การกำหนดค่าความคลาดเคลื่อนของตำแหน่งการฉายรังสีในผู้ป่วยมะเร็งต่อมลูกหมากที่รักษาด้วยเทคนิคการปรับความเข้มของลำรังสี (VMAT) โดยใช้เครื่องถ่ายภาพเอกซเรย์คอมพิวเตอร์แบบโคน

PLANNING TARGET VOLUME MARGIN DETERMINATION IN VMAT PROSTATE REGION USING CBCT

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ABSTRACT

Backgrounds: In advanced radiation therapy technique, the determination of adequate clinical target volume (CTV) to planning target volume (PTV) margin is mandatory to reduce dose and side effect to normal tissue meanwhile increasing the dose to the tumor.

Objective:The purpose of this study is to determine PTV margins for prostate region in volumetric modulated arc therapy (VMAT) based on inter and intra-fraction motion using cone beam computed tomography (CBCT) images.

Materials and Methods: First, the QA for couch and imaging system were performed. Then 15 prostate patients who treated with TrueBeam linear accelerator were acquired weekly CBCT image before and after treatment and the CBCT images were registered to CT-simulator images with bony anatomy and natural calcium matching. The position deviations from standard image in X, Y and Z directions were recorded. The CTV to PTV margins were calculated using Van Herk's equation according to random and systematic errors approach.

Results: The mechanical test of couch movement was very accurate within 0.2 mm error. The image quality of CBCT with pelvis protocol was good enough for IGRT due to passing all of the Varian criteria needed. The software for image registration was also in good agreement between known shifted values and calculated from the program with the maximum error of 0.6 mm. For clinical application, patient setup variations as inter-fraction motion have greater effect than patient movement during treatment as intra-fraction motion because of the patient fixation used and short time in VMAT treatment. The higher values in random error than systematic error were demonstrated because the high accuracy of machine itself with good IGRT system can reduce the systematic error; in contrast, the random error was unavoidable, especially from the effect of bladder-rectum filling. From 8 mm margin in our routine protocol at King Chulalongkorn

Memorial Hospital, the calculated PTV margins in the lateral (X), longitudinal (Y), vertical (Z) directions were reduced to 6.38, 5.24 and 6.33 mm, respectively. The Y direction is less effect from bladder and rectum filling and body change compared to other directions.

Conclusion: From our calculated margins, it is possible to reduce the dose to bladder and rectum and improve the target coverage of prostate cancer patients who is treated with VMAT technique.

Keywords: CONE-BEAM COMPUTED TOMOGRAPHY (CBCT), PTV MARGIN, SETUP UNCERTAINTY

บทคัดย่อ

หลักการและเหตุผล: การรักษาผู้ป่วยโรคมะเร็งได้มีการพัฒนาเพิ่มประสิทธิภาพ เนื่องจากการก้าวหน้าของเทคนิคการฉายรังสีที่มีการกำหนดขอบเขตการฉายรังสีที่เหมาะสม ทำให้สามารถลดปริมาณรังสีและผลข้างเคียงของอวัยวะที่อยู่บริเวณรอบๆ ก้อน ขณะเดียวกันเพิ่มปริมาณรังสีที่ก้อนมะเร็งได้มากขึ้น

วัตถุประสงค์: เพื่อกำหนดขอบเขตความคลาดเคลื่อนที่เหมาะสมของตำแหน่งการฉายรังสีในผู้ป่วยมะเร็งต่อมลูกหมากที่รักษาด้วยเทคนิคการปรับความเข้มแบบหมุนรอบตัวโดยทำการถ่ายภาพเอกซเรย์คอมพิวเตอร์แบบโคนก่อนการฉายรังสีและหลังฉายรังสี

วัสดุและวิธีการ: เริ่มจากการทำการประกันคุณภาพเตียงและระบบภาพ แล้วจึงทำการศึกษาผู้ป่วยมะเร็งต่อมลูกหมากจำนวน 15 คน ที่ฉายรังสีด้วยเทคนิค VMAT ในห้อง TrueBeam และได้รับการถ่ายภาพเอกซเรย์คอมพิวเตอร์แบบโคนก่อนและหลังการฉายรังสี สัปดาห์ละครั้งโดยใช้กายวิภาคของกระดูกและตำแหน่งของก้อนแคลเซียมบริเวณอุ้งเชิงกรานเป็นตำแหน่งอ้างอิงเปรียบเทียบกับภาพเอกซเรย์คอมพิวเตอร์ที่ได้จากการจำลองการรักษา เพื่อหาความคลาดเคลื่อนของตำแหน่งการฉายรังสีในแนวแกน X, Y และ Z จากนั้นนำค่าที่ได้หาขอบเขตความคลาดเคลื่อนที่เหมาะสม จากสูตรของ Van Herkโดยคำนวณจากค่าความผิดพลาดที่เกิดแบบสุ่ม และแบบระบบ

ผลการศึกษา: พบว่าการเคลื่อนที่ของเตียงฉายรังสีมีความถูกต้องสูง มีค่าความคลาดเคลื่อนสูงสุดที่ 0.2 มิลลิเมตร ในส่วนของคุณภาพของภาพเอกซเรย์คอมพิวเตอร์แบบโคนพบว่าภาพที่ได้มีคุณภาพดี ผ่านตามเกณฑ์ที่กำหนด เมื่อทำการตรวจสอบระบบซอฟแวร์ที่ทำการเปรียบเทียบภาพพบว่าค่าความคลาดเคลื่อนของเตียงที่ได้จากซอฟแวร์แตกต่างจากค่าจริงเล็กน้อย ค่าแตกต่างสูงสุดพบเพียง 0.6 มิลลิเมตร ในส่วนผลทางคลินิกความคลาดเคลื่อนที่เกิดจากการจัดท่าผู้ป่วยมีผลกระทบมากกว่าการขยับตัวของผู้ป่วยระหว่างการฉายรังสี เนื่องจากมีการใช้อุปกรณ์ช่วยยึดตรึงผู้ป่วยและได้นำเทคนิคการฉายรังสีปรับความเข้มหมุนรอบตัวผู้ป่วยมาใช้ ทำให้ลดเวลาในการฉายรังสี และพบว่าค่าความผิดพลาดแบบสุ่มมีค่ามากกว่าแบบระบบ เพราะเครื่องฉายรังสีเป็นเครื่องที่มีประสิทธิภาพ มีระบบภาพนำวิถีแบบ 3 มิติเข้ามาช่วยในการตรวจสอบตำแหน่งของก้อนก่อนการฉายรังสี ในทางตรงกันข้ามผลกระทบจากความผิดพลาดแบบสุ่มไม่สามารถหลีกเลี่ยงได้ โดยเฉพาะปริมาตรของกระเพาะปัสสาวะและลำไส้ที่แตกต่างในแต่ละวัน เมื่อเปรียบเทียบกับค่าขอบเขตการฉายรังสีที่โรงพยาบาลจุฬาลงกรณ์กำหนดไว้ที่ 8 มิลลิเมตร พบว่าขอบเขตที่เหมาะสมในการฉายรังสีบริเวณต่อมลูกหมากที่ได้จากกการคำนวณมีค่าลดลงเหลือ 6.38, 5.24 และ 6.33 มิลลิเมตร ในแกน X, Y และ Z ตามลำดับ จะเห็นว่าแกน Y มีความคลาดเคลื่อนต่ำที่สุด เนื่องจากผลของการเคลื่อนที่ของกระเพาะปัสสาวะและลำไส้รวมถึงผลของการเปลี่ยนของหน้าท้องที่มีผลน้อยที่สุด ทำให้สามารถลดปริมาณรังสีบริเวณกระเพาะปัสสาวะและลำไส้ได้

สรุป: จากการศึกษาวิจัยได้พบว่าขอบเขตการฉายรังสีที่ใช้อยู่ปัจจุบันนั้นเพียงพอ และเหมาะสมกับผู้ป่วยโรคมะเร็งต่อมลูกหมากที่รักษาด้วยเทคนิคการปรับความเข้มแบบหมุนรอบตัวผู้ป่วย

I. INTRODUCTION

The aim of curative radiotherapy is to deliver a high dose of radiation to the tumor tissue at the same time contributes the minimum dose to the normal tissues [1, 2], so it is important to keep in mind that margins needed to apply in three dimensions and even a small margin reduction can result in a significantly reduced irradiated volume. The optimization in radiotherapy planning and treatment are to keep the margin as small as possible. However, it is also impossible to direct radiation perfectly well to a target due to the patient movement and setup uncertainty. Therefore, it is essential for radiotherapy planning to define the suitable treatment target margin. The errors can be mathematically divided into systematic and random in the fractionated treatment. The most important errors are setup uncertainty, organ motion and patient movement leading to day-to-day and intra treatment variations. The optimum clinical target volume (CTV) to planning target volume (PTV) margin is commonly calculated using Van Herk's formula for 2.5 standard deviation (SD) of systematic errors plus 0.7 SD of random errors ($2.5\Sigma+0.7\sigma$).[3,4] The PTV margins needed to deliver with 95% of the prescription dose in the CTV for 90% of the patient could be computed.

Nowadays, the conformal radiotherapy and image guided radiotherapy (IGRT)[5] have increased the precision of radiation dose delivery and routinely used in the treatment of cancers. The conformal radiotherapy (CRT) provides dose distributions that accurately shaped to the PTV. The 3DCRT is the standard treatment technique that the treatment fields are opened using multileaf collimator (MLC) to conform the dose distribution to target shape. The intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) are introduced as the modern radiotherapy treatment techniques that provide very conform of high dose according to tumor volume while it can spare more normal tissues simultaneously. VMAT[6] technique is the most advanced treatment techniques that delivers the radiation during gantry rotate around the patient. The radiation doses can be modulated by moving the MLC, adjusting the dose rate, and changing the gantry speed. This technique can reduce the treatment time of dose delivery and also organ motion during treatment compared with previous modulated treatment technique, IMRT. Therefore, it is possible to reduce the CTV to PTV margin in order to decrease the radiation exposure of a large volume to normal tissues in VMAT.

The important factor of radiotherapy treatment is not only the high conform doses to target and the low dose to normal tissue, but the improving of reproducibility of patient positioning is vital as well. The immobilization devices with IGRT checking are needed for this issue. The on-board imager (OBI) is attached to the treatment machine for the beam verification purpose that is able to create the 2D or 3D images. The kV cone beam computed tomography (CBCT) is one of the good choices of IGRT modalities that can show the high quality 3D image and used to increase geometric precision of patient setup error. The imaging of patient anatomy on the treatment machine just prior to each daily dose fraction provides an accurate knowledge of the target location on a daily basis and helps with the daily patient set-up as the inter-fraction motion to check the setup position. For patient movement during treatment, it can be defined by intra-fraction motion that acquired from post-treatment CBCT compared with the pre-treatment CBCT.

Juan-Senabre X.J, et al [7] studied the uncertainties and CTV to PTV margins quantitative assessment using IGRT. A total of 100 prostate and 26 head and neck cancer patients treated with 3D CRT and used Van Herk's formula to calculate margin. The result showed the CTV to PTV margins in the three dimensions (right-left, superior-inferior, anterior-posterior) were (5.3, 3.5, 3.2) mm for H&N and (7.3, 7.0, 9.0) mm for prostate cancer treatments. The PTV margin of prostate was more than head and neck region and PTV margin of prostate in AP direction was more expansion than the other direction because of the effects of bladder and rectum filling.

The purpose of this study is to determine adequate PTV margins in VMAT of prostate cancer patients based on inter-fraction and intra-fraction motion using CBCT technique.

II. MATERIALS AND METHODS

The patients were treated in Varian TrueBeamTM linear accelerator (Varian Medical system, Inc, Palo Alto, USA) with the On-Board Imager (OBI) version 2.0 and Eclipse treatment planning version 11.0.3 (Varian Medical System, Palo Alto, CF, and USA). First, the measurements were undertaken for QA of couch and imaging system so that the accuracy of couch position, the quality of images and accuracy of image registration were verified.

Quality assurance of couch and imaging system

A. The accuracy of couch position.

The accuracy of couch position indicator is an important part to verify. The source to surface distance was set at 100 cm. Then the couch was moved to various distances (-50,-20,-10,-5.0, 5.0,10, 20, 50 mm) in lateral, longitudinal and vertical directions according to the accurate measurement tape. The shifted couch positions were read on the in-room monitor and the results were recorded.

B. The quality control of CBCT images.

The center of CATPHAN 504 phantom was placed on the treatment couch at the imaging isocenter. The pelvis CBCT protocols were selected for scanning of phantom. The CBCT images were analyzed according to Varian acceptance test protocol for density calibration, spatial linearity measurement, image uniformity, high and low contrast resolution.

C. The accuracy of image registration software.

This part was the verification of image registration software using the Alderson Rando phantom. The phantom was scanned at pelvis region by CT simulator scanner with 120 kVp, 2.5 mm thickness and automatic mAs. The image data was exported to the Eclipse treatment planning system (TPS). The setup fields were created in TPS and the plan was exported to treatment workstation. The Rando phantom was placed in treatment room using laser systems to achieve the same position as set in CT simulator room. After that, the known couch shift values of -20,-10, -5, 5, 10, and 20 mm for all axes were applied and the CBCT was performed. Then, the automatic software matching was employed and the displayed couch shifts values were recorded.

Clinical application for CTV to PTV margins in prostate cancer.

The 15 prostate cancers were employed in the setup error and patient movement during treatment for CTV to PTV margins determination. A total of 240 assessments using CBCT were performed for weekly CBCT before and after treatment. The ethics approval was obtained by Faculty of Medicine, Chulalongkorn University. The signed informed consent was acquired in order to allow the acquisition of multiple CBCT during the treatment.

- **Patient preparation and planning**

For prostate cancer treatment, the patients were setup in supine position on treatment couch with foot support and the skins were marked according to the laser projections for patient positioning. A non-flatulent diet was recommended to the patients before CT scan and each treatment session to ensure an empty rectum through-out the course of treatment. The patient preparation was 500 ml of water drinking 20 minutes before CT scan and each treatment session to achieve a full bladder. The 2.5 mm slice thickness were acquired from GE CT simulator and exported to the TPS. The target and critical structures were delineated by experienced radiation oncologist. The CTV to PTV margins expansion was 5 mm towards posterior direction (to limit the volume of irradiated rectum) and 8 mm in all remainder directions. The dose prescriptions were 80 Gy in 40 fractions with the daily fraction dose of 2 Gy for VMAT prostate treatment. The VMAT plan of 10 MV photon with 2 full rotational arcs was optimized and calculated using RTOG prostate protocol for normal tissue constraints. The patients were treated in Varian TrueBeamTM linear accelerator equipped with 3D on-board computed tomography.

- **IGRT clinical protocol**

The daily pre-treatment setup was based on laser and skin marked established during simulation process. The patient setup error as the inter-fraction motion was performed using weekly CBCT before treatment with parameters of Pelvis CBCT mode of 125 kV and 1080 mAs. The 120 images from inter-fraction motion scenario were registered with the CT planning images to obtain the shifts in the lateral (X), longitudinal (Y) and vertical (Z) directions. The online correction was applied by shifting the couch when any translations less than 5 mm, while the reposition was done if the shifted was larger than 5 mm. Patients were treated after treatment couch repositioning. For post-treatment, the intra-fraction motion represented patient movement during treatment was checked again using the second CBCT after completion of radiation delivery compared with the pretreatment image. The 120 images were also registered with the planning CT scan images for acquiring the patient movement verification. The translations of treatment couch shifted were recorded. The bony anatomy and natural mark calcification matching with automatic and manual-match methods by experienced technologist were used for images registration between weekly pelvic CBCT images and planning CT images. The error in bony anatomy and natural mark calcification registration for both registration methods were determined from the position of one clearly defined calcification in the prostate gland.

- **CTV to PTV margin calculation**

The first CBCT before irradiation was used to calculate the setup error (Inter-fraction motion), while the second CBCT after irradiation was used to analyze the patient movement (Intra-fraction motion).The CTV to PTV margins for all population of 240 images set were calculated using Van Herk's formula. The X, Y and Z shifts of individual patient for patient setup and patient movement errors were reported. Then, the mean and SD of the systematic and random error of individual and population were calculated. The systematic error of population was represented by the standard deviation of mean error for each patient in various subgroups, while the random error of population was defined by the mean error of standard deviation for individual patient. The total systematic and total random error can be calculated from the root mean square of patient setup error and patient movement as express in equation (1) and (2). The suggested CTV to PTV margins from each axis could be calculated by equation (3). This ensures a minimum dose of 95% of that prescribed in the CTV gets 90% of the patient.

$$\Sigma^2 tot = \Sigma^2 setup + \Sigma^2 Patient\ movement \quad (1)$$

$$\sigma^2 tot = \sigma^2 setup + \sigma^2 Patient\ movement \quad (2)$$

$$PTVmargin = 2.5\Sigma tot + 0.7\sigma tot \quad (3)$$

III. RESULTS

Quality assurance of couch and imaging system

A. The accuracy of couch position.

The results of mechanical check of the couch indicator are shown in table 1. The maximum differences between known couch shift and actual couch position were only 0.2, 0.2 and 0.1 mm deviation in lateral (at -5.0 mm shift), longitudinal (at 10.0 mm shift) and vertical (at -10.0 mm shift), respectively.

B. The quality control of CBCT images.

- **Density calibration**

The reading values of the HU of air, acrylic and LDPE are shown in table 2.The mean HU of air, acrylic and LDPE were -991.29, 121.59 and -89.82, respectively. The maximum HU differences compared with specification was 10.2 HU that less than 50 HU from specification. (Figure 1)

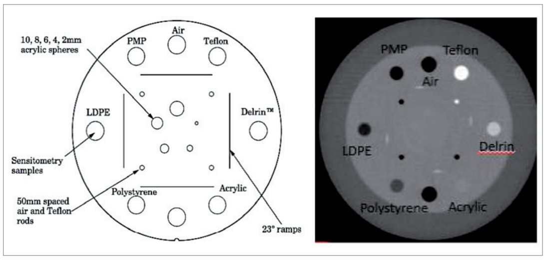

Figure 1 Density calibration (a) diagram, (b) image result

- **Spatial linearity (Distance)**

The checking accuracy of distances between the verification holes located (three Air and one Teflon) on Catphan phantom using the measuring tool are shown in table 3. Two vertical lines (position 2 and 4) had the error of -0.2 mm and two horizontal lines (position 1 and 3) showed the error of 0.1mm those were less than the specification limit of ±0.5 mm. (Figure 2)

- **Image uniformity**

The results of checking image uniformity are shown in table 4. The difference in HU between center and position 1, 2, 3 and 4 were -10.8, -10.2, -6.3 and -9.16, respectively. All of the measurement results were within the limitation of ±30 HU. (Figure 3)

- **High contrast resolution**

The gauge can be clearly differentiated each other at the fifth group, this represented to 5 line pair/cm resolution of 0.1 cm gap size as illustrated in table 5, while the high contrast resolutions criteria of 4 line pair/cm is 0.125 cm gap size. (Figure 4)

Table 1: Couch position shift value

known couch shift	Actual couch position (mm)		
	Lateral	Longitudinal	Vertical
-50.0	-50.0	-50.0	-50.0
-20.0	-20.0	-20.0	-20.0
-10.0	-10.0	-10.0	-9.9
-5.0	-5.2	-5.0	-5.0
5.0	5.0	4.9	5.0
10.0	9.9	9.8	10.0
20.0	20.0	19.9	20.0
50.0	50.0	49.9	50.0

Table 2: The HU data for density calibration test

Material	Specification	Actual	Difference	Pass/ fail
Air	-1000±50	991.29	8.8	Pass
Acrylic	120±50	121.59	1.6	Pass
LDPE	-100±50	-89.82	10.2	Pass

- **Low contrast resolution**

The results of 1% supra–slice contrast of low contrast resolutions are illustrated in table 6. The biggest hole of supra-slice at 1% target diameter that equivalent to 15.0 mm diameter was the lowest criteria to be seen on the image. The whole circle up to the hole number 6 which represents to 5.0 mm diameter could be observed. (Figure 5)

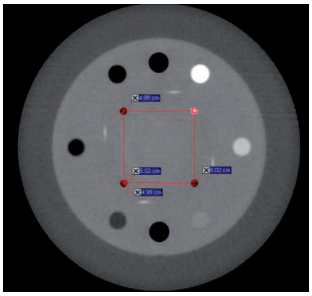

Figure 2 The spatial linearity test

Table 3: The distance for spatial linearity measurements test

Position	Specification	Actual(mm)	Difference	Pass/fail
1	50 mm±0.5 mm	49.9	0.1	Pass
2		50.2	-0.2	Pass
3		49.9	0.1	Pass
4		50.2	-0.2	Pass

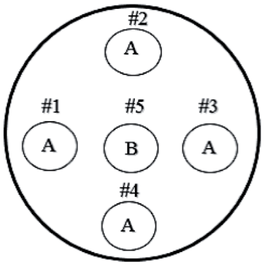

Figure 3 The image uniformity module

Table 4: Image uniformity test

Position	HU Value	HU Value Center (#5)	Calculated HU Difference	Specification	Pass/fail
Left(#1)	99.32	110.12	-10.8	±30HU	Pass
Top(#2)	99.92	110.12	-10.2		Pass
Right(#3)	103.82	110.12	-6.3		Pass
Bottom(#4)	100.96	110.12	-9.16		Pass

C. The accuracy of image registration software

The calculated couch shifts in lateral, longitudinal, and vertical from automatic matching software are illustrated in table 7. The maximum differences between known shift value and actual shifted were only 0.2, 0.6 and 0.6 mm error in lateral (at-20.0, -5.0 mm shift), longitudinal (at 10.0 mm shift) and vertical (at 10.0 mm shift) directions, respectively.

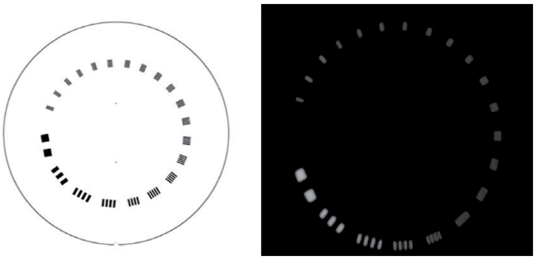

Figure 4 The high resolution module with 1 to 21 lp /cm (a) diagram, (b) image result

Table 5: The high contrast resolution

Specification	Actual	Pass/fail
>4 line pair/cm	5	Pass

Clinical application for CTV to PTV margins in prostate cancer

The calculated systematic (Σ) and random (σ) errors of patient setup error and patient movement for population in lateral, longitudinal and vertical directions are illustrated in table 8. The deviation data were comparable for all axes.

The average of three directions result for population of systematic setup error, systematic movement, random setup and random movement were around 1.5, 0.5, 2.7, and 1.0 mm, respectively. The calculated PTV margins using Van Herk's formula in each direction are shown in table 9.

The result of the calculated PTV margins of VMAT prostate cases were 6.38, 5.24 and 6.33 mm for lateral, longitudinal and vertical directions, respectively.

IV. DISCUSION

Quality assurance of couch and imaging system

A. The accuracy of couch position

For this test, the maximum differences between known couch shift and actual couch position were only 0.2 mm error in lateral and longitudinal axes as well as only 0.1 mm in vertical axis. The specification of the couch traveling should coincide with the digital display within ± 2 mm according to the AAPM TG 142 recommendation,[8] therefore the very good

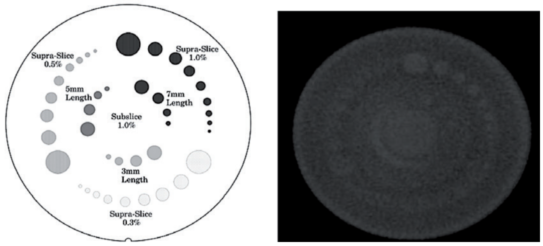

Figure 5 The low contrast module with supra- slice contrast target (a) diagram, (b) image result

Table 6: The low contrast resolution at supra-slice 1%target diameters test

Specification(mm)	Actual	Pass/Fail
Target Size: 15.0	5.0	Pass

Table 7: Shifts value in image registration for three axes

Known shifted value	Actual shifted (mm)		
	Lateral	Longitudinal	Vertical
-20.0	-20.2	-19.9	-20.1
-10.0	-10.1	-10.0	-10.0
-5.0	-5.2	-4.6	-5.1
5.0	5.0	5.4	5.0
10.0	9.9	9.4	9.4
20.0	19.9	19.7	19.6

Table 8: The calculated systematic and random of error and patient movement for patient population in three axes.

Parameters	Deviation (mm)		
	Lateral	Longitudinal	Vertical
Σ_{pop} Set-up	1.59	1.37	1.59
Σ_{pop} Movement	0.49	0.28	0.59
σ_{pop} Set-up	2.94	2.38	2.74
σ_{pop} Movement	1.23	0.68	1.15

Table 9: The calculated PTV margins of prostate cancer in each direction

Parameters	Lateral (mm)	Longitudinal (mm)	Vertical (mm)
Σtot	1.66	1.40	1.70
σtot	3.19	2.48	2.97
PTV margins	6.38	5.24	6.33

agreement results were actually obtained. It can be confirmed that this mechanical movement of treatment couch was very accurate.

B. The quality control of CBCT images

The CBCT images were analyzed according to Varian acceptance test protocol for density calibration, spatial linearity measurement, image uniformity, high and low contrast resolution. The high image quality of CBCT with pelvis protocol were obtained due to passing all of the Varian criteria [9] needed.

C. The accuracy of image registration software

The results of the calculated couch shifts in lateral, longitudinal, and vertical from automatic matching software showed the very good agreement in lateral direction with the maximum error of only 0.2 mm, while vertical and longitudinal gave the larger deviation with maximum of 0.6 mm. The more error in the latter directions might be the effect of slice thickness in the axial CT slice reconstructed to 3D volume image that was more influence on vertical and longitudinal than lateral direction. However, these deviations were acceptable because the maximum disagreement between known shifted and calculated auto matching values were ± 1 mm in all three directions. The results were within criteria as similar to the study from Djordjevic M.[10], who reported the accuracy of image registration software with the automatic 3D/3D match for translational shifts with an anthropomorphic phantom of 0.4±0.6, 0.8±0.6, 0.6±0.6 mm in vertical, longitudinal and lateral directions, respectively. The uncertainty in automatic image registration was ±1 mm in all three directions, his results was adequate uncertainty for clinical use.

Clinical application for CTV to PTV margins in prostate cancer

From the data, the uncertainty due to inter-fraction motion was higher than intra-fraction motion, indicated that the setup error had more effect than the patient movement during treatment. The average of three directions result for population in systematic setup error, systematic movement, random setup and random movement were 1.5, 0.5, 2.7 and 1.0 mm, respectively. The overall systematic and random errors of this patient group together with the calculated PTV margins using Van Herk's formula in each direction are shown in table 9. The higher values in random error than systematic error were demonstrated because the high accuracy of machine itself with suitable immobilization system and the same group of radiotherapist performed the patient setup could reduce the systematic deviation. In contrast, the random error was unavoidable, especially from the effect of bladder-rectum filling. These results were the same trend as the studied from Tanyi J.A., et al.[4]who reported the set up for prostate cancer patients treated with IMRT. From this study, the intra-fraction motion was less impacted than inter-fraction motion and systematic error was also less impacted compared with random error.

The calculated PTV margins of VMAT prostate cases were 6.38, 5.24 and 6.33 mm for lateral (X), longitudinal (Y) and vertical (Z) directions, respectively. The Y direction was less effect from bladder-rectum filling. These margins were smaller than the study from Juan-Senabre.[7]who reported the margins of 7.30, 7.00 and 9.00 mm in left-right (X), superior-inferior (Y) and anteror-posterior (Z) directions, respectively, for 3D CRT treatment technique. The difference from Juan-Senabre. were due to the different machine model, immobilization used, the smaller size of Thai patient and less treatment time in VMAT treatment technique.

V. CONCLUSIONS

The quality assurance of the image system has been carried out to verify the accuracy of the images before collecting the patient data. The information for the mechanical test of couch movement is very accurate within 0.2 mm error. The image quality of CBCT with pelvis protocol is good enough for IGRT in pelvis region with Varian pelvis protocol due to the passing of all Varian and AAPM criterions[7] needed. The software for image registration is also in good agreement between known shifted values and calculated from the program with the maximum error of 0.6 mm.

For clinical application, the inter-fraction setup errors and intra-fraction patient movement can be interpreted from pre- and post-treatment using CBCT evaluation, the CBCT images are registered to CT simulator images as a reference images with bony anatomy and natural calcification matching. The CTV to PTV margins are calculated using Van Herk's equation according to random and systematic errors approach. The results revealed the average of three directions for population of systematic setup error, systematic movement, random setup and random movement of 1.5, 0.5, 2.7 and 1.0 mm, respectively. From these results, patient setup variation between fractions had more effect than patient movement during treatment.

From 8 mm margins in the routine protocol at King Chulalongkorn Memorial Hospital, it can cover the calculated PTV margins in the lateral (X), longitudinal (Y), vertical (Z) directions of 6.38, 5.24 and 6.33 mm, respectively. The Y direction is less effect from bladder and rectum filling and body change compared to other directions. From our calculated margins, it is possible to reduce the dose to bladder and rectum and improve the target coverage of prostate cancer patients who is treated with VMAT technique.

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