การตรวจสอบความไวของเครื่องมือประกันคุณภาพในการวัดความผิดพลาดของแผนการรักษาผู้ป่วยแบบปรับความเข้ม

นางสาวซุย ซิน เลท

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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SENSITIVITY IN ERROR DETECTION OF PATIENT-SPECIFIC QA TOOLS FOR IMRT PLANS

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ซุย ซิน เลท : การตรวจสอบความไวของเครื่องมือประกันคุณภาพในการวัดความผิดพลาดของแผนการรักษาผู้ป่วยแบบปรับความเข้ม (SENSITIVITY IN ERROR DETECTION OF PATIENT-SPECIFIC QA TOOLS FOR IMRT PLANS) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ศิวลี สุริยาปี, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ทวีป แสงแห่งธรรม, 58 หน้า.

ปัจจุบันเครื่องมือตรวจสอบความถูกต้องของแผนการรักษาผู้ป่วยมีหลากหลายชนิด แต่ละชนิดมีรูปร่างคุณลักษณะและประสิทธิภาพในการวัดที่แตกต่างกัน ดังนั้นการเลือกใช้เครื่องมือตรวจสอบความถูกต้อง ของแผนการรักษาผู้ป่วยจำเป็นต้องเลือกตามประสิทธิภาพและความสะดวกในการใช้ประจำวัน วัตถุประสงค์ของการศึกษาเพื่อตรวจหาประสิทธิภาพในการตรวจพบความผิดพลาดในแผนการรักษาแบบปรับความเข้มจากเครื่องวัดรังสีชนิด Portal, MapCHECK 2 และ MatriXX แผนการรักษาที่ทำการศึกษาได้แก่ ศีรษะและลำคอ จำนวน 4 แผน (แผนการรักษาที่ซับซ้อน) ต่อมลูกหมากจำนวน 4 แผน (แผนการรักษาที่ไม่ซับซ้อน) แผนการรักษาบริเวณศีรษะและลำคอ ใช้พลังงาน 6 เมกะโวลต์ด้วยลำรังสี 9 ลำ ขณะที่แผนการรักษาบริเวณต่อมลูกหมากใช้พลังงาน 10 เมกะโวลต์ด้วยลำรังสี 7 ลำ ทำการวัดปริมาณรังสีจากเครื่องวัดรังสีทั้ง 3 ชนิดทั้งในแผนการรักษาเริ่มต้นและแผนการรักษาที่ใส่ค่าความผิดพลาด ได้แก่การเพิ่มและลดปริมาณรังสี (±2, ±4 และ ±6%) และการเลื่อนตำแหน่งในแนวแกน X และ Y(±1, ±2, ±3 และ ±5 มม.) หลังจากทำการวัดในส่วนแผนการรักษาเริ่มต้น ทำการเปรียบเทียบค่าปริมาณรังสีที่วัดได้กับค่าปริมาณรังสีที่ได้จากการคำนวณโดยใช้ดัชนีแกมมาที่ 3%/3 มม.พบว่าค่าเฉลี่ยดัชนีแกมมาของแผนการรักษาบริเวณศีรษะและลำคอจาก Portal, MapCHECK 2 และ MatriXX อยู่ที่ 96.9, 98.6 และ 98.8% ตามลำดับ ส่วนผลของแผนการรักษาบริเวณต่อมลูกหมากจาก Portal, MapCHECK 2 และ MatriXX อยู่ที่ 99.4, 99.0 และ 99.7% ตามลำดับ เมื่อทำการเปรียบเทียบปริมาณรังสีจากแผนการรักษาเริ่มต้นกับแผนการรักษาที่ใส่ค่าความผิดพลาดลงไป ในแผนการรักษาบริเวณศีรษะและลำคอ สามารถตรวจพบความผิดพลาดในการเลื่อนของตำแหน่งที่ 1 มม. จากเครื่องวัดรังสี Portal 2 มม.จากเครื่องวัดรังสี MapCHECK 2 และ 3 มม.จากเครื่องวัดรังสี MatriXX ในส่วนแผนการรักษาบริเวณต่อมลูกหมาก สามารถตรวจพบความผิดพลาดในการเลื่อนของตำแหน่งที่ 2 มม. จากเครื่องวัดรังสี Portal 3 มม. จากเครื่องวัดรังสี MapCHECK 2 และ 5 มม. จากเครื่องวัดรังสี MatriXX สำหรับการตรวจสอบปริมาณรังสีที่ผิดพลาด เครื่องวัดรังสี Portal สามารถตรวจพบความผิดพลาดของปริมาณรังสีที่ 2% ในแผนการรักษาบริเวณศีรษะและลำคอ และ 4% ในแผนการรักษาบริเวณต่อมลูกหมาก ขณะที่เครื่องวัดรังสีอีก 2 ชนิดตรวจพบความผิดพลาดที่ 4% ในแผนการรักษาทั้งสองแบบ จะเห็นว่าประสิทธิภาพในการตรวจพบความผิดพลาดขึ้นกับความละเอียดของเครื่องวัดรังสี และประเภทของแผนการรักษา ถ้าใช้เครื่องวัดปริมาณรังสีมีความละเอียดสูงจะสามารถตรวจพบความผิดพลาดน้อยๆ ได้ดีกว่าเครื่องที่มีความละเอียดต่ำ.

ภาควิชา รังสีวิทยา ลายมือชื่อนิสิต .....

สาขาวิชา ฉายาเวชศาสตร์ ลายมือชื่อ อ.ที่ปรึกษาหลัก .....

5774123830 : MAJOR MEDICAL IMAGING
KEYWORDS: IMRT/PATIENT SPECIFIC QA/QA TOOL/INTENTIONAL ERRORS/SENSITIVITY

SWE ZIN LAT: SENSITIVITY IN ERROR DETECTION OF PATIENT-SPECIFIC QA TOOLS FOR IMRT PLANS. ADVISOR: ASSOC. PROF. SIVALEE SURIYAPEE, CO-ADVISOR: TAWEAP SANGHANGTHUM,58 pp.

Currently, there are many patient specific QA tools that are available in the commercial. The configuration of each device and their efficiencies are also difference from each other. Thus the patient specific QA tools that used in the clinical fields need to be chosen according to their efficiency and daily routine needs. The purpose of this study is to investigate the error detection capability of the portal dosimetry system, MapCHECK2 system and MatriXX system in IMRT plans. These three devices used for the 2D patient specific QA tools in this study. The 4 head and neck plans (the complicated plan) and 4 prostate plans (the simple plan) were studied for error detection of QA devices. The 6 MV beams were employed with 9 field arrangement for head and neck IMRT cases while 10 MV beams with 7 fields were optimized and calculated for prostate IMRT plans. Measurements were undertaken for the original plan and the modified plans with errors introduced in order to check the sensitivity of the QA tools system. The intentional errors composed of increasing and decreasing of prescribe dose (±2, ±4 and ±6%) and position shifting in X-axis and Y-axis (±1, ±2, ±3 and ±5 mm) both representing the setup uncertainty. After measurement, the results were compared between calculated and measured values of the original plan using gamma analysis at 3%/3mm criteria. Then the gamma pass between original and the intentional error were compared. The average gamma pass of original head and neck plans analyzed by 3%/3mm were 96.9, 98.6 and 98.8 for portal dosimetry, MapCHECK2 system and MatirXX system, respectively. The average gamma pass for prostate plans were 99.4, 99.0 and 99.7 for portal dosimetry, MapCHECK2 system and MatirXX system, respectively. In head and neck plans, the shift error detections were 1mm for portal dosimetry, 2mm for MapCHECK2 and 3mm for MatriXX system, respectively. In prostate plan, the shift error detections were 2mm for portal dosimetry, 3mm for MapCHECK2 and 5mm for MatriXX system, respectively. For the dose error detection, the portal dosimetry could detect 2% dose in head and neck plan and 4% dose in prostate plan. The other two devices could detect 4% dose in both head and neck and prostate plans. The error detection depends on the detector resolution and the type of plan. If the QA device has higher resolution, it can have more sensitivity to small error detection than less resolution detector.

Department:	Radiology	Student's Signature	.....
Field of Study:	Medical Imaging	Advisor's Signature	.....
Academic Year:	2015	Co-Advisor's Signature	.....

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LIST OF ABBREVIATION

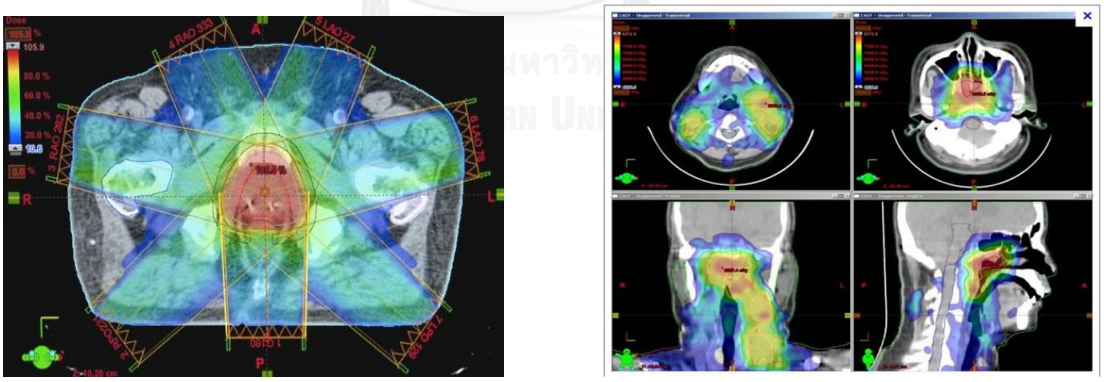
ABBREVIATION	TERMS
1 D	One Dimension
2 D	Two Dimensions
3 D	Three Dimensions
6 MV	Six Megavoltage
10 MV	Ten Megavoltage
CT	Computed Tomography
CU	Calibrated Unit
DNA	Deoxyribonucleic Acid
DTA	Distance to Agreement
EPID	Electronic Portal Imaging Device
IDU	Imaging Detection Unit
IMRT	Intensity Modulated Radiation Therapy
MeV	Million Electron Volt
MLC	Multileaf Collimator
MRI	Magnetic Resonance Imaging
MU	Monitor Unit
PMMA	Polymethyl Methacrylate
QA	Quality Assurance
SDD	Source to Detector Distance
SSD	Source to Surface Distance
TFT	Thin Film Transistor
VMAT	Volumetric Modulated Arc Therapy

CHAPTER 1

INTRODUCTION

1.1 Background and Rationale

Radiation therapy is widely used to kill the cancer cells by damaging their DNA. Radiation can kill not only cancer cells but also can damage to the normal tissues around the cancer cells. A small displacement in delivered dose distribution can result under dose to the tumor and exceed tolerance value for critical organ. Delivering high radiation dose to tumor accompany with minimizing dose to the surrounding tissue is the goal of radiation therapy treatment plans. With the aids of cross-sectional CT images and improvements of computer technology, the advanced treatment techniques can achieve this treatment goal. The radiation beam in 3D conformal therapy plan can shape the tumor volume and also give shielding of normal tissues. But it cannot completely spare the normal tissues surrounded by the tumor cell. To overcome this, more advanced treatment techniques are need to be invented such as intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT).



(a) (b)

Figure1. 1 Intensity modulated radiation therapy (IMRT) dose distribution for (a) pelvis and (b) head and neck region

Intensity modulated radiation therapy (IMRT) technique shown in figure 1.1, gives precise radiation dose to tumor while minimizing the dose to surrounding normal tissues. The IMRT plan achieves desired dose distribution in a complex shaped volume by modulating the intensity map of each treatment field. The

complexity in planning and delivery of radiation demands a high level of quality control to verify the MLC pattern. The dosimetry systems include films, diode arrays, ionization chamber arrays and electronic portal imaging devices are commonly used in patient specific IMRT QA.

Patient specific QA procedure can be categorized from 1D to 3D verification. The one dimensional verification carried out with single point detector system such as ionization chamber. It has excellent stability, linear response to absorbed radiation, small directional dependence and beam quality response independence. Measurement with ionization chamber results in average dose over the whole volume. Higher complexity of dose calculation in the treatment planning system of IMRT and also accuracy and reproducibility in delivery of IMRT plans need higher precision of verification method. So 2D (planes) and 3D (volumes) verification methods play an important role in QA procedure. Devices with detector arrays (MapCHECK and MatriXX) and also films (radiographic or radiochromic film) can provide 2D information for dose measurements. The dose distribution is measured in a plane perpendicular to the central axis of the beam. Two dimensional detectors give good spatial resolution, fast response and easy analysis of the measured data.

Each QA tools have different configuration of detectors and also different kind of detector. Some tools are composed of diode and some use ion chamber array. The numbers of ion chamber or diode are also not the same from each other. Certain QA tool can move along with the gantry rotation. According to different design and configuration, the capability of each detector differs from each other. The sensitivity of each QA tool depends on type and number of detector, arrangement and spacing between them.

That is why, it is important to study the sensitivity of detector that is suitable for error detection in patient specific QA procedure. In this study, we use 2D planar QA tools because they can provide good spatial resolution, fast response and easy analysis of the measured data. The sensitivity of error detection of MapCHECK2, MatriXX and Portal Dosimetry system will be investigated in this study.

1.2 Research Objectives

To investigate the error detection capability of patient-specific QA tools for IMRT plans.

CHAPTER 2

LITERATURE REVIEWS

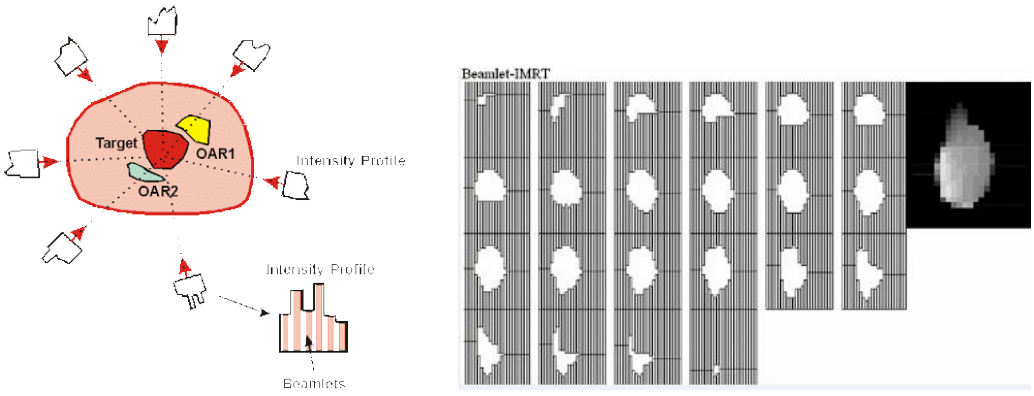
2.1 Theories

2.1.1 Intensity Modulated Radiation Therapy

Intensity Modulated Radiation Therapy is an advanced mode of high-precision radiation therapy treatment technique. It uses the advanced computer controlled linear accelerators machine to deliver highly precise radiation doses to tumor while sparing the surrounding normal tissues. With the aids of 3D computed tomography (CT) or magnetic resonance imaging (MRI) for computerized dose calculations of IMRT plan, the best dose distribution pattern that is best conform to the tumor shape can be provided.

The most distinct feature of IMRT is the inverse planning. It specifies the plan outcome in terms of the tumor dose and normal structure dose limits and then the computer system adjusts the beam intensities to find a configuration best matched to the desired plan.

An IMRT plan composes of several beams with the number of 5 or 7 or 9 beams. The use of several beams can build up a highly conformal dose distribution, allowing precise shaping to a curved target and thus further sparing of normal tissues. Each beam is subdivided into hundreds of beamlets and each beamlet has an individual intensity as shown in figure 2.1.



(a) (b)

Figure 2. 1 Example of IMRT plan (a) beam orientation and (b) beamlet configuration

There are two types of IMRT treatment delivery, namely dynamic or sliding window IMRT and segmental IMRT, which use multi-leaf collimator (MLC) to modulate the beam intensity. For segmental IMRT, radiation is on when the MLC are in position, so it is also called step and shoot method. In dynamic MLC method, MLC are moving continuously during radiation. By moving MLC at fixed gantry position, the desired modulated field intensity is created.

The complexity in planning and delivery of radiation demands a high level of quality control to verify the MLC pattern. The dosimetry systems include films, diode arrays, ionization chamber arrays and electronic portal imaging devices are commonly used in patient specific IMRT QA.

2.1.2 Patient Specific QA

Sophisticated cancer treatments techniques in radiation therapy used multileaf collimator (MLC) for optimization of dose distribution. Continuous moving of MLC during treatment generates the dose distribution that created by treatment planning system. So during beam on time the motion of MLC need to be monitored for the best outcome from the IMRT treatment plans.

The IMRT plans composed of several treatment fields which delivered high dose to the tumor, it is close to the organs at risk which are the low radiation tolerance organ. So misdelivery of IMRT treatment fields might lead to severe consequences for the radiation therapy procedure. That is why, patient specific QA is needed to be performed for all IMRT plans before delivered to the patient. Patient specific QA is the procedure that is used to check whether the Linac machine delivered the correct amount of radiation calculated in the treatment planning system. Pretreatment quality assurance (QA) is a major concern in complex radiation therapy treatment plans especially complex plans like IMRT/VMAT. Patent specific procedure ensures that the dose distribution calculated by the treatment planning system is correctly delivered by the Linac machine. In other word, the MLC movement that creates the dose distribution is correctly transferred from the treatment planning system to the Linac machine and the machine delivered the dose distribution accurately to the patient.

2.1.3 EPID (Electronic Portal Imaging Device)

The primary purpose of electronic portal imaging device (EPID) is patient set up verification for the radiation therapy treatment process. With the aids of EPID image verification the patient set up errors for day to day procedure are effectively reduced. Nowadays, EPID is used as image verification and also portal dosimetry, which can be used as patient specific QA for the dosimetric verification of treatment plan.

Electronic portal imaging device of the Varian is made of amorphous silicon and it is mounted with the retractable robotic arm (the exact-arm). The exact-arm is used to position the image detection unit (IDU). The sensitive area or active area of the imager is 40 x 30 cm^2 (at an SSD of 105 cm). The image matrix consists of 1024 x 768 pixels, so the size of each pixel is 0.39 mm x 0.39 mm at the detector surface. The maximum frame acquisition rate is 9.574 frames /second. It allows the energy range 4-25 MV and the permitted dose rates are 50-600 MU/min.

Figure 2.2 displays the configuration of amorphous silicon imager that can be divided into four main parts. The first component is the 1 mm thick copper build-up plate, which is located just beneath the external plastic cover. It serves to absorb X-ray photons and emits recoil electrons. It also absorbs the scatter radiation, so that it prevents the arriving of scatter radiation to the underneath components and improve the whole imaging system efficiency. The second component below copper plate is a scintillating phosphor screen which is made of terbium dropped gadolinium oxysulphide (Gd_2O_2S:Pb). It absorbs the recoil electron emitted from copper plate and converts them into visible light. Below this phosphor, there is a pixel matrix where each pixel is made of a photodiode and a TFT (Thin Film Transistor). The photodiode integrates the incoming charge into light and the TFT act as a three-terminal switch for readout. The electronic part is the final component of the imager and it serve to read out the charge from the transistor and translates it into the image data.

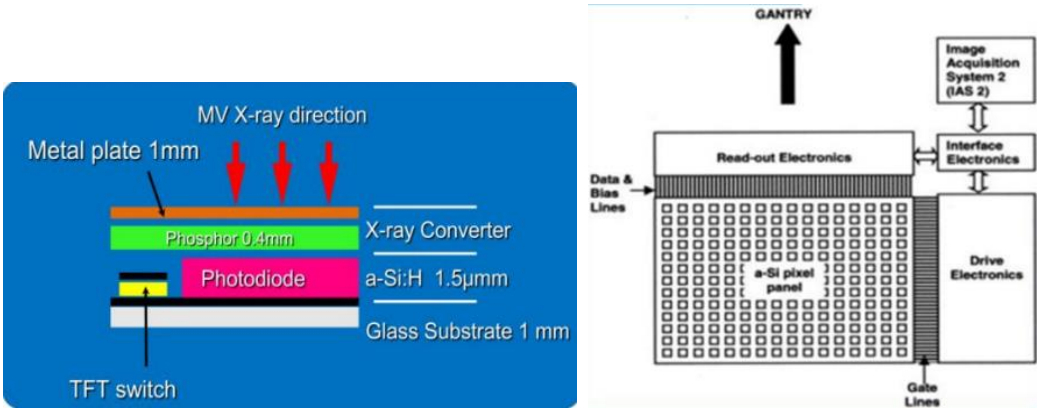


Figure 2. 2 Configuration of Varian portal dosimetry system

2.1.3.1 Energy Response

Amorphous silicon EPID can handle energy range from 4 MV to 25 MV. So that it is known to have energy dependent response. Due to high atomic number of phosphor, a photoelectric interaction is the major concern and it is over response to low energy radiation (below 1 MeV). If the EPID is used for dosimetry, care must be taken on this effect for correction response of radiation. Because the radiation used in radiation therapy are poly-energetic and so they have wide range of energy in the treatment beam.

2.1.3.2 Linearity

The linearity of dose response is one of the most important properties for the dosimeter. The linearity response of EPID can be investigated by using a range of monitor unit. Some literature reported that 6% lower response can be found for the lowest dose of 5 MU.

2.1.3.3 Reproducibility

The reproducibility is the response of the detector over a certain period of time (short term reproducibility means during hours and long term reproducibility means over months). According to previous study reports, EPID have high reproducibility properties. [15]

2.1.3.4 Ghosting Effect

The term ghosting generally describes the modification of detector response due to foregoing irridations. The magnitude of ghosting depends on the number of monitor units and the time interval between exposures. It is the memory effect and mainly dependent on the number of MUs of previous exposure rather than the latter exposure. [16]

2.1.4 MapCHECK2 system

The MapCHECK2 system (Image Courtesy of Sun Nuclear Corporation, Melbourne, USA) contain 1527 diode (n-type silicon diodes) detectors with the uniform detector spacing of 0.7 mm. The detectors are arranged in 32 x 26 cm. The sampling frequency of MapCHECK2 system is 50 ms and each detector has active area of 0.64 mm^2. The detector sensitivity is 32 nC/Gy and the dose limit of this device is 56 Gy/min. It has inherent bulid up of 1.2 cm and inherent backscatter is 2.75 g/cm^3. The MapCHECK2 system can measured the electrons beam from 4 MeV to 25 MeV and photon beam of including cobalt 60 and the measurable energy range is up to 25 MV. The dimension of MapCHECK2 system is 28.7 cm width, 56 cm length and 4.3 cm thick and it has the weight of 7.1 kg, so it can easily handle for used. The dose calibration of MapCHECK2 system was done before it's used for measurement.

2.1.4.1 Energy Dependence

Because of the relatively high atomic number of silicon (Z = 14) compared to that of water or air, diodes exhibit severe energy dependence in photon beams of non-uniform quality. Although some diodes are designed to provide energy compensation through filtration, the issue of energy dependence never goes away and therefore, their use in x-ray beams is limited to relative dosimetry in situations where spectral quality of the beam is not changed significantly, for example, profile measurements in small fields, dose constancy checks. The diodes are qualitatively similar to films so far as their energy dependence is concerned. The MapCHECK2 diode array system can overcome the energy dependence effect by using calibration files provided by the manufacture.

2.1.4.2 Angular Dependence

Diodes exhibit angular dependence, which must be taken into account if the angle of beam incidence is changed significantly. The angular dependence of the MapCHECK 2 system is pronounced in the 90˚ and 270˚ angles. The effect is reduced as the beam energy is increased.

2.1.4.3 Temperature Dependence

Diodes show a small temperature dependence that may be ignored unless the change in temperature during measurements or since the last calibration is drastic. The temperature dependence of diodes is smaller than that of an ion chamber. Even though the diodes establish the effect of temperature dependence, the MapCHECK2 diode array system can solve that problem by doing dose calibration before every measurement.

2.1.4.4 Linearity

MapCHECK2 system shows quite linearity response start form 1 MU to 300 MU for the energy range from 6 MV to 15 MV.

2.1.4.5 Reproducibility

The MapCHECK2 system found to be reproducible over a period of one hour (short term) and one month (long term) to within 1%.

2.1.5 MatriXX System (Ionization chamber)

The MatriXX (IBA Dosimetry GmbH, Schwarzenbruck, Germany) contain 1020 single air vented plane parallel cylindrical ionization chambers with 0.55 cm height, 0.45 cm chamber diameter, 0.76 cm chamber to chamber distance and 0.07 cm^3 sensitive volumes. The detectors are arranged in 32 x 32 cm^2 and no detectors in the corners of the array. Effective point for measurement is 3 mm below surface of the array. The released charge is separated by means of an electrical field between the bottom and the top electrodes. The current, which is proportional to the dose rate, is measured and digitized by a non-multiplexed 1020 channels current sensitive analog to digital converter. The maximum dose rate detectable by the detectors are 5 Gy/min and minimum detectable dose rate is 0.1 Gy/min.[22] The MatirXX was given a 15-minute warm-up time and greater than or equal to 10Gy of pre-irradiation before each use.

The ionization chamber is the simplest of all gas filled radiation detectors, and is widely used for the detection and measurement of certain types of ionizing radiation such as X-rays, gamma rays and beta particles. The term ionization chamber

is used to describe those detectors which collect all the charges created by direct ionization within the gas through the application of an electric field. It only uses the discrete charges created by each interaction between the incident radiation and the gas. There are many type of ionization chamber; thimble chamber, parallel plate, chamber monitor, vented chamber, sealed low pressure chamber and high pressure chamber.

The chamber type used in the MatriXX array QA system is vented ion chamber and it is cylindrical shape. The chambers are operated at atmospheric pressure. They are made of aluminium or plastic a few millimeters thick. The material is selected to have an atomic number similar to that of air so that the wall is said to be "air equivalent" over a range of radiation beam energies. This has the effect of ensuring the gas in the chamber is acting as though it were a portion of an infinitely large gas volume, and increases the accuracy by reducing interactions of gamma with the wall material. The higher the atomic number of the wall material, the greater the chance of interaction. The wall thickness is a trade-off between maintaining the air effect with a thicker wall, and increasing sensitivity by using a thinner wall. Vented chambers are susceptible to small changes in efficiency with air pressure and correction factors can be applied for very accurate measurement applications.

Dose and energy dependence, response during initial warm-up and stability over time are examined by Kishore M et al study. The linear correlation between dose and signal are found for all energies. The signal from the MatriXX increased linearly with dose and signal are not found to depend on beam energy for the range of 4 MV to 15 MV X-rays. The MatriXX ion chamber underestimated with low dose rates and overestimated with high dose rates. The reproducibility of MatirXX system is also found to be good.

Air humidity and room temperature also affect the chamber response. So the MatriXX system has automatic temperature and pressure sensor for temperature and pressure correction. The charge collection efficiency is also high (approximately more than 97% at 1 mGy/pulse). The response of MatriXX system is quite linear (less than 1%).

2.1.6 Summary of Three Dosimetry Systems

Table 2. 1 Configuration of Portal Dosimetry System, MapCHECK2 System and MatriXX System

	Poral Dosimetry System	MapCHECK2 System	MariXX System
Detecor type	Amorphous Silicon (aSi) Diode	Diode	Ionization Chamber
Matrix size/No. of detector	1024 x 768	1527	1020
Detector spacing	-	0.5 cm	0.7 cm
Active area of detector	-	0.64 cm^2	0.07 cm^3
Active area for measurement	40 x 30 cm^2	32 x 26 cm^2	24.4 x 24.4 cm^2

Table 2. 2 Characteristics of Portal Dosimetry System, MapCHECK2 System and MatriXX System

	Portal Dosimetry System	MapCHECK2 System	MatriXX System
Energy dependence	Over response to low energy radiation (below 1 MeV)	Solve by using calibration files.	Energy dependence for low enregy (<4MV)
Linearity	6% lower response if the dose is lower than 5 MU	Linear response (1 MU to 300 MU)	Excellent (2MU to 500)
Reproducibility	High	High	High
Angular dependence	Low	High at 90˚ and 270˚ (especially for low energy)	Low
Temperature dependence	Low	Solve by dose calibration before measurement	Low (build in automatic temperature and pressure sensor)

2.1.7 Gamma Analysis for IMRT Verification Plan [19]

Quantitative evaluation methods directly compare the measured and calculated dose distribution values. Van Dyk *et al* [20] describe the quality assurance procedures of treatment planning systems and subdivide the dose distribution comparisons into regions of high and low dose gradients, each with a different acceptance criterion. In low gradient regions, the doses are compared directly, with an acceptance tolerance placed on the difference between the measured and calculated doses. A dose-difference distribution can be displayed that identifies the regions where the calculated dose distributions disagree with measurement.

In high dose gradient regions (assuming that the spatial extent of the region is sufficiently large), a small spatial error, either in the calculation or the measurement, results in a large dose difference between measurement and calculation. Dose differences in high dose gradient regions may therefore be relatively unimportant, and the concept of a distance-to-agreement (DTA) distribution is used to determine the acceptability of the dose calculation. The DTA is the distance between a measured data point and the nearest point in the calculated dose distribution that exhibits the same dose. The dose-difference and DTA evaluations complement each other when used as determinants of dose distribution calculation quality. A composite analysis uses a pass–fail criterion of both the dose difference and DTA. Each measured point is evaluated to determine if both the dose difference and DTA exceed the selected tolerances (e.g., 3% and 3 mm, respectively). Points that fail both criteria are identified on a composite distribution. Because the composite distribution is a binary distribution, it does not lend itself to a convenient display. Therefore, by convention, the quantity displayed in the composite distribution is the dose difference. While the composite distribution highlights regions of disagreement, the display of the dose difference may accentuate the impression of failure in high dose gradient regions. An additional limitation to this technique is that there is no unique numerical index that enables the presentation and analysis of a distribution that measures the calculation quality. An extension of the isodose comparison tools is presented that simultaneously incorporates the dose and distance criteria.

It provides a numerical quality index that serves as a measure of disagreement in the regions that fail the acceptance criteria and indicates the calculation quality in regions that pass. Unlike the existing composite distribution, the index can be presented in a graphical form to enable a rapid and efficient evaluation of the algorithm quality by the physicist. An implicit assumption is made that once the passing criteria are selected, the dose-difference and distance-to agreement analyses have equivalent significance when determining calculation quality.

The measure of acceptability is the multidimensional distance between the measurement and calculation points in both the dose and the physical distance, scaled as a fraction of the acceptance criteria. In a space composed of dose and spatial coordinates, the acceptance criteria form an ellipsoid surface, the major axis scales of which are determined by individual acceptance criteria and the center of which is located at the measurement point in question.

When the calculated dose distribution surface passes through the ellipsoid, the calculation passes the acceptance test for the measurement point. The minimum radial distance between the measurement point and the calculation points (expressed as a surface in the dose distance space) is termed the gamma index. The surface representing acceptance criteria is an ellipsoid shown in figure 2.3.

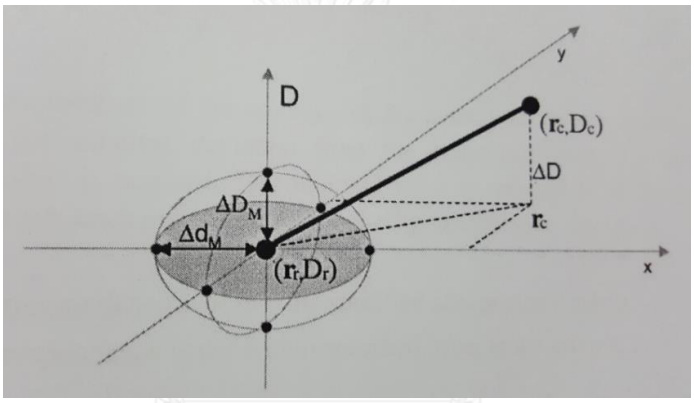


Figure 2. 3 The theoretical concept of the gamma evaluation method

Acceptance criteria are an ellipsoid defined by: equation 2.1

$$1 = \sqrt{\frac{\Delta r^2}{\Delta d_M^2} + \frac{\Delta D^2}{\Delta D_M^2}} \quad \text{.....} \quad 2.1$$

Where,

$\Delta r = |r_r - r_c|$ is the distance between the reference and compared point.

Δd_M = distance to agreement criterion

ΔD_M = dose difference criterion

$\Delta D = D_c(r_c) - D_r(r_r)$ is the dose difference the point r_c relative to the reference dose D_r in r_r. For the compared distribution to match the reference dose in r_r, it needs to contain at least one point (r_c, D_c) lying within the ellipsoid of acceptance, i.e. one point for which:

$$\gamma_r(r_c, D_c) = \sqrt{\frac{\Delta r^2}{\Delta d_M^2} + \frac{\Delta D^2}{\Delta D_M^2}} \leq 1 \quad \text{.....} \quad 2.2$$

A quantitative measure of the accuracy of the correspondence is determined by the point with the smallest deviation from the reference point, i.e. the point for which $r_r(r_c, D_c)$ is minimal as shown in equation 2.2. This minimal value is referred to as the quality index $\gamma(r_{rr})$ of the reference point. The pass- fail criterion therefore becomes;

$\gamma(r_{rr}) \leq 1$, correspondence is within the specified acceptance criteria,

$\gamma(r_{rr}) \geq 1$, correspondence is not within the specified acceptance criteria.

2.2 Reviews of Related Literature

Fredh A et al[3] studied about patient QA systems for rotational radiation therapy. The purpose of this study was to investigate the ability of patient specific QA systems to detect the errors that can occur on the LINAC machine. The QA systems used in this study were Delta[4], COMPASS, OCTAVIUS and Epiqa. Each system has different configuration of detectors. Twenty cases with anatomical site of head and neck, prostate and brain were chosen when creating the treatment plans. Different types of plans were chosen since the complexity of the plans will be different. From these original plans, the new plans were created which contain introduced errors. The introduced intentional errors were; increasing the number of monitor unit, widening of MLC banks and rotation of collimator. The original plans and modified plans were measured by each QA system in order to investigate the error detection efficiency of these tools. The measurements were analyzed using inherent gamma evaluation with 2%/2 mm criterion and 3%/3 mm criterion. The 20 cases of measurement were done for this study. By using 3%3 mm criterion, OCTAVIUS system can detect 3 of 20 errors, Delta4 detected 9 of 20 errors, COMPASS detected 5 of the error with 10% isodose structure and Epiqa detected 11 errors. When 2%/2 mm criterion was used, Compass and OCTAVIUS detected 8 of 20 errors, Delta4 detected 15 of 20 errors and Epiqa detected 20 of 20 errors. The error detection capability of each system using 2%/2 mm criterion were 75%, 40%,40%, and 100% for the Delta4, OCTAVIUS, COMPASS and Epiqa system respectively. The result 2%/2 mm criterion is better than 3%/3 mm criteria in error detection. But lowering the criteria higher the chance of detection of errors that are not importance.

Li G et al[2] evaluated the sensitivity of 3D diode array to set up error for the volumetric modulated arc therapy (VMAT). It is important to study because the analysis software available in ArcCHECK and Delta^4 system is unable to correct for positioning errors. The errors in this study were translation set up error of ± 1 to ± 3 mm and rotational set up error of 1-2 degree. Dose distribution of two systems were compared by gamma analysis with 3%/3 mm, 3%/2 mm and 2%/2 mm criteria. Eleven VMAT plans were delivered on each system for dose verification measurements. All the plans were delivered by Elekta Synergy Linear accelerator. They compared the measured dose distributions of each array with the calculated dose distributions generated by the planning system. They also analyzed the combined effect of 2 mm translational and 1 degree rotational errors. For the translation error of ± 1 to ± 3 mm in the direction of right-left and superior-inferior showed significant different result. The result indicated that ArcCHECK was higher sensitivity than Delta^4 in detection of translational error in both directions. The results of rotational set up error also showed significant different result between two systems. For rotational error of 1 to 2 degree, pass rate of gamma analysis by 3%/3 mm decreased by 5.5% and 9.9% for ArcCHECK and 2.5% and 5.0% for Delta4 in the pitch direction and also the different result showed for other two directions (row and yaw). ArcCHECK had higher sensitivity in rotational error detection than Delta^4. The combined effect of 2 mm translational and 1 degree rotational error result, ArcCHECK show 3.4%, 3.1%, 3.3%, 2.9%, and 5.6%, respectively, for esophageal, prostate, cervix, rectal, and nasopharyngeal cancer but the result of Delta4 was slightly lower than ArcCHECK. That's why; ArcCHECK was slightly more sensitive to all type of set up error in this study.

Bawazeer O et al[7] studied the ability of MatriXX system and EPID to detect the systematic delivery errors in IMRT plans. The aim of this work was to investigate the ability of two commercially available QA tools to detect the systematic MLC leaf position and collimator errors. They set three hypotheses for their study. The first one was that the smallest significant error can be detected by the detector. The second was that the sensitivity to errors varies with the detector systems. When the gamma tolerances were tightened, whether the detector systems more sensitive to errors or not was the third hypothesis. Two step and shot IMRT plans (head and neck plan and prostate plan) were used in this study. Same direction and opposite direction shifted MLC errors and collimator errors of one degree to five degree were introduced in the plan for measurement. By using Elekta Synergy linear accelerator the original and edited plans were delivered. As a result both the system seem to be had similar lack of ability in detection of smallest significant errors of 1mm MLC shift and 2 degree

collimator rotation. And also both detector systems had similar sensitivity for all types of error except collimator rotation error in head and neck plan. For that kind of error, MatriXX was more sensitive than EPID. As the gamma criterion was tighten, the rate of reduction in pass rates with increasing error magnitude did not change.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Research Design

This research is an observational analytical study.

3.2 Research Question

What are the sensitivity in error detection of EPID, MapCHECK2 and MatriXX system?

3.3 Research Design Model

The research design model is shown in figure 3.1.

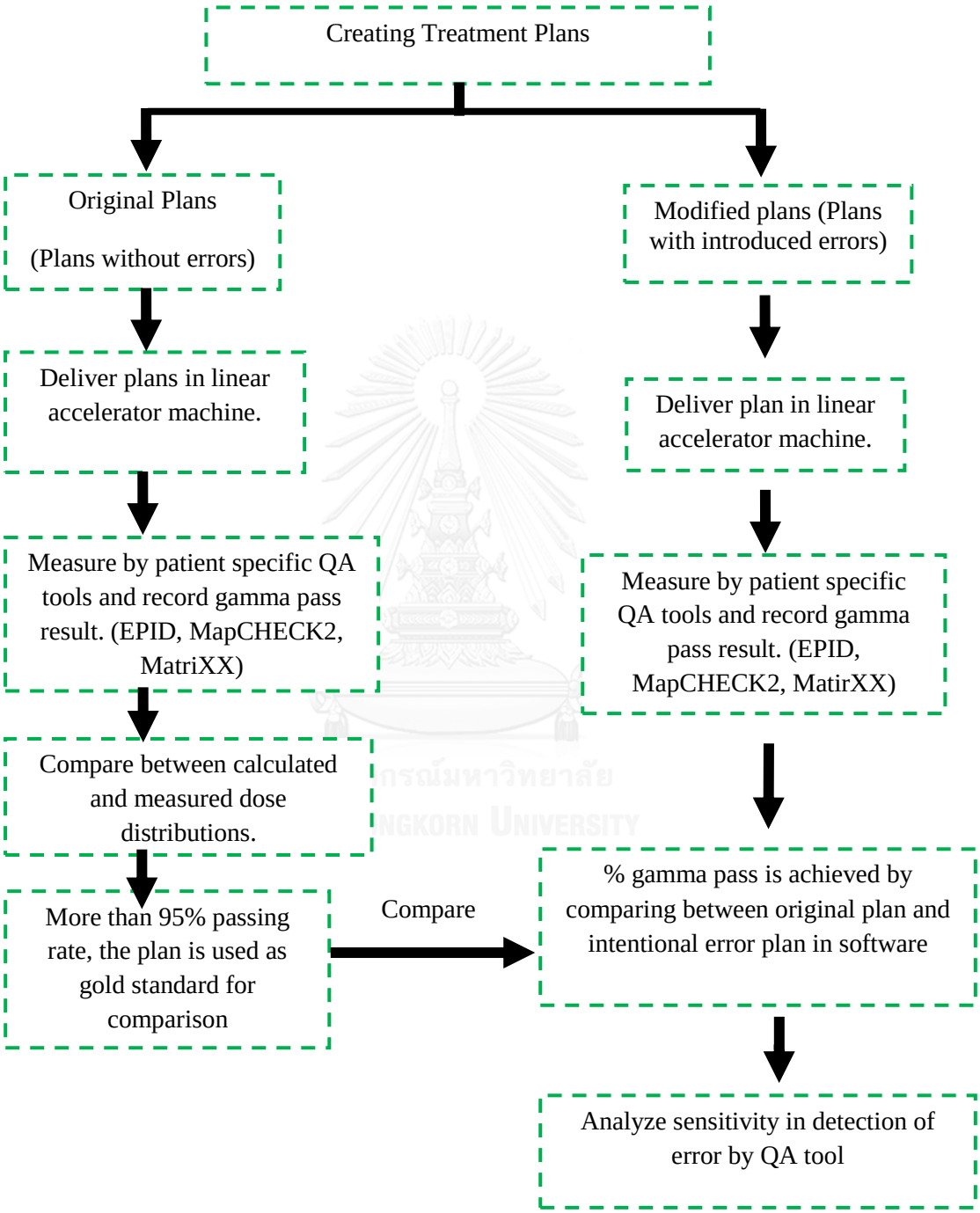


Figure 3. 1 Research design model

3.4 Conceptual Framework

Sensitivity of error detection of each patient specific QA tool is mainly affected by type of detector, type of error and the gamma criteria used to analyze. It is also affected by number of fields in IMRT plan and shape and site of tumor located that represent to the complexity of plan as presented in figure 3.2.

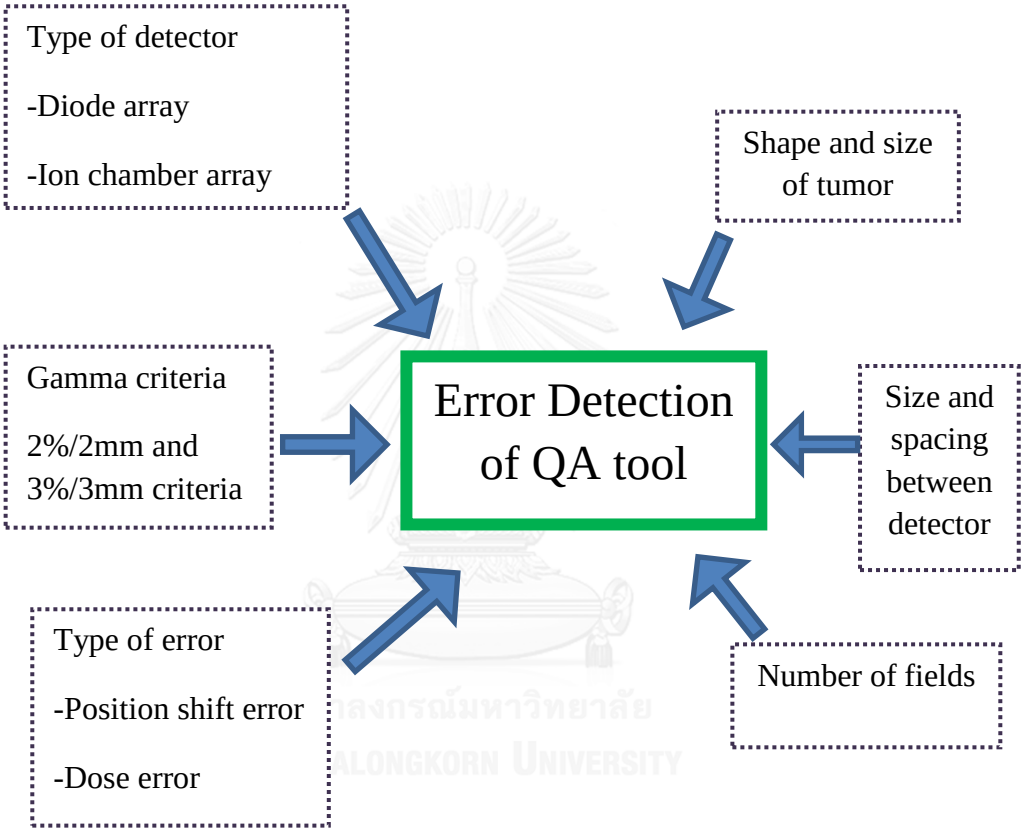


Figure 3. 2 Conceptual framework

3.5 Materials

The materials used in this study are supplied from the Division of Therapeutic Radiology and Oncology, Department of Radiology, Faculty of Medicine, Chulalongkorn University.

3.5.1 Eclipse Treatment Planning System

Eclipse treatment planning (Varian Medical System, Palo Alto, CA, USA) version 11.0.31, shown in figure 3.3, is a treatment planning system used to create all kind of treatment plans including 3D conformal, IMRT, brachytherapy, electron and proton therapy. The IMRT and VMAT plans are created by inverse planning using analytical and isotopic algorithm (AAA) or Acuros XB algorithm. Eclipse allows clinicians to import and optimize plans across multiple linear accelerators.

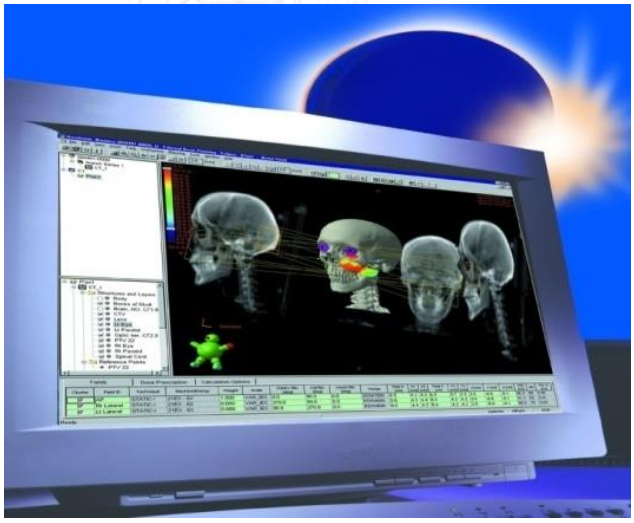


Figure 3. 3 Eclipse treatment planning system

3.5.2 ClinaciX Varian Linear Accelerator

Varian ClinaciX (Varian Oncology system, Palo Alto, CA, USA), which is shown in figure 3.4, provides dual photon beam energy of 6 MV and 10 MV. It can also deliver the electron energy start from 4 MeV to 20 MeV (4, 6, 9, 12, 16 and 20 MeV). The dose rates are ranging from 100-600 monitor units per minute. It is

attached with cone beam CT and EPID for position verification procedure. There are 120 leaves of MLC that can provide conformal shaping of radiotherapy treatment beam to tumor. The field size is ranging from 0.5 x 0.5 cm^2 to 40 x 40 cm^2.

Figure 3. 4 Clinac iX Linear Accelerator (Varian Medical System)

3.5.3 Solid Water Phantom

The solid water phantom (Gammex, Middleton, WI 53562 U.S.A) in figure 3.5 made from epoxy resin based mixture which has similar mass density (1 g/cm^3) and electron density to water (3.34 x 10^{23} electrons/g). It was widely used in radiotherapy to perform qualitative and quantitative quality assurance measurements. The slabs size are 30 x 30 cm^2 with thicknesses ranging from 0.2 to 5 cm. They are commonly used in stacks and serve as build up or backscatter for measurement.

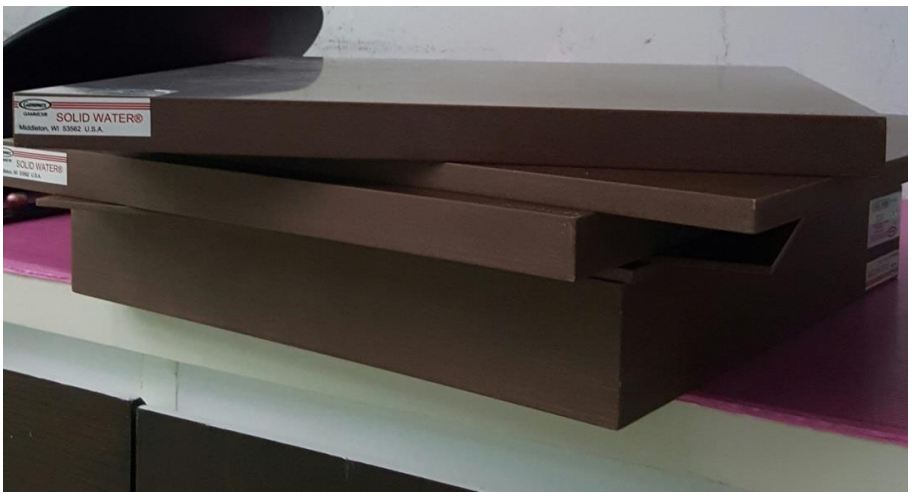
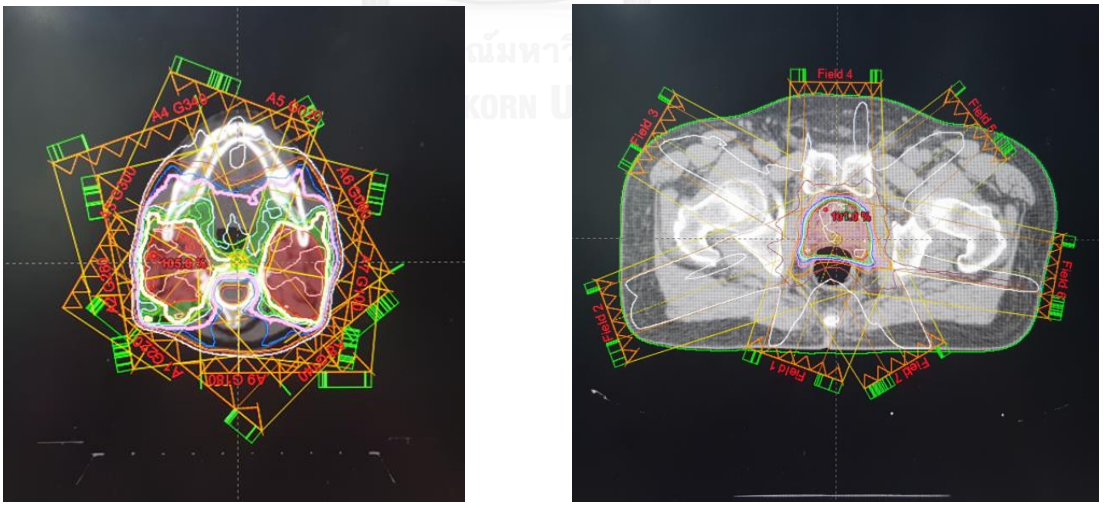


Figure 3. 5 Solid water phantoms

3.5.4 IMRT Plans

Four head and neck IMRT plans and four prostate IMRT plans were undertaken for the measurements. The 6 MV beams were employed with 9 field arrangement for head and neck IMRT cases while 10 MV beams with 7 fields were optimized and calculated for prostate IMRT plans as shown in figure 3.6 (a) and (b) for head and neck and prostate, respectively.

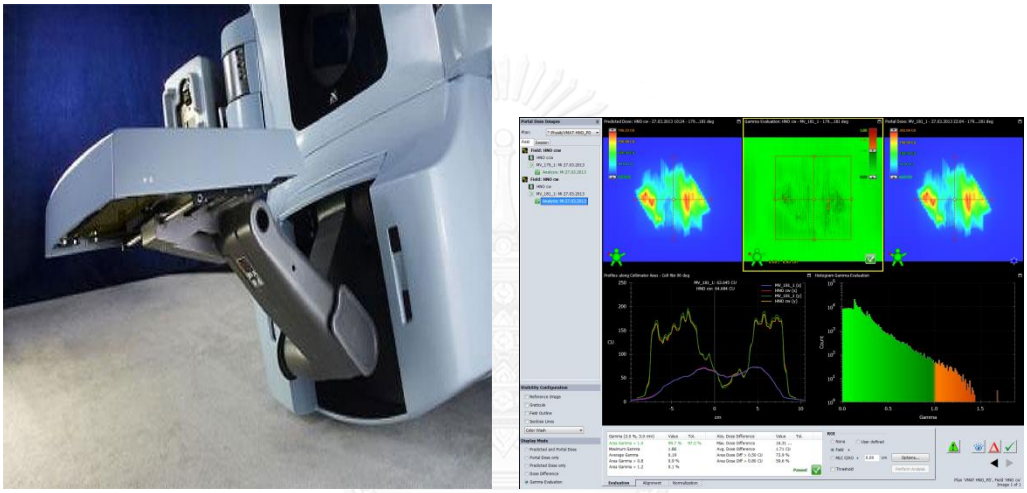


(a) (b)

Figure 3. 6 Dose distribution and beam arrangement of (a) head and neck plan and (b) prostate plan

3.5.5 EPID (Electronic Portal Imaging Device)

EPID of the machine which is shown in figure 3.7 allows patient position verification before treatment and it can also be used as 2D planar dose verification tool for treatment plan. The detector is made of amorphous silicon (aSi) diode that provides precise and well defined megavoltage image. It has active imaging area of 30 x 40 cm^2 and support for the photon energy ranging from 4 to 25 MV. Minimum image dose of 1 MU to maximum exposure of 999 MU can be delivered onto this flat panel. Dose rate from 50 to 600 MU/min are supported for both imaging and portal dosimetry purposes.

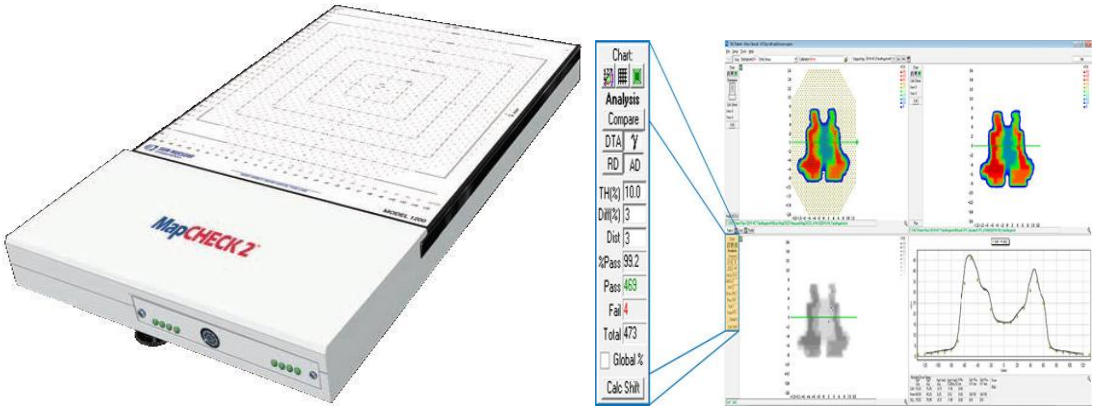


(a) (b)

Figure 3. 7 (a) Electronic portal imaging device of the Clinac iX varian medical system and (b) the varian portal dosimetry software

3.5.6 MapCHECK2 System

MapCHECK2 (Image courtesy of Sun Nuclear Corporation, Melbourne, USA), which is shown in figure 3.8, is an advanced two dimensional detector array for quick and precise verification of radiotherapy dose distribution. It is composed of 1527 diode detectors which are 0.7 cm apart from each other. Due to small size of diode, they allow the accurate measurement. Diode detectors can also provide absolute dose measurement, excellent stability, long lifetime and excellent sensitivity. The largest field size that can be used is 32 x 26 cm.

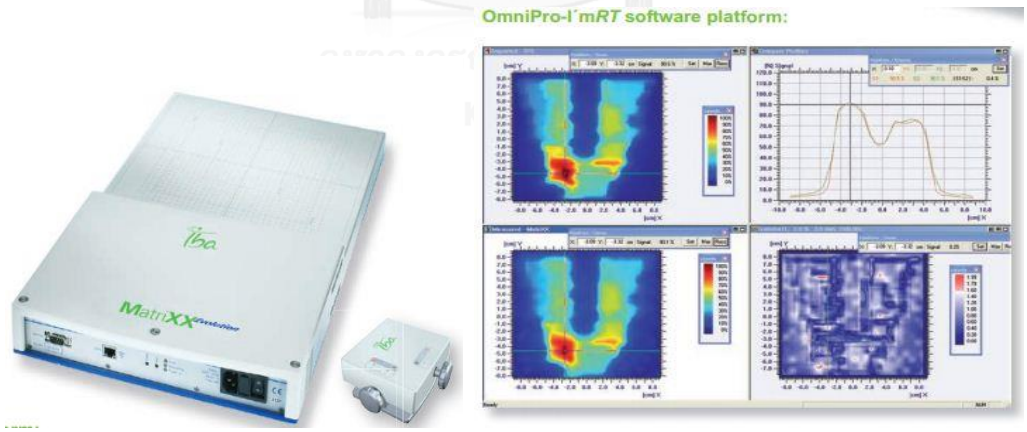


(a) (b)

Figure 3. 8 (a) MapCHECK2 system and (b) the Sun Nuclear Software

3.5.7 MatriXX System

MatriXX system (IBA dosimetry, Bartlett, TN), which is shown in figure 3.9, is also a 2D detector array like MapCHECK2 system. The differences from MapCHECK2 are the fact that MatriXX use ionization chamber to build the detector array. It consists of 1020 ionization chamber distributed over 24.4 x 24.4 $cm^2$of active area. It can provide long term stability and no dead time during the data acquisition.



(a) (b)

Figure 3. 9 (a)MatriXX system and (b) the analyzing OmniPro-I'mRT software

3.6 Methods

3.6.1 Treatment Plan Creating

Standard field (10 x 10 cm^2) plan was created in treatment planning system (Eclipse version, Varian Medical Systems, Inc, Palo Alto, CA, USA) for dose calibration. The four head and neck IMRT plans and four prostate plans were created in the treatment planning system (TPS). The 6 MV beams were planned with 9 beams arrangement for head and neck cases, while 10 MV beams with 7 fields were used for prostate plans. The clinical IMRT plans were converted to the IMRT QA verification plan by calculating the dose in the water phantom for the EPID, MapCHECK phantom for the MapCHECK2 system and the MultiCube phantom for the MatriXX system. All the beam angles were set to zero degree in QA verification plan. All the plans were approved by radiation oncologist with the dose criteria according to RTOG protocol.

3.6.2 Intentional Errors Introducing

After creating original plans, the new plans which contained intentional errors were created. All the errors introduced were based on the realistic clinical data. The intentional errors were composed of prescribed dose and position shift. Prescribed dose of increasing and decreasing from 2% to 6% and position shift of 1 mm to 5 mm in positive and negative ways in X and Y directions were used and shown in table 3.1. The errors were created in treatment plan for measurement of error detection.

Table 3. 1 The intentional errors which were introduced to original plans

Devices	Position Shift Error (X-axis and Y-axis)				Prescribed Dose Error (Increase or Decrease)		
Portal Dosimetry	1mm	2mm	3mm	5mm	2%	4%	6%
MapCHECK 2	1mm	2mm	3mm	5mm	2%	4%	6%
MatriXX	1mm	2mm	3mm	5mm	2%	4%	6%

3.6.3 Work Flow for IMRT Verification Plan Delivery

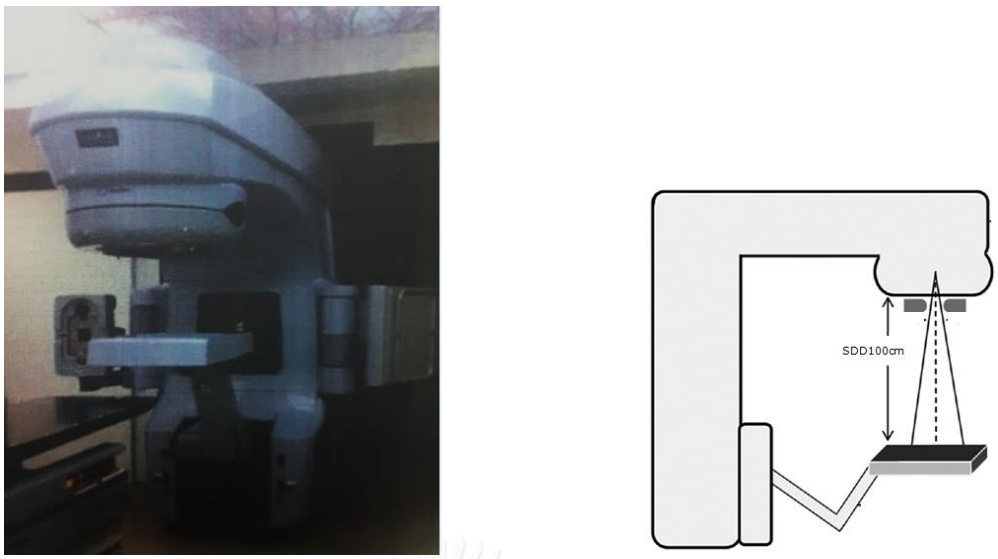
- The IMRT plans that needed to do verification procedure were copied as a QA course.
- All of the treatment plan parameters such as beam energy, field size, monitor units and MLC movement were transferred to QA phantom images with all gantry angles were set to zero degree and the dose were calculated on these images.
- The QA plans were exported to LINAC machine for delivery.
- The delivered plans were measured by patient specific QA tool
- The results were evaluated by respective software.
- The analysis tools used were gamma criteria 3%/3 mm and 2%/2 mm.

3.6.4 Procedure for QA Devices Setting up

The created plans were imported to Varian Clinac iX machine for measurement. Plan with no error were measured first by each QA tool. After that, the plans with errors were also delivered for measurement by QA tools. All the plans were measured by EPID, MapCHECK 2 and MatriXX system. Measurements were saved in respective software for further analysis.

3.6.4.1 Set up Procedure for EPID

- Set source to detector at 100cm as shown in figure 3.10.
- Measure original and modified plans.
- Analyze gamma evaluation pass rate by using Portal dosimetry System Software from Varian Medical System.



(a) (b)

Figure 3. 10 (a) Set up for portal dosimetry measurement in Clinac iX machine and (b) set up diagram

3.6.4.2 Set up Procedure for MapCHECK2 System

- MapCHECK2 was placed on the couch as shown in figure 3.11 and the position was adjusted according to the laser system.
- The 3 cm solid water phantom sheet was added on its detector surface to acquire nearly 5 cm water equivalent thickness.
- The SSD was set at 95.8 cm on the surface of solid water phantom.
- The original plans and plans with intentional errors were measured by MapCHECK2 system and analyzed by Sun Nuclear software.

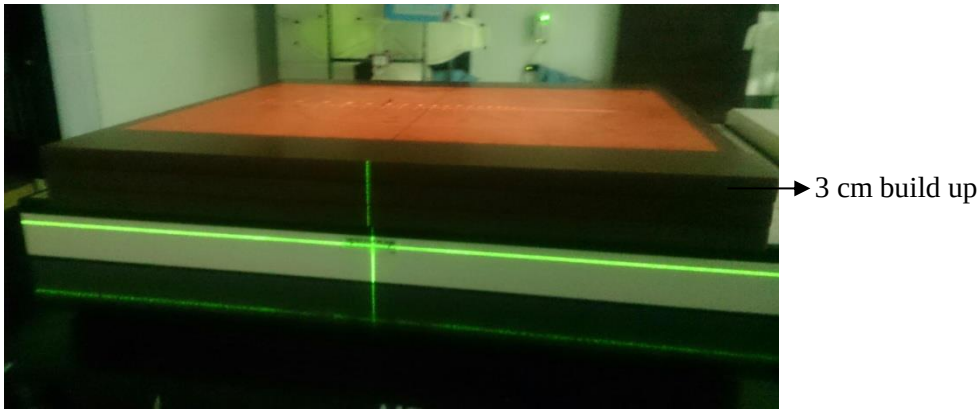


Figure 3. 11 Set up for MapCHECK2 System Measurement

3.6.4.3 Set up Procedure for MatriXX System

- MatriXX inserted in MultiCube Phantom were placed on the treatment couch as shown in figure 3.12.
- The lines on the MultiCube phantom were set to coincide with the laser.
- Leave about 10 min for warm up time.
- The original plans and plans with intentional errors were measured by MatirXX and analyzed by OmniPro-ImRT Software.

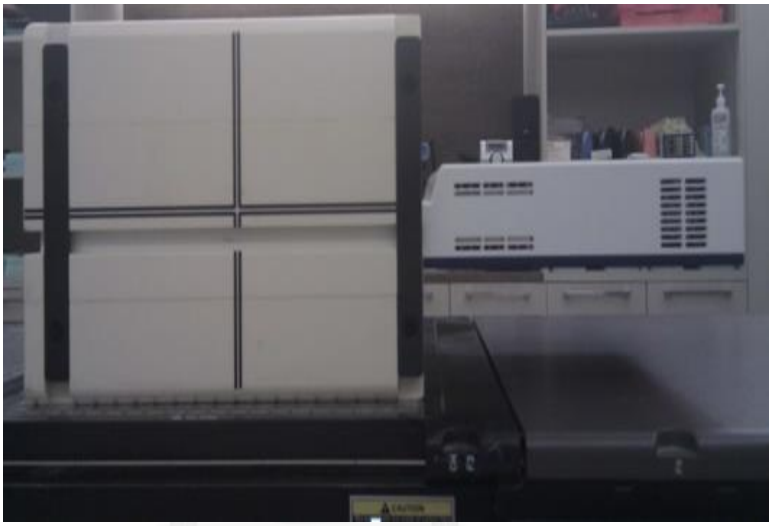


Figure 3. 12 Set up for MatriXX system measurement

3.7 Sample Size Determination

The sample size was determined by following equation.

$$N = \left(\frac{Z_{\alpha/2}\,\sigma}{E} \right)^2 = 7.84$$

$Z_{\alpha/2}$=1.96 (95% confidence level)
σ=variance of different= 0.2
E=error rate = 0.14
n=7.84, so will choose 8 plans for measurement

3.8 Inclusion Criteria

From the radiation therapy treatment technique, IMRT treatment technique was selected. The IMRT plan of head and neck and prostate plans were included in this study.

3.9 Exclusion Criteria

The original IMRT plans were measured by patient specific QA tool and the plan that does not pass the criteria were excluded for measurement.

3.10 Outcome Measurement

The outcome for the error detection of QA tool was gamma result comparison between original plan and modified plan. From this result the sensitivity of error detection of each system was evaluated.

3.11 Statistical Analysis

The mean, standard deviation and percent difference between original plan and modified plan will be analyzed by using Microsoft excel 2010 software. The Paired t-test was designed for analyzing the data.

3.12 Expected Benefit

The suitable IMRT QA tool that could detect the type of error and condition on IMRT plans would be evaluated.

3.13 Limitation

Among many kinds of error that can occur in clinical field, only certain type of errors were introduced and studied for sensitivity of QA tools. Evaluation on sensitivity of error detection was done only by two dimensions.

3.14 Ethical Consideration

According to the ethic consideration, this study respect for person authority, principle of beneficence/non-maleficence and justice rule. Although this study does not contact directly to the patients for data collection, the research proposal was approved by Ethics Committee of Faculty of Medicine, Chulalongkorn University.

CHAPTER 4

RESULTS

4.1 The Original Plans Measurement

The measurements were undertaken by measuring the original plan as the first step using Portal dosimetry System, MapCHECK2 system and MatriXX system. The gamma pass results of original plans were recorded. The plans with gamma passing result of more than 95% were used as a gold standard for error detection comparison. If the plans had gamma pass lower than 95%, it was excluded in this study. The plan only with the pass rate equal to or more than 95% analyzed by 3%/3 mm with 10% threshold was actually used in the clinical field for patient treatment. The gamma analysis criteria to analyze for this plans were 3%/3 mm and 2%/2 mm criteria. Table 4.1 and 4.2 show the gamma pass result of original plans measured by three patient specific QA devices for head and neck, and prostate plans, respectively. The example of the planning fluence of the head and neck plan measured by portal dosimetry system and prostate plans measured by MapCHECK2 system are shown in figure 4.1 and 4.2, respectively.

Table 4. 1 Gamma pass result of the original plans (4 Head and Neck plans) measured by Portal dosimetry system, MapCHECK2 system and MatriXX system and analyzed by 3%/3 mm and 2%/2 mm gamma criteria with 10% threshold

Case No.	Portal Dosimetry System		MapCHECK2 System		MatriXX System	
	3%/3mm	2%/2mm	3%/3mm	2%/2mm	3%/3mm	2%/2mm
1 (H&N)	95.2	82.4	97.9	88.5	97.5	86.0
2 (H&N)	96.6	85.3	98.6	91.4	99.3	94.0
3 (H&N)	98.9	91.9	99.3	96.9	99.7	96.1
4 (H&N)	96.8	86.0	98.5	92.3	98.2	90.1
Average	96.9 ±1.3	86.4 ±3.5	98.6 ±0.6	92.3 ±3.5	98.75±1	91.6±4.5

Table 4. 2 Gamma pass result of the original plans (4 prostate plans) measured by Portal dosimetry system, MapCHECK2 system and MatriXX system and analyzed by 3%/3 mm and 2%/2 mm gamma criteria with 10% threshold

Case No.	Portal Dosimetry System		MapCHECK2 System		MatriXX System	
	3%/3mm	2%/2mm	3%/3mm	2%/2mm	3%/3mm	2%/2mm
1 (Prostate)	99.6	97.9	100	98.0	99.8	98.7
2 (Prostate)	99.9	97.8	100	100	99.9	93.2
3 (Prostate)	99.8	96.7	96.5	91.7	99.5	99.0
4 (Prostate)	98.3	93.8	99.4	98.8	99.8	99.2
Average	99.4±0.7	96.6 ±1.9	99.0±1.7	97.1 ±2.7	99.7±0.2	97.5±2.9

At the gamma 3%/3 mm, all of the plans were passed the gamma criteria at 95% pass rate. The gamma pass rate both in head and neck plans and prostate plans did not indicate evidence difference compared between three devices. But the pass rate was higher for the prostate plan compared to head and neck plan in all three devices, especially at gamma 2%/2 mm criteria.

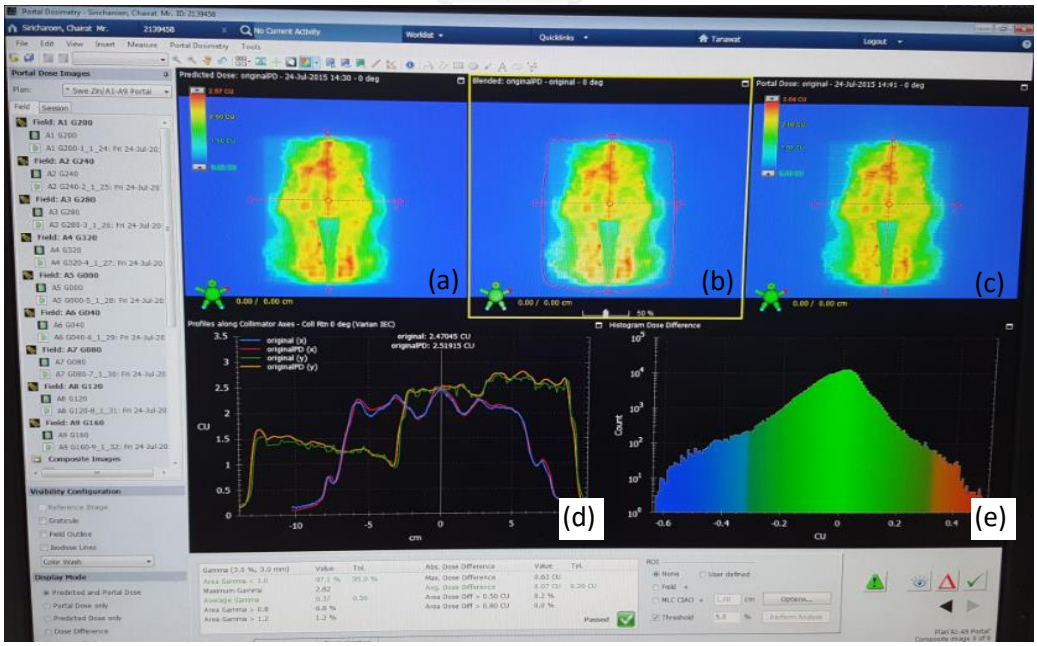


Figure 4. 1 An example of the head and neck fluence map in original plan measured by portal dosimetry system (a) predited dose, (b) gamma evaluation, (c) portal dose, (d) profiles along collimator axes and (e) histogram of gamma evaluation

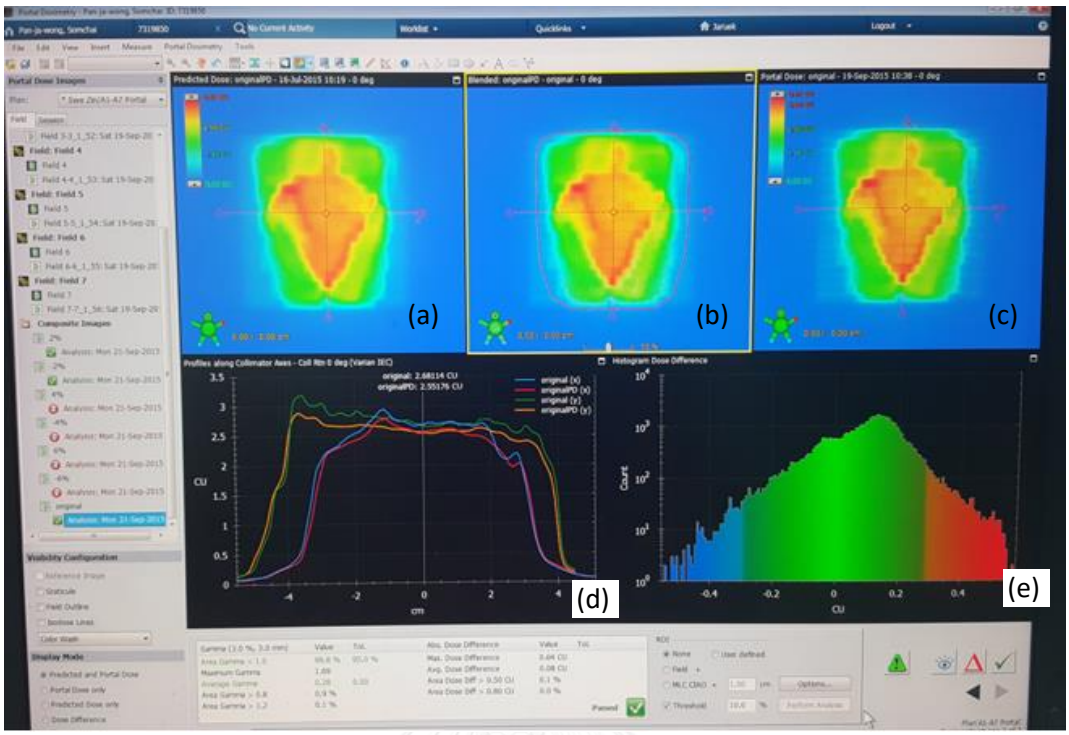


Figure 4. 2 An example of the prostate fluence map in original plan measured by portal dosimetry system (a) predited dose, (b) gamma evaluation, (c) portal dose, (d) profiles along collimator axes and (e) histogram of gamma evaluation

4.2 Portal Dosimetry System Measurement

4.2.1 Position Shift Error Measurement

The error detection sensitivity upon position shift of portal dosimetry system was evaluated by repeated measuring of IMRT plans. After measuring original plan that pass 95% gamma result, the plans introduced with 1 mm to 5 mm shift in X and Y axis were measured and the gamma pass results were recorded in two criteria (3%/3 mm and 2%/2 mm). The smallest error detections were 1 mm shift in head and neck and 2 mm shift in the prostate plans by analyzing 3%/3 mm gamma criteria. Considering to different direction, the error detection in some axis showed error started from 3 mm shift in head and neck plan and 5 mm shift in the prostate. By using 2%/2 mm gamma criterion, the error started from 1 mm shift introduced in almost all direction. They were detected in both head and neck plans and prostate plans and the results were shown in table 4.3 and table 4.4 respectively. The results were also displayed in bar graph of figure 4.3 and 4.4 for head and neck and figure 4.5 and 4.6 for prostate plans.

Table 4. 3 The percent gamma pass of position shift errors measured in head and neck plans for portal dosimetry system

Position shift error		Case 1		Case 2		Case 3		Case 4		Average	
		3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm
X-axis	1mm	95.0	84.2	96.9	86.6	98.0	94.6	96.2	85.3	96.5±1.1	87.7±4.1
	2mm	94.3	80.4	96.3	82.9	98.9	89.6	95.5	81.2	96.3±1.7	83.5±3.6
	3mm	90.4	71.6	93.6	71.6	95.3	69.6	91.6	69.3	92.7±1.9	70.5±1.1
	5mm	74.8	55.1	74.5	52.3	62.0	40.0	69.1	47.1	70.1±5.2	48.6±5.7
X-axis	-1mm	93.2	75.1	95.8	78.8	96.9	79.0	92.0	70.9	94.5±2.0	76.0±3.3
	-2mm	87.0	65.3	88.3	63.4	86.8	56.4	82.3	56.7	86.1±2.3	60.5±4.0
	-3mm	78.3	58.0	76.9	55	67.1	42.0	69.6	45.5	73.0±4.7	50.1±6.6
	-5mm	65.8	47.9	62.9	45.2	43.3	27.6	51.6	33.8	55.9±9.0	38.6±8.3
Y-axis	1mm	93.4	76.4	95.2	78.4	97.8	84.9	93.1	73.1	94.9±1.9	78.2±4.3
	2mm	88.4	69.9	84.6	70.6	93.2	74.0	85.0	63.9	87.8±3.4	69.6±3.6
	3mm	82.7	65.6	83.9	65.3	85.5	66.2	77.0	57.5	82.3±3.2	63.7±3.6
	5mm	81.8	68.8	75.3	57.8	74.6	55.0	65.3	47.8	74.3±5.9	57.4±7.6
Y-axis	-1mm	95.7	84.3	97.2	86.8	99.1	94.0	95.7	84.2	96.9±1.4	87.3±4.0
	-2mm	95.5	83.4	97.1	86.0	98.9	92.9	95.0	82.1	96.6±1.5	86.1±4.2
	-3mm	94.4	78.9	96.2	80.7	97.6	85.8	92.5	73.8	95.2±1.9	79.8±4.3
	-5mm	85.1	68.3	86.1	68.0	87.6	71.3	76.5	55.3	83.8±4.3	65.7±6.2

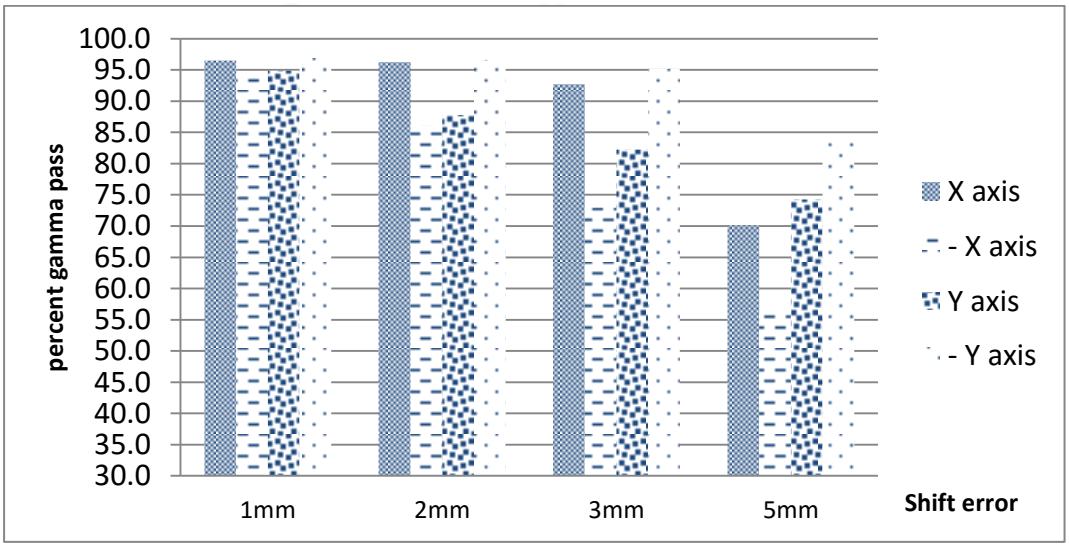


Figure 4. 3 The percent gamma pass of the plan with position shift errors analyzed by 3%/3 mm criterion in head and neck plans for portal dosimetry system

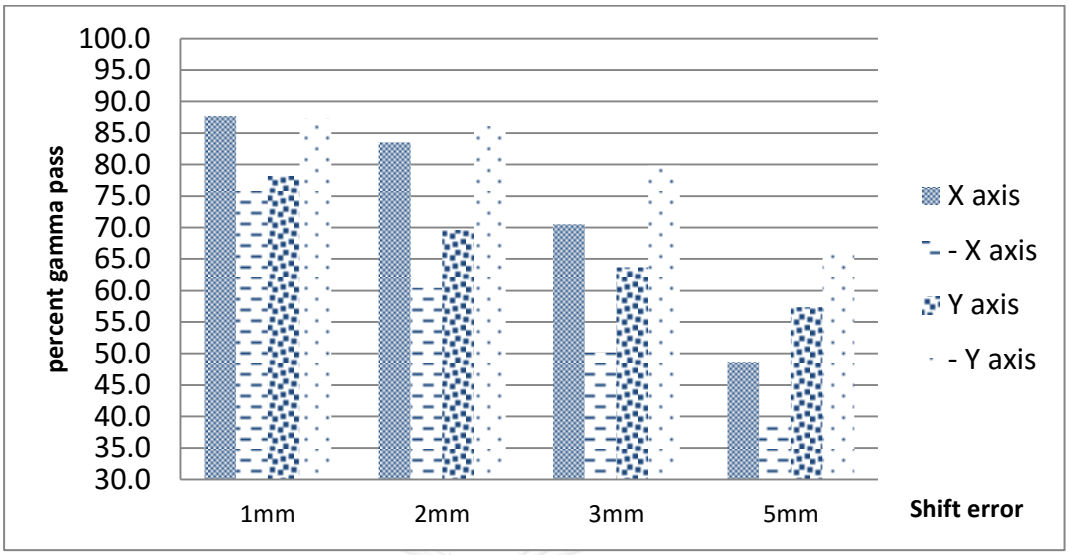


Figure 4. 4 The percent gamma pass of the plan with position shift errors analyzed by 2%/2 mm criterion in head and neck plans for portal dosimetry system

Table 4. 4 The percent gamma pass of position shift errors measured in prostate plans for portal dosimetry system

Position shift error		Case 1		Case 2		Case 3		Case 4		Average	
		3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm
X-axis	1mm	99.6	98.2	99.8	98.1	99.8	98.2	98.3	93.0	99.4±0.7	96.9±2.6
	2mm	99.3	96.3	99.8	96.8	99.7	95.6	97.7	89.9	99.1±1.0	94.7±3.2
	3mm	98.4	85.2	99.1	86.3	98.4	68.3	95.8	66.9	97.9±1.5	76.7±10.5
	5mm	82.0	70.2	83.7	68.1	58.5	39.3	61.1	43.5	71.3±13.4	55.3±16.1
X-axis	-1mm	99.5	93.6	99.6	93.8	99.4	83.6	97.8	84.6	99.1±0.9	88.9±5.6
	-2mm	96.9	80.3	97.3	81.3	91.1	51.8	91.4	58.8	94.2±3.4	68.1±15
	-3mm	86.1	73.2	87.8	72.5	62.9	36.8	69.0	49.1	76.5±12.4	57.9±18
	-5mm	75.1	64.7	74.6	60.8	39.2	25.7	52.6	40.1	60.4±17.6	47.8±18.3
Y-axis	1mm	99.3	93.8	99.3	92.9	99.5	89.6	97.4	82.5	98.9±1.0	89.7±5.1
	2mm	96.7	82.8	95.4	77.1	95.5	73.2	89.0	67.8	94.2±3.5	75.2±6.3
	3mm	89.0	73.8	84.3	68.5	84.2	63.0	77.7	59.0	83.8±4.6	66.1±6.5
	5mm	75.7	61.2	71.8	58.1	70.1	49.5	64.6	45.1	70.6±4.6	53.5±7.5
Y-axis	-1mm	99.7	98.5	99.8	98.4	99.8	97.7	98.3	93.0	99.4±0.7	96.9±2.6
	-2mm	99.7	97.2	99.6	96.5	99.8	95.2	98.0	91.0	99.3±0.9	95.0±2.8
	-3mm	98.9	87.5	98.3	85.1	98.6	80.5	97.6	81.3	98.4±0.6	83.6±3.3
	-5mm	84.0	70.9	80.5	65.1	79.3	60.3	78.2	58.9	80.5±2.5	63.8±5.4

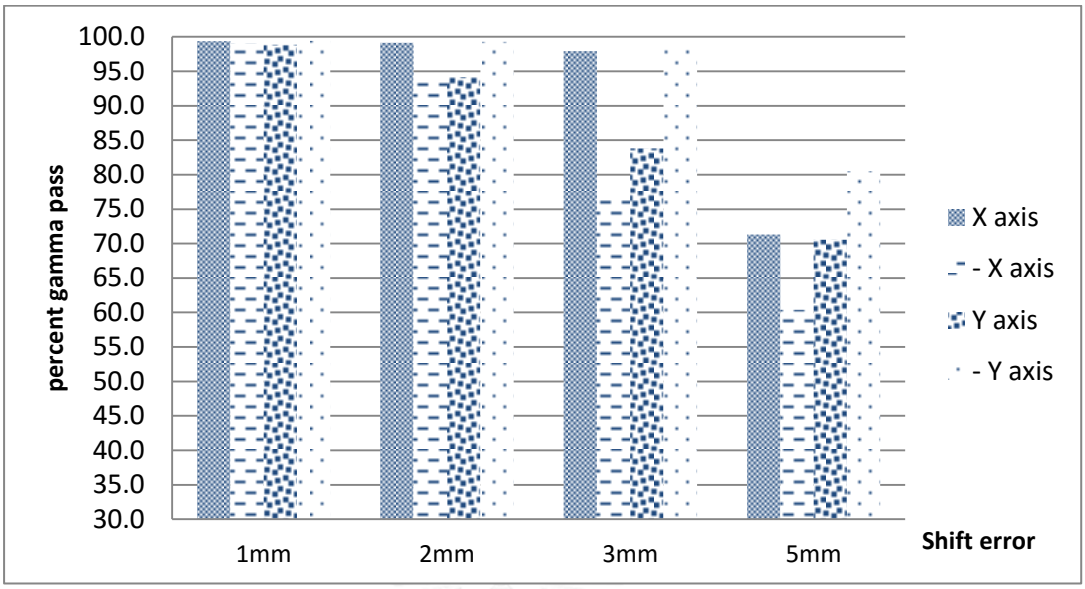


Figure 4. 5 The percent gamma pass of the plan with position shift errors analyzed by 3%/3 mm criterion in prostate plan for portal dosimetry system

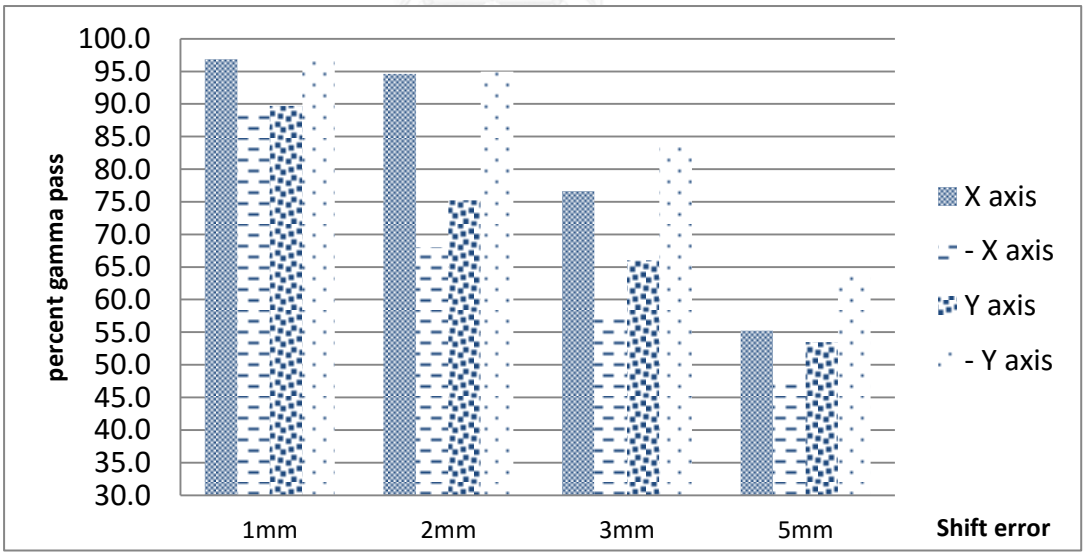


Figure 4. 6 The percent gamma pass of the plan with position shift errors analyzed by 2%/2 mm criterion in prostate plans for portal dosimetry system

4.2.2 Prescribed Dose Error Measurement

Table 4.5 and 4.6 show the results of prescribed dose error measurements by portal dosimetry system in head and neck and prostate IMRT plans, respectively. The plans which introduced with intentional prescribed dose error were measured and analyzed by 3%/3 mm and 2%/2 mm gamma criteria for both head and neck region and prostate region IMRT plans. The error of 2% increasing of prescribed dose and 4% decreasing of prescribed dose were detected in the head and neck plans analyzed by 3%/3 mm criteria. In the prostate IMRT plans, using 3%/3 mm gamma criteria, the error of 4% in both increasing and decreasing dose were observed. If 2%/2 mm analyzing criterion was used, the dose error were detected starting from 2% in all the plans. The results were also displayed in bar graph of figure 4.7 and 4.8 for head and neck and 4.9 and 4.10 for prostate plans.

Table 4. 5 The percent gamma pass of prescribed dose errors measured in head and neck plans for portal dosimetry system

Prescribed dose error		Case 1		Case 2		Case 3		Case 4		Average	
		3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm
Increasing	2%	91.0	75.6	92.9	78.2	85.4	67.1	88.5	70.2	89.5±2.8	72.8±4.4
	4%	85.0.	68.6	86.0	69.8	80.5	60.0	78.9	58.4	82.6±3.0	64.2±5.0
	6%	79.1	63.3	78.7	63.3	73.7	53.0	68.8	48.8	75.1±4.2	57.1±6.4
Decreasing	-2%	97.2	86.9	97.4	85.5	87.2	70.6	98.5	90.9	95.1±4.6	83.5±7.7
	-4%	96.9	85.1	94.6	77.1	83.6	63.8	98.1	90.1	93.3±5.7	79.0±9.9
	-6%	93.5	77.8	86.7	65.1	75.5	54.7	93.5	80.4	87.3±7.4	69.5±10.3

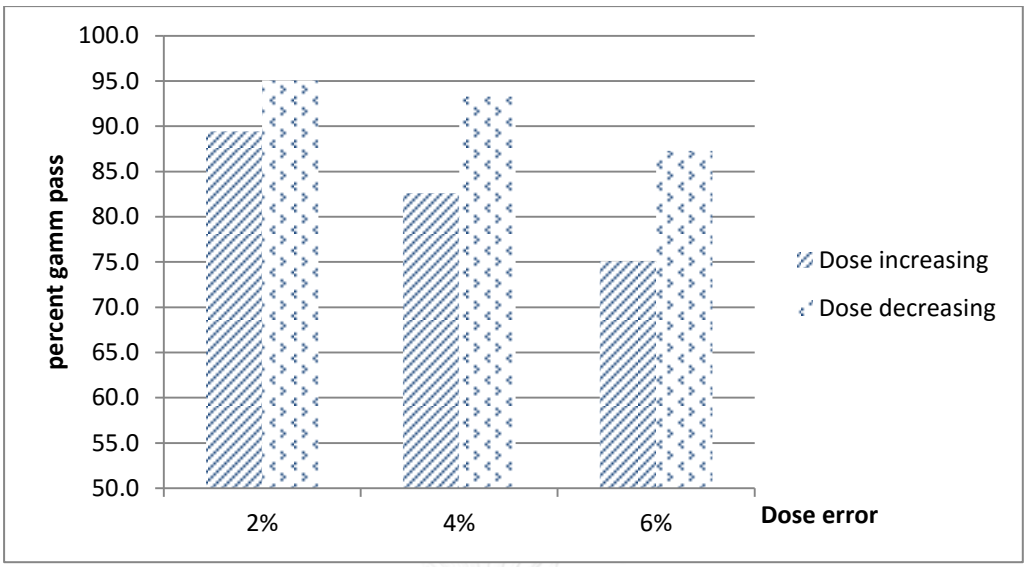


Figure 4. 7 The percent gamma pass of the plan with prescribed dose error analyzed by 3%/3 mm criterion in head and neck plans for portal dosimetry system

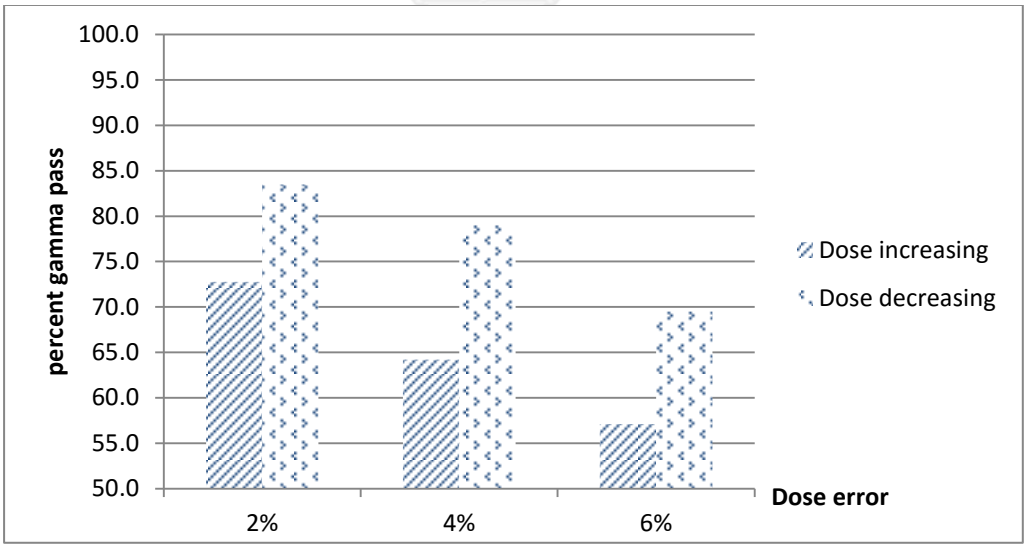


Figure 4. 8 The percent gamma pass of the plan with prescribed dose error analyzed by 2%/2 mm criterion in head and neck plans for portal dosimetry system

Table 4. 6 The percent gamma pass of prescribed dose errors measured in prostate plans for portal dosimetry system

Prescribed dose error		Case 1		Case 2		Case 3		Case 4		Average	
		3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm
Increa-sing	2%	99.6	97.1	99.8	97.8	96.8	87.8	98.0	89.8	98.6±1.4	93.1±5.1
	4%	96.9	90.9	95.8	87.6	87.5	76.4	83.2	70.9	90.9±6.6	81.5±9.4
	6%	92.7	85.4	89.0	80.5	80.0	65.7	69.3	61.0	82.8±10.4	73.2±11.7
Decre-asing	-2%	97.6	93.6	97.1	90.2	97.5	90.5	90.7	75.7	95.7±3.4	87.5±8.0
	-4%	92.4	87.6	87.8	79.2	87.8	73.6	65.6	52.0	83.4±12.1	73.1±15.2
	-6%	88.7	83.3	80.9	73.5	73.3	59.5	51.1	47.4	73.5±16.2	65.9±15.7

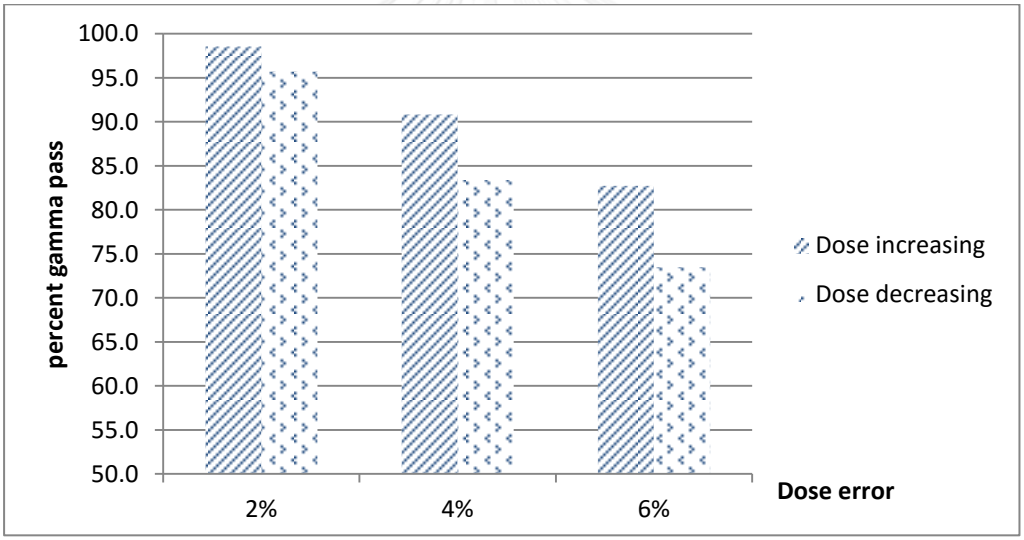


Figure 4. 9 The percent gamma pass of the plan with prescribed dose error analyzed by 3%/3 mm criterion in prostate plans for portal dosimetry system

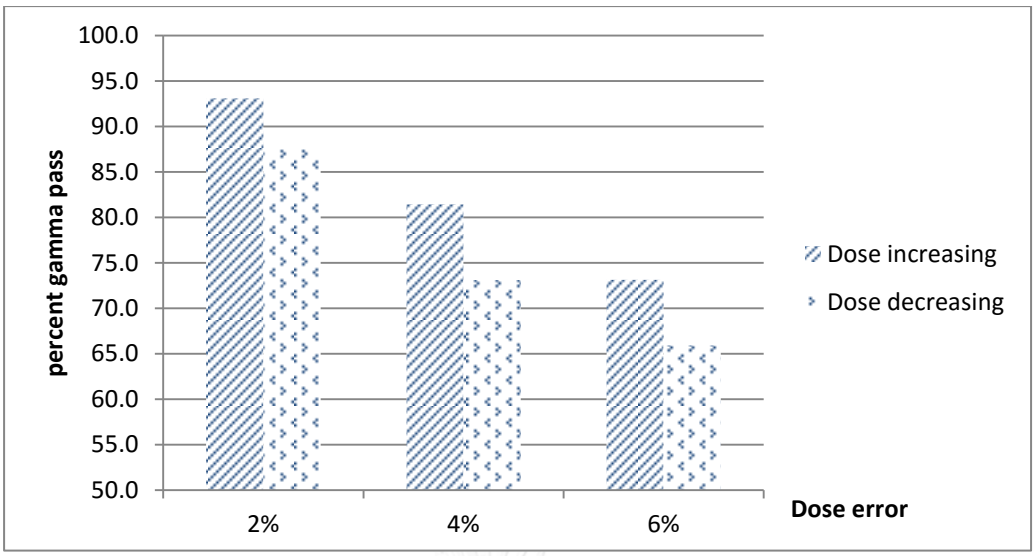


Figure 4. 10 The percent gamma pass of the plan with prescribed dose error analyzed by 2%/2 mm criterion in prostate plans for portal dosimetry system

4.3 MapCHECK2 System Measurement

4.3.1 Position Shift Error Measurement

The data of MapCHECK2 system measurement on position shift errors are shown in table 4.7 and 4.8. The errors that were detected by MapCHECK2 system were started from 2 mm shift in the head and neck plans. The errors in all direction shifted of 3 mm were detected in the prostate plans. If the lower gamma criterion was used the smaller magnitude of error (1 mm shift) in all direction was detected in the head and neck plan. The errors of 2 mm shift in all direction were observed in the prostate plans when the analyzed criterion was changed to 2%/2 mm. The results were also displayed in bar graph of figure 4.11 and 4.12 for head and neck and figure 4.13 and 4.14 for prostate plans.

Table 4. 7 The percent gamma pass of position shift error measured in head and neck plans for MapCHECK2 system

Position shift error		Case 1		Case 2		Case 3		Case 4		Average	
		3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm
X-axis	1mm	97.7	89.5	98.6	92.6	99.4	96.7	98.8	93.2	98.6±0.7	93.0±3.0
	2mm	96.5	81.7	98.5	84.7	98.8	92.1	98.1	89.8	98.0±1.0	87.1±4.7
	3mm	89.4	63.0	93.1	67.6	95.7	65.6	95.4	76.0	93.4±2.9	68.1±5.6
	5mm	62.4	43.0	64.1	46.0	57.2	36.2	73.3	52.3	64.3±6.7	44.4±6.7
X-axis	-1mm	94.5	80.2	96.9	84.2	98.8	91.0	96.9	83.3	96.8±1.8	84.7±4.6
	-2mm	87.5	61.9	90.9	66.8	95.0	71.0	90.9	68.2	91.1±3.1	67.0±3.8
	-3mm	70.8	48.0	76.3	50.9	77.7	51.4	77.8	55.9	75.7±3.3	51.6±3.3
	-5mm	50.7	35.7	50.1	35.4	46.1	26.4	51.5	33.8	49.6±2.4	32.8±4.4
Y-axis	1mm	95.4	80.7	96.5	87.1	99.4	92.9	96.6	86.1	97.0±1.7	86.7±5.0
	2mm	89.8	73.6	92.3	79.7	96.2	87.0	92.2	78.9	92.6±2.6	79.8±5.5
	3mm	83.3	64.7	86.7	71.6	92.3	81.5	86.8	72.5	87.3±3.7	72.6±6.9
	5mm	72.3	51.1	73.4	53.5	81.4	63.1	72.7	54.7	75.0±4.3	55.6±5.2
Y-axis	-1mm	97.9	89.3	98.6	93.1	98.6	95.0	98.8	94.2	98.5±0.4	92.9±2.5
	-2mm	96.5	82.6	96.5	86.6	96.6	90.8	97.8	93.1	96.9±0.6	88.3±4.6
	-3mm	91.3	76.0	92.5	79.7	94.0	84.8	96.5	86.8	93.6±2.2	81.8±4.9
	-5mm	78.7	62.3	80.2	68.2	81.3	65.6	84.2	68.6	81.1±2.3	66.2±2.9

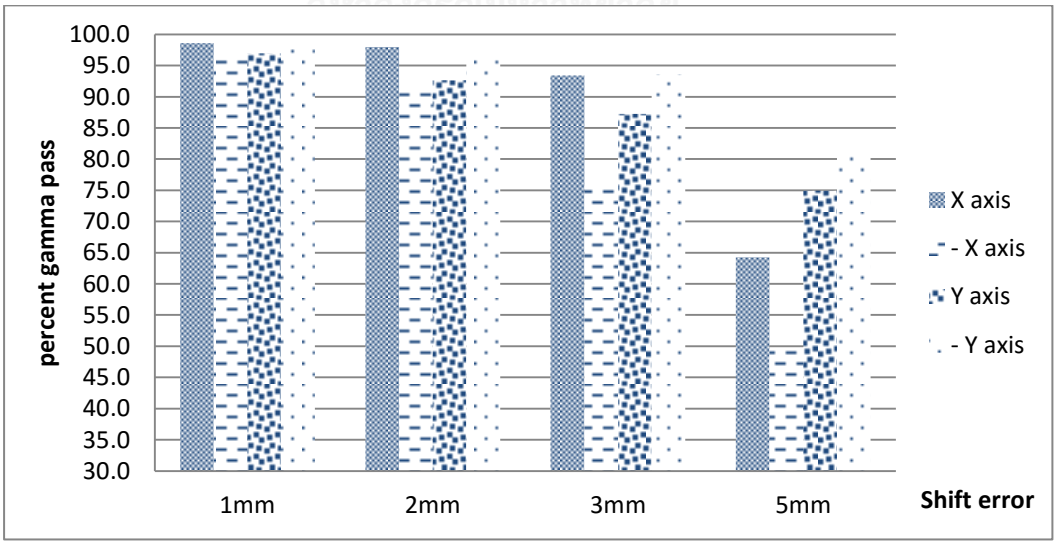


Figure 4. 11 The percent gamma pass of the plan with position shift error analyzed by 3%/3 mm criterion in head and neck plans for MapCHECK2 system

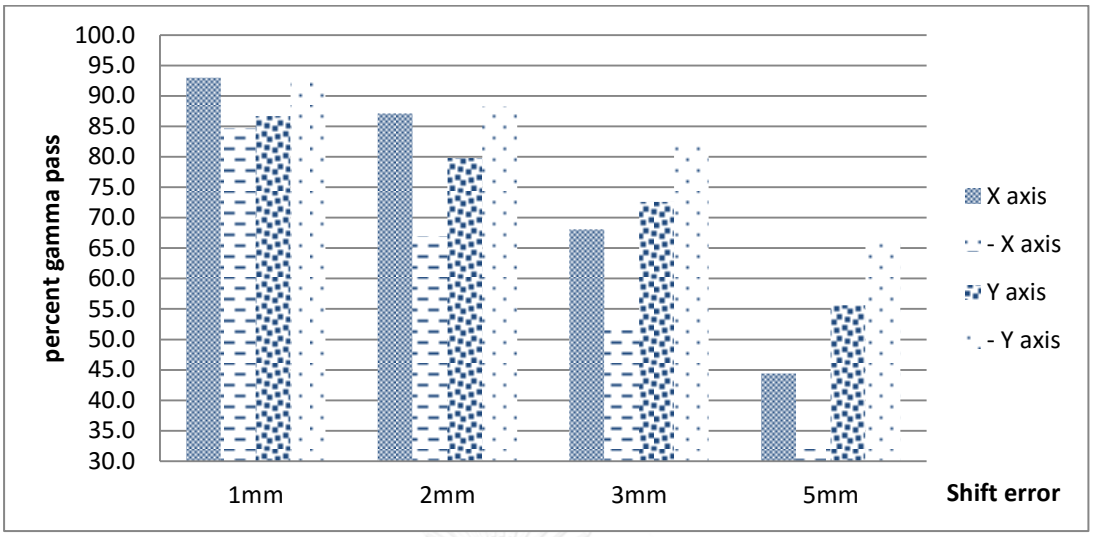


Figure 4. 12 The percent gamma pass of the plan with position shift error analyzed by 2%/2 mm criterion in head and neck plans for MapCHECK2 system

Table 4. 8 The percent gamma pass of position shift error measured in prostate plans for MapCHECK2 system

Position shift error		Case 1		Case 2		Case 3		Case 4		Average	
		3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm
X-axis	1mm	99.4	96.1	100	100	96.2	91.0	99.4	97.5	98.8±1.7	96.2±3.8
	2mm	98.7	89.0	99.9	99.3	95.2	82.1	98.8	85.4	98.2±2.0	89.0±7.5
	3mm	92.8	65.4	98.1	88.6	89.7	48.6	90.9	59.8	92.9±3.7	65.6±16.8
	5mm	59.6	39.1	79.9	59.2	49.7	26.5	53.8	39.6	60.8±13	41.1±13.5
X-axis	-1mm	100	94.7	100	100	95.9	89.0	99.4	95.1	98.8±2.0	94.7±4.5
	-2mm	99.3	69.7	100	99.5	92.5	63.3	96.4	77.7	97.1±3.4	77.6±15.8
	-3mm	82.4	51.0	98.0	88.4	71.4	40.8	84.4	49.7	84.1±10	57.5±21.1
	-5mm	52.2	37.6	80.8	57.9	34.0	26.7	48.5	32.5	53.9±19	38.7±13.6
Y-axis	1mm	100	93.5	100	100	96.5	84.6	99.4	88.3	99.0±1.7	91.6±6.7
	2mm	98.1	78.2	100	99.3	90.2	77.6	93.8	77.2	95.5±4.4	83.1±10.8
	3mm	84.7	56.7	95.4	81.5	87.2	64.2	82.4	67.9	87.4±5.7	67.6±10.4
	5mm	92.0	38.8	72.9	51.2	66.2	51.7	69.3	48.2	75.1±11	47.5±6.0
Y-axis	-1mm	98.7	97.4	100	100	96.6	91.1	99.4	93.3	98.7±1.5	95.5±4.0
	-2mm	98.0	84.1	99.9	97.7	94.6	77.0	95.1	90.2	96.9±2.5	87.3±8.8
	-3mm	89.7	67.7	94.7	82.9	83.1	68.2	92.7	82.3	90.1±5.1	75.3±8.5
	-5mm	61.9	43.1	75.1	54.4	66.4	49.0	71.2	51.2	68.7±5.7	49.4±4.8

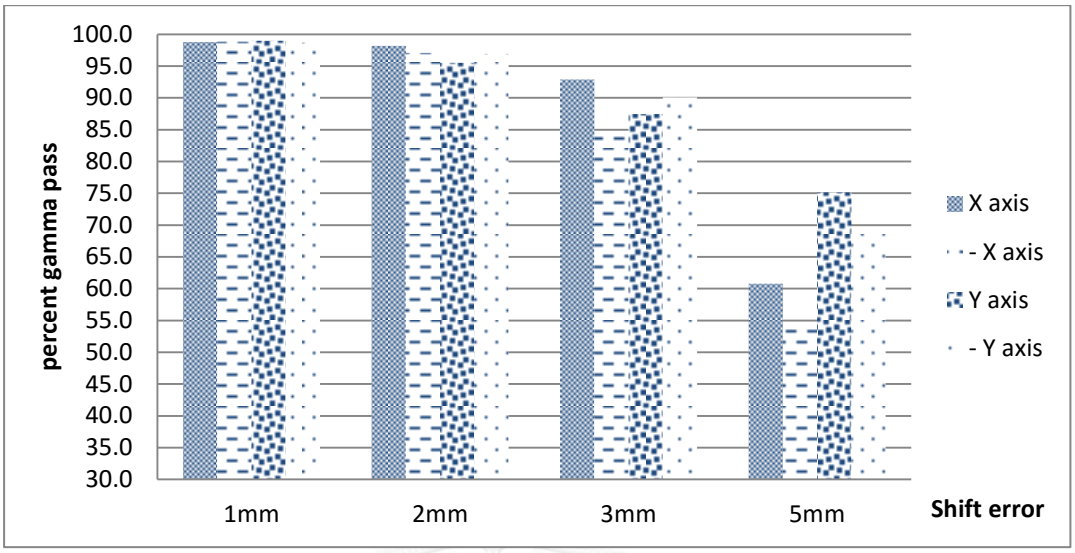


Figure 4. 13 The percent gamma pass of the plan with position shift error analyzed by 3%/3 mm criterion in prostate plans for MapCHECK2 system

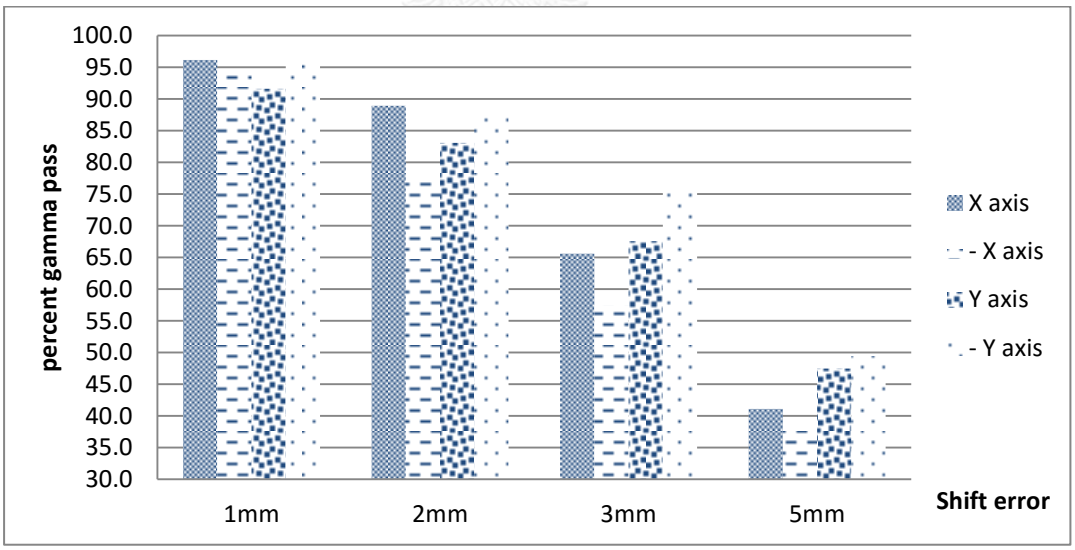


Figure 4. 14 The percent gamma pass of the plan with position shift error analyzed by 2%/2 mm criterion in prostate plans for MapCHECK2 system

4.3.2 Prescribed Dose Error Measurement

The average percent passing analyzed by 3%/3 mm for head and neck plans were 98.1, 96.0 and 89.3 for increasing dose and 95.4, 88.9 and 80.3 for decreasing dose of 2%, 4% and 6% respectively. The measurement results are described in table 4.9 and 4.10. So the plan which had percent pass lower than 95, dose increasing and decreasing of 4% and 6%, were considered as detected errors by MapCHECK2 system. The error of 4% in both increasing and decreasing dose were detected in prostate plans. The smallest magnitude of 2% dose errors could be detected by MapCHECK2 system when the 2%/2 mm gamma analysis criterion was used. The results were also displayed in bar graph of figure 4.15 and 4.16 for head and neck and 4.17 and 4.18 for prostate plans.

Table 4. 9 The percent gamma pass of prescribed dose error measured in head and neck plans for MapCHECK2 system

Prescribed dose error		Case 1		Case 2		Case 3		Case 4		Average	
		3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm
Increas-ing	2%	98.5	93.4	97.9	89.7	98.1	92.8	97.8	93.2	98.1±0.3	92.3±1.7
	4%	97.2	89.6	94.3	82.4	96.2	84.0	96.4	87.5	96.0±1.2	85.9±3.3
	6%	93.6	79.6	87.1	70.0	88.8	72.2	87.8	80.1	89.3±2.9	75.5±5.1
Decrea-sing	-2%	90.0	76.0	94.0	83.2	99.3	96.7	98.1	90.4	95.4±4.2	86.6±9.0
	-4%	80.0	64.8	83.0	68.1	97.8	90.0	94.8	83.2	88.9±8.7	76.5±12.0
	-6%	68.8	53.9	70.9	52.8	91.9	75.8	89.7	79.4	80.3±12.2	65.5±14.1

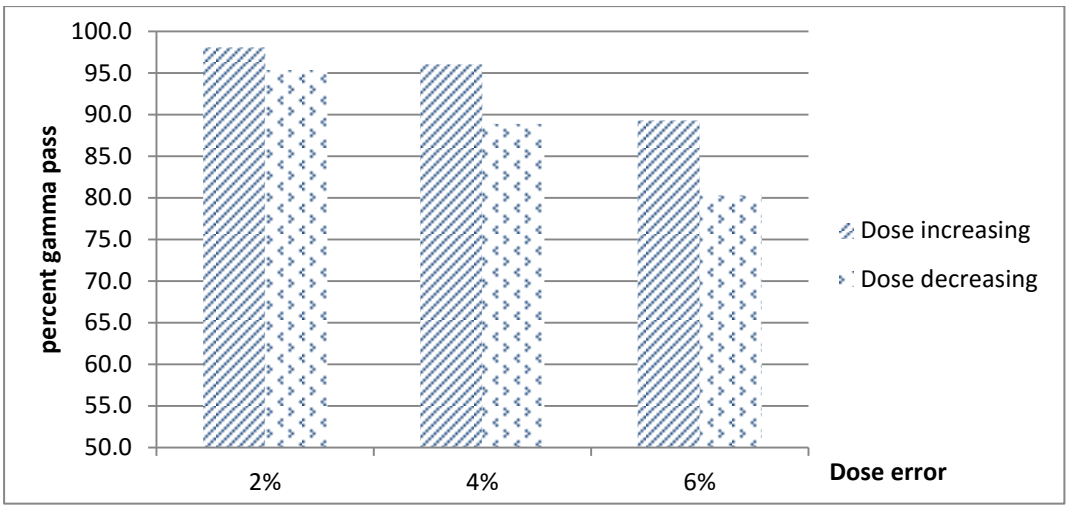


Figure 4. 15 The percent gamma pass of the plan with prescribed dose error analyzed by 3%/3 mm criterion in head and neck plans for MapCHECK2 system

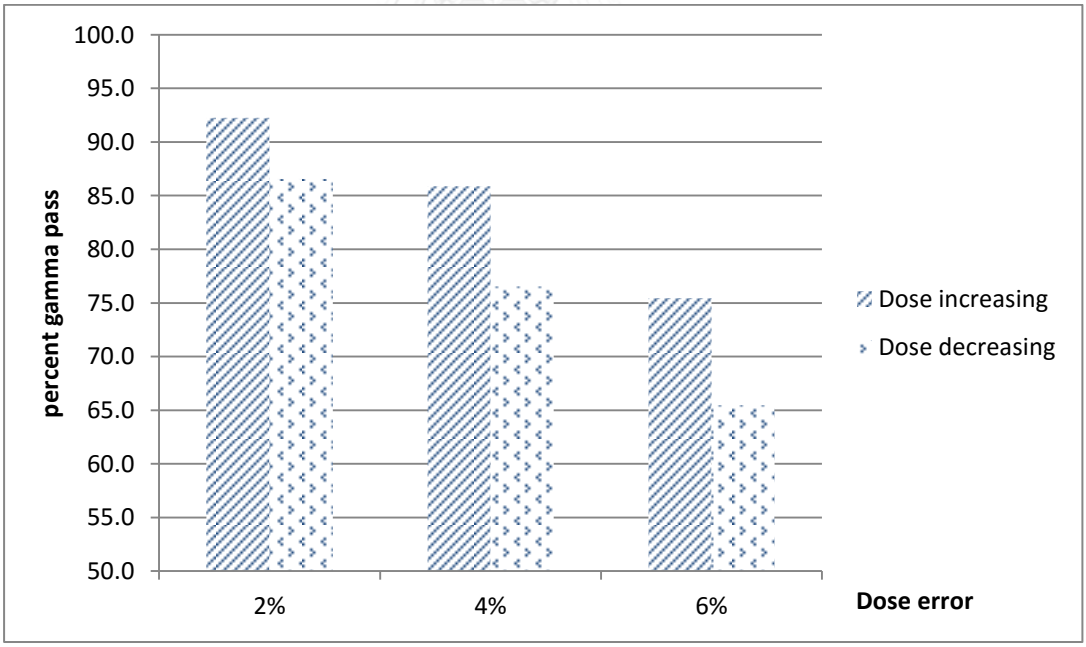


Figure 4. 16 The percent gamma pass of the plan with prescribed dose error analyzed by 2%/2 mm criterion in head and neck plans for MapCHECK2 system

Table 4. 10 The percent gamma pass of prescribed dose error measured in prostate plans for MapCHECK2 system

Prescribed dose error		Case 1		Case 2		Case 3		Case 4		Average	
		3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm
Increas-ing	2%	97.2	91.9	99.1	93.8	99.3	97.2	99.4	89.5	98.8±1.0	93.1±3.3
	4%	88.8	83.2	87.2	79.0	100	96.5	88.3	74.1	91.1±6.0	83.2±9.6
	6%	83.4	77.6	79.3	70.9	93.8	88.2	74.7	65.4	82.8±8.1	75.5±9.8
Decrea-sing	-2%	97.1	91.7	98.9	93.1	88.2	75.7	97.5	95.1	95.4±4.9	88.9±8.9
	-4%	88.0	82.3	85.8	77.7	74.3	63.9	93.2	80.9	85.3±8.0	76.2±8.4
	-6%	82.0	76.1	77.3	68.8	69.4	57.6	74.7	62.3	75.9±5.3	66.2±8.0

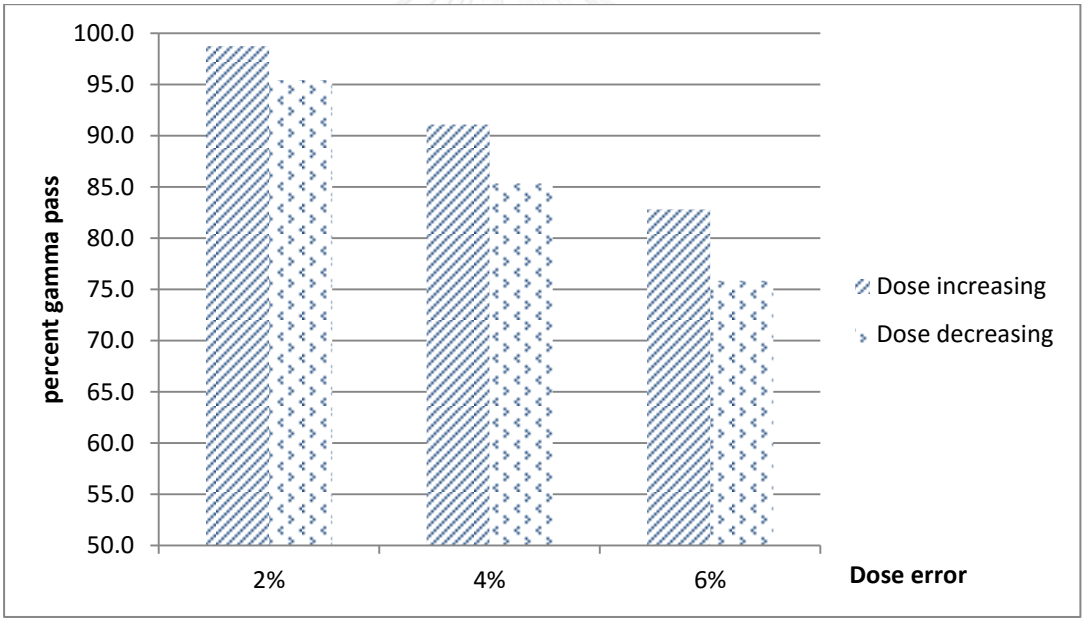


Figure 4. 17 The percent gamma pass of the plan with prescribed dose error analyzed by 3%/3 mm criterion in prostate plans for MapCHECK2 system

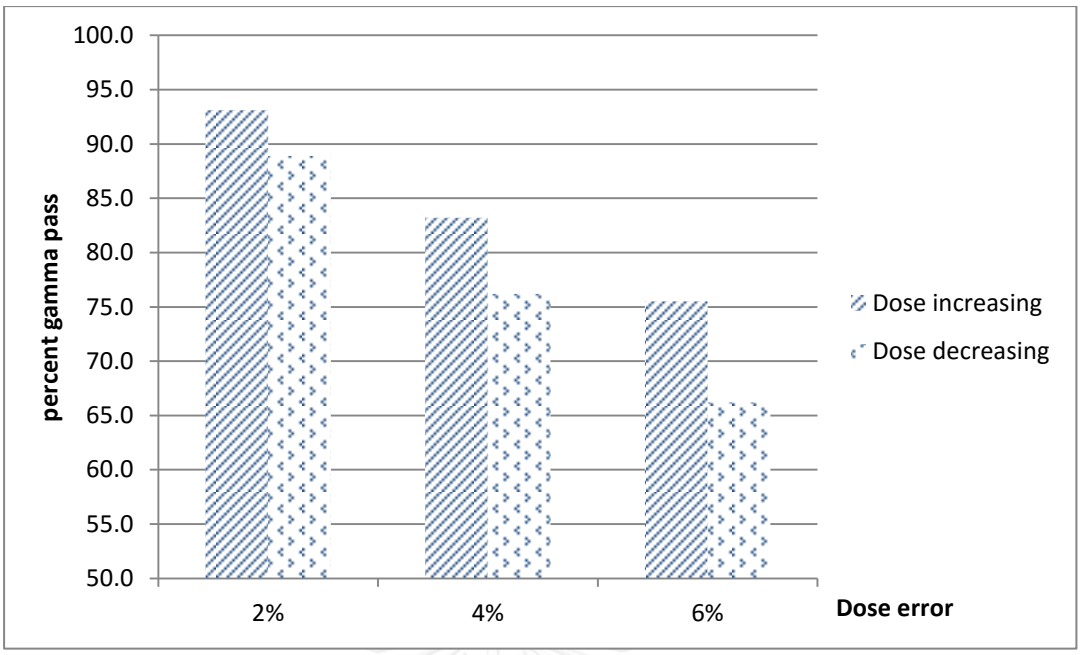


Figure 4. 18 The percent gamma pass of the plan with prescribed dose error analyzed by 2%/2 mm criterion in prostate plans for MapCHECK2 system

4.4 MatriXX System Measurement

4.4.1 Position Shift Error Measurement

The table 4.11 and 4.12 illustrated the results of position shift error measurement by MatriXX system. The error detection by MatriXX system using 3%/3 mm criterion were started from 3 mm shift and higher magnitude of error in all direction for head and neck plans and started from 5 mm shift in all direction for the prostate plans, respectively. The error of 1 mm in head and neck plans and 2 mm in prostate plans were detected when the analyzing criterion is changed to 2%/2 mm. The results were also displayed in bar graph of figure 4.19 and 4.20 for head and neck and 4.21 and 4.22 for prostate plans.

Table 4. 11 The percent gamma pass of position shift error measured in head and neck plans for MatriXX system

Position shift error		Case 1		Case 2		Case 3		Case 4		Average	
		3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm
X-axis	1mm	95.9	76.0	97.4	92.5	99.4	95.9	96.7	74.6	97.4±1.5	84.8±11
	2mm	94.5	56.4	95.3	84.5	97.8	91.4	92.8	62.5	95.1±2.1	73.7±16
	3mm	84.1	41.7	81.5	69.6	89.2	83.4	78.4	51.4	83.3±4.6	61.6±18
	5mm	69.8	35.2	63.4	47.7	75.9	70.7	58.0	36.1	66.8±7.8	47.5±16
X-axis	-1mm	96.4	74.8	98.5	89.4	99.7	92.8	97.9	87.5	98.2±1.4	86.2±7.9
	-2mm	93.2	60.0	94.3	76.4	99.3	84.3	94.9	78.2	95.5±2.7	74.8±10
	-3mm	87.4	41.7	85.8	63.3	97.0	75.7	86.7	65.6	89.3±5.2	61.6±14
	-5mm	74.8	32.7	66.9	44.0	81.0	67.0	65.8	42.0	72.2±7.1	46.5±14
Y-axis	1mm	97.1	76.8	99.3	93.8	99.7	86.9	98.0	82.8	98.6±1.2	85.1±7.2
	2mm	96.3	71.0	98.8	90.9	99.5	82.9	96.8	77.2	97.9±1.5	80.6±8.5
	3mm	94.4	70.7	96.9	86.2	97.5	79.4	94.1	71.2	95.8±1.7	76.9±7.4
	5mm	88.8	63.9	89.0	77.2	89.7	73.5	84.3	61.9	88±2.5	69.2±7.4
Y-axis	-1mm	96.6	71.8	99.0	92.0	99.7	91.3	97.4	86.5	98.2±1.4	85.4±9.4
	-2mm	95.4	59.7	97.8	86.4	99.3	87.6	94.9	84.0	96.9±2.1	79.5±13
	-3mm	92.7	45.2	94.3	79.5	97.9	84.1	90.6	79.7	93.9±3.1	72.2±18
	-5mm	85.7	42.3	85.1	68.5	91.1	77.7	80.8	69.5	85.7±4.2	64.5±15

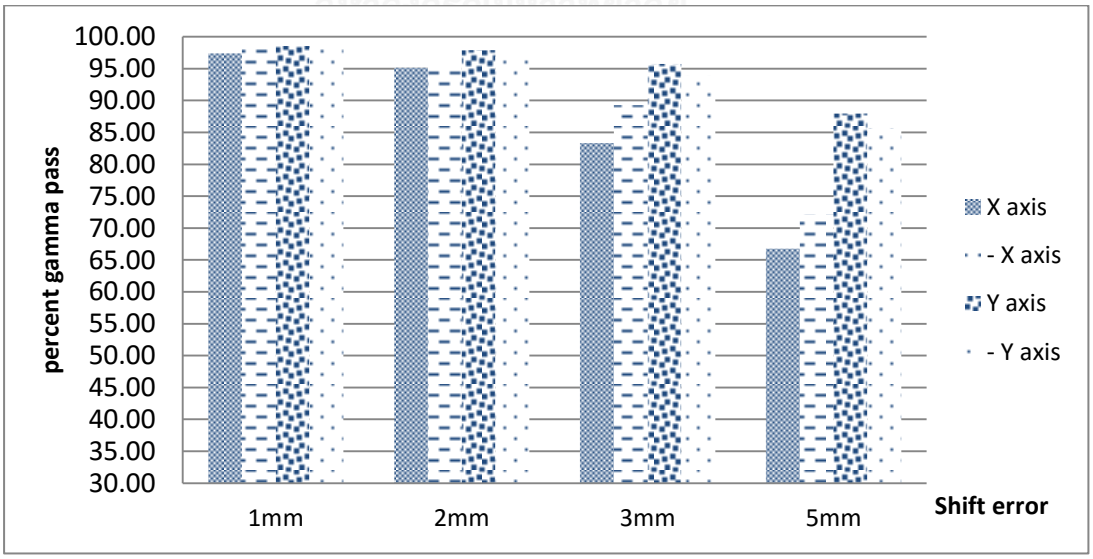


Figure 4. 19 The percent gamma pass of the plan with position shift errors analyzed by 3%/3 mm criterion for head and neck plans for MatriXX system

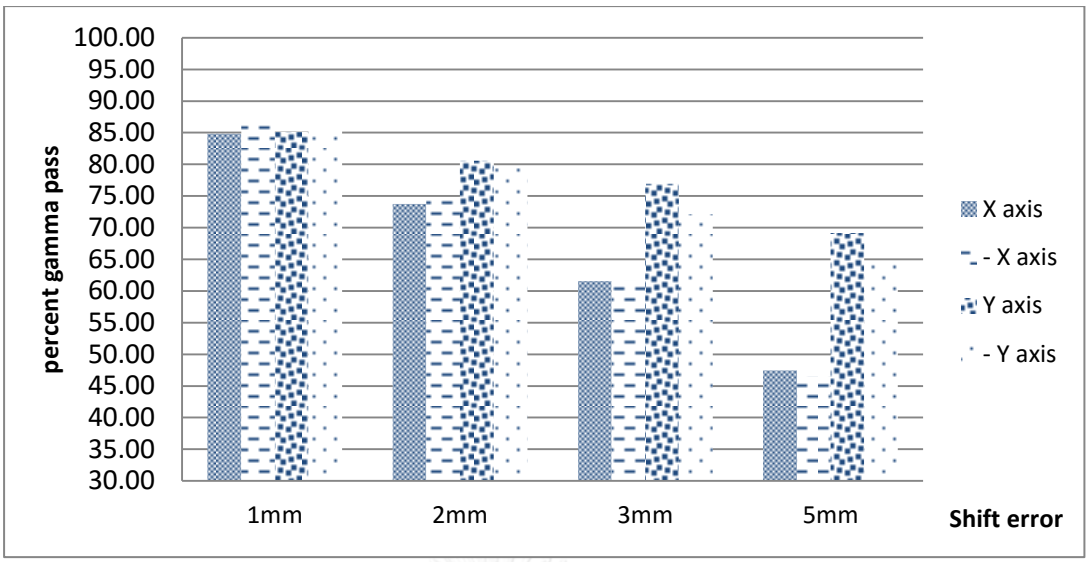


Figure 4. 20 The percent gamma pass of the plan with position shift errors analyzed by 2%/2 mm criterion for head and neck plans for MatriXX system

Table 4. 12 The percent gamma pass of position shift error measured in prostate plans for MatriXX system

Position shift error		Case 1		Case 2		Case 3		Case 4		Average	
		3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm
X-axis	1mm	98.8	98.1	99.8	96.1	99.4	98.0	99.6	95.1	99.4±0.4	96.8±1.5
	2mm	98.3	96.6	99.4	91.0	98.4	94.6	98.4	91.7	98.6±0.5	95.5±2.6
	3mm	97.2	94.5	97.7	90.1	95.7	90.8	96.0	90.3	96.7±0.9	91.4±2.1
	5mm	93.7	91.3	91.9	87.0	90.9	87.3	91.6	88.1	92.0±1.2	88.4±2.0
X-axis	-1mm	98.8	98.4	99.9	92.3	99.5	98.9	99.8	98.9	99.5±0.5	97.1±3.2
	-2mm	98.2	97.0	99.8	91.2	99.1	97.0	99.7	95.3	99.2±0.7	95.1±2.7
	-3mm	96.7	95.1	99.2	90.4	97.7	92.9	98.7	94.0	98.1±1.1	93.1±2.0
	-5mm	93.9	91.6	94.2	87.3	91.5	87.7	94.3	90.4	93.5±1.3	89.2±2.1
Y-axis	1mm	99.8	98.1	99.9	93.3	99.4	99.4	99.5	99.0	99.7±0.2	97.4±2.8
	2mm	99.2	96.2	99.7	90.5	99.1	98.8	97.9	97.0	99.0±0.8	95.6±3.6
	3mm	98.3	94.9	97.8	89.7	97.9	97.2	96.3	95.1	97.6±0.9	94.2±3.2
	5mm	93.0	91.5	89.9	85.3	94.7	93.2	93.6	92.2	92.8±2.1	90.6±3.6
Y-axis	-1mm	99.6	98.3	99.9	91.6	99.5	97.8	99.8	99.2	99.7±0.2	96.7±3.5
	-2mm	99.0	97.2	99.7	89.2	99.1	95.8	99.8	98.7	99.4±0.4	95.2±4.2
	-3mm	97.3	94.7	97.7	89.6	98.2	93.9	99.3	96.2	98.1±0.9	93.6±2.8
	-5mm	94.8	90.8	90.5	83.7	94.8	91.0	96.1	93.7	94.1±2.4	89.8±4.3

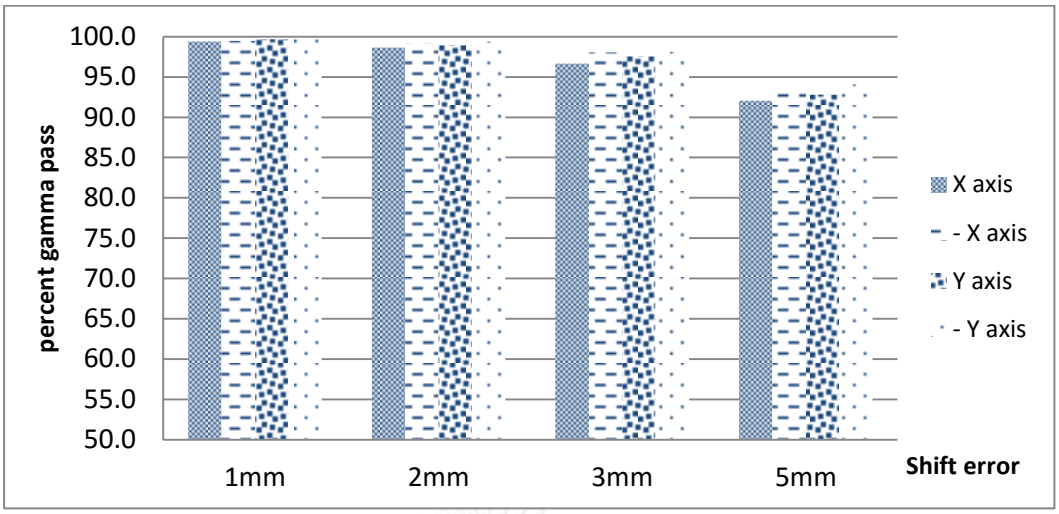


Figure 4. 21 The percent gamma pass of the plan with position shift errors analyzed by 3%/3 mm criterion for prostate plans for MatriXX system

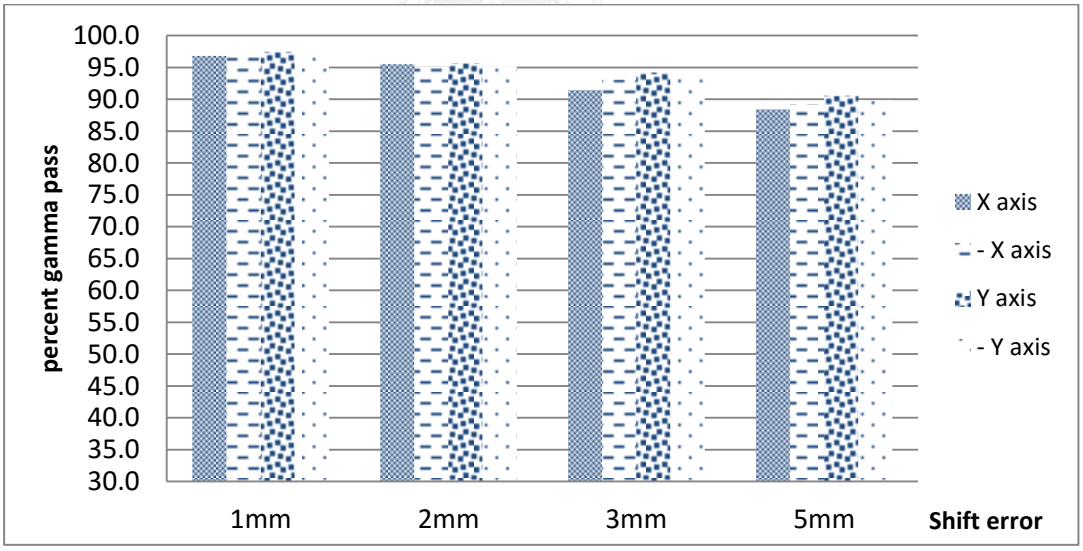


Figure 4. 22 The percent gamma pass of the plan with position shift errors analyzed by 2%/2 mm criterion for prostate plans for MatriXX system

4.4.2 Prescribed Dose Error Measurement

The percent gamma results of prescribed dose error measured by MatriXX system were shown in the table 4.13 and 4.14. The detected errors were starting from 4% for head and neck plans and 6% for prostate plan by analyzing with 3%/3 mm criterion. If 2% dose difference and 2 mm distance to agreement criterion was used, the dose error detection was started from 2% for head and neck plans and 4% for the prostate plans. The results were also displayed in bar graph of figure 4.23 and 4.24 for head and neck and 4.25 and 4.26 for prostate plans.

Table 4. 13 The percent gamma pass of prescribed dose error measured in head and neck plans for MatriXX system

Prescribed dose error		Case 1		Case 2		Case 3		Case 4		Average	
		3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm
Increas-ing	2%	96.5	82.0	97.8	97.4	99.3	95.2	97.8	78.4	97.9±1.1	88.2±9.4
	4%	94.5	77.8	96.1	94.4	95.3	91.8	93.4	76.4	94.8±1.2	85.1±9.3
	6%	84.2	74.4	86.1	81.6	91.0	87.0	75.8	73.6	84.3±6.3	79.2±6.4
Decrea-sing	-2%	93.3	80.5	95.1	83.0	99.5	94.4	92.5	56.2	95.1±3.1	78.5±16.1
	-4%	83.2	76.7	85.5	69.0	96.3	89.0	76.9	47.9	85.5±8.1	70.7±17.3
	-6%	76.1	71.2	76.3	60.6	88.9	83.2	61.2	39.0	75.6±11.3	63.5±18.8

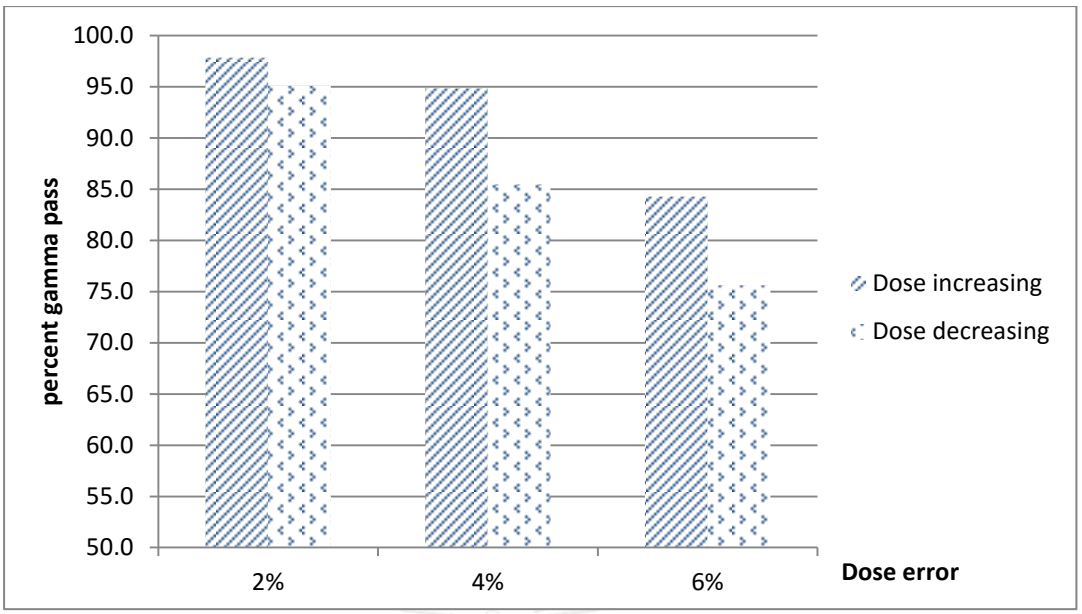


Figure 4. 23 The percent gamma pass of the plan with prescribed dose error analyzed by 3%/3 mm criterion for head and neck plans for MatriXX system

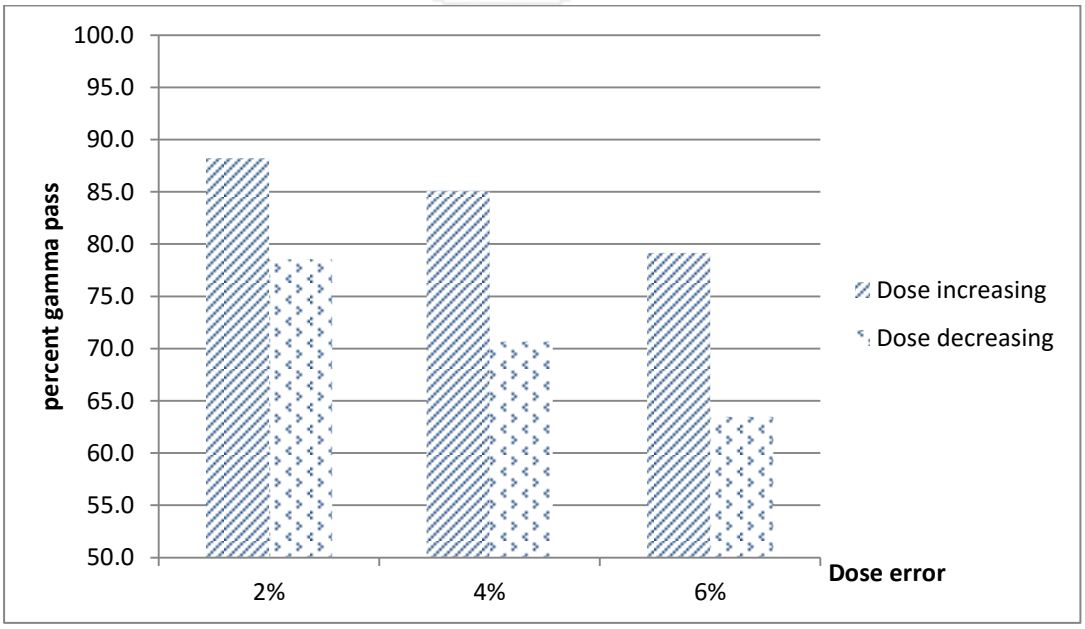


Figure 4. 24 The percent gamma pass of the plan with prescribed dose error analyzed by 2%/2 mm criterion for head and neck plans for MatriXX system

Table 4. 14 The percent gamma pass of prescribed dose error measured in prostate plans for MatriXX system

Prescribed dose error		Case 1		Case 2		Case 3		Case 4		Average	
		3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm
Increasing	2%	99.5	98.2	97.5	90.5	98.8	97.9	99.9	99.0	98.9±1.1	96.4±4
	4%	98.9	96.6	95.4	89.4	97.1	95.1	98.3	95.2	97.4±1.5	94.1±3.2
	6%	97.7	94.9	94.0	88.8	95.0	94.6	97.4	94.2	96.0±1.8	93.1±2.9
Decreasing	-2%	99.8	98.6	97.8	88.1	99.2	95.8	98.3	98.4	98.8±0.9	95.2±4.9
	-4%	99.0	97.8	96.8	86.1	96.8	92.1	96.5	95.9	97.3±1.2	93.0±5.1
	-6%	98.3	96.1	93.4	85.4	94.7	91.1	95.7	94.8	95.5±2.1	91.8±4.8

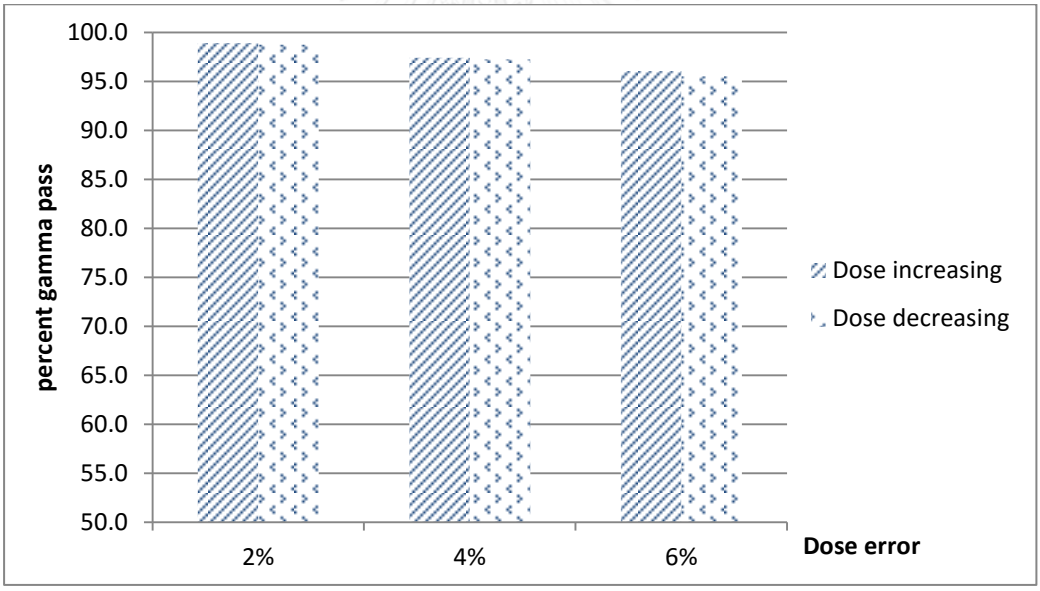


Figure 4. 25 The percent gamma pass of the plan with prescribed dose error analyzed by 3%/3 mm criterion for prostate plans for MatriXX system

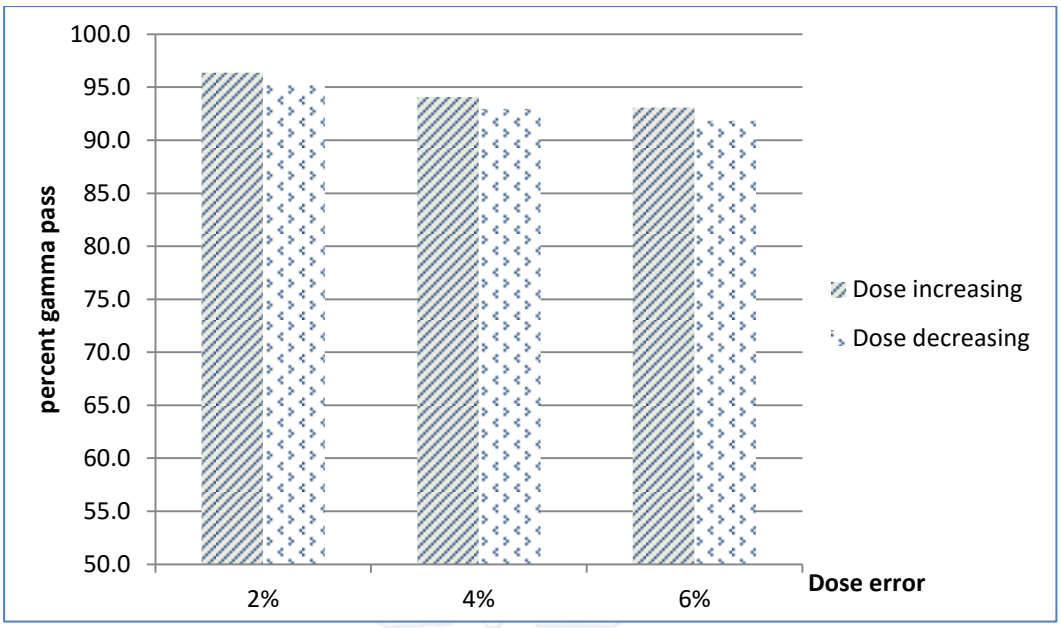


Figure 4. 26 The percent gamma pass of the plan with prescribed dose error analyzed by 2%/2 mm criterion for prostate plans for MatriXX system

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Discussion

5.1.1 Average Gamma Pass Results of Original Plans

In this study, the patient specific QA measurement for head and neck plans and the prostate IMRT plans were performed by portal dosimetry system, MapCHECK2 system and MatriXX system. The measurements were undertaken with 4 head and neck plans and 4 prostate pans. The percent gamma pass result analyzed by 3%/3 mm criterion with 10% threshold of the original head and neck plans were 96.9, 98.6 and 98.8 for portal dosimetry system, MapCHECK2 system and MatriXX system respectively. The results of prostate were 99.4, 99.0 and 99.8 for portal dosimetry system, MapCHECK2 system and MatriXX system respectively. These results were agreed with the gamma passing rate reported by the Jaeman Son et al.[21] The average gamma pass of the head and neck plans that measured by all devices were lower than the result of the prostate because the head and neck plan was more complex than the prostate plans. This was attributed to the increased modulation and irregular field shapes in the head and neck plan. In addition, due to the large field sizes in the head and neck plan, for some fields part of the beam extended outside the detector area, resulting in missing data.[7]

The percent gamma pass result analyzed by 2%/2 mm criterion of the original head and neck plans were 86.4, 92.3 and 98.8 for portal dosimetry system, MapCHECK2 system and MatriXX system, respectively. The results of prostate were 96.6, 97.0 and 97.5 for portal dosimetry system, MapCHECK2 system and MatriXX system respectively. By using 2%/2 mm the gamma pass were quite low for the head and neck even without any intentional errors especially measured by the portal dosimetry system. For the prostate plan it was reasonable to use with the 95% pass rate gold standard. But for the head and neck plan, if it was designed to use with 2%/2 mm criterion the standard pass rate of 95% needed to be lower to 85% for this study. So it is impossible to apply in the actual clinical field because acceptance tolerance is quite low for 2%/2 mm.

Table 5. 1 The gamma pass result of original plans analyzed by 3%/3 mm criterion

Case	Portal Dosimetry System	MapCHECK2 System	MatriXX System
This study (H&N)	96.9 ±1.3	98.6 ±0.6	98.7 ±1.0
This study (Prostate)	99.4 ±0.7	99.0 ±1.7	99.8 ±0.2
Jaeman Son et al study(Non specific region)	99.6 ± 0.4	99.0 ± 0.2	99.3 ±0.2

5.1.2 Position Shift Error Detection by the Three QA Devices

The position shift errors were applied by shifting in X-axis (lateral direction) and Y-axis (longitudinal direction) with the magnitude of 1 mm, 2 mm, 3 mm and 5 mm. The error detection by the portal dosimetry showed the smallest error detection of 1 mm shift in the X-axis (negative direction) and Y-axis (positive direction). At the same condition the error of 2 mm and 3 mm shift were detected by MapCHECK2 system and MatriXX system respectively for the head and neck IMRT plans.

In the prostate plans, the smallest error detection of 2 mm shift can be seen with the portal dosimetry system in X-axis (negative direction) and Y-axis (positive direction). In the other direction, portal dosimetry could detect the error of 5 mm shift. The other two devices can detect 3 mm shift with MapCHECK2 system and 5 mm shift with MatriXX system in all directions. For the prostate, the target organ was quite round shape and the error detection in the different direction show the same magnitude but in the head and neck plan, the error detection in different direction showed different results because of irregular shape of the target volume.

When the error magnitude was increase the gamma passing results was decreased. The decrease percent gamma pass for 1 mm shift was around 1% for all devices. But the higher magnitude of error was introduced; the decrease percent gamma result was more different for each device. For the 5 mm shift error MapCHECK2 system showed 32% gamma pass decreases from the original plan result, whereas the portal dosimetry decrease 28% gamma pass and MatriXX system is 13% gamma pass respectively. The MatriXX is less sensitive to the more error introduced. These changes of gamma pass with position shift were shown in figure 5.1.

Because of the fine resolution of portal dosimetry system (0.39 x 0.39 mm) compared to the other two devices, small displacement in fluence map of the IMRT plan results the higher drop of the percent gamma pass. Once the error was introduced (1mm, 2mm and so on) the fine detection point of the portal dosimetry system could show more deviation of the fluence from the original plan rather than MapCHECK2 system and MatriXX system which had 0.5 cm and 0.7 cm detector spacing respectively. So even the same magnitude of shift, the portal dosimetry could find more point of disagreement for original plan and the modified plans. That was the reason the portal doismetry system can detect the small magnitude of error than the two other QA devices.

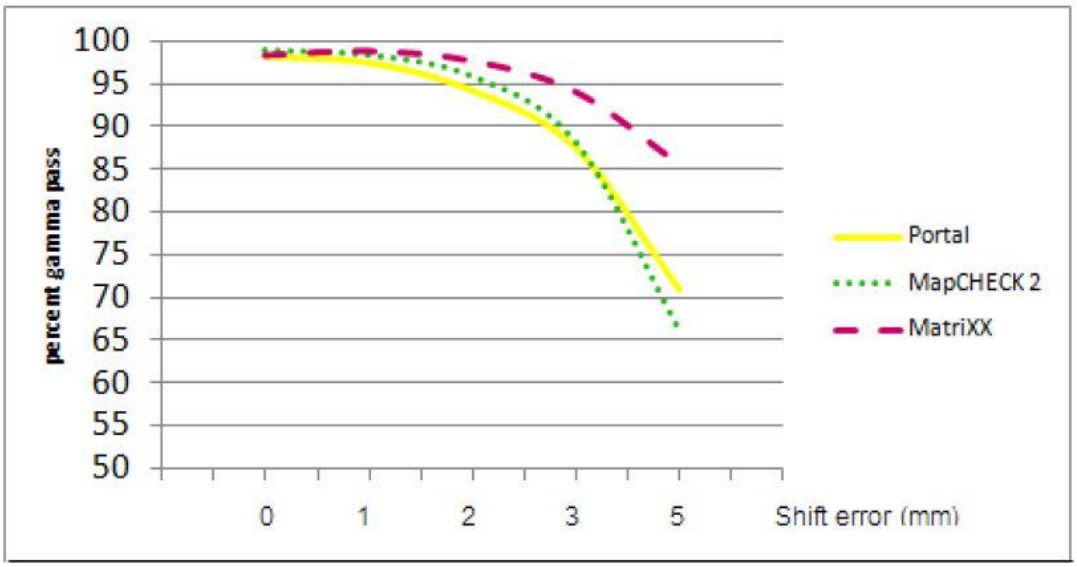


Figure 5. 1 The comparison of percent gamma pass result of three QA devices measured in the plan with position shift error

5.1.3 Prescribed Dose Error Detection by Three Devices

The prescribed dose error measurements were performed by increasing or decreasing the dose from 2% to 6%. The measurements were repeated for all the devices. The results were not evidently different for the error detection of all devices. These attributes to the response of the dose of all detectors were not differences significantly. The portal dosimetry could detect the 2% increasing dose error in the head and neck plan and the other two devices could detect 4% dose error. In the prostate plan the portal dosimetry system and MapCHECK 2 system could detect the 4% dose error and the MatriXX system could detect 6% dose error. And the gamma passing rate of three devices showed not significantly drop like in the position shift error plan.

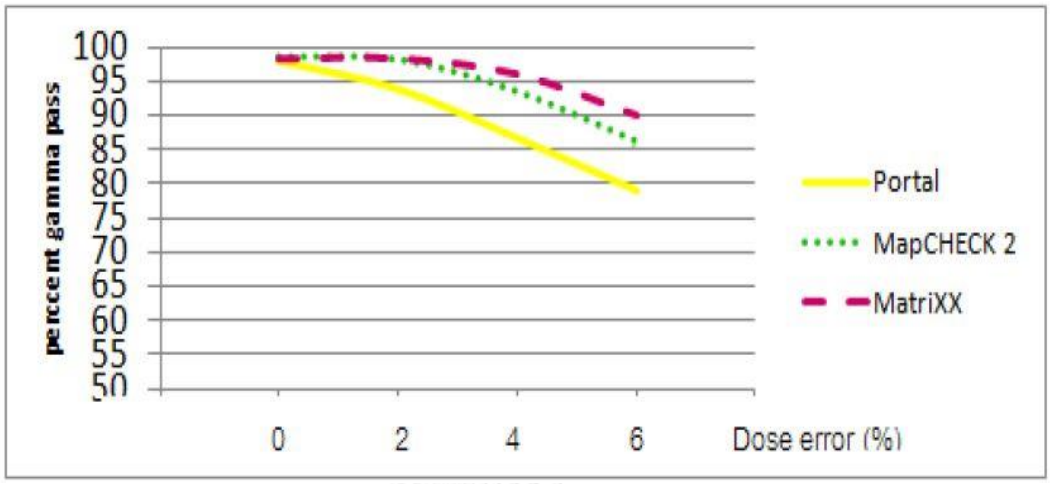


Figure 5. 2 The comparison of percent gamma pass result of three QA devices measured in the plan with dose increasing

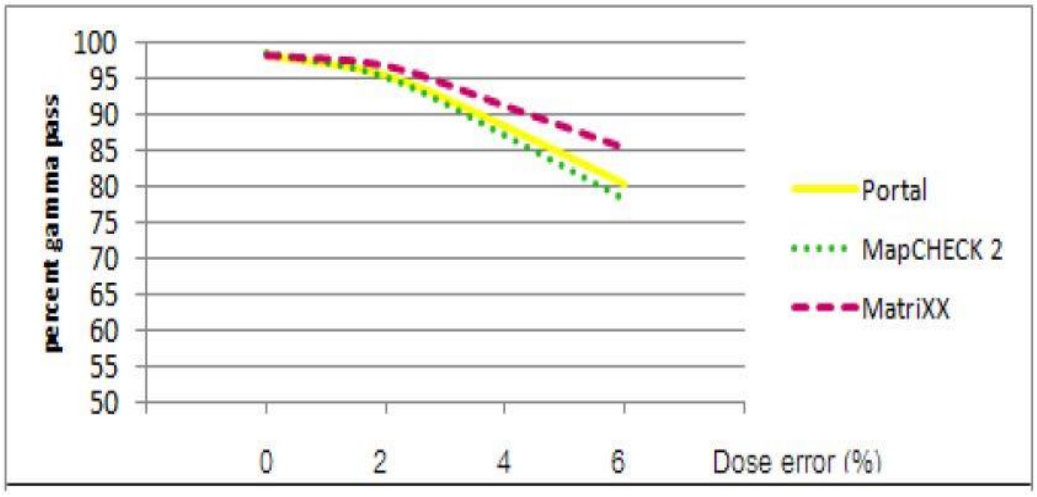


Figure 5. 3 The comparison of percent gamma pass result of three QA devices measured in the plan with dose decreasing

When the introducing error was increase the percent gamma was decreased and it is shown in figure 5.2 and 5.3. The higher decreasing of result was seen in the portal dosimetry system which had 94, 86.7 and 78.9 for the 2%, 4% and 6% dose errors respectively. The results of MapCHECK2 system were 98.4, 93.6 and 86.1 and the results of MatirXX were 98.4, 96.1 and 90.2. So the portal dosimetry had a good trend of percent gamma pass result for the increasing error magnitude than the other two devices. The result for the decreasing dose error showed same trend as the increasing dose error. As the error magnitude was increased, the portal dosimetry system reacted evidently with the rapid change of the percent gamma pass.

The introduced prescribed dose was distributed over all the area of the fluence rather than at a single point. Even the measurement over the entire fluence map was same for all devices but fine resolution point could meet all deviation of dose from original plan and modified plans. Once the error was introduced (2%, 4% and 6% prescribed dose increasing or decreasing) the fine detection point of the portal dosimetry system could show more deviation of the fulence from the original plan rather than MapCHECK2 system and MatriXX system. So even the same magnitude of dose change, the portal dosimetry could find more point of disagreement for original plan and the modified plans. That was the reason the portal doismetry system can detect the small magnitude of error than the two other QA devices.

5.2 Conclusion

The error detection of three devices indicated different results for dose and the position shift error. The error detection by the three devices is summarized in the table 5.2.

Table 5. 2 Smallest error detection by portal dosimetry, MapCHECK 2 and MatriXX system

	Error Detection	
	Position Shift Error	Prescribed Dose Error
Portal Dosimetry	1mm (H&N) 2mm (Prostate)	2% (H&N) 4% (Prostate)
MapCHECK 2	2mm (H&N) 3mm (Prostate)	4% (H&N) 4% (Prostate)
MatriXX	3mm (H&N) 5mm (Prostate)	4% (H&N) 6% (Prostate)

The portal dosimetry system is the higher sensitivity to detect in both position shift and prescribed dose error than the two other devices. The reason is that the portal dosimetry has the fine resolution of detector than the two other devices. Error detection in the different plan also gives rise to the different results. From this result we can notice that position shift error effect more in the head and neck plan than the prostate plan because the tumor shape in head and neck region is irregular than the prostate plan. The prescribed dose error detection are comparable in all devices except 2% dose error of the head and neck plan measured by the portal dosimetry system.

Improvement in the ability of devices to detect the errors can be observed when using 2%/2 mm criteria. But in the clinical IMRT QA verification 2%/2 mm criterion is not suitable to use because of the very low gamma pass result are obtained by this criterion.

All the devices performed well in terms of error detection. The sensitivity of error detection depends on the detector resolution, type of errors, plan complexity and also gamma criteria used to analyze. Various type of detector can detect various kinds of errors but some errors cannot be observed by using these systems. However, each device has their own properties to detect different kind of errors. Every device has advantages and disadvantages upon their usage. In conclusion the devices employed in this study can be used widely in the clinical field as a patient specific QA device and can detect the various kinds of errors according to their efficiency.

REFERENCES

1. Jonathan G Li et al. Comparison of two commercial detector arrays for IMRT quality assurance. Journal of Applied Clinical Medical Physics Vol. 10, No. 2, Spring 2009:62-74

2. Guangjun Li et al. Evaluation of the sensitivity of two 3D diode array dosimetry systems to setup error for quality assurance (QA) of volumetric-modulated arc therapy (VMAT). Journal of Applied Clinical Medical Physics Vol. 14, No. 5, 2013:13-24

3. Anna Fredh et al. Patient QA systems for rotational radiation therapy: A comparative experimental study with intentional errors. Med. Phys. Vol. 40, No. 3, March 2013:031716-9

4. Jayesh Kunnanchath et al. Influence of different parameters on the optimization of IMRT patient specific QA. Transworld Medical Journal. Vol. 2, No.4:187-192

5. Nzhde Agazaryan et al. Patient specific quality assurance for the delivery of intensity modulated radiotherapy. Journal of Applied Clinical Medical Physics, Vol. 4, No. 1, winter 2003:40-50

6. Gordon M et al. Comparison of action levels for patient-specific quality assurance of intensity modulated radiation therapy and volumetric modulated arc therapy treatments. Med. Phys. Vol. 39, No. 7, July 2012:4378-4385

7. Omemh Bawazeer et al. Evaluation of the ability of a 2D ionization chamber array and an EPID to detect systematic delivery errors in IMRT plans. Journal of Physics: Conference Series 489 (2014):012071

8. Jean M. Moran et al. A dose-gradient analysis tool for IMRT QA Journal of Applied Clinical Medical Physics Vol. 6, No. 2, 2005:62-73

9. Guang-hua Jin et al. Gantry angle-dependent correction of dose detection error due to panel position displacement in IMRT dose verification using EPIDs. Physica Medica 30 (2014):209-214

10. Guanghua Yan et al. On the sensitivity of patient-specific IMRT QA to MLC positioning errors. Journal of Applied Clinical Medical Physics, Vol. 10, No. 1, Winter 2009:120-128

11. Daniel A. Low et al. Dosimetry tools and techniques for IMRT. Medical Physics, Vol. 38, No. 3, March 2011:1313-1338

12. Benjamin E. Nelms et al. Evaluation of fast method of EPID-based dosimetry for intensity modulated radiation therapy. Journal of Applied Clinical Medical Physics, Vol. 11, No. 2, Spring 2010: 140-157

13. Sotirios Stathakis et al. Characterization of a novel 2D array dosimeter for patient specific quality assurance with volumetric arc therapy. Medical Physics, Vol. 40, No. 7, July 2013:071731

14. A Taylor and M E B Powell. Intensity modulated radiotherapy- what it is? 2004, International Cancer Imaging Society, (2004)4, 68-73

15. L N McDermott, J-J Sonke, M Wendling, M B van Herk, B J Mijnheer, M Lööf, H Nyström and M Partridge, A comparison of ghosting effects for two commercial a-Si EPIDs, in: EPI 2004 Abstract book and Programme, 8th International Workshop on Electronic Portal Imaging, Brighton, U.K., 2004

16. Peter Winkler et al. Dose-response characteristics of amorphous silicon EPID. Medical Physics, Vol. 32, No. 10, October 2005:3095-105

17. Khan FM.*Physics of Radiation Therapy*. Lippincott Williams & Wilkins, 2003, third edition.

18. Sathiyan Saminathan et al. Dosimetric study of 2D ion chamber array matrix for the modern radiotherapy treatment verification, Journal of Applied Clinical Medical Physics, Vol. 11, No. 2, Spring 2010:116-127

19. Daniel A. Low et al. A technique for the quantitative evaluation of dose distributions. Medical Physics, Vol. 25, No. 5, May 1998:656-661

20. J. Van Dyk et al. Commissioning and quality assurance of treatment planning computers. Journal of Radiation Oncology Biology Physics, Vol. 26, No. 2, 1993:261–273

21. Jaeman Son et al. A comparison of the quality assurance of four dosimetric tools for intensity modulated radiation therapy. Radiology Oncology, Vol. 49, No. 3, 2015:307-313

22. I'mRT MatriXX User Manual. Schwarzenbruck, Germany: Scanditronix Wellhofer; 2006

APPENDIX

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