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A novel applicator design for intracavitary brachytherapy of the nasopharynx: Simulated reconstruction, image-guided adaptive brachytherapy planning, and dosimetry

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ABSTRACT

PURPOSE: In nasopharyngeal cancer, brachytherapy is given as boost in primary treatment or as salvage for recurrent or persistent disease. The Rotterdam nasopharyngeal applicator (RNA) allows for suboptimal reduction of soft palate radiation dose, based on image-guided brachytherapy plans. Building on the RNA, we propose a novel design, the Benavides nasopharyngeal applicator (BNA).
METHODS AND MATERIALS: The virtual BNA was reconstructed on two cases (one T1, one T2) previously treated with intracavitary brachytherapy using the RNA. Dose was prescribed to the high-risk clinical target volumes (CTVs) and optimization was such that high-risk CTV D90 $\geq$ 100% of prescribed dose (PD), intermediate-risk-CTV D90 $\geq$ 75% PD, and soft palate D2cc $\leq$ 120% PD. The optimized RNA and BNA image-guided brachytherapy plans were compared in terms of CTV coverage and organs-at-risk sparing.
RESULTS: Optimization objectives were more easily met with the BNA. For the T1 case, all three planning objectives were easily achieved in both the RNA and BNA, but with 18−19% lower soft palate doses with the BNA. For the T2 case, the CTV planning objectives were achieved in both the RNA and BNA, but the soft palate constraint was only achieved with the BNA, with 38−41% lower soft palate doses.
CONCLUSIONS: Compared to the RNA, the BNA permits easier optimization and improves therapeutic ratio by a significant reduction of soft palate doses, based on simulation using a proposed system for CTV/organs-at-risk delineation, prescription, and optimization for image-guided adaptive brachytherapy. Clinical piloting using a prototype is necessary to evaluate its feasibility and utility. © 2018 American Brachytherapy Society. Published by Elsevier Inc. All rights reserved.

Keywords: Nasopharyngeal cancer; Intracavitary brachytherapy; Image-guided adaptive brachytherapy; Applicator design

Introduction

Nasopharyngeal carcinoma (NPC) is rare globally but is notable for its ethnographic endemicity with the highest incidence rates reported in Southeast Asia, Southeastern China, and India (1). Standard treatment consists of radiotherapy (RT) alone for Stage I and chemoradiotherapy (CRT) for Stage II to IVB disease (2−4). While intensity-modulated radiotherapy (IMRT) is the current standard for curative RT, brachytherapy being reserved mostly for salvage treatment of recurrences or persistent disease (5,6); the latter is still used in several centers as a boost after RT to dose escalate (7−10).

Multiple methods for personalized applicators (11,12) and applicator designs have been developed for intracavitary brachytherapy (ICBT). Personalized applicators require important resources and expertise. Among commercial applicators, the most commonly used are the nasopharyngeal balloon applicators (13) and the Rotterdam nasopharyngeal

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applicator (RNA) (14). The balloon applicator allows easy transnasal insertion but does not allow preferential displacement of the catheter away from the soft palate and closer to the nasopharynx. Moreover, it is not compatible with multiple treatments over several days as the relation of the balloon catheters is not stable or fixed. The RNA requires retrograde insertion through the oropharynx, which can be more difficult, but allows for a more stable geometry and may remain in place for several days. It consists of two silicone catheters fixed on a silicone base, which displaces the catheters away from the soft palate (14).

Before the advent of three-dimensional (3D) image-guided adaptive brachytherapy (IGABT) techniques, the Levendag points, marked on two standard orthogonal films, were used in two-dimensional (2D) treatment planning for ICBT using the RNA (14). The use of axial imaging now allows for better delineation of target volumes and organs at risk. Based on our initial experience, the design of the RNA allows for suboptimal reduction of radiation dose to the soft palate. Furthermore, while the RNA was designed to remain in place for several days, there is no mechanism for lavage or transnasal delivery of medications (i.e., local or topical anesthesia or analgesic), which could significantly improve patient hygiene and comfort.

Building on the RNA, we propose a novel applicator design, hereafter referred to as Benavides nasopharyngeal applicator (BNA), and a system for delineation of clinical target volumes (CTVs) and organs-at-risk (OARs), dose prescription, optimization, and reporting. We then compare the dosimetric properties of the BNA with that of the RNA.

Methods

Novel design

The proposed design comprising a silicone base, two silicone tubes, four plastic catheters, and a silicone flange designed to facilitate insertion, improve radiation dosimetry, and improve patient hygiene and comfort during treatment.

The silicone base, spatulate, flexible, and 8-mm thick, is oriented such that the narrower end (8 mm) faces the nasal cavities and the broader end (12 mm) faces the oropharynx. The central length is 30 mm. The thickness and shape allow easy retrograde maneuvering through the nasooropharyngeal passage. A pocket is incorporated into the base, which can house a 3-mm thick lead or tungsten alloy shield to provide additional soft palate protection, which is desirable in cases of reirradiation.

Each silicon tube, with 8.8-mm outer diameter and 6-mm inner diameter, is joined to the base laterally, along each side, such that there is a 15-mm long free limb on the oropharyngeal end and a 180-mm long free limb on the nasal end. The curved junction is along the level of a septum that divides each tube into superior and inferior compartments. A pair (a medial and a lateral) of semirigid plastic catheters, with 2-mm outer diameter, are housed in the superior compartment, running along the length of the tube, and fixed at the oropharyngeal end.

The superior compartment, designed to have a catheter deploy-and-lock mechanism, is open at two segments, exposing the catheters. The anteriormost segment, roofed and 30-mm long, serves to secure the free ends of the catheters when in storage or not in use. The second segment, roofless and 50-mm long, provides for a mechanism for advancing each catheter forward by up to 30 mm and locking them in place. Along this length, in storage, the catheters have five locking beads 10-mm apart, the first bead situated at 30 mm from the free tip of the catheter. In storage, the length bounded by the fourth and fifth beads is secured by a locking mechanism. In use, each catheter may be advanced forward in 10-mm increments and locking it in place using the beads. The third segment, roofed, serves to keep the catheters within the tunnel such that advancing them results in a protrusion outside the tube only at the level of the fourth, roofless segment. The latter, 35 mm in length, runs along the curved junction between the tube and the base. Along this segment, the catheters are oriented such that when advanced, the medial catheter protrudes superiorly and the lateral catheter protrudes superolaterally, into the nasopharyngeal recess. The superior compartment terminates in a 15-mm roofed segment that secures the fixed ends of the catheters. The catheters are detachable and replaceable.

The inferior compartment, designed to have a lavage system, is open on both ends and has five apertures on its inferior aspect along the junction with the base. The anterior end serves to receive a plastic tube, which is inserted through the nostril, into the oropharynx and inserted and fixed into the silicone tube by tying a knot using a silk suture. The nasal catheter is then retracted at the same time maneuvering the applicator through the oropharynx and into the nasopharynx. The apertures allow for lavage or delivery of medications (such as a local anesthetic).

Once the applicator is positioned in the nasopharynx, the nasal limbs of the silicon tubes are secured together using a silicon flange at approximately midway the length of the limbs, such that the flange abuts the nasal columella. The catheters are then deployed and locked to desired lengths.

Simulated reconstruction

Two NPC patients, one T1 and one T2 tumor (American Joint Committee on Cancer seven classification), treated with ICBT boost using the RNA, were retrieved. For both cases, noncontrast 2-mm thick axial CT scans were coregistered with preexternal beam radiotherapy (EBRT) contrast-enhanced T1-weighted MRI axial images.

Two 3D plans were created for each patient—one with the reconstructed RNA and the other with the virtual BNA simulated, using the RNA base and tubes as references and reconstructing the medial and lateral catheters according to the above-detailed dimensions and relations, and patient anatomy.

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