Set-up errors in head and neck cancer treated with IMRT technique assessed by cone-beam computed tomography: a feasible protocol

Durim Delishaj, MD¹, Stefano Ursino, MD¹, Francesco Pasqualetti, MD¹, Fabrizio Matteucci, MD¹, Agostino Cristaudo, MD¹, Carlo Pietro Soatti, MD², Amelia Barcellini, MD³, Fabiola Paiar, PhD¹

¹Department of Radiation Oncology, University Hospital Santa Chiara, Pisa; ²Department of Radiation Oncology, “A. Manzoni” Hospital, Lecco; ³Radiotherapy Unit, IRCCS Istituto Nazionale dei Tumori, Milan, Italy

Purpose: To investigate set-up errors, suggest the adequate planning target volume (PTV) margin and image-guided radiotherapy frequency in head and neck (H&N) cancer treated with intensity-modulated radiotherapy (IMRT) assessed by kV cone-beam computed tomography (CBCT).

Methods: We analyzed 360 CBCTs in 60 patients with H&N cancer treated with IMRT. The target delineation was contoured according to ICRU62. PTVs were generated by adding a 3–5 mm margin in all directions to the respective clinical target volumes. The kV CBCT images were obtained at first three days of irradiation and weekly thereafter. The overall mean displacement, range, systematic (∑) and random (σ) errors were calculated. Adequate PTV margins were calculated according to the van Herk formula (2.5∑ + 0.7σ).

Results: The mean of set-up errors was less than 2 mm in any direction. The overall frequency of set-up displacements greater than 3 mm was 3.9% in medial-lateral (ML) direction, 8% in superior-inferior (SI) direction, and 15.5% in anterior-posterior (AP) direction. The range of translations shifts was 0–9 mm in ML direction, 0–5 mm in SI direction and 0–10 mm in AP direction, respectively. After systematic set-up errors correction, the adequate margin to overcome the problem of set-up errors was found to be less than 3 mm.

Conclusion: Image-guided kV CBCT was effective for the evaluation of set-up accuracy in H&N cancer. The kV CBCT at first three fractions and followed-by weekly appears adequate for reducing significantly set-up errors in H&N cancer treated with IMRT technique. Finally, 3–5 mm PTV margins appear adequate and safe to overcome the problem of set-up errors.

Keywords: Head and neck cancer, Radiotherapy, Chemotherapy, Cone-beam computed tomography, IMRT technique, Oncology

Introduction

In Western countries head and neck (H&N) cancer accounts for about 5% of all tumors. Squamous cell carcinoma is the most common histotype reaching about 90%, and generally arises from the mucosa of the upper aerodigestive tract [1,2]. The etiology of these tumors has traditionally been related to tobacco and alcohol consumption, whereas in the last

Received 18 October 2017, Revised 04 December 2017, Accepted 18 December 2017.
Correspondence: Durim Delishaj, MD, Department of Radiation Oncology, University Hospital Santa Chiara, Via Roma 67, Pisa 56126, Italy. Tel: +39-050992718, Fax: +39-050992830, E-mail: delishaj@hotmail.com
© This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (http://creativecommons.org/licenses/by-nc/4.0/) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

www.e-roj.org
Set-up errors in head and neck cancer treated with IMRT

Materials and Methods

1. Patient and tumor characteristics

Between September 2014 and September 2015, 360 CBCT scans of 60 patients affected by histologically confirmed H&N cancer who were treated with the IMRT technique were analyzed. The majority of patients treated were male (75%) and only 25% were female. The median age was 68 years with a range from 44 to 88 years. Regarding the histology examinations, the majority of patients (86.5%) exhibited squamous cell carcinoma and 13.4% of the examinations yielded undifferentiated carcinoma. The types of H&N cancer treated were larynx (28%), oral cavity (28%), oropharynx (23.5%), hypopharynx (7%), nasopharynx (5%), and parotid cancer (8.5%). Of the total patients treated, 42 patients (70%) underwent curative chemoradiotherapy treatment and 18 patients (30%) were treated with adjuvant intent after surgery.

Concurrent platinum-based chemotherapy was administered when clinically indicated according to international guidelines [4,5]. In details, chemotherapy was prescribed (if not contraindicated) in all patients with LAHNC underwent curative radiotherapy treatment and in patients with major risk factors after surgery (such as positive margins and extracapsular extension). Chemotherapy was given weekly using cisplatin 40 mg/m² intravenous (IV) over 1 hour during the 6-week RT course for a maximum of 6 cycles, or cisplatin 100 mg/m² IV once every 3 weeks for a maximum of 3 cycles. Patients and tumor characteristics are summarized in Table 1.

2. Simulation, immobilization system and treatment planning

All patients underwent planning CT simulation on supine position on a GE LightSpeed RT 16 CT simulator (GE Healthcare, Waukesha, WI, USA) using 2.5 mm slice thicknesses and contrast medium injection due to better definition of gross tumor volumes (GTVs) and clinical target volumes (CTVs). We utilized a head-shoulder thermoplastic mask (Klarity Green; Klarity Medical Products, Newark, OH, USA) as immobilization system. The use of a thermoplastic head and shoulder immobilization device makes the set-up procedure easily reproducible allowing the detection of systematic errors with a low number of image-guided fractions [20]. The position of room lasers was marked on the mask and markers were put on the laser crossings to define a reference point according to tumor localization and to the volume to be treated.

The CT data sets were transferred to the Focal and Varian Eclipse treatment planning system through DICOM network.
The target delineation was performed by a radiation oncologist according to ICRU62; the PTVs were generated to compensate for geometrical uncertainties by adding an isotropic 3–5 mm margin in all directions to the respective clinical CTVs [21]. A GTV-Tumor/GTV-Nodal was contoured in all cases of curative treatment. The CTV was delineated around the GTV to cover areas at risk for the presence of microscopic disease. A margin of 3 mm was added around the spinal cord and the brainstem to generate a planning at risk volume. According to international guidelines, the prescribed doses were as follow: 66 Gy (delivered in 30 fractions; 2.2 Gy/fraction) for high risk PTVs, 60–63Gy (delivered in 30 fractions; 2–2.1 Gy/fraction) for intermediate risk PTVs, and 54 Gy (delivered in 30 fractions; 1.8 Gy/fraction) for low risk PTVs [4,5,19,20].

The RT treatment was performed with IMRT technique. The IMRT plans were created on the Varian Eclipse treatment planning system using coplanar beams with 6 MV photons and the treatment was performed with DHX LINAC, VARIAN System. Before the treatment all patients were re-positioned in the treatment room aligning the signs marked on the mask with room lasers. If necessary, couch shifts were applied according to planning indications to reach the treatment isocenter, aligning the signs marked on the mask with room lasers.

3. Image guidance procedures and set-up errors analyses
In all patients pretreatment kV CBCT images were obtained at first 3 days of irradiations and set-up error corrections were made before treatment if the translational set-up error was greater than 3 mm in any direction. Subsequently a weekly kV CBCT was repeated for whole duration of treatment and if translational shifts in any directions were greater 3 mm were corrected.

One CBCT image acquisition was not repeated after correction or after treatment delivery. Image registration was usually performed by an automatic algorithm applied to an extensive region of interest (clip-box) encompassing the whole PTV.

If necessary offline view was utilized to calculate the translation shifts and data extraction. Observed translational displacements in three axes—medial-lateral (ML), superior-inferior (SI), anterior-posterior (AP)—were recorded and always corrected online before delivering treatment.

The entire procedure, starting from the patient set-up to the beginning of treatment, took approximately 6 minutes. Quality assurance procedures for CBCT images included a monthly check of mechanical system and image quality, as well as weekly geometrical accuracy tests to verify that the CBCT reconstruction center was coincident with the isocenter of the linear accelerator.

Also, the mean value of the first three CBCTs recorded in each of three axes was calculated and in case of a mean error greater than 3 mm a systematic set-up correction (modifying laser alignment signs on the mask) was performed. One CBCT image acquisition was repeated after correction or after treatment delivery.

Fig. 1 describe the summary diagram used in our center due to minimize set-up errors through CBCT in H&N cancer treated with IMRT.

4. Statistical analysis
Before performing the analysis, an exploration phase was carried out. Categorical data were described by frequency and percentage, whereas continuous data were done by mean, median, and range.

All errors entered and analyzed separately for each direction (ML, SI, AP). For each patient, the mean and standard deviation (SD) of all recorded errors were calculated. Systematic error

---

**Table 1. Patient and tumor characteristics**

| Characteristic                  | Value         |
|--------------------------------|---------------|
| Age (yr)                       | 68 (44–88)    |
| Gender                         |               |
| Male                           | 45 (75)       |
| Female                         | 15 (25)       |
| Smoking status                 |               |
| Smokers                        | 48 (80)       |
| Non-smokers                    | 12 (20)       |
| Alcohol                        |               |
| Potus                          | 33 (55)       |
| Non-potus                      | 27 (45)       |
| Site                           |               |
| Nasopharynx                    | 3 (5)         |
| Oropharynx                     | 14 (23.5)     |
| Oral cavity                    | 17 (28)       |
| Hypopharynx                    | 4 (7)         |
| Larynx                         | 17 (28)       |
| Parotid                        | 5 (8.5)       |
| Histology                      |               |
| Squamous cell carcinoma        | 52 (86.6)     |
| Undifferentiated carcinoma     | 8 (13.4)      |
| Radiotherapy treatment         |               |
| Definitive RT+/-CT             | 42 (70)       |
| Adjuvant RT+/-CT               | 18 (30)       |

Values are presented as median (range) or number (%).

RT, radiotherapy; CT, computed tomography.
Set-up errors in head and neck cancer treated with IMRT

(∑) stands for the overall mean (M) calculated as the average value of all individual means, measuring the overall accuracy of disease-specific set-up procedures. The SD of the group systematic error (Σ̃) was calculated as the SD of the individual means. The overall indicator of the group random error (σ) was calculated as the root mean square of the individual SD of all patients.

Finally, for the calculation of the margin to be added to CTV to obtain PTV we used the van Herk formula (2.5∑ + 0.7r) [22] which ensures that 90% of the doses is given a CTVs of at least 95% of the prescribed dose.

Analyses were performed using the SPSS version 22 software (IBM, Armonk, NY, USA).

Results

A total of 360 CBCT scans in 60 patients affected by H&N cancer treated with the IMRT technique were acquired and analyzed. The mean ± SD of set-up errors was 1.26 ± 1.5 mm in the ML direction, 1.28 ± 1.3 mm in the SI direction and 1.97 ± 1.6 mm in the AP direction.

Table 2 reports the analysis of the displacement of set-up errors both with and without systematic correction; the ranges of translational shifts were 0–9 mm in the ML direction, 0–5 mm in the SI direction, and 0–10 mm in the AP direction. The overall frequencies of setup displacements greater than 3 mm were 3.9% in the ML direction, 8% in the SI direction and 15.5% in the AP direction (Table 2).

When the CBCT scans were analyzed before systematic corrections, the frequencies of the setup errors greater than 3 mm were 17.8%, 10.6% and 5.6% in the AP, SI, and ML directions, respectively. After set-up error correction (i.e., corrections via couch shifts or patient repositioning) these rates were reduced to 13.3%, 7.2%, and 2.2% in the ML, SI, and AP directions, respectively.

In Fig. 2A–C, the scatter-plots of translational displacements in three axes (ML, SI and AP) with or without the application of the systematic corrections are reported. Additionally, overall set-up displacements in any direction that were greater than 5 mm and which consequently required an online shift correction were present in 5.3% of the 360 CBCT scans analyzed (19/360).

Finally, according to the van Herk formula, taking a margin of 3–5 mm in all directions from CTVs to obtain the respective PTVs was adequate to overcome the set-up error problem; after the correction of systematic set-up errors, this margin was less than 3 mm (Table 3).

Discussion and Conclusion

Recent studies demonstrated that the IMRT technique enables the delivery of high, curative radiation doses to the gross tumor, lymph nodes and high-risk areas while sparing the adjacent organs [8-11]. For these reasons, IMRT is the ideal technique for the treatment of H&N cancer because it can potentially improve local–regional control, reduce side effects.
(especially xerostomia) and improve quality of life [12-16].

The improved dose conformality and the possibility of delivering high-radiation curative doses to the gross tumor achieved with IMRT requires greater accuracy in treatment planning and registration during the course of RT, due to reduced target delineation uncertainty and setup errors.

Several studies have investigated setup errors in H&N cancer, analyzing the required number (N) of first fractions to be imaged in order to detect systematic errors [23-42]. They also reported that weekly imaging after the first set of verifications was effective in further reducing the value of N while achieving the same accuracy [28].

The study of Houghton et al. [29] evaluated different imaging strategies in H&N cancer. They demonstrated that the systematic displacement registered after 3 fractions correlated well with the mean error of the other fractions delivered, and no additional benefit was noted when the mean error from the first 5 fractions was considered.

In our center, we applied a protocol that provides three CBCT scans in the first 3 fractions with the correction of setup errors greater than 3 mm in any direction, followed by weekly CBCT scans.

Based on the results of our study, a margin of 3–5 mm and weekly CBCT scans after the first three CBCTs on day 1, 2, and 3 of irradiation can reduce significant setup errors during the RT treatment.

As shown in Table 2, of the 360 CBCTs analyzed in our study only 28% of cases required correction (exhibited shift displacement greater than 3 mm). In particular, analyzing the CBCT scan before setup error correction yielded a frequency of setup displacements greater than 3 mm of 34.5%. After setup error corrections were applied (corrections via couch shifts or patient repositioning) this rate was reduced to 21%.

Furthermore, setup displacements greater than 5 mm in any direction had a frequency of 7.8% before setup error corrections were applied, and these rates were reduced to 2.8% after setup error correction.

As shown in Table 3, based on the van Herk formula (2.5Σ + 0.7r), the margin of 3–5 mm added from CTVs to PTVs was sufficient to overcome the setup errors in H&N cancer.

Moreover, after the correction of systematic setup errors, a 3-mm margin was sufficient to overcome the problem of set-up errors.

### Table 2. Frequencies of CBCT translational shifts greater than 3 and 5 mm in ML, SI, AP directions with and without the application of the systematic correction protocol

|                  | ML   | SI   | AP   | All  |
|------------------|------|------|------|------|
| Translational shifts >3 mm |      |      |      |      |
| Before corrections (180 CBCT) | 10 (5.6) | 19 (10.6) | 33 (18.3) | 62 (34.5) |
| After corrections (180 CBCT) | 4 (2.2) | 11 (6.1) | 24 (13.3) | 39 (21.6) |
| Globally (360 CBCT) | 14 (3.8) | 30 (8.3) | 57 (15.9) | 101 (28) |
| Translational shifts >5 mm |      |      |      |      |
| Before corrections (180 CBCT) | 2 (1.1) | 2 (1.1) | 10 (5.6) | 14 (7.7) |
| After corrections (180 CBCT) | 0 (0) | 1 (0.5) | 4 (2.2) | 5 (2.7) |
| Globally (360 CBCT) | 2 (0.5) | 3 (0.8) | 14 (3.9) | 19 (5.2) |

Values are presented as number (%). CBCT, cone-beam computed tomography; ML, medial-lateral; SI, superior-Inferior; AP, anterior-posterior.

### Table 3. Overall setup accuracy with and without the application of the systematic correction protocol

|                        | No systemic correction | Systemic correction | All 360 CBCT |
|------------------------|------------------------|---------------------|--------------|
|                        | ML     | SI     | AP     | ML     | SI     | AP     | ML     | SI     | AP     |
| Mean (mm)              | 1.28   | 1.56   | 1.99   | 1.23   | 1.28   | 1.95   | 1.26   | 1.28   | 1.97   |
| Range (mm)             | 0–9    | 0–6    | 0–10   | 0–4    | 0–6    | 0–6    | 0–9    | 0–5    | 0–10   |
| Systematic error (Σ)   | 1      | 1      | 1.3    | 0.8    | 0.7    | 0.8    | 0.7    | 0.8    | 0.9    |
| random error (σ)       | 1.8    | 1.4    | 1.8    | 1.1    | 1.2    | 1.4    | 1.5    | 1.3    | 1.6    |
| CTV–PTV margin (mm)    | 3.76   | 3.48   | 4.51   | 2.84   | 2.59   | 2.98   | 2.8    | 2.91   | 3.37   |

CBCT, cone-beam computed tomography; ML, medial-lateral; SI, superior-Inferior; AP, anterior-posterior; CTV, clinical target volume; PTV, planning target volume.
Fig. 2. Scatter-plot of translational displacements in the three axes without and with the application of the systematic correction protocol: (A) ML direction, (B) SI direction, and (C) AP direction. CBCT, cone-beam computed tomography; ML, medial-lateral; SI, superior-inferior; AP, anterior-posterior.
Similar findings were reported by Dionisi et al. [30], where a total of 420 CBCT scans of patients with H&N cancer were analyzed. A systematic correction was necessary in 43% of patients and the overall mean displacement was less than 1 mm in all directions. The PTV margins calculated after online correction were less than 2.5 mm in all directions. The authors concluded that a margin of 5 mm added to CTVs to obtain the respective PTVs was safe in order to overcome the problem of set-up errors, and in particular situations, such as re-irradiation, the close proximity of organs at risk and high-dose regions or IGRT, these margins can be reduced to 3 mm.

Moreover, in 2015, Xu et al. [37] reported the data of a prospective study which investigated the set-up errors in 30 patients affected by nasopharyngeal cancer treated with IMRT, based on weekly CBCT evaluation. Each patient had a weekly CBCT scan before radiation therapy. In the entire study, 201 CBCT scans were analyzed and the author concluded that adding a margin of 3 mm in all directions from the CTVs to obtain the respective PTVs was adequate to overcome the problem of set-up errors. Finally, Velec et al. [38], in a prospective study, compared the intrafraction and interfraction set-up errors in two different thermoplastic masks in patients affected by H&N cancer treated with IMRT. The authors evaluated 762 CBCT scans and the set-up errors before and after corrections were less than 3 mm in any direction. There was no statistical significance between the two different thermoplastic masks, with respect to interfraction and intrafraction set-up errors.

In conclusion, the results of our study confirmed that image guided kV CBCT is effective in evaluating set-up accuracy in H&N cancer patients. This study suggested that kV CBCT at the first 3 fractions and subsequently once a week seems adequate to overcome the problem of set-up errors in H&N cancer treated with the IMRT technique. Finally, adding a margin of 3–5 mm in all directions to the CTVs to obtain the respective PTVs is adequate and safe to overcome the problem of set-up errors. In particular situations or in the case of IGRT, these margins can be reduced to 3 mm.

**Conflict of Interest**

No potential conflict of interest relevant to this article was reported.
postoperative IMRT for head-and-neck cancer. Int J Radiat Oncol Biol Phys 2003;55:312-21.
12. Ursino S, D’Angelo E, Mazzola R, et al. A comparison of swallowing dysfunction after three-dimensional conformal and intensity-modulated radiotherapy: a systematic review by the Italian Head and Neck Radiotherapy Study Group. Strahlenther Onkol 2017;193:877-89.
13. Eisbruch A, Kim HM, Terrell JE, Marsh LH, Dawson LA, Ship JA. Xerostomia and its predictors following parotid-sparing irradiation of head-and-neck cancer. Int J Radiat Oncol Biol Phys 2001;50:695-704.
14. Chao KS, Deasy JO, Markman J, et al. A prospective study of salivary function sparing in patients with head-and-neck cancers receiving intensity-modulated or three-dimensional radiation therapy: initial results. Int J Radiat Oncol Biol Phys 2001;49:907-16.
15. Delishaj D, Ursino S, Lombardo E, et al. Impact of treatment volumes in loco-regional failure of oral cancer in patients treated with IMRT. Radiother Oncol 2016;119:5985.
16. Parliament MB, Scrimger RA, Anderson SG, et al. Preservation of oral health-related quality of life and salivary flow rates after inverse-planned intensity- modulated radiotherapy (IMRT) for head-and-neck cancer. Int J Radiat Oncol Biol Phys 2004;58:663-73.
17. Jaffray DA, Siewerdsen JH, Wong JW, Martinez AA. Flat-panel cone-beam computed tomography for image-guided radiation therapy. Int J Radiat Oncol Biol Phys 2002;53:1337-49.
18. Nielsen M, Bertelsen A, Westber J, Jensen HR, Brink C. Cone beam CT evaluation of patient set-up accuracy as a QA tool. Acta Oncol 2009;48:271-6.
19. Den RB, Doemer A, Kubicek G, et al. Daily image guidance with cone-beam computed tomography for head-and-neck cancer intensity-modulated radiotherapy: a prospective study. Int J Radiat Oncol Biol Phys 2010;76:1353-9.
20. Korremans S, Rasch C, McNair H, et al. The European Society of Therapeutic Radiology and Oncology-European Institute of Radiotherapy (ESTRO-EIR) report on 3D CT-based in-room image guidance systems: a practical and technical review and guide. Radiother Oncol 2010;94:129-44.
21. Stroom JC, Heijmen BJ. Geometrical uncertainties, radiotherapy planning margins, and the ICRU-62 report. Radiother Oncol 2002;64:75-83.
22. van Herk M. Errors and margins in radiotherapy. Semin Radiat Oncol 2004;14:52-64.
23. Amer AM, Mackay RI, Roberts SA, Hendry JH, Williams PC. The required number of treatment imaging days for an effective off-line correction of systematic errors in conformal radiotherapy of prostate cancer: a radiobiological analysis. Radiother Oncol 2001;61:143-50.
24. Delishaj D, Ursino S, Lombardo E, et al. OC-0274: Analysis of set-up errors in head and neck cancer treated with IMRT technique assessed by CBCT. Radiother Oncol 2016;119(Suppl 1):S127–S128.
25. Bortfeld T, van Herk M, Jiang SB. When should systematic patient positioning errors in radiotherapy be corrected? Phys Med Biol 2002;47:N297–302.
26. Zeidan OA, Langen KM, Meeks SL, et al. Evaluation of image-guidance protocols in the treatment of head and neck cancers. Int J Radiat Oncol Biol Phys 2007;67:670-7.
27. Suzuki M, Nishimura Y, Nakamatsu K, et al. Analysis of interfractional set-up errors and intrafractional organ motions during IMRT for head and neck tumors to define an appropriate planning target volume (PTV)- and planning organs at risk volume (PRV)-margins. Radiother Oncol 2006;78:283-90.
28. Su J, Chen W, Yang H, et al. Different setup errors assessed by weekly cone-beam computed tomography on different registration in nasopharyngeal carcinoma treated with intensity-modulated radiation therapy. Onco Targets Ther 2015;8:2545-53.
29. Houghton F, Benson RJ, Tudor GS, et al. An assessment of action levels in imaging strategies in head and neck cancer using TomoTherapy. Are our margins adequate in the absence of image guidance? Clin Oncol (R Coll Radiol) 2009;21:720-7.
30. Dionisi F, Palazzi MF, Bracco F, et al. Set-up errors and planning target volume margins in head and neck cancer radiotherapy: a clinical study of image guidance with on-line cone-beam computed tomography. Int J Clin Oncol 2013;18:418-27.
31. Bissonnette JP, Moseley D, White E, Sharpe M, Purdie T, Jaffray DA. Quality assurance for the geometric accuracy of cone-beam CT guidance in radiation therapy. Int J Radiat Oncol Biol Phys 2008;71(1 Suppl):S57-61.
32. McKenzie A, van Herk M, Mijnheer B. Margins for geometric uncertainty around organs at risk in radiotherapy. Radiother Oncol 2002;62:299-307.
33. Pisani L, Lockman D, Jaffray D, Yan D, Martinez A, Wong J. Setup error in radiotherapy: on-line correction using electronic kilovoltage and megavoltage radiographs. Int J Radiat Oncol Biol Phys 2000;47:825-39.
34. Wang J, Bai S, Chen N, et al. The clinical feasibility and effect of online cone beam computer tomography-guided intensity-modulated radiotherapy for nasopharyngeal cancer. Radiother Oncol 2009;90:221-7.
35. Johansen J, Bertelsen A, Hansen CR, Westberg J, Hansen O,
Brink C. Set-up errors in patients undergoing image guided radiation treatment. Relationship to body mass index and weight loss. Acta Oncol 2008;47:1454-8.

36. Barker JL Jr, Garden AS, Ang KK, et al. Quantification of volumetric and geometric changes occurring during fractionated radiotherapy for head-and-neck cancer using an integrated CT/linear accelerator system. Int J Radiat Oncol Biol Phys 2004;59:960-70.

37. Xu F, Wang J, Bai S, et al. Detection of intrafractional tumour position error in radiotherapy utilizing cone beam computed tomography. Radiother Oncol 2008;89:311-9.

38. Velec M, Waldron JN, O’Sullivan B, et al. Cone-beam CT assessment of interfraction and intrafraction setup error of two head-and-neck cancer thermoplastic masks. Int J Radiat Oncol Biol Phys 2010;76:949-55.

39. Zhang L, Garden AS, Lo J, et al. Multiple regions-of-interest analysis of setup uncertainties for head-and-neck cancer radiotherapy. Int J Radiat Oncol Biol Phys 2006;64:1559-69.

40. Clarizio M, Zani M, Delishaj D, et al. EP-1619: Comparison between two different commercial thermoplastic mask systems in image-guided radiation therapy. Radiother Oncol 2015;115:S887–S888.

41. Osman SO, de Boer HC, Astreinidou E, Gangsaas A, Heijmen BJ, Levendag PC. On-line cone beam CT image guidance for vocal cord tumor targeting. Radiother Oncol 2009;93:8-13.

42. van Kranen S, van Beek S, Rasch C, van Herk M, Sonke JJ. Setup uncertainties of anatomical sub-regions in head-and-neck cancer patients after offline CBCT guidance. Int J Radiat Oncol Biol Phys 2009;73:1566-73.