6		
Oral cavity			
Oral cavity tube	194.7 ± 28.6		
Swallowing structures			
Lower tube	67.8 ± 12.6		
Medial tube	60.1 ± 18.2		
Upper tube	66.1 ± 10.7		

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