Dosimetric impact of tracheostomy devices in head and neck cancer patients

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Abstract

**Introduction:** The tracheostomy site and adjacent skin is at risk for recurrence in head/neck squamous cell cancer patients. The tracheostomy tube is an in situ device located directly over the tracheostomy site and may have clinical implications on the radiation dose delivered to the peristomal region. This study aimed to investigate this effect by comparing the prescribed treatment planning dose with the actual dose in vivo to the peristomal clinical target region. A retrospective, dosimetric study was performed with approval of the institutional research ethics board.

**Methods:** Fifteen patients who had received high-dose radiotherapy to the tracheostomy region with in vivo dose measurements were included. The radiation dose at the skin surface underneath the tracheostomy device was measured using an optically stimulated luminescent dosimeter (OSLD) and was compared with the prescribed dose from the radiation planning system. The effect of the tracheostomy flange and/or soft tissue equivalent bolus on the peristomal dose was calculated.

**Results and discussion:** Patients with tracheostomy equipment in situ were found to have a 3.7% difference between their prescribed and actual dose. With a tissue equivalent bolus there was a 2.0% difference between predicted and actual. The mean prescribed single fraction dose (mean = 191.8 cGy, SD = 40.18) and OSLD measured dose (mean = 194.02 cGy, SD = 44.3) were found to have no significant difference. However, with the flange excluded from the planning simulation (density = air) target skin dose deviated from predicted by an average of 55.3% (range = 12.4–72.9, SD = 22.5) and volume coverage was not achieved.

**Conclusion:** In summary, the tracheostomy flange acts like bolus with a twofold increase in the skin surface dose. Changes in the peristomal apparatus from simulation to treatment needs to be considered to ensure that the simulated dose and coverage is achieved.

**KEY WORDS**
head and neck cancer, optically stimulated luminescent dosimetry, radiation therapy, tracheostomy devices
1 | INTRODUCTION

Radiotherapy is the primary treatment for many head and neck cancer patients and plays an important role in the postoperative setting for patients with locally advanced disease. When locally advanced tumors cause dyspnea, orthopnea, and stridor, patients may undergo an emergency tracheostomy procedure to protect the airway. In addition, tracheostomy is required following total laryngectomy and other radical surgeries to help manage secretions. This is clinically important as it can affect the ability to effectively deliver radiation therapy to this region. Rates of peristomal recurrence have been described between 1 and 11% and are associated with significant morbidity and mortality.1-3 Accurate dose delivery to the peristomal region is a key factor in reducing peristomal recurrence.4,5 It is generally recommended that clinical target volumes (CTVs) include the stoma site and adjacent skin as these areas are at risk for locoregional recurrence in patients who had preoperative or intraoperative tracheostomy.6,7

Although modern treatment planning systems (TPS) are reliably accurate for regions located beyond the depth of maximum dose, there remains an element of dosimetric uncertainty in the surface and build-up regions.8 Linear accelerators emit significant levels of electron contamination (EC) that are difficult to model in a TPS that computes dose based upon kernel superposition methods. A common way to compensate for the EC problem is to empirically model the EC effect and superimpose it on the kernel superposition dose calculation. Although this empirical fit technique does improve the modeling of the surface/build-up region considerably, accurate dosimetry is still a challenge for complex beam arrangements such as those seen in intensity-modulated radiation therapy (IMRT).9 One indication of the challenges faced when modeling the build-up region is demonstrated in AAPM’s Task Group 53 report on commissioning and quality assurance of TPS.10 In this report an example recommendation for build-up region dose accuracy is stated as 20% for square, rectangular, and asymmetric fields. Modern TPS can typically achieve accuracies of better than ±10% for the surface region (0–0.5 cm depth), and ±5% in the build-up region (0.5 cm to depth at maximum dose) for simple square fields.11-13

The issues around dose uncertainty in superficial regions is of particular relevance for head and neck cancer, where the planning target volume (PTV) often encroaches upon the patient surface.14 In the present IMRT application, it is desired to confirm that the dose received by peristomal tissue lying beneath the plastic/silicone components of a tracheostomy flange is at the desired level. Since this peristomal region is in the surface/build-up region, there is an inherent uncertainty to the dose planned by the TPS. Chung et al15 reported a phantom study that simulated head and neck IMRT treatments for shallow (0.5 cm depth) and deep (6 cm depth) targets. Using Pinnacle 3 as the TPS and radio chromic film as the dosimeter, there was a 5.6% and 6.5% agreement for surface dose for the shallow and deep targets, respectively.

Due to the uncertainties in TPS predictions for dose in the surface/build-up regions, in vivo dosimetry is occasionally required. This technique allows for direct measurements of the dose to ensure that the patient is exposed by the appropriate amount for the region of interest. Traditionally, TLDs, diodes, or metal oxide semiconductor field effect transistors (MOSFETs) have been used for in vivo dosimetry. Recently, dosimeters based upon optically stimulated luminescence (OSL) have been proven to be useful and increasingly popular.16,17 The objective of taking direct OSL measurements of peri-stomatal tissue is to confirm that the bolus effect of the tracheostomy equipment in the peristomal area is adequately modeled by the Pinnacle3 TPS.

To our knowledge the dosimetric effect of the actual tracheostomy tube and flange in situ has not been previously described. Therefore, a dosimetric study was performed to evaluate the impact of the tracheostomy hardware on the measured dose delivered to patients and the predicted dose calculated by the TPS.

2 | MATERIALS AND METHODS

A retrospective, dosimetric study to assess the impact of tracheostomy hardware was performed with approval of the institutional research ethics board. All head and neck cancer patients were identified from a retrospective database and included in the study if they met several criteria. These criteria included patients who: had tracheostomy, received radiotherapy and had a physical OSL dosimeter (OSLD) measurement of the dose at the stoma site between 2013 and 2017. The dosimeter location was known to be a pre-determined region associated with the highest prescribed dose from the planning distribution. This is an institutional policy that is followed for all patients.

2.A | Radiation planning and treatment

Head and neck contouring was completed by the attending radiation oncologist based on the institutional standard agreed upon for contouring of organs at risk and target volumes.18,19 The tracheostomy site and surrounding skin were considered to be a region at risk of microscopic disease and a CTV was contoured with a PTV margin of 5 mm. The prescribed doses were determined based on institutional practice and provincial guidelines.19 If macroscopic disease was present, the prescribed dose was 70 Gy. However, the range of prescribed doses in this study reflects various clinical factors such as disease site, stage, high-priority dose-limiting structures, prior surgery, or presence of macroscopic disease. Intensity-modulated radiation treatment (IMRT) planning for head and neck cancer patients was performed using a Philips Pinnacle3 TPS version 9.2 (Philips Medical Systems, Andover, MA) for all patients. Plans typically employed a six or seven co-planar beam arrangement with additional noncoplanar beams if required. Patients were aligned in the supine position and immobilized with a thermoplastic mask. No treatment plans using electrons, orthovoltage tomotherapy, or VOLUMETRIC arc therapy (VMAT) were included in this study. The IMRT plans were optimized so that at least ninety five percent of tracheostomy

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site PTV received the prescribed dose, for example, V56 Gy > 95%. The radiation treatment plans for all patients were copied to a research database for review and dosimetric analysis.

2.B | Optically stimulated luminescence (OSL) measurements in vivo

For in vivo dosimetry, a commercial OSL system was used consisting of the InLight microStar reader (Landauer, Glenwood, IL) with Landauer nanoDot dosimeters. These devices were prescreened by the manufacturer for accuracy. This system can be used to measure dose at or near the skin surface.²⁰,²¹ The OSL sensitive material is aluminum oxide with carbon impurities (Al₂O₃:C) encapsulated in 0.2 mm thick, 5 mm diameter discs. This sensitive material is enveloped by a lightweight plastic casing that measures 10 × 10 × 2 mm. In the first year of using OSLDs at our institution, monthly quality control tests determined that the OSL system is accurate within ±3% for therapeutic doses (approximately 10–300 cGy/fraction) These results are in line with the manufacturer’s specifications and prior data.²⁰,²¹ Quality control tests were then performed on an ongoing basis to ensure that the OSLD measurements stayed within this accuracy range.

2.C | Quality assurance/verification

For any high dose head and neck radiotherapy plan, the treating radiation oncologist may request OSLD measurement for verification of the delivered dose relative to the planned dose. The institutional policy was that the measurement would not result in any treatment changes unless a discrepancy of >5% was detected and felt to be clinically significant. An OSLD measurement was performed for one of the fractions during the treatment course for each individual patient involved in this study. Once the patient was set up on the treatment couch, an OSLD was placed on the skin directly adjacent to the stoma. This was a predetermined region associated with the highest prescribed dose from the planning distribution. The tracheostomy flange was located directly over top of the OSLD and centered over the stoma as per the usual clinical practice. The OSLDs were left on during cone-beam CT imaging for positioning and verification. This was done for practical purposes, since patients were treated in an immobilizing thermoplastic mask. This made it unfeasible to position the patient with CBCT and then place the OSLD under the mask and other apparatus. It was determined that the CBCT dose only added between 0.2 and 0.6 cGy of dose reading (uncorrected for the kV response of the OSLDs) to the OSLD during a phantom study. This was determined with OSLDs that were taped to an anthropomorphic head-and-neck phantom (Rando® phantom, The Phantom Laboratory, Salem, NY). These phantoms were then CBCT-scanned using the clinical H&N settings. The imaging dose was a small, negligible percentage as compared to the typical 200 cGy dose per fraction delivered in a head and neck radiation treatment plan.

After irradiation, the OSLDs were read out by the microStar reader after at least 10 min had elapsed.²² Each OSLD was read out three times, and the results were averaged and then reported. These results were compared to the OSLD dose as predicted by the TPS in the patient treatment plan. A contour was then drawn to approximate the OSLD in the location that the dosimeter was placed during the treatment fraction as seen in Fig. 1. The mean dose to this OSLD was reported and compared to the OSLD reading.

2.D | Measurement of tracheostomy material density

The density of the tracheostomy hardware was calculated using CT images. This result was then compared to physical measurements of the device’s density. This was done in order to ensure that the tracheostomy tube and flange were not composed of any high atomic number elements that would erroneously increase the calculated density on CT images.

CT images of patients with a tracheostomy tube and flange were acquired. These scans were obtained using a Philips Brilliance Big Bore CT scanner (Philips Healthcare, Best, The Netherlands). The images were acquired at 1.2 mm × 1.2 mm axial pixel pitch with a 1.5 mm voxel thickness using 120 kVp. The CT images were used to delineate the tracheostomy tube and the flange. The mean density of the flange volume was then calculated using Pinnacle³ TPS. The physical measurements of the density involved careful determination of flange volume using the Archimedes’ principle of displacement.²³ This was followed by an accurate measurement of the objects mass with a calibrated scale. A Sagittal view and physical representation of the tracheostomy placement and hardware can be seen in Fig. 2.

2.E | Dosimetric plan evaluation

In order to evaluate the tracheostomy tube and flange’s impact on the dose to the adjacent target region, a retrospective dosimetric
analysis was performed. The OSLD location was contoured using a $5 \times 5 \times 1$ mm volume at the skin surface directly adjacent to the stoma site. This was done to estimate a CTV and this region was defined as the peristomal volume. The tracheostomy tube and flange were then contoured using a fine 1 mm brush on lung density CT window (W:1601, L:-300) and is referred to as the trach contour. The mean dose to this OSLD volume was measured from the published patient treatment plan.

The number of monitor units was held constant for each patient’s treatment plan and then a smaller dose grid with a resolution of 0.1 mm was used for further analysis. To estimate the dose to the peristomal volume without the tracheostomy equipment, the density of the trach contour was set to zero and the dose was recomputed.

For cases where additional bolus material was applied overttop of the tracheostomy flange, this additional material was contoured. The treatment plans were then evaluated again with normal density and then a second time with the bolus density set to zero using fixed monitor units for each plan. A screenshot of the tracheostomy tube, flange, 95% isodose line, and the effect that zeroing the trach contour has on the isodose line can be seen in Fig. 3.

2.F | Statistical methods

The patient, tumor, and treatment characteristics (n = 15) were analyzed and summarized using descriptive statistics. The difference between the prescribed dose from the radiation plan and the measured OSLD dose was calculated as an absolute value (cGy) and as a percentage difference to normalize for the variation in the absolute prescribed doses. The mean of the differences was calculated along with the standard deviation of the differences. For each patient, a paired t-test was carried out to assess the mean difference between the OSLD measurement and the radiation dose predicted by the planning system at the peristomal region.

3 | RESULTS

This single institution study identified 15 patients with biopsy proven head and neck cancer. These patients had tracheostomy prior to radiation and at least one measurement of the dose received using an OSLD. A complete set of patient, tumor, and characteristic information can be seen in Table 1. Density of the tracheostomy flange was measured directly to be $1.189 \pm 0.2$ g/cm$^3$ which was comparable to the predicted value from CT planning datasets, measured as $1.168 \pm 0.2$ g/cm$^3$. Radiation plans consisted of IMRT technique with the prescribed dose to the tracheostomy site ranging from 50 to 70 Gy (median 70 Gy). Tables 2 and 3 outline the complete set of dose data for the 15 patients.

In Fig. 4 the average percentage difference between the various measured and planned dosages can be seen. For patients with tracheostomy equipment in place the average percentage difference between prescribed and actual measured dose was 3.8% (SD 2.1). When tissue equivalent bolus material was used, with or without a tracheostomy tube and flange, the average difference between the
The study demonstrates that the tracheostomy tube and flange have a significant impact on head and neck radiation target coverage in the peristomal region. This was achieved through analysis of 15 separate patients. Patients 1–10 only had a tracheostomy device and did not have any bolus material. With the tracheostomy device density set to air equivalent a significant difference between the predicted plans can be seen. For patients 11–13 a bolus material was present in addition to the tracheostomy device. By comparing the dose changes with the tracheostomy device and bolus set to air equivalent we can directly observe the similar effect that these two materials have on the predicted dosage. Additionally, patients 14 and 15 further reinforce this conclusion, as even without a tracheostomy device the significant dose effect of the bolus can be seen. This dose effect is caused by how the radiotherapy beams interact with materials. Radiotherapy penetrates the surface layer it encounters and then irradiates deeper layers. Therefore, to treat superficial lesions a bolus material is commonly used to act as a layer of scattering material to replicate the skin surface. By setting the density of our tracheostomy applicator to zero we see a significant drop in the radiation dose delivered to the peristomal region. This directly demonstrates how the tracheostomy device is acting as a bolus material to cause an increase in the dose that the skin surface and subcutaneous tissues receive. To our knowledge, this is the first study to demonstrate the effect of tracheostomy equipment on radiation dose, using in vivo surface measurements to validate the predicted doses.

An important consideration for these findings is the accuracy of the OSLD measurements, and the differences between the measured and planned dosages. There are a couple of factors which can cause deviation between these values. The first major cause is related to the location of the dosimetry measurements. The dosimeters were placed on the skin directly adjacent to the stoma, within a region of high-dose gradient. In this region there is the largest potential for deviation between the OSLD measurement and predicted dose value. Since there is a large gradient in this area, minor changes in positional accuracy will have large effects on the OSLD’s measurement accuracy as compared to the predicted value. Second, the calculated TPS density for the applicator flap could potentially cause a deviation from the actual radiation dose delivered. However, the calculated density from the CT images of the applicator flap correlated with the measured physical density. This indicates that the applicator is constructed out of a polymer material with a low average atomic number; as such, the electron density used for the dose computation is accurate. Despite these sources of potential error, the difference predicted and actual doses was 2.0% (SD 1.3). For all patients, a paired t-test was carried out to compare the prescribed dose to the OSLD measured dose in the peristomal region of interest. There was no significant difference between the prescribed dose (mean = 191.5 cGy, SD = 41.7) and the measured dose (mean 193.5 cGy, SD = 46.0); t(13) = 0.99, P = 0.34.

When the trach contour was excluded from the planning CT scan (density set to air equivalent) the target coverage and dose to the peristomal volume decreased significantly. The predicted mean dose was reduced by an average of 53.5% (SD 22.5) and therefore coverage of the peristomal target volume was inadequate.
between the planned and measured doses were on average <4%.
This is within acceptable limits as described by evidence-based
treatment guidelines.\textsuperscript{19} Accurate dosimetry is important to ensure proper
treatment delivery and can help to limit peristomal recurrence, par-
ticularly for head/neck squamous cell cancer patients.

As seen with the tracheostomy devices in this study, medical
devices can have a significant effect on radiation treatment plan-
ing. The dosage effects of medical devices must be carefully
accounted for to ensure target coverage and to avoid excessive
toxicity.\textsuperscript{24,25} An optimal radiotherapy plan needs to be able to
effectively deliver the radiation dose to the targeted treatment area
while minimizing dose delivery to adjacent structures. To achieve
this goal the impact of any internal or external medical devices
must be measured and accounted for in the radiation plan. The
impact of dental implants and amalgam, intravenous ports, and
breast and hip prosthesis has previously been described.\textsuperscript{26–29} These
devices may create dose inhomogeneity with the potential for
increased toxicity or inadequate target coverage. Different medical
devices can have unique impacts on the delivered radiation dosage
and should be individually evaluated for their potential effect on
the prescribed treatment plan.

This study has several important limitations. This was a retro-
spective study with variation in the clinical presentation, primary dis-
ease sites, and total prescribed dose, which re
fl
ects clinical practice.
All patients included in the study had IMRT and therefore it is not
possible to extrapolate these results to patients who may undergo
other treatment techniques/modalities such as conventional radio-
therapy, VMAT, electrons, or proton therapy. The OSLD measure-
ments were taken on average once or twice per patient and it is
possible that there may be differences in setup due to air gaps,
device placement or inter/intra-treatment motion through the full
course of radiotherapy. The number of patients included in this
study is low and reflects an uncommon but important clinical situa-
tion. Future studies are needed with a larger cohort of patients to
allow for further statistical validation of these findings for specific
clinical presentations and disease sites.

### Table 3

| Patient number | Dose\textsubscript{OSLD} (Gy) | Dose\textsubscript{Plan} (Gy) | Dose\textsubscript{Plan, Trach $\rho$ = air + Bolus $\rho_{\text{act}}$ (Gy) | Dose\textsubscript{Plan, Trach $\rho$ = air + Bolus $\rho_{\text{act}}$ (Gy) |
|----------------|----------------|----------------|-------------------------------------------------|-------------------------------------------------|
| 11             | 73.26          | 71.50          | 46.85                                           | 28.80                                           |
| 12             | 65.67          | 64.31          | 56.35                                           | 21.52                                           |
| 13             | 71.28          | 68.76          | 59.67                                           | 26.29                                           |
| 14 (no applicator) | 58.59          | 58.51          | N/A                                             | 30.65                                           |
| 15 (no applicator) | 50.20          | 51.14          | N/A                                             | 27.67                                           |

Note: Patients 11–15 all had 1-cm-thick tissue equivalent bolus placed over the tracheostomy site. Within this group, Patients 11–13 had both tra-
cheostomy equipment and bolus over the tracheostomy site. Dose\textsubscript{OSLD} = Measured OSLD dose; Dose\textsubscript{Plan} = planned pinnacle dose; Dose\textsubscript{Plan, Trach $\rho$ = air + Bolus $\rho_{\text{act}}$ = actual} = Planned Pinnacle dose with bolus density not modified and only trach density set to air equivalent; Dose\textsubscript{Plan, Trach $\rho$ = air + Bolus $\rho_{\text{act}}$ = air} = Planned Pinnacle dose with trach density and bolus density both set to air equivalent.

### Figure 4

Mean difference between the measured, planned, and predicted dose plans for patients receiving treatment with/without bolus.
Dose plan refers to the original dose calculated by the pinnacle plan. Originally there is minimal deviation between the planned dosage and the
measured dosages from the optically stimulated luminescent dosimeter with or without a bolus. When the trach/bolus were set to air equivalent ($\rho =$ air) a new predicted dose was calculated by the pinnacle software, this shows the effect that a bolus or tracheostomy equipment has on the planned pinnacle dosage. For the 13 patients that did not have a bolus, setting the Trach density to air equivalent changed the calculated plan by 55%. For the three patients with a Bolus, and the two patients with a bolus and no Trach, setting the Bolus/ Trach density to air equivalent changed the plan by 62% and 46%, respectively.
CONCLUSIONS

This is a retrospective, dosimetric study of 15 head and neck cancer patients who underwent high-dose radiotherapy and had in vivo OSLD measurements at the peristomal region. The tracheostomy flange applicator was found to have a density similar to water equivalent bolus. Using OSLD measurements during treatments, the actual measured dose in the peristomal tissues was, on average, within 4% of the predicted dose from the radiation treatment plan. This was deemed to be clinically acceptable. Overall the tracheostomy of the predicted dose from the radiation treatment plan. This was measured dose in the peristomal tissues was, on average, within 4% alent bolus. Using OSLD measurements during treatments, the actual CONFLICT OF INTEREST

This is a retrospective, dosimetric study of 15 head and neck cancer 5 | REFERENCES

1. Brenerman JC, Bradshaw A, Gluckman J, et al. Prevention of stomal recurrence in patients requiring emergency tracheostomy for advanced laryngeal and pharyngeal tumors. Cancer. 1988;62:802–805.
2. Zbären P, Greiner R, Kengelbacher M. Stoma recurrence after laryngectomy: an analysis of risk factors. Otolaryngol Head Neck Surg. 1996;114:569–575.
3. Halfpenny W, McGurk M. Stomal recurrence following temporary tracheostomy. J Laryngol Otol. 2001;115:202–204.
4. Spencer SA, Harris J, Wheeler RH, et al. Final report of RTOG 9610, a multi-institutional trial of reirradiation and chemotherapy for unresectable recurrent squamous cell carcinoma of the head and neck. Head Neck. 2008;30:281–288.
5. Dawson LA, Anzai Y, Marsh L, et al. Patterns of local-regional recurrence following parotid-sparing conformal and segmental intensity-modulated radiotherapy for head and neck cancer. Int J Radiat Oncol Biol Phys. 2000;46:1117–1126.
6. Kramer S, Gelber RD, Snow JB, et al. Combined radiation therapy and surgery in the management of advanced head and neck cancer: final report of study 73-03 of the Radiation Therapy Oncology Group. Head Neck Surg. 1987;10:19–30.
7. Cooper JS, Pajak TF, Forastiere AA, et al. 25: long-term survival results of a phase III intergroup trial (RTOG 95-01) of surgery followed by radiotherapy vs. radiochemotherapy for resectable high risk squamous cell carcinoma of the head and neck. Int J Radiat Oncol Biol Phys. 2006;66:1198–1205.
8. Wang L, Li J, Paskalev K, et al. Commissioning and quality assurance of a commercial stereotactic treatment-planning system for extracranial IMRT. J Appl Clin Med Phys. 2006;7:21–34.
9. Hsu SH, Moran JM, Chen Y, et al. Dose discrepancies in the buildup region and their impact on dose calculations for IMRT fields. Med Phys. 2010;37:2043–2053.
10. Fraass B, Dopke K, Hunt M, et al. American Association of Physicists in Medicine Radiation Therapy Committee Task Group 53: quality assurance for clinical radiotherapy treatment planning. Med Phys. 1998;25:1773–1829.
11. Dempsey JF, Romeijn HE, Li JG, et al. A fourier analysis of the dose grid resolution required for accurate IMRT fluence map optimization. Med Phys. 2005;32:380–388.
12. Benedict SH, Yenice KM, Followill D, et al. Stereotactic body radiation therapy: the report of AAPM Task Group 101. Med Phys. 2010;37:4078–4101.
13. Milten M, Olch A, Mihailidis D, et al. Tolerance limits and methodologies for IMRT measurement-based verification QA: recommendations of AAPM Task Group No. 218. Med Phys. 2018;45:e53–e83.
14. Chen AM, Farwell DG, Luu Q, et al. Prospective trial of high dose reirradiation using daily image guidance with intensity-modulated radiotherapy for recurrent and second primary head-and-neck cancer. Int J Radiat Oncol Biol Phys. 2011;80:669–676.
15. Chung H, Jin H, Dempsey JF, et al. Evaluation of surface and build-up region dose for intensity-modulated radiation therapy in head and neck cancer. Med Phys. 2005;32:2682–2689.
16. Batters-Jensen L, Thomsen KJ, Jain M. Review of optically stimulated luminescent (OSL) instrumental developments for retrospective dosimetry. Radiat Meas. 2010;45:253–257.
17. Yukihara EG, Mc Keever SW. Optically stimulated luminescence (OSL) dosimetry in medicine. Phys Med Biol. 2008;53:R351.
18. O’Sullivan B, Rumble RB, Warde P. Intensity-modulated radiotherapy in the treatment of head and neck cancer. Clin Oncol. 2012;24:474–487.
19. Cancer Care Ontario. Dose Objectives for Head and Neck IMRT Treatment Planning. Recommendation Report 2014. https://www.canccerontario.ca/sites/ccocancerscare/files/guidelines/full/DoseObj_HN_IMRT_TrtmtPlngRec_0.pdf. Published February 2014. Accessed May 30th 2019.
20. Yusof FH, Ung NM, Wong JH, et al. On the use of optically stimulated luminescent dosimeter for surface dose measurement during radiotherapy. PLoS ONE. 2015;10:e0128544.
21. Zhuang AH, Olch AJ. Validation of OSLD and a treatment planning system for surface dose determination in IMRT treatments. Med Phys. 2014;41:081720.
22. Jursinic PA. Characterization of optically stimulated luminescent dosimeters, OSLDs, for clinical dosimetric measurements. Med Phys. 2007;34:4594–4604.
23. Hughes SW. Archimedes revisited: a faster, better, cheaper method of accurately measuring the volume of small objects. Phys Educ. 2005;40:468.
24. Eiblbruch A, Harris J, Garden AS, et al. Multi-institutional trial of accelerated hypofractionated intensity-modulated radiation therapy for early-stage oropharyngeal cancer (RTOG 00–22). Int J Radiat Oncol Biol Phys. 2010;76:1333–1338.
25. Peters LJ, O’Sullivan B, Giralt J, et al. Critical impact of radiotherapy protocol compliance and quality in the treatment of advanced head and neck cancer: results from TROG 02.02. J Clin Oncol. 2010;28:2996–3001.
26. Ozan J, Dirican B, Oysul K, et al. Dosimetric evaluation of the effect of dental implants in head and neck radiotherapy. Oral Surg Oral Med Oral Pathol Oral Radiol Endodontol. 2005;99:743–747.
27. Ho AY, Hu ZI, Mehrara BJ, et al. Radiotherapy in the setting of breast reconstruction: types, techniques, and timing. Lancet Oncol. 2017;18:e742–e753.
28. Reft C, Alecu R, Das U, et al. Dosimetric considerations for patients with HIP prostheses undergoing pelvic irradiation. Report of the AAPM Radiation Therapy Committee Task Group 63. Med Phys. 2003;30:1162–1182.
29. Gossman MS, Seuntjens JP, Serban MM, et al. Dosimetric effects near implanted vascular access ports: an examination of external photon beam calculation. J Appl Clin Med Phys. 2009;10:2886.

CONFLICT OF INTEREST

The authors do not have any conflicts of interest to declare.