Prediction and prevention of radiation-induced swallowing dysfunction

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CHAPTER 2
Delineation of organs at risk involved in swallowing for radiotherapy treatment planning

Miranda E.M.C. Christianen, Johannes A. Langendijk, Henriëtte E. Westerlaan, Tara A. van de Water, Hendrik P. Bijl

Radiotherapy and Oncology 101 (2011) 394-402
CHAPTER 2

Abstract

Background and purpose: Radiotherapy (RT), alone or combined with chemotherapy, is a treatment modality used frequently in head and neck cancer. In order to report, compare and interpret the sequelae of radiation treatment adequately, it is important to delineate organs at risk (OARs) according to well-defined and uniform guidelines. The aim of this paper was to present our institutional Computed Tomography (CT)-based delineation guidelines for organs in the head and neck at risk for radiation-induced swallowing disorders (SWOARs).

Material and methods: After analyses of the human anatomy of the head and neck area and literature review, CT-based guidelines for delineation of the most relevant SWOARs were described by a panel of experts.

Results and conclusions: This paper described institutional guidelines for the delineation of potential SWOARs, accompanied by CT-based illustrations presenting examples of the delineated structures and their corresponding anatomic boundaries. This paper is essential to ensure adequate interpretation of future reports on the relationship between dose distribution in these SWOARs and different aspects of post-treatment swallowing dysfunction.
Introduction

Many head and neck cancer (HNC) patients treated with (chemo) radiation (CH) RT have to deal with devastating side-effects of their treatment\(^1\). In particular, a significant increase in the incidence of swallowing dysfunction after intensified regimens, such as the addition of concurrent chemotherapy to radiotherapy, has been observed\(^2\). Numerous studies revealed that swallowing dysfunction after completion of treatment has a significant impact on the general dimensions of quality of life\(^2-4\), which is probably even more important than radiation-induced xerostomia\(^1,5\).

Studies on swallowing dysfunction using videofluoroscopy after (CH) RT for HNC revealed a large variety of motility disorders\(^2,6-17\). These swallowing disorders can lead to clinically apparent as well as silent or subclinical aspiration or continued alternate feeding such as placement of a nasogastric or a percutaneous endoscopic gastrostomy tube\(^2,4,6-8,16-18\).

Given the complexity of swallowing and the large variety of disorders after (CH) RT, there are a large number of potential organs at risk (OARs) for radiation-induced swallowing dysfunction. Several authors investigated the relationship between the dose distributions in potential swallowing organs at risk (SWOARs) and different aspects of swallowing dysfunction\(^5,19-28\). These studies retrieved different results, which may be due to a number of methodological issues, including the relatively small number of patients in most of these studies, differences in eligibility criteria and differences in study design and endpoints chosen. Even more important, the definition and delineation of the SWOARs among the studies that reported on dose-volume effect relationships differ which may also account for different outcomes in terms of associations between dose-volume histogram (DVH) parameters and swallowing dysfunction. Therefore, in order to compare and interpret the results among studies, it becomes increasingly important to accurately describe the way potential SWOARs are defined and delineated.

The past 3 years, a number of prospective studies on risk factors for post-treatment swallowing dysfunction have been carried out at the departments of Radiation Oncology of the VU University Medical Center (VUMC) and the University Medical Center Groningen (UMCG), including studies on dose effect relationships. To ensure proper interpretation of the results of these studies in future publications, we felt it was important to describe how the different structures were defined and delineated, in particular for potential SWOARs.

Therefore, the main objective of this paper was to present our institutional CT-image based delineation guidelines for anatomic structures involved, or potentially involved in radiation-induced swallowing dysfunction that eventually permit unambiguous interpretation of dose-volume-effect relationships for SWOARs as will be reported in a number of upcoming publications.
The normal swallowing process

Swallowing involves multiple muscles and other structures. The pharyngeal musculature, including the circular constrictors (the superior, middle and inferior pharyngeal constrictor muscle (PCM)) and longitudinal muscles (the stylopharyngeal, salpingopharyngeal, and palatopharyngeal muscles) are required to prevent food from entering the nose (in collaboration with the soft palate) and for peristalsis and synchronization among the pharyngeal contraction wave. In addition, they are responsible for the opening of the cricopharyngeal sphincter, and closure of the larynx. The base of tongue drives the bolus through the pharynx and makes contact with the posterior pharyngeal wall assuring that no residue remains in the vallecula. Glottic adductor muscles (the thyroarytenoid, lateral cricoarytenoid, and transverse arytenoid muscles) and supraglottic adductors (oblique arytenoids and aryepiglottic muscles) take care of glottic closure and adduction of the supraglottic larynx during swallow. The cricopharyngeal sphincter opens by relaxation of the cricopharyngeal muscle, upward and forward motion of the cricoid cartilage by the suprahyoide muscles (the geniohyoid, mylohyoid, and digastric muscles), and the pressure generated on the bolus which widens both the cricopharyngeal sphincter and the inlet muscles of the esophagus.

Thus, a number of valves are involved to direct food into the esophagus and prevent food from entering the airway or the nose. These valves include (1) the velopharyngeal valve, which is comprised of the soft palate and the pharyngeal walls; (2) the larynx, operating at the levels of epiglottis and aryepiglottic folds, the false vocal folds and arytenoid cartilages, and the true vocal folds; (3) the base of tongue; and (4) the cricopharyngeal sphincter, which is comprised of the cricoid cartilage and the cricopharyngeal muscle.

Guidelines for SWOARs

General methodology

In the next paragraph, we present our guidelines for SWOARs based on normal anatomy and function, while at the same time keeping as close as possible to the definitions used in former studies when appropriate.

The definitions of the SWOARs were described by a panel of experts, including two specialized head and neck radiation oncologists (HB and JL) and an experienced head and neck radiologist (HW).

In addition, the SWOARs were delineated on a contrast-enhanced planning CT-scan from an edentate female patient with a T2N0 nasal cavity tumor that did not affect the shape of the anatomic structures concerned. Contouring was carried out using the Pinnacle treatment planning system (TPS) (version 8.0 h, Philips Radiation Oncology Systems, Fitchburg, WI). The SWOARs were delineated by one radiation oncologist and reviewed and adjusted when considered appropriate by...
DELINEATION GUIDELINES SWALLOWING STRUCTURES

the other experts. Overall, the center and width values (window settings) used to delineate the SWOARs were set to 900 Hounsfield Unit (HU) and 326 HU, respectively. In some cases these specific values were changed to improve the visibility of certain anatomical structures and/or boundaries. We did not specify these settings as the exact values resulting in the best display may vary among different patients.

A general overview of potential SWOARs are depicted in Figure 1. For each SWOAR included in this paper, we described the normal anatomy and guidelines used by other authors (Table 1) were taken into account, ultimately ending up with the definitions and delineation guidelines for each SWOAR (Table 2 and Figure 2).

**Pharyngeal constrictor muscles**

The pharyngeal wall is composed of two layers of muscles, including an external circular layer consisting of the pharyngeal constrictor muscles (PCM) and an internal mainly longitudinal layer consisting of the two levators. The PCM can be divided in a superior, middle and inferior part. The distal parts of the levators (the stylopharyngeal, salpingopharyngeal, and palatopharyngeal muscles) approach and blend with the PCM. In general, it is hard to distinguish these longitudinal muscles from the PCM. Therefore, we decided not to contour these two structures separately as the most distal parts of these longitudinal muscles are already enclosed in the PCM.

Figure 1. General overview of anatomical structures involved in swallowing. The following reference anatomical structures are shown: (1) processus pterygoideus, (2) levator veli palatine, (3) fascia pharyngobasilaris, (4) raphe pterygomandibularis, (5) superior PCM, (6) styloglossus, (7) anterior tubercle of atlas, (8) stylopharyngeus, (9) middle PCM, (10) geniohyoideus (cut), (11) hyoid, (12) inferior PCM (thyropharyngeal part), (13) thyroid cartilage, (14) cricoid cartilage, (15) cricopharyngeus, and (16) esophagus.
<table>
<thead>
<tr>
<th>Author</th>
<th>Pharyngeal constrictor muscles</th>
<th>Esophagus inlet muscle</th>
<th>Cricopharyngeus</th>
<th>Cervical esophagus</th>
<th>Base of tongue</th>
<th>Larynx</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Superior PCM</td>
<td>Middle PCM</td>
<td>Inferior PCM</td>
<td>Cranial</td>
<td>Caudal</td>
<td>Supraglottic</td>
</tr>
<tr>
<td>Bhide (2009)*</td>
<td>Cranial: base of the skull</td>
<td>Caudal: superior end of the hyoid bone</td>
<td>Cranial: Caudal end of the cricoid cartilage</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
</tr>
<tr>
<td></td>
<td>Caudal: superior end of the hyoid bone</td>
<td>Caudal: Caudal end of the hyoid bone</td>
<td>Cranial: Caudal end of the cricoid cartilage</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
</tr>
<tr>
<td></td>
<td>Posterior: pre-vertebral muscles</td>
<td>Anterior: pharyngeal lumen (mucosa included)</td>
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</tr>
<tr>
<td>Caglar (2008)*</td>
<td>Cranial: pterygoid plates</td>
<td>Cranial: inferior edge of the cricoid</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
<td>Cranial: lower edge of the cricoid</td>
<td>Not mentioned</td>
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<tr>
<td></td>
<td>Caudal: upper edge of the hyoid bone</td>
<td>Cranial: inferior edge of the hyoid bone</td>
<td>Caudal: lower edge of the hyoid bone</td>
<td>Not mentioned</td>
<td>Caudal: most extent of the low-neck target</td>
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</tr>
<tr>
<td>Caudell (2010)*</td>
<td>Cranial: pterygoid plates</td>
<td>Cranial: inferior edge of the cricoid cartilage</td>
<td>Not mentioned</td>
<td>Cranial: inferior edge of the cricoid cartilage</td>
<td>Cranial: inferior edge of the cricoid cartilage</td>
<td>Cranial: inferior edge of the cricoid cartilage</td>
</tr>
<tr>
<td></td>
<td>Caudal: superior portion of the hyoid bone</td>
<td>Cranial: inferior portion of the hyoid bone</td>
<td>Caudal: inferior edge of the cricoid cartilage</td>
<td>Not mentioned</td>
<td>Caudal: inferior portion of the hyoid bone</td>
<td>Cranial: inferior edge of the cricoid cartilage</td>
</tr>
<tr>
<td></td>
<td>Caudal: upper edge of the hyoid bone</td>
<td>Caudal: upper edge of the hyoid bone</td>
<td>Caudal: lower edge of the hyoid bone</td>
<td>Not mentioned</td>
<td>Caudal: upper edge of the hyoid bone</td>
<td>Caudal: lower edge of the hyoid bone</td>
</tr>
</tbody>
</table>

**Table 1:** Anatomical borders of swallowing organs at risk used in the eight studies published between 2000 and 2010.
<table>
<thead>
<tr>
<th>Author</th>
<th>Pharyngeal constrictor muscles</th>
<th>Cricopharynxus</th>
<th>Esophagus inlet muscle</th>
<th>Cervical esophagus</th>
<th>Base of tongue</th>
<th>Larynx</th>
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<tbody>
<tr>
<td></td>
<td>Superior PCM</td>
<td>Middle PCM</td>
<td>Inferior PCM</td>
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<tr>
<td>Feng (2007)*</td>
<td>Cranial: caudal tips of the pterygoid plates</td>
<td>Cranial: upper edge of the hyoid bone</td>
<td>Caudal: inferior edge of the hyoid bone</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
<td>Cranial: inferior border of the cricoid</td>
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<td>Caudal: caudal-most extent of the low neck targets</td>
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<td></td>
<td></td>
<td>Contoured as a single structure</td>
</tr>
<tr>
<td>Jensen (2007)</td>
<td>Cranial: lower part of transverse process of C2</td>
<td>Caudal: top of the cricoid cartilage</td>
<td>Anterior: widest diameter of rhinopharynx, base of tongue, hyoid bone and larynx</td>
<td>Not mentioned</td>
<td>At the level of the cricoid cartilage</td>
<td>Cranial: below soft palate</td>
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<td></td>
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<td></td>
<td>Caudal: first slice with epiglottis</td>
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<td></td>
<td>Anterior: posterior 0.5-1.0 cm rim of the tongue</td>
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<td></td>
<td>Caudal: top of the cricoid cartilage</td>
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<td></td>
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<td></td>
<td>Anterior: posterior 0.5-1.0 cm rim of the tongue</td>
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<td></td>
<td></td>
<td>Lumen excluded</td>
</tr>
<tr>
<td>Li (2009)</td>
<td>Cranial: caudal tips of the pterygoid plates</td>
<td>Cranial: below the hyoid</td>
<td>Caudal: inferior edge of the hyoid</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
<td>Cranial: 1 cm caudal from the caudal inlet</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>Caudal: caudal cricoid</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Caudal: thoracic inlet</td>
</tr>
</tbody>
</table>

* Refers to guidelines as defined by Eisbruch 2004. Abbreviations: PCM=pharyngeal constrictor muscle.
The superior PCM
The superior PCM is a quadrilateral sheet of muscles originating from the pterygoid hamulus of the sphenoid bone. The insertion of all fibers unites in the median raphe and in the aponeurosis that is attached to the pharyngeal tubercle on the basilar part of the occipital bone.

Levendag et al. defined the cranial border of the superior PCM in the middle of the 2nd vertebra, which is lower than the actual cranial border of the superior PCM. In most studies, the authors defined the caudal tip of the pterygoid plates as the cranial border of the superior PCM. Indeed, the caudal tip of the pterygoid plates corresponds with the pterygoid hamulus of the sphenoid bone and thus with the actual cranial border of the most cranial fibers of the superior PCM (Figure 3). Some authors only mentioned the pterygoid plates as cranial border. However, the pterygoid plate generally extents through a number of slides in cranial-caudal direction and therefore provides a less accurate definition of the cranial border of the superior PCM. Therefore, we decided to define the cranial border of the superior PCM as the caudal tip of the pterygoid plate, i.e., the pterygoid hamulus (Table 2).

The lowest fibers of the superior PCM are roughly separated from the middle PCM by the stylopharyngal muscle and the glossopharyngeal nerve but also partly overlap with the highest fibers of the middle PCM. However, it is hardly possible to distinguish these structures on CT. Most authors defined the caudal border of the superior PCM as the upper edge of the hyoid bone, although the most caudal fibers of the superior PCM attach to the hyoid bone. If the upper edge of the hyoid bone would be defined as the lower border, almost half of the middle PCM will be missed (see Figure 1). Therefore, we decided to define the lower border of the 2nd cervical vertebra as the caudal border of the superior PCM.

The posterior border of the superior PCM is defined by the prevertebral muscles and fascia, from which it is separated by the retropharyngeal space.

Anteriorly, the superior PCM is attached to the pterygoid hamulus (clearly visible on CT), the pterygomandibular raphe (not visible on CT), the posterior end of the mandible (to which the pterygomandibular raphe is attached), and to the base of tongue. However, it is difficult to define exactly how these structures can be used on CT to define the anterior borders of the superior PCM. We assume, that for this reason, two authors decided to define the anterior border as the widest diameter of the rhinopharynx, the base of tongue and the hyoid bone as the anterior border as surrogate anterior borders, which approximately corresponds with the actual anterior border of the superior PCM (Table 1). With regard to the part of the superior PCM anteriorly from the prevertebral muscles, the anterior border is defined as the pharyngeal lumen. As a consequence, the pharyngeal mucosa overlying the superior PCM will be included in this structure.
The middle PCM
The middle PCM originates from the lesser horns and the greater horns of the hyoid bone. The insertion of all fibers unites in the median pharyngeal raphe. The lower fibers descend deep to the inferior PCM to reach the lower end of the pharynx and thus overlap in the transverse plane with the fibers of the inferior PCM, while the highest fibers ascend and overlap with the fibers of the superior PCM. Therefore, it should be noted that cranial and caudal borders of these anatomical structures are always somewhat arbitrary.

The upper border of the middle PCM corresponds with the lower border of the superior PCM.

In most studies, the caudal border of the middle PCM was defined as the lower edge of the hyoid bone, which roughly corresponds with the actual caudal border of the PCM. In addition, the anterior borders for the middle PCM were defined in a similar way as for the superior PCM, including the widest diameter of the base of tongue, the hyoid bone and the larynx, which approximately corresponds with the actual anterior border of the middle PCM, while the posterior border is defined by the prevertebral muscles (Table 2).

The inferior PCM
The inferior PCM is the thickest of the three constrictor muscles. It is composed of the thyropharyngeal part originating from the linea obliqua of the thyroid cartilage and the cricopharyngeal part originating from the lateral edges of the cricoid cartilage. In some studies, the thyropharyngeal part (often referred to as inferior PCM) and the cricopharyngeal part (often referred to as cricopharyngeal muscle) are defined as two separate anatomical structures. From a functional point of view, it makes sense to distinguish these two structures as lack of relaxation of the cricopharyngeal muscle in particular plays a role in the pathophysiology of aspiration during swallow. The borders of the cricopharyngeal muscle will therefore be discussed in a separate paragraph, while the definition of the borders of the inferior PCM, as described here, actually corresponds with the thyropharyngeal part of the inferior PCM.

In line with most authors, the cranial border of the inferior PCM is defined as the caudal border of the middle PCM, starting at the lower edge of the hyoid bone. Practically, the delineation should start at the first slice caudally from the lower edge of the hyoid bone.

As we defined the cricopharyngeal muscle as a separate SWOAR, we defined the caudal border of the inferior PCM as the upper edge of the cricoid cartilage just below the lower edge of the arytenoid cartilage. This is somewhat different from the definitions used by other investigators who made a distinction between the thyropharyngeal part of the inferior PCM and the cricopharyngeal muscle, since they all referred to the caudal edge of the cricoid as the caudal border of the inferior PCM. In fact, the cricopharyngeal muscle fibers are horizontal in direction and are mainly located posteriorly from the cricoid cartilage.
Table 2: overview of all SWOARs and their corresponding anatomic borders

<table>
<thead>
<tr>
<th>Organ at risk</th>
<th>Cranial</th>
<th>Caudal</th>
<th>Anterior</th>
<th>Posterior</th>
<th>Lateral</th>
<th>Medial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior PCM</td>
<td>Caudal tip of the ptery-</td>
<td>Hamulus of pterygoid</td>
<td>Prevertebral muscle</td>
<td>Medial pterygoid muscle</td>
<td>Pharyngeal lumen</td>
<td></td>
</tr>
<tr>
<td></td>
<td>goid plates (hamulus)</td>
<td>plate; mandibula; base</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>of tongue; pharyngeal</td>
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<td></td>
<td></td>
<td>lumen</td>
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<tr>
<td>Middle PCM</td>
<td>Upper edge of C3</td>
<td>Base of tongue; hyoid</td>
<td>Prevertebral muscle</td>
<td>Greater horn of hyoid bone</td>
<td>Pharyngeal lumen</td>
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<td></td>
<td></td>
<td>bone; pharyngeal lumen</td>
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<tr>
<td>Inferior PCM (thyropha-</td>
<td>First slice caudal to the</td>
<td>Soft tissue of supraglot-</td>
<td>Prevertebral muscle</td>
<td>Superior horn of thyroid cartilage; thyroid cartilage</td>
<td></td>
<td></td>
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<tr>
<td>ryneal part)</td>
<td>lower edge of hyoid bone</td>
<td>tic/glottic region</td>
<td></td>
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</tr>
<tr>
<td>Cricopharyngeal muscle</td>
<td>First slice caudal to the</td>
<td>Posterior edge of cri-</td>
<td>Prevertebral muscle</td>
<td>Thyroid cartilage, fatty tissue, thyroid gland</td>
<td></td>
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<tr>
<td></td>
<td>arytenoid cartilages</td>
<td>coid cartilage</td>
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<tr>
<td>Esophagus inlet muscle</td>
<td>First slice caudal to the</td>
<td>Tracheal lumen</td>
<td>Prevertebral muscle</td>
<td>Fatty tissue, thyroid gland</td>
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<td>lower edge of the crio-</td>
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<td></td>
<td>did cartilage</td>
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<tr>
<td>Cervical esophagus</td>
<td>1 cm caudal to the lower</td>
<td>Sternal notch</td>
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<td></td>
<td>edge of the coid cartilage</td>
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<tr>
<td>Base of tongue</td>
<td>Lower edge of anterior</td>
<td>Posterior one third from</td>
<td>Width of the pharyngeal lumen</td>
<td></td>
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<tr>
<td></td>
<td>tubercle of atlas</td>
<td>pharyngeal lumen</td>
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<td></td>
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<td>mandibular bone to</td>
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<td></td>
<td>pharyngeal lumen</td>
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<tr>
<td>Supraglottic larynx</td>
<td>Tip of epiglottis</td>
<td>First slice cranial to</td>
<td>Pharyngeal lumen, inferior PCM</td>
<td>Thyroid cartilage</td>
<td>Pharyngeal lumen (lumen excluded)</td>
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<tr>
<td></td>
<td></td>
<td>the upper edge of the ary-</td>
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<td></td>
<td></td>
<td>tenoid cartilages</td>
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<tr>
<td>Glottic larynx</td>
<td>Upper edge of the ary-</td>
<td>Lower edge of the crico-</td>
<td>Inferior PCM, pharyngeal lumen</td>
<td>Thyroid cartilage</td>
<td>Pharyngeal lumen (lumen excluded)</td>
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<tr>
<td></td>
<td>tenoid cartilages</td>
<td>did cartilage</td>
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<td>(if soft tissue is present)</td>
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</table>

Abbrreviations: C2 = second cervical vertebra, C3 = third cervical vertebra, cm = centimeter, PCM = pharyngeal constrictor muscle.
Figure 2. Most relevant CT-slices for the delineation of SWOARs, including: superior PCM (red); middle PCM (light blue); inferior PCM (thyropharyngeal part) (yellow); cricopharyngeus (dark blue); EIM (dark green); CE (purple); base of tongue (orange) and: supraglottic (pink) and glottic larynx (light green). The following reference anatomical structures are shown: (1) hamulus of pterygoid plates, (2) soft palate, (3) uvula, (4) palatopharyngeal folds, (5) tip of epiglottis, (6) lingual tonsil, (7) greater horn of hyoid bone, (8) superior horn of thyroid cartilage, (9) pre-epiglottic space, (10) arytenoid cartilage, (11) thyroid cartilage, (12) cricoid cartilage, (13) soft tissue of lower larynx, (14) no soft tissue present anterior to cricoid cartilage, (15) thyroid gland, and (16) sternal notch.
Anteriorly, the inferior PCM attaches to the posterior edge of thyroid cartilage, which can be recognized easily on CT, while the posterior border is defined by the prevertebral muscles.

The cricopharyngeal muscle

The cranial border of the cricopharyngeal muscle is similar to the caudal border of the inferior PCM as described in the former paragraph. Practically, the delineation should start at the first slice caudal to the arytenoid cartilages.

Caudally, the cricopharyngeal muscle blends with the circular esophageal fibers around the narrowest part of the pharynx. The lower border of the cricoid cartilage corresponds with the caudal border of the cricopharyngeal muscle.

The cricopharyngeal muscle attaches anteriorly to the outer posterior edge of the cricoid cartilage. The posterior border is defined by the prevertebral muscles.

Esophagus inlet muscle (EIM)

The most proximal part of the esophagus, is the most frequently involved area of radiation-induced strictures. As the dose given to the esophagus drops rapidly in the lower parts of the esophagus, this suggests a dose response relation for stricture. According to Levendag et al., we defined the first centimeter of the esophagus as a separate SWOAR, the EIM. The cranial border of the esophagus starts immediately caudally from the caudal border of the cricopharyngeal muscle. Practically, the cranial border of the EIM is the first slice caudal from the lower edge of the cricoid cartilage.

The anterior border is formed by the trachea and the posterior border is defined by the prevertebral muscles.

Cervical esophagus (CE)

Some authors also took into account the dose distributions in the CE, which certainly makes sense as in the case of elective nodal irradiation, the CE may receive a clinically relevant dose, in particular when IMRT is used. However, the definition of the CE differed widely among the different studies (Table 1).

For the purpose of consistency, the cranial border of the CE was defined as 1 cm caudal from the lower edge of the cricoid cartilage which corresponds to the caudal border of the EIM. Generally, the CE is defined as the part of the esophagus extending from the pharynx to the thoracic inlet. Therefore, we decided to use the thoracic inlet as the caudal border of the CE which, on CT, corresponds to the sternal notch. Normally, in the transversal plane, the CE can be easily recognized on CT, so we did not define anterior and posterior borders.
**Base of tongue**

The base of tongue is the posterior part of the tongue as it curves down into the throat. It composes the anterior wall of the oropharynx and is attached to the hyoid bone and mandible. Guidelines for the anatomical borders of the base of tongue were only provided in three studies. In these studies the cranial border was defined as below the soft palate. Since this border is hard to distinguish on CT, and often is made invisible due to artefacts, we decided to take a cranial border which is clearly visible on CT, the lower edge of the anterior tubercle of the 1st cervical vertebra (Figure 3), which actually resembles the same level.

However, the caudal border of the base of tongue was defined differently as the upper edge of the hyoid bone, the vallecula, and the first slice with epiglottis. We decided, again, for the purpose of consistency, to define the upper edge of the body of the hyoid bone as the caudal border.

The anterior part of the tongue, including the genioglossal, the hyoglossal, the palatoglossal and the styloglossal muscle, are not part of the base of tongue. However, these muscles are often hard to distinguish on CT-scan, therefore, for the purpose of consistency; we created a surrogate structure which includes the posterior one third of the tongue measured from the inner side of the mandibular bone to the pharyngeal lumen, just above the hyoid bone on the sagittal view of the CT as illustrated in Figure 3.

![Figure 3. Superior PCM, middle PCM and base of tongue (BOT) in sagittal and coronal CT-slices. The upper two CT-slices are in bone-setting. Two cranial borders are shown: (a) lower edge of anterior tubercle of atlas (cranial border of BOT) and (b) upper edge of C3 (cranial border of middle PCM). The following reference anatomical structures are shown: (1) hamulus of pterygoid plates, (2) medial pterygoid muscles, (3) soft palate, and (4) uvula.](image-url)
Larynx

The larynx includes the supraglottic, the glottic and subglottic region. The supraglottis encompasses the epiglottis, the supraglottic adductor muscles, the aryepiglottic folds, the arytenoids, and the false vocal cords. The glottis is composed of the true vocal cords. The region extending from the lower boundary of the glottis to the lower edge of the cricoid cartilage is the subglottis.

A limited number of authors provided definitions of the boundaries of the glottic and supraglottic larynx which were slightly different.

In the delineation guidelines, we decided to categorize the larynx in a supraglottic part and a glottic part. It should be stressed that this distinction between supraglottic and glottic larynx does not fully resemble the generally used distinction between glottic and supraglottic region. The distinction between supraglottic and glottic larynx was mainly chosen from a functional point of view. The supraglottic larynx as defined in the following paragraph includes the supraglottic adductors (oblique arytenoids and aryepiglottic muscles) and epiglottis that take care of glottic closure and adduction of supraglottic larynx during swallow, while the glottic larynx mainly includes the vocal cords.

Supraglottic larynx

The supraglottic larynx encompasses the region of the larynx located at the level just above the arytenoid cartilages, and thus part of the supraglottic region. For delineation purposes, the epiglottis, the median glossoepiglottic fold, the supraglottic adductors, the hyoepiglottic ligament and the aryepiglottic folds are included. The cranial border is defined by the tip of the epiglottis, and the caudal border is defined as the upper edge of the arytenoid cartilages.

The anterior border of the upper larynx are formed by the inner side of the sternohyoid and thyrohyoid muscles and the inner side of the thyroid cartilages, while the posterior border is defined as the pharyngeal lumen.

Glottic larynx

The glottic larynx encloses part of the supraglottic, the glottic and subglottic larynx. The cranial border is composed of the upper edge of the arytenoid cartilages. To delineate the glottic larynx in a consistent way, the arytenoid cartilages, the glottic adductor muscles and the false and true vocal folds are included. Apart from the lower edge of the arytenoid cartilages, the cricoid cartilage itself will not be included in the delineation of the glottic larynx. Only the soft tissue between the thyroid cartilage and the cricoid cartilage is included in the glottic larynx, this soft tissue represents the vocal and the thyroarytenoid muscle, which are needed to close the vocal cords and to maintain the pressure at the level of the vocal cords, which is needed to prevent aspiration.

The caudal border is formed by the lower edge of the cricoid cartilage (if there is still soft tissue present).
Discussion

In the current paper, we defined institutional guidelines for the delineation of OARs that are involved, or potentially involved, in the development of radiation-induced swallowing dysfunction\textsuperscript{5,20–23,25–28}. The guidelines as presented in this paper are CT-based, and defined in such a way that they can be used easily in studies investigating the relationship between dose distributions and the risk on swallowing dysfunction. In addition, when these dose-effect relationships become clearer, they can also be used for contouring purposes in daily clinical practice. Delineation guidelines for CTVs\textsuperscript{36,37} and OARs involved in radiation-induced salivary dysfunction and xerostomia\textsuperscript{38} are available and are now commonly used in daily practice and clinical trials. However, delineation guidelines for the SWOARs as presented in this paper have not been published so far.

Eisbruch et al.\textsuperscript{22} were one of the first who reported on the results of a prospective study including 26 patients with locally advanced head and neck cancer treated with radiotherapy and concomitant gemcitabine. Based on the findings of videofluoroscopy, direct endoscopy and computed tomography pre- and post-treatment, they suggested that malfunction of the pharyngeal constrictor muscles, the supraglottic larynx and the glottic larynx were most likely causing radiation-induced dysphagia and aspiration. After this publication, a number of other authors reported on the results of studies in which the relationship between the dose distributions to anatomical structures involved in swallowing and post-treatment swallowing dysfunction was analyzed. The literature review as presented in this paper showed a number of differences in the definition of SWOARs. This may result in subsequent differences in DVH-parameters from the same treatment plan. As a consequence, the results of the different studies that investigate the relationship between DVH-parameters and swallowing function after radiotherapy will be hard to compare. Furthermore, translation of the results of dose-volume-effect relationship studies into clinical practice can only be introduced safely, if radiation oncologists use the similar guidelines in clinical practice. Therefore, delineation guidelines are the first prerequisite for unambiguously contouring of SWOARs and for a reliable comparison and interpretation of results from different studies.

As the CT-scan currently is the gold standard for target volume and OAR delineation, and therefore we decided to define CT-image based delineation guidelines. However, it should be noted that the visualization of relevant anatomic swallowing structures could be improved by using Magnetic Resonance Imaging (MRI). MRI can help to discriminate the muscles from surrounding tissues in more detail. Therefore, the use of co-registered MRI in conjunction with CT may improve and facilitate the delineation of the pharyngeal muscles.

Furthermore, when the tumor extends in one of the SWOARs, or when the tumor or involved lymph nodes alter the normal anatomy, delineation of the SWOARs may be burdensome. Hampered interpretation could also be the case when the CT-scan images are
blurred due to artefacts. To delineate in a consistent way, the solution would be to delineate the contours in the well perceptible slices, and interpolate the delineations in between.

Conclusion

This paper described institutional guidelines for the delineation of potential SWOARs in order to ensure adequate interpretation of future reports on the relationship between dose distribution in these SWOARs and different aspects of post-treatment swallowing dysfunction.

References

Delineation guidelines swallowing structures
