Original Article

Estimation of CTV to PTV Margins in Head and Neck Cancer Patients Using On-Board Imager [OBI]

Sangutid Thongsawad MSc[1,2], Wilai Masa-nga BSc[2],
Sawanee Suntiwong MSc[2], Kittipol Dachaworakol MSc[1,2],
Chirasak Khamfongkhruea MSc[1,2], Sasikarn Chamchod MD[1,2], Chirapha Tannanonta MS[2]

[1] Faculty of Medicine and Public Health, HRH Princess Chulabhorn College of Medical Science, Chulabhorn Royal Academy, Bangkok, Thailand
[2] Department of Radiation Oncology, Chulabhorn Hospital, HRH Princess Chulabhorn College of Medical Science, Chulabhorn Royal Academy, Bangkok, Thailand

Background: At Chulabhorn Hospital, uniform clinical target volume [CTV] to planning target volume [PTV] margin of 0.5 cm is used for head and neck cancer radiation therapy treatment as Radiation Therapy Oncology Group [RTOG] protocol suggested. However, PTV margins relate to types of thermoplastic mask, image verification modality, and image guidance protocol.

Objective: To estimate the CTV to PTV margins in head and neck cancer patients treated with intensity modulated radiation therapy [IMRT] at Chulabhorn Hospital in order to verify whether our current addition of 0.5 cm was appropriate.

Materials and Methods: Twenty-three head and neck cancer patients treated with IMRT technique were included in this study. The population systematic (Σ_{total}) and random errors (σ_{total}) of patient setup were determined to estimate the CTV to PTV margins by using Van Herk equation in 1D and 3D.

Results: The CTV to PTV margins calculated with 1D margin were 0.12, 0.16, and 0.10 cm for Vert, Lng, and Lat couch directions, respectively. The CTV to PTV margin calculated with anisotropic 3D margin expansion was 0.32 cm.

Conclusion: This study indicated that the uniform CTV to PTV margin of 0.5 cm used for head and neck cancer patients at our hospital is adequate to cover set up errors.

Keywords: PTV margins estimation; Setup errors; On-board imager; Head and neck cancer

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Intensity modulated radiation therapy [IMRT] was developed to improve dose to tumor and to reduce dose to surrounding normal organs[1-3]. In head and neck cancer, the IMRT technique is used to improve the treatment results[4-7]. Although patients are fixed by using thermoplastic mask, residual error could occur due to variations of set up errors, tumor motion, and tumor delineation errors. To ensure that radiation dose covering a tumor, clinical target volume [CTV] is expanded as planning target volume [PTV]. The Radiation Therapy Oncology Group [RTOG] protocol H-0022 suggested using a uniform CTV to PTV margin of at least 0.5 cm until institution-specific uncertainty has been evaluated[8]. At Chulabhorn Hospital, uniform CTV to PTV margin of 0.5 cm has been used for head and neck cancer as RTOG protocol suggested. The formula to estimate CTV to PTV margins was published by Van Herk M et al[9]. Many studies estimated CTV to PTV margins in head and neck cancer, and found that adequate PTV margins could be less than 0.5 cm which were related to types of thermoplastic mask,

Correspondence to:
Thongsawad S. Faculty of Medicine and Public Health, HRH Princess Chulabhorn College of Medical Science, Chulabhorn Royal Academy, 54 Kamphaengphet 6 Road, Talat Bangkhen, Laksi, Bangkok 10210, Thailand.
Phone: +66-2-5766038, **Fax:** +66-2-5766000
E-mail: sangutid.tho@pccms.ac.th

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image verification modality, and image guidance protocol[10-12].

The purpose of the present study was to estimate the CTV to PTV margins in head and neck cancer treated with IMRT at Chulabhorn Hospital in order to verify whether our current addition of 0.5 cm was appropriate.

Materials and Methods

Patient setup and data acquisition

The data of 23 head and neck cancer patients treated with IMRT technique were retrospectively collected and analyzed. All patients in this study were treated with 6 MV photon beams of a linear accelerator (LINAC) machine (Trilogy model, Varian, Palo Alto, USA) at Chulabhorn Hospital, Bangkok, Thailand. The On-Board Imager system (On-Board Imager®, Varian Medical Systems, Inc., Palo Alto, CA) was used to verify patient position.

The patients were immobilized using thermoplastic mask (MedTech®, Orange City, USA) as shown in Figure 1. Thermoplastic mask were fixed to the base plate on the table couch top of the treatment machine. The patients were scanned with the protocol of 0.3 cm slice thickness and 5.0 cm extended length from the target volume to account for scattered dose. Three isocenter setup points for anterior, right and left lateral directions of each patient were marked on the thermoplastic mask. In the LINAC room, the patients were setup using the three isocenter markers then the planar images (anterior and lateral) from On-Board Imager [OBI] were taken before each treatment.

OBI image analysis

Digitally reconstructed radiographs [DRRs] created from the treatment planning system were used as the reference images and the anatomical bony landmarks were drawn in the DRRs as the reference organs for comparing with the OBI images[13,14]. Using the OBI software, comparison of DRRs and planar images (Figure 2) were used to determine the positioning errors. The anterior-posterior (AP) image was used to determine the errors in Lng and Lat directions while the lateral one was used to determine the errors or couch displacement in Vert and Lng directions.

Systematic and random errors

From couch displacement data of individual patients, the systematic errors were calculated using the standard deviation of the mean couch displacement, and the random errors were calculated using root-mean-square of the standard deviation of couch displacement[15,16].

PTV margin estimation

In this study, the PTV margins were calculated by using Van Herk equation for two types of margins, one dimensional ($1D_{PTV}$), and anisotropic three dimensional ($3D_{PTV}$) expansion margins as the following equations[9]:

$$PTV = 1.64\,\Sigma_{ecah\_direction} + 0.7\sigma_{ecah\_direction} \quad (1)$$

$$3D_{PTV} = 2.5\Sigma_{total} + 0.7\sigma_{total} \quad (2)$$

The total systematic (Σ_{total}) and random errors (σ_{total}) were calculated by using the equations:

$$\sigma_{total} = (\Sigma^2_{Lng} + \Sigma^2_{Lat} + \Sigma^2_{Vert})^{1/2} \quad (3)$$

$$\sigma_{total} = (\sigma^2_{Lng} + \sigma^2_{Lat} + \sigma^2_{Vert})^{1/2} \quad (4)$$

Where Σ^2_{Lng},$\Sigma_{Lat,}$ and Σ_{Vert} are the systematic errors and σ_{Lng}, σ_{Lat}, and σ_{Vert} are the random errors in Lng, Lat, and Vert directions, respectively.

The protocol of this research was reviewed and approved by the Human research ethics commette Chulabhorn Research Institute No. 15/2553.

Results

Table 1 shows mean and standard deviation [SD] of couch displacement for 23 head and neck cancer patients, which were used to calculate systematic errors. Mean couch displacement were 0.033 to 0.222 cm, 0.040 to 0.417 cm, and 0.033 to 0.214 cm in Vert,

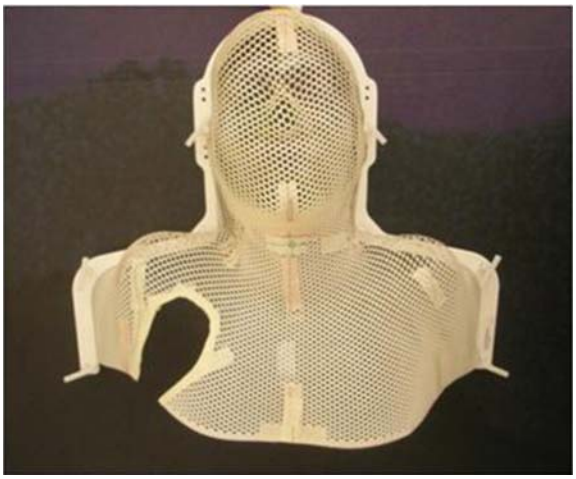

Figure 1. Thermoplastic long masks (MedTeh®, Orange City, USA).

Figure 2. OBI software used for planar image matching in Lateral (Left) and Anterior (Right) views.

Lng, and Lat directions, respectively. Standard deviations of mean couch displacement were 0.05, 0.08, and 0.05 cm in Vert, Lng, and Lat directions, respectively.

Table 2 shows standard deviation [SD] and root-mean-square [RMS] of couch displacement for 23 head and neck cancer patients, which were used to calculate random errors. Standard deviations of couch displacement were 0.026 to 0.283 cm, 0.012 to 0.170 cm, and 0.001 to 0.147 cm in Vert, Lng, and Lat direction, respectively. Root-mean-square of standard deviation of couch displacement were 0.05, 0.04, and 0.03 cm in Vert, Lng, and Lat directions, respectively.

Table 3 shows the systematic and random errors in terms of each couch direction and total errors. The highest systematic and random errors were found in Lng couch direction with 0.08 cm and in Vert couch direction with 0.05 cm, respectively. The total systematic errors

(Σ_{total}) were 0.11 cm, and the total random errors (σ_{total}) were 0.07 cm.

Table 4 shows the PTV margins in terms of 1D and anisotropic 3D expansion. From Van Herk equation, the 1D margin were 0.12 cm, 0.16 cm, and 0.10 cm for Vert, Lng, and Lat couch directions, respectively. The PTV margins for anisotropic 3D expansion were 0.32 cm.

Discussion

For the IMRT and VMAT treatment techniques, the PTV margin estimation is essential because it can confirm that the margins determined by oncologist were adequate for radiation treatment. Moreover, PTV margin estimation may help oncologist to reduce PTV margins in the future, which may decrease patient complication[12]. To meet a plan evaluation, IMRT plan requires conformal dose distribution to tumor and steep dose gradient between tumor and normal organs. Reproducibility of immobilization tool and skill of radiation therapist, which relate to PTV margins estimation, are concerned. This study also gives us a confidence of reproducibility of immobilization tool and skill of radiation therapist.

In the margin calculation, the impact of treatment systematic errors and random errors is fully separated. Generally, systematic errors have more influence to PTV margins than random errors because systematic errors are determined to compensate an unknown shift of the CTV but the random errors are determined to compensate the blurring of the dose distribution as day-to-day variation. In this study, weighting factor of systematic (2.5) and random (0.7)

Table 1. Mean and standard deviation (SD) of couch displacement for 23 head and neck cancer patients

Patient #	Mean of couch displacement (cm)		
	Vert	Lng	Lat
1	0.133	0.083	0.083
2	0.222	0.186	0.150
3	0.162	0.100	0.124
4	0.145	0.195	0.090
5	0.133	0.133	0.033
6	0.140	0.040	0.133
7	0.063	0.075	0.125
8	0.078	0.100	0.156
9	0.100	0.075	0.119
10	0.200	0.086	0.043
11	0.214	0.143	0.114
12	0.075	0.150	0.150
13	0.167	0.083	0.083
14	0.114	0.129	0.086
15	0.086	0.100	0.086
16	0.214	0.057	0.214
17	0.060	0.200	0.080
18	0.033	0.200	0.067
19	0.144	0.115	0.163
20	0.200	0.200	0.100
21	0.150	0.200	0.167
22	0.112	0.054	0.062
23	0.100	0.417	0.048
SD	0.050	0.080	0.050

Table 2. Standard deviation [SD] and root-mean-square [RMS] of couch displacement for 23 head and neck cancer patients

Patient #	SD of couch displacement(cm)		
	Vert	Lng	Lat
1	0.082	0.075	0.098
2	0.145	0.146	0.110
3	0.116	0.100	0.100
4	0.105	0.170	0.085
5	0.05	0.096	0.050
6	0.106	0.063	0.098
7	0.074	0.046	0.089
8	0.083	0.071	0.073
9	0.061	0.073	0.083
10	0.115	0.069	0.079
11	0.069	0.098	0.090
12	0.050	0.129	0.058
13	0.082	0.075	0.075
14	0.069	0.076	0.107
15	0.090	0.058	0.069
16	0.121	0.053	0.107
17	0.055	0.100	0.045
18	0.026	0.012	0.022
19	0.128	0.082	0.147
20	0.283	0.141	0.001
21	0.176	0.126	0.081
22	0.091	0.065	0.070
23	0.104	0.080	0.057
RMS	0.05	0.04	0.03

errors in 3D margins estimation are based on 90% of the patient population which has coverage of 95% isodose level to CTV[9].

Although the maximum margin calculated with 1D equation was 0.16 cm, the PTV margin was still less than 0.5 cm as recommended by the RTOG[8]. Thus, this may imply that our PTV margin with an uniform expansion of 0.5 cm is adequate for all directions. Basically, the true margins may be less than our calculation because the couch will be shifted to the correct position before beam delivery if the IGRT has been executed; hence, the calculated PTV margin may be overestimated. Our study found the 3D margins was 0.32 cm which were comparable with the other study. Wang et al found the PTV margins of 0.5 to 0.6 cm was required to ensure adequate coverage of CTV if no online correction was performed[17,18]. Kapanen et al found that 3D margins was less than 0.5 cm with planar images verification in head and neck cancer radiation treatment immobilized with 5-point C-frame (Candor, Gislev, Denmark)[11]. Baron et al estimated 3D margins in head and neck cancer radiation treatment with daily CT on-rails imaging, and found the 3D margins was 0.46 cm[10]. Lu et al estimated 1D margin with Cone beam Computed Tomography [CBCT] and found the margins of 4.9 mm, 4.0 mm and 6.3 mm were required in the RL, SI and AP directions, respectively[19].

Although our study emphasized on CTV to PTV margins, the organ at risk [OAR] to the planning organ at risk volume [PRV] margins can also be calculated with the same data by using equation of McKenzie[18]. Thus, the OAR to PRV margins were calculated as:

$$3D^{PRV} = 1.3\Sigma_{total} + 0.5\,\sigma_{total} \quad (5)$$

Additionally, this study also estimated the OAR to PRV margins calculated using the McKenzie equation, and found that the PRV margin was 0.18 cm which appeared to be adequate for our PRV margin with 0.5 cm for spinal cord. Our PRV margin estimation

Table 3. The values of systematic (Σ), random (σ), total systematic (Σ_{total}) , and total random (σ_{total}) errors in Vert, Lng, and Lat directions in cm.

Error Type	Couch direction			Total error
	Vert	Lng	Lat	
Σ	0.05	0.08	0.05	0.11 (Σ_{total})
σ	0.05	0.04	0.03	0.07 (σ_{total})

Table 4. PTV margins in terms of 1D and 3D in cm.

PTV margins	Couch direction		
	Vert	Lng	Lat
1D	0.12	0.16	0.10
3D	Anisotropic expansion		
	0.32		

was comparable with the other studies that was found 0.27 and 0.4 cm[10,20].

Conclusion

This study showed the maximum PTV margins for 1D was 0.16 cm in Lng direction and for anisotropic 3D expansion was 0.32 cm which were less than the RTOG recommendation values of 0.5 cm. The uniform CTV to PTV margin of 0.5 cm used for head and neck cancer at our hospital is thus adequate to cover the set up errors.

What is already known on this topic?

The RTOG protocol suggestion for radiation treatment in head and neck cancer, a uniform CTV to PTV margin of at least 0.5 cm, was suggested to use until the institution-specific uncertainty has been evaluated. CTV to PTV margin could be varied in different hospitals, depending on immobilization device, setup error, systematic error in radiation machine, imaging modality used, and imaging protocol.

What this study adds?

The PTV margins calculated in 1D and 3D anisotropic expansion with institution-specific uncertainty were established at our department. Additionally, the PRV margins were also estimated in this study.

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Potential conflicts of interest

The authors declare no conflict of interest.

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