EVALUATION OF INITIAL SETUP ERRORS AND DETERMINATION OF SETUP MARGIN IN VMAT RADIOTHERAPY FOR PELVIC TREATMENT PATIENTS AT VINMEC TIMESCITY HOSPITAL

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ABSTRACT

Introduction and purpose: In radiation therapy, accurate dose distribution to the target volume requires precision in treatment setup. Patient setup errors are unavoidable and always present during the treatment process. By identifying these errors, it is possible to determine the setup margin from the Clinical Target Volume (CTV) to the Planning Target Volume (PTV) to cover the target volume while minimizing the dose to adjacent healthy tissues. This study aims to evaluate the random and systematic errors occurring during the setup of pelvic radiation therapy using the On-Board Imaging (OBI) system, and subsequently propose an optimal setup margin distance from CTV to PTV for patients with pelvic cancer.

Materials and methods: A total of 40 patients evenly divided between rectal and cervical cancer for VMAT treatment were given radiation therapy at Vinmec Times City International Hospital from 01/2023 to 8/2024. The patients were scanned by CT simulation on CT Optimal 580 (GE Medical System, Milwaukee, Wisconsin USA), planning on the Eclipse software (ver 13.0) of varian firm (USA), The patients were taken photo verification 2D-KV images (daily) and 3D-CBCT (Monday and Thursday) are analyzed online on OBI software and compared with DRR images from the plan, thereby evaluating and recording errors in 3 directions front after (AP Anterior-Posterior); above and below (SI Superior-Inferior); left right (LR Lateral). Random and systematic errors are identified based on the collected error data, The set-up margin for CTV to PTV was calculated by published margin formulae of Van Herk et al.

Results: A total of 534 pairs of 2D-KV cervical images and 448 pairs of 2D-KV rectal images were performed and evaluated. For cervical cancer, the systematic error and random error in the AP, SI, and LR directions were (1.28 ± 1.92 mm), (2 ± 3.5 mm) and (1.41 ± 1.78 mm), respectively. For rectal cancer, the systematic error and random error in the AP, SI, and LR directions were (1.18 ± 1.57 mm), (2.01 ± 3.06 mm), and (0.89 ± 1.89 mm), respectively. The setup margin required to cover the target volume retrospectively was calculated based on Van Herk et al were: 5 mm (AP), 7 mm (SI), 5 mm (LR) for the cervix uteri and 5 mm (AP), 7.5 mm (SI), 5 mm (LR) for the rectum.

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Conclusion: The assessment and verification of images before treatment with OBI system helps reduce setting errors, increase dose in tumors, reduce unwanted side effects and allows estimating the setup of the planning target volume (PTV) expansion according to our configuration. Based on the results of the study, we propose that setup margin with radiotherapy for the pelvis at our hospital are: 5mm (AP), 7mm (SI), 5mm (LR) for the cervix uteri and 5mm (AP), 7.5mm (SI), 5mm (LR) for the rectum.

Keywords: Setup errors; setup margin; VMAT radiotherapy; cervical cancer; rectal cancer…

I. INTRODUCTION

Over the past decade, there have been significant advancements in cancer treatment, particularly for pelvic tumors such as rectal cancer and cervical cancer. External treatment modalities like radiotherapy demand a very high level of precision. However, numerous errors can occur from the simulation and planning stages to daily treatment delivery, potentially affecting treatment quality. Therefore, accurate daily patient repositioning in radiotherapy is critically important and represents a significant potential source of error that must be carefully addressed. These daily setup deviations also known as setup errors can be classified as either systematic or random errors.

Such errors arise from discrepancies between the treatment planning process and the actual treatment setup and may lead to variations in radiation dose distribution [1]. Random errors may vary from day to day, reflecting the uncertainty of reproducibility and positional stability during treatment. To account for these uncertainties, the International Commission on Radiation Units and Measurements (ICRU) introduced the concept of the Planning Target Volume (PTV), which includes these setup uncertainties [2]. Van Herk et al. identified approximately ten potential sources of error and developed a formula to estimate the required margin from a homogeneous patient group to ensure a 90% probability that the Clinical Target Volume (CTV) is within the 95% isodose region [3]. The PTV is defined as the safety margin necessary to ensure that the CTV receives the prescribed dose. This concept is indispensable in treatment planning and evaluation and encompasses the CTV, an internal target volume (ITV) margin, and a setup margin accounting for positioning and reproducibility errors. Defining the setup margin helps to minimize the influence of mechanical and technical factors from the machine (systematic errors) and residual uncertainties (random errors) [4].

One of the most critical factors in ensuring radiotherapy accuracy is determining the setup margin (SM) the safety distance around the treatment volume to compensate for setup errors. This margin must be determined accurately and appropriately to ensure that the tumor receives the necessary dose without causing excessive harm to surrounding healthy tissues. However, determining the optimal SM is not always straightforward and requires a careful balance between protecting healthy tissues and ensuring effective tumor control.

At our center, patients are prioritized for radiotherapy using VMAT (Volumetric Modulated Arc Therapy) with the modern Clinac iX linear accelerator (Varian Medical Systems, Palo Alto, CA). Errors are assessed and corrected daily prior to treatment using the Portal Vision and OBI systems, which enable 2D-KV imaging and 3D-CBCT for error detection and repositioning based on the treatment plan [5-6].

Although many previous studies have examined setup errors in radiotherapy and methods for determining SM, there is still a lack of detailed and updated analysis regarding the application of these methods in VMAT treatment for the pelvic region. This article aims to evaluate setup errors in VMAT pelvic radiotherapy at our center, analyze factors affecting treatment setup accuracy, and determine

the optimal SM to improve treatment efficacy and minimize side effects. Conducting this study will provide deeper insight into managing setup errors and developing more appropriate treatment strategies, ultimately enhancing the quality of care for patients.

2. SUBJECTS AND METHODS

2.1. Subjects

This retrospective study randomly selected 40 patients with pelvic cancers, equally divided between cervical cancer and rectal cancer cases, who were treated with VMAT (Volumetric Modulated Arc Therapy) at the Department of Radiation Oncology, Vinmec Times City International Hospital from January 2023 to August 2024. A total of 982 pairs of daily 2D-KV images (from Monday to Friday) were collected, including 534 image pairs for cervical cancer patients and 448 image pairs for rectal cancer patients.

2.2. Patient preparation and Immobilization devices prior to simulation

All patients undergoing pelvic radiotherapy were carefully prepared with attention to bladder and rectal conditions to ensure reproducibility and stability throughout the treatment process. Typically, at our center, patients are instructed to completely empty their bowels. The bladder and rectum are then checked by the radiation technologist using a CT scanner (Computed Tomography) to confirm an empty bladder and clean rectum (free of gas and stool; if not, enemas may be prescribed by the physician). Following that, patients are instructed to drink approximately 400-500 ml of water, including a diluted contrast mixture in a water-to-contrast ratio of about 10:1 (to aid physicians in contouring the bowel structures during treatment planning) and wait for 45-60 minutes before the simulation scan.

The immobilization devices used for pelvic radiotherapy in patients with cervical or rectal cancer include: a hipfix system with or without a vac-lock, an appropriate headrest, feetfix leg support, and a pelvic mask for immobilization.

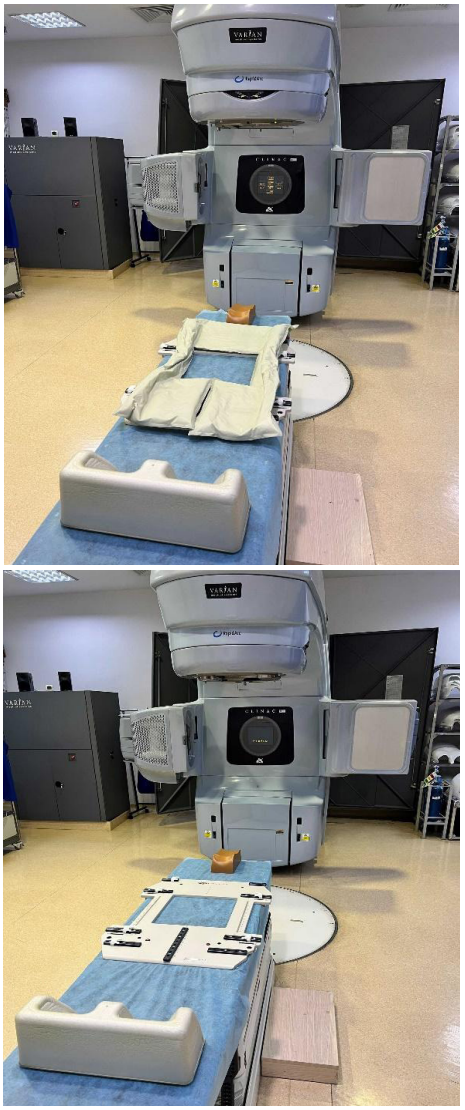


Figure 1. Pelvic radiotherapy Immobilization device set

2.3. Simulation imaging

All patients lay in the supine position on a hipfix system, in a comfortable posture. The glabella philtrum xiphoid process pubic symphysis points were aligned along the laser axis. Arms were placed over the chest and legs were immobilized

using a feetfix system. A tight-fitting thermoplastic mask was molded to cover the pelvic-abdominal region. Patients underwent simulation CT scans using a 16-slice CT scanner (CT 580-Optima, GE Healthcare), with a slice thickness of 2.5 mm. Intravenous contrast was administered, and the scan range extended from vertebral level L1 to the upper third of the femur.

2.4. 2D-KV image verification before treatment

Prior to radiation delivery, all 40 patients underwent daily 2D-KV imaging and 3D-CBCT imaging on Mondays and Thursdays as part of the VMAT protocol. The 2D-KV images were X-ray images showing bone anatomical structures. A total of 534 2D-KV image pairs for cervical cancer and 448 pairs for rectal cancer were acquired in three directions: anteroposterior (AP), superoinferior (SI), and left-right (LR). These images were recorded using the OBI system and directly compared with digitally reconstructed radiographs (DRRs) to determine setup errors in all three directions.

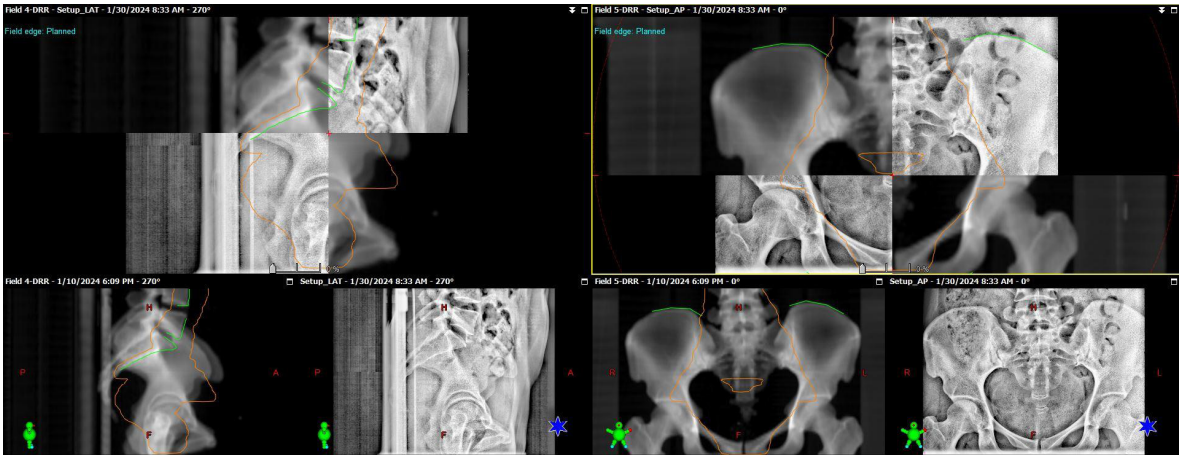


Figure 2. Comparison of 2D-KV image with DRR image before treatment

2.5. Retrospective study design and error calculation method

In each patient group, all setup errors in the three directions-anterior-posterior (AP), superior-inferior (SI) and left-right (LR)-were recorded after each treatment session by comparing the 2D-KV images with the DRR images based on bony landmarks. A total of 534 sets of cervical cancer setup errors and 448 sets for rectal cancer were collected across all three directions to determine:

- The average setup error in each direction for each patient in both groups.

- The mean (M) of the average setup errors in each direction for each patient.

- The standard deviation (SD) of the setup errors in each direction per patient.

- The standard deviation of the mean setup errors (M) for each patient.

- The average of the standard deviations across all patients.

The setup margin (CTV–PTV) for each group (cervical and rectal cancer) was calculated using the Van Herk et al. formula[7]:

$$SM = 2{,}5\Sigma + 0{,}7\sigma$$

Where:

Σ represents the systematic error, determined as the standard deviation of the mean setup errors across the three directions;

σ represents the random error, calculated as the average of the standard deviations for each individual patient.

3. RESULTS AND DISCUSSION

A total of 40 patients were included in the study, comprising 20 patients (50%) with cervical cancer and 20 patients (50%) with rectal cancer. All patients were treated with the VMAT technique using the immobilization devices as previously described.

A total of 982 pairs of 2D-KV images were acquired during treatment to assess setup deviations in all three directions for all 40 patients. From these, we calculated the overall mean setup error (M) and the overall standard deviation (SD) for each direction per patient. The average values for each direction were: Anterior-posterior (AP): 0.62 ± 1.75 mm, Superior-inferior (SI): 1.88 ± 2.75 mm, Left-right (LR): 1.02 ± 1.83 mm. Among the 534 initial setups for cervical cancer treatments and 448 for rectal cancer treatments, we observed that the proportion of initial setup errors exceeding 3 mm in the AP, SI, and LR directions were: For cervical cancer: 14.04% (AP), 32.58% (SI), 14.04% (LR), for rectal cancer: 8.93% (AP), 30.36% (SI), 19.20% (LR).

Table 1. Setup errors (Mean) and standard deviation of patients receiving pelvic radiotherapy

Direction	M ± SD	SD (range)
AP	0.62 ± 1.23	1.75 ± 0.61
SI	1.88 ± 1.96	2.75 ± 2.25
LR	1.02 ± 1.28	1.83 ± 0.54

At the treatment position, the setup error (M) and standard deviation (SD) of patient positioning errors in the AP, SI, and LR directions were as follows: For cervical cancer patients: 0.58 ± 1.92 mm (AP), 1.96 ± 2.45 mm (SI), and 0.52 ± 1.77 mm (LR). For rectal cancer patients: 0.67 ± 1.57 mm (AP), 1.79 ± 3.06 mm (SI), and 1.53 ± 1.89 mm (LR).

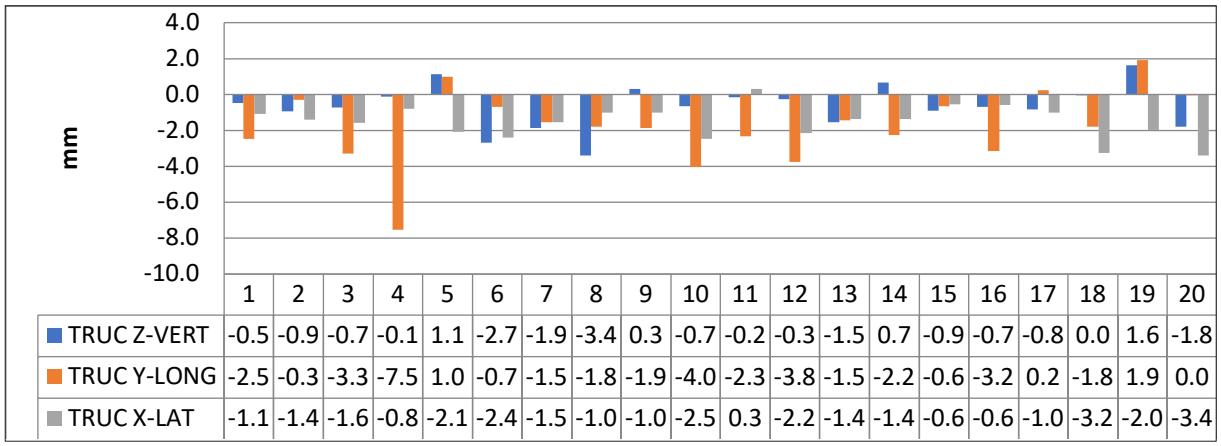
Table 2. Mean setup errors (M) and mean standard deviations (SD) by cancer type (mm)

Site	AP		SI		LR	
	M ± SD	Range	M ± SD	Range	M ± SD	Range
Cervical	0.58 ± 1.92	0.1 – 2.2	1.96 ± 2.45	0.09 – 6.5	0.52 ± 1.77	0.04 – 3.7
Rectal	0.67 ± 1.57	0.04 – 3.4	1.79 ± 3.06	0.04 – 7.54	1.53 ± 1.89	0.32 – 3.4

The systematic error (Σ) and random error (σ) were calculated based on the standard deviations of the mean setup errors and the average of individual standard deviations. From these values, the setup margin (SM, CTV–PTV) was determined using the Van Herk et al. formula. For cervical cancer patients, the calculated SM values in the AP, SI, and LR directions were 4.54 mm, 6.75 mm, and 4.75 mm, respectively. For rectal cancer patients, the corresponding SM values were 4.05 mm, 7.16 mm and 3.55 mm.

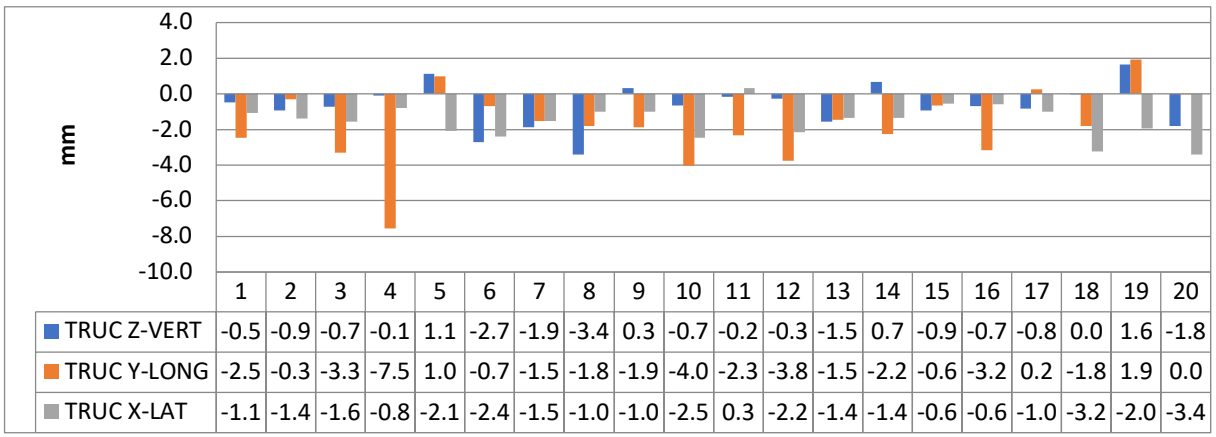
Table 3. Comparison of systematic error (Σ), random error (σ) and setup margin (SM) by cancer type (mm)

Site	AP			SI			LR		
	Σ	σ	$SM_{vanHerk}$	Σ	σ	$SM_{vanHerk}$	Σ	σ	SMv_{anHerk}
Cervical	1.28	1.92	4.54	2	3.5	6.75	1.41	1.78	4.75
Rectal	1.18	1.57	4.05	2.01	3.06	7.16	0.89	1.89	3.55



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
TRUC Z-VERT	-0.5	-0.9	-0.7	-0.1	1.1	-2.7	-1.9	-3.4	0.3	-0.7	-0.2	-0.3	-1.5	0.7	-0.9	-0.7	-0.8	0.0	1.6	-1.8
TRUC Y-LONG	-2.5	-0.3	-3.3	-7.5	1.0	-0.7	-1.5	-1.8	-1.9	-4.0	-2.3	-3.8	-1.5	-2.2	-0.6	-3.2	0.2	-1.8	1.9	0.0
TRUC X-LAT	-1.1	-1.4	-1.6	-0.8	-2.1	-2.4	-1.5	-1.0	-1.0	-2.5	0.3	-2.2	-1.4	-1.4	-0.6	-0.6	-1.0	-3.2	-2.0	-3.4

Figure 3. Distribution chart of setup errors for each cervical cancer radiotherapy patient



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
TRUC Z-VERT	-0.5	-0.9	-0.7	-0.1	1.1	-2.7	-1.9	-3.4	0.3	-0.7	-0.2	-0.3	-1.5	0.7	-0.9	-0.7	-0.8	0.0	1.6	-1.8
TRUC Y-LONG	-2.5	-0.3	-3.3	-7.5	1.0	-0.7	-1.5	-1.8	-1.9	-4.0	-2.3	-3.8	-1.5	-2.2	-0.6	-3.2	0.2	-1.8	1.9	0.0
TRUC X-LAT	-1.1	-1.4	-1.6	-0.8	-2.1	-2.4	-1.5	-1.0	-1.0	-2.5	0.3	-2.2	-1.4	-1.4	-0.6	-0.6	-1.0	-3.2	-2.0	-3.4

Figure 4. Distribution chart of setup errors for each rectal cancer radiotherapy patient

This study presents our center's clinical experience in using VMAT (Volumetric Modulated Arc Therapy) technique for the treatment of cervical and rectal cancers. The primary goal was to assess the overall accuracy of the radiotherapy process and calculate the appropriate margin from the Clinical Target Volume (CTV) to the Planning Target Volume (PTV), thereby providing useful guidance for physicians during treatment planning.

Evaluating errors and patient setup deviations

is crucial, as treatment effectiveness relies heavily on the consistency and reproducibility of organ positioning, fixation devices and the clinical experience of radiation therapists [8]. Furthermore, insufficient definition of the Planning Target Volume (PTV) can lead to inaccurate targeting of the tumor or unnecessarily high radiation doses to surrounding healthy tissues adjacent to the CTV.

Systematic and random errors have been discussed in numerous previous studies. Errors occurring from the simulation to daily treatment sessions are a major contributor to systematic errors. One significant cause is inaccurate tattoo marking on the skin, especially when patient setup relies on these marks. Other contributing factors may include machine-related errors such as laser misalignment, collimator angle deviations, or treatment couch inaccuracies [9].

Organs within the pelvic region especially the cervix and rectum are subject to anatomical variability and can shift or change position, which is a major cause of random errors. Contributing factors include bladder filling, gas or fecal matter in the rectum, patient movement, and differences in body composition (e.g., obesity or thinness). These factors directly impact patient positioning, treatment time, and setup errors, ultimately affecting the precision and efficacy of radiotherapy. They may result in underdosing the tumor or overdosing nearby healthy tissue. To minimize such errors and enhance setup consistency and reproducibility, our center has emphasized meticulous patient preparation, particularly concerning bladder and rectal status during pelvic simulation. Achieving this requires cooperation and adherence from patients, as well as close coordination among physicians, physicists, therapists, and nurses during the simulation and treatment process, combined with the experience of radiation technologists.

From the error data analyzed at our center, we observed that the setup margin (CTV-PTV) for rectal cancer was slightly larger than that for cervical cancer, though the difference was not significant. This similarity can be attributed to the fact that both organs are located within the pelvis and share comparable anatomical and mobility characteristics, largely influenced by the filling status of the bladder and rectum. The datasets used in our study to calculate setup margins for each group were derived from initial patient positioning. Re-verification using 2D-KV imaging was performed if the setup error exceeded 3 mm, and patient repositioning was done if needed. The SM was calculated based on daily setup errors using the Van Herk formula, which accounts for positional uncertainties in pelvic radiotherapy [7]. Our estimated CTV-PTV margins for pelvic cancers are: 5 mm (AP), 7 mm (SI), 5 mm (LR) for cervical cancer and 5 mm (AP), 7.5 mm (SI), 5 mm (LR) for rectal cancer. These values align closely with the margins typically applied by physicians at our center.

Evaluating initial setup errors in treatment sessions, along with identifying systematic and random errors and standard deviations, provides us with a deeper and more comprehensive understanding of setup reproducibility and patient stability throughout the treatment course. Moreover, the statistical data obtained allow for the establishment of specific setup margins for each cancer type, which is extremely important in guiding physicians to expand margins from CTV to PTV appropriately ensuring that the prescribed radiation dose is delivered accurately and effectively to the intended target volume.

4. CONCLUSION

Each radiotherapy center has its own unique characteristics and conditions; therefore, these differences need to be assessed and used to calculate an appropriate and specific margin expansion for each center. The daily use of 2D-KV imaging in VMAT technique helps to detect and correct setup errors in accordance with the treatment plan,

allowing the expansion of the PTV margin based on our center's setup error data. Through this study, we identified the average setup errors for each anatomical location, enabling us to calculate a setup margin (SM) for each group. This provides valuable guidance for physicians when expanding from CTV to PTV, in addition to considering the internal margin (IM). At our center, the recommended SM for pelvic radiotherapy is: 5 mm (AP), 7 mm (SI) and 5 mm (LR) for cervical cancer; and 5 mm (AP), 7.5 mm (SI), and 5 mm (LR) for rectal cancer.

REFERENCES

[1]. International Atomic Energy Agency (2016), *IAEA Human Health Report No.31. Accuracy requirements and uncertainties in radiotherapy*, Vienna: IAEA; 2016.

[2]. Chavaudra J, Bridier A, *Definition of volumes in external radiotherapy: ICRU Reports 50 and 62*, Cancer/Radiother. 2001;5(5):472-478. https:// doi.org/10.1016/s1278- 3218(01)00117-2.

[3]. Kron T, *Reduction of margins in external beam radiotherapy*, J Med Phys. 2008;33(2): 41-42. https://doi.org/10.4103/0971-6203.41190.

[4]. ICRU, *ICRU Report No. 50. Prescribing, recording and reporting photon beam therapy*, Bethesda: ICRU; 1993.

[5]. Amaoui B, Mohssine D, Bouih N, et al, *VMAT dosimetric study in rectal cancer patients*, Int Res J Med Biomed. 2020;5(1):1-6. https://doi. org/10.15739/ irjmbs.20.001.

[6]. Amaoui B, Mohssine D, Bourhim MM, et al, *Dosimetric comparison of conformal radiotherapy and arc-therapy of ineligible cervical cancers for intracavitary brachytherapy*, J Cancer Sci Clin Ther. 2019;3(4):221-228. https://doi.org/ 10.26502/ jcsct.5079036.

[7]. Van Herk M, Remeijer P, Rasch C, et al, *The probability of correct target dosage: dose-population histograms for deriving treatment margins in radiotherapy*, Int J Radiat Oncol Biol Phys. 2000;47(4):1121-1135. https://doi. org/10.1016/s0360- 3016(00)00518-6.

[8]. Cacicedo J, Perez J, Ortiz de Zarate R, et al, *A Prospective analysis of inter- and intrafractional errors to calculate CTV to PTV margins in head and neck Patients*, Clin Transl Oncol. 2015;17(2):113-120. https://doi. org/10.1007/s12094-014-1200-z.

[9]. Hurkmans CW, Remeijer P, Lebesque JV, et al, *Set-up verification using portal imaging: review of current clinical practice*, Radiother Oncol. 2001;58(2):105-120. https://doi.org/10.1016/ s0167-8140(00)00260-7.