การตรวจสอบการวางแผนการรักษาในเทคนิคการฉายรังสีแบบปรับความเข้ม และการฉายรังสีแบบปรับความเข้มรอบตัวผู้ป่วยด้วยเครื่องมือวัดรังสีชนิดไดโอดแบบ 2 มิติ และแบบ 3 มิติ

นางสาวคณนันท์ อุทิตสาร

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Dosimetric verification of 2D planar diode arrays and 3D cylindrical diode arrays in intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT)

Miss Kananan Utitsarn

A Thesis Submitted in Partial Fulfillment of the Requirements

for the Degree of Master of Science Program in Medical Imaging

Department of Radiology

Faculty of Medicine

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Thesis Title	Dosimetric verification of 2D planar diode arrays and 3D cylindrical diode arrays in intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT)
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Field of Study	Medical Imaging
Thesis Advisor	Associate Professor Sivalee Suriyapee, M.Eng.

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คณนันท์ อุทิตสาร: การตรวจสอบการวางแผนการรักษาในเทคนิคการฉายรังสีแบบปรับความเข้ม และการฉายรังสีแบบปรับความเข้มรอบตัวผู้ป่วยด้วยเครื่องมือวัดรังสีชนิดไดโอดแบบ 2 มิติ และแบบ 3 มิติ (Dosimetric verification of 2D planar diode arrays and 3D cylindrical diode arrays in IMRT and VMAT) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ.ศิวลี สุริยาปี, 69 หน้า.

การตรวจสอบปริมาณรังสีในเทคนิคการฉายรังสีแบบปรับความเข้ม และการฉายรังสีแบบปรับความเข้มรอบตัวผู้ป่วยก่อนการฉายรังสีแก่ผู้ป่วยมีความสำคัญ เนื่องจากเทคนิคการฉายรังสีทั้งสองมีความซับซ้อนของการให้รังสีแก่ผู้ป่วย จุดประสงค์ของงานวิจัยนี้เพื่อศึกษาคุณลักษณะของเครื่องมือวัดรังสีชนิดไดโอดแบบ 2 มิติ และแบบ 3 มิติ ในการตรวจสอบปริมาณรังสีในทั้ง 2 เทคนิคของการฉายรังสี งานวิจัยนี้ศึกษาคุณสมบัติของเครื่องวัดรังสี MapCHECKและArcCHECK และตรวจสอบแผนการรักษาผู้ป่วยมะเร็งบริเวณศีรษะและลำคอ จำนวน 15 แผนการรักษา ในเทคนิคการฉายรังสีแบบปรับความเข้ม และการฉายรังสีแบบปรับความเข้มรอบตัวผู้ป่วย ปริมาณรังสีที่วัดได้จะเทียบกับการคำนวณจาก Eclipse treatment planning กำหนดค่าดัชนีแกมมาที่ 3%/3 มิลลิเมตร 10% threshold เครื่องวัดรังสี MapCHECK และ ArcCHECK มีการตอบสนองต่อปริมาณรังสีสัมพันธ์เป็นเส้นตรง และมีความแม่นยำในการวัดรังสีในระยะเวลาสั้นอยู่ในช่วง ± 0.2% และระยะยาวอยู่ในช่วง ±1% ใน MapCHECK และ ±2% ใน ArcCHECK เมื่อทำการเปลี่ยนค่าปริมาณรังสีต่อหน่วยเวลาพบว่าอยู่ในช่วง ±0.25% ถ้าเปลี่ยนอัตราปริมาณรังสีพบว่ามีค่าอยู่ในช่วง ±1% และ เมื่อปรับขนาดลำรังสีพบว่ามีค่าอยู่ในช่วงเดียวกับหัววัดชนิดไอออนไนเซชั่น ในทั้งสองเครื่องมือวัดรังสี การตอบสนองของไดโอดที่พลังงาน 6 และ 10 เมกะโวลต์มีค่าอยู่ในช่วง ±4% สำหรับ MapCHECK และ ±2% สำหรับ ArcCHECK โพรไฟล์ที่ได้จากไดโอดทั้งสองชนิดทั้งจากลำรังสีปกติและลำรังสีผ่านแผ่นกรองรูปลิ่มเทียบกับการคำนวณพบว่าอยู่ในเกณฑ์ดี การตรวจสอบแผนการรักษาเทียบกับปริมาณรังสีจากการคำนวณในเทคนิคการฉายรังสีแบบปรับความเข้ม พบว่าค่า % pass เฉลี่ย ของ MapCHECK คือ 97.31 โดยมีค่าเฉลี่ย γ คือ 0.45 จำนวนไดโอดเฉลี่ยของ MapCHECK คือ 344.80, ในขณะที่ % pass เฉลี่ย ของ ArcCHECK คือ 97.21 โดยมีค่าเฉลี่ย γ คือ 0.46 จำนวนไดโอดเฉลี่ยของ ArcCHECK คือ 1049.31 ในเทคนิคการฉายรังสีแบบปรับความเข้มรอบตัวผู้ป่วย พบว่ามีค่า % pass เฉลี่ย ของ MapCHECK คือ 98.55 โดยมีค่าเฉลี่ย γ คือ 0.37 จำนวนไดโอดเฉลี่ยของ MapCHECK คือ 410, ในขณะที่ % pass เฉลี่ย ของ ArcCHECK คือ 97.04 โดยมีค่าเฉลี่ย γ คือ 0.43 จำนวนไดโอดเฉลี่ยของ ArcCHECKคือ1054 จำนวนไดโอดเฉลี่ยของ ArcCHECK มากกว่า MapCHECK ทำให้การวัดรังสีเกิดการแตกต่าง และลักษณะราบของ MapCHECK ทำให้ไม่สามารถวัดปริมาณรังสีบริเวณที่มีความแตกต่างของปริมาณรังสีสูงในบางตำแหน่งได้ ในขณะที่ ArcCHECK มีลักษณะทรงกระบอกซึ่งสามารถวัดปริมาณรังสีได้ทุกมุมการหมุนของเครื่องฉายรังสี จึงทำให้เกิดการแตกต่างของการวัดปริมาณรังสี เครื่องมือวัดรังสีทั้งสองมีคุณสมบัติที่ดีในการใช้เพื่อตรวจสอบแผนการรักษา ในเทคนิคการฉายรังสีแบบปรับความเข้ม และการฉายรังสีแบบปรับความเข้มรอบตัวผู้ป่วย อย่างไรก็ตามควรศึกษาคุณลักษณะก่อนการใช้งาน

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##5374612030: MAJOR MEDICAL IMAGING
KEYWORDS: IMRT/VMAT/MAPCHECK/ARCCHECK/QA

KANANAN UTITSARN: DOSIMETRIC VERIFICATION USING 2D PLANAR DIODE ARRAYS and 3D CYLINDRICAL DIODE ARRAYS in IMRT and VMAT. ADVISOR: ASSOCIATE PROFESSOR SIVALEE SURIYAPEE, 69pp.

Dosimetric verification of intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) before treatment is necessary due to the complexity of delivery beams. This work aims to evaluate the performance of 2D planar and 3D cylindrical diode arrays for patient specific QA in IMRT and VMAT. MapCHECK and ArcCHECK were studied for their properties before clinical use. The clinical performance was demonstrated with IMRT and VMAT plans, the measured results were compared with the calculation from Eclipse treatment planning. The γ index of 3% /3mm with 10% threshold dose were the criteria of agreement between measured and calculated.MapCHECK and ArcCHECK showed linearly dose response and demonstrated a short term reproducibility within ±0.02 and long term reproducibility within ±1% for MapCHECK and ±2% for ArcCHECK. The repeatability rate effect was within ±0.25% and the dose rate response was within ±1% for both detectors. The field size dependence was close to ionization chamber response. The variation in energy response was within ±4% for MapCHECK and ±2% for ArcCHECK. The beam profile of open and 30° of hard and enhance dynamic wedge showed good agreement with calculated dose. Both detectors illustrated the excellent passing rates for all 15 IMRT and VMAT plans. For IMRT, The average of the % pass of MapCHECK was 97.31 with the mean γ of 0.45. The average number of detector was 344.80, while the average of the % pass of ArcCHECK was 97.21 with the mean γ of 0.46. The average number of detector was 1049.31. For VMAT, The average of the % pass of MapCHECK was 98.55 with the mean γ of 0.37. The average number of detector was 410, while the average of the % pass of ArcCHECK was 97.04 with the mean γ of 0.43. The average number of detector was 1054. The more detectors of ArcCHECK than MapCHECK make more dose measurement points that increase the chance of dose difference. In addition, MapCHECK is a planar geometry which cannot detect high dose gradient in the sensitive area in some gantry angle, while ArcCHECK is a cylindrical geometry which can measure dose distribution for all gantry angles, so less point missing attributed to more dose difference. Both detectors have excellent performance for IMRT and VMAT verification, however, the characteristics of the devices should be studied before clinical used.

Department: ......Radiology........................Student's Signature...Kannan...

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LIST OF ABBREVIATIONS

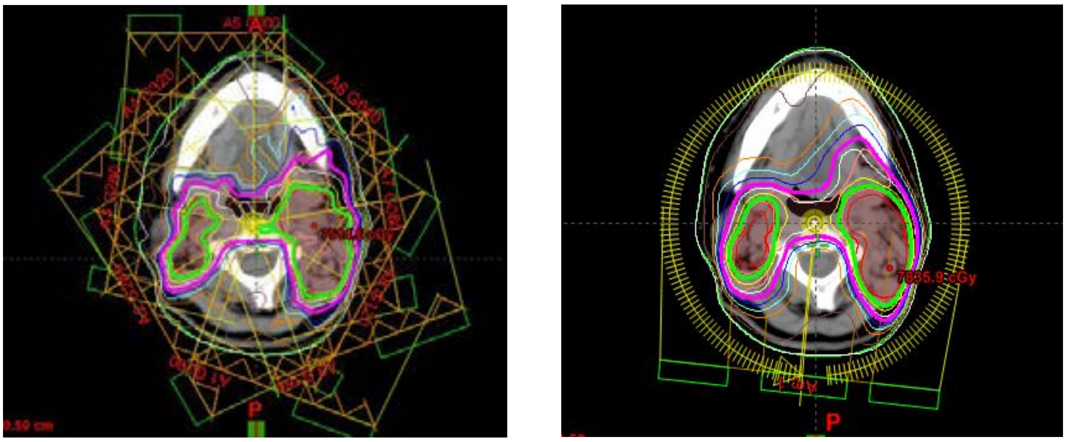
ABBREVIATION	TERMS
2D	Two-Dimension
3D	Three-Dimension
AAA	Analytical and Isotopic Algorithm
AAPM	American Association of Physicists in Medicine
ACR	American College of Radiology
ASTRO	American Society for Radiation Oncology
cGy	Centigray
cm	Centimeter
COV	Coefficients of Variation
CT	Computed Tomography
DRR	Digital Reconstructed Radiograph
DTA	Distance to Agreement
DVH	Dose Volume Histogram
eV	Electron Volt
IC	Ionization Chamber
ICRU	International Commission on Radiation Units
IMRT	Intensity Modulated Radiotherapy
LINAC	Linear Accelerator
MeV	Mega Electron Volt
MLC	Multileaf Collimator
mm	Millimeter
MRI	Magnetic Resonance Imaging
MU	Monitor Unit
MV	Megavoltage
QA	Quality Assurance
SAD	Source to Axis Distance
SD	Standard Deviation
SSD	Source to Surface Distance
TLD	Thermoluminescent Dosimeter
TPS	Treatment Planning System
VMAT	Volumetric modulated Arc Therapy

CHAPTER I

INTRODUCTION

1.1 Background and Rationale

The desire to improve local tumors control and cure more cancer patients, coupled with advances in computer technology and linear accelerator (LINAC) design, has spurred the developments of intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) techniques. The treatment plans of IMRT and VMAT are shown in figure 1.1. IMRT technique is the process of delivering the highly conformal dose distribution using nonstandard field shapes and sizes, overlapping and abutting fields with computer aided optimization to achieve superior dose distribution. Because of capability in manipulating the intensity of individual rays within each beam, IMRT allows greater control of dose distributions. VMAT technique establishes new standards for radiation therapy treatment speed and dose reduction to the patient. VMAT delivers radiation by rotating the gantry of a LINAC through one or more arcs with the radiation continuously on. As it does so, a number of parameters can be varied. The gantry rotation speed, leaf translation speed, and dose rate maximum could be varied but do not excessively limit the delivery efficiency while multileaf collimator (MLC) leaf motion and number of monitor unit (MU) per degree of gantry rotation are restricted during the optimization [1].



a) IMRT b) VMAT

Figure 1.1 Dose distributions in a) IMRT and b) VMAT techniques

IMRT and VMAT are inverse treatment planning which makes use of dose optimization techniques to satisfy the user specified criteria for the dose to the target and critical structures. Radiation treatment planning for both techniques, IMRT and VMAT, require the calculation for a set of parameters for the delivery of a certain radiation dose to the patient in term of intensity map. An intensity map is a matrix of pencil beams with different weights and different intensity levels. It reflects the sculpted desired dose for each field and their combination. The initial continuous map is transformed into segments with different intensity levels. That is the basis of MLC segments. Ideally, radiation dose distribution should be designed to conform perfectly to the entire tumor volume while completely avoiding surrounding normal tissues [2].

The dosimetric verification of IMRT and VMAT before treatment is necessary due to the complexity of delivery beams**.** To ensure that the intensity map pattern matches that intended by the treatment planning system and that the MU specified by the treatment planning system will in fact deliver the intended dose.

In addition, patient planning parameters and MLC movement should be verified. As part of the process, one should scan the dose measurement device, transfer it to the planning computer, generate inverse plans, pass the treatment data to the record and verification system, schedule this dose measurement device for treatment, and finally deliver the treatment plan for the test dose measurement device in full clinical mode [3]. So the dose measurement device is treated in the same parameters of beam energy, field size, dose, dose rate, MLC setting and MU as the patient and then compare with the calculated dose For The dose measurement device, two dimensional (2D) detector arrays have become increasingly popular due to their ease of use and immediate readout of the results for dose verification. A planar dose at a certain depth can be extracted from the treatment planning system (TPS) and compared with measurement using 2D detector arrays in the same geometry at the depth of interest [4]. The newly available 3 dimensional (3D) cylindrical detector array device was designed specifically for rotational dosimetry by arranging detector on a cylindrical planeA cylindrical array display beam eye view dose distribution throughout the entire rotational delivery [5]. The 2D and cylindrical diode arrays from Sun nuclear co., MapCHECK and ArcCHECK, are the example of dosimetric verification tools for IMRT and VMAT as shown in figure 1.2.

a) b)

Figure 1.2 a) MapCHECK and b) ArcCHECK

MapCHECK and ArcCHECK have been studied in some detail but no direct comparison between the two kinds of detector arrays was made under the same conditions. This work aim to study the performance of 2 types of diode arrays detector: MapCHECK and ArcCHECK. The linearity of detector response, short term and long-term reproducibility, dose rate response, repeatability rate effect, field size effect and energy response will be examined. The efficiency to measure dose distributions with conventional technique and advanced technique, IMRT and VMAT techniques, of both detector arrays will be evaluated by comparing the measurement with the treatment planning system.

Comparisons of measured and calculated dose distributions for two techniques are evaluated by the gamma evaluation. The criterion for acceptable calculation performance is generally defined as a tolerance of the dose and distance to agreement (DTA) in regions of low and high dose gradients. The gamma evaluation of 3% dose difference and 3 mm DTA are the criteria of agreement between measured and calculated dose. The minimum radial distance between the measurement point and the calculation points is termed the gamma index. Regions where gamma is more than 1 correspond to locations where the calculation does not meet the acceptance criteria [6]. The determination of gamma throughout the measured dose distribution provides a presentation that quantitatively indicates the calculation accuracy. The percent passed and average gamma value will be analyzed for the suitable of detector to the treatment techniques.

Patients’ cases of IMRT and VMAT plan verification which were measured by MapCHECK and ArcCHECK and compared with the calculation from treatment planning were demonstrated by focusing on the fluence map, the absolute dose distribution, beam profile and gamma value. The percent pass of the diodes agreement with calculation from the treatment planning of more than 95% was set to be an acceptable criteria for IMRT/VMAT verification [7].

1.2 Research Objectives

To evaluate the difference of dosimetric verification result in patient planning using 2D planar diode arrays and 3D cylindrical diode arrays in IMRT and VMAT.

CHAPTER II

LITERATURE REVIEWS

2.1 Theories

2.1.1 Intensity modulated radiation therapy [8]

IMRT is an advanced mode of high precision radiotherapy that utilizes computer-controlled linear accelerators to deliver precise radiation doses to a malignant tumor or specific areas within the tumor. IMRT allows for the radiation dose to conform more precisely to the three dimensional shape of the tumor by modulating or controlling the intensity of the radiation beam in multiple small volumes. IMRT also allows higher radiation doses to be focused to regions within the tumor while minimizing the dose to surrounding normal critical structures. Treatment is carefully planned by using 3D computed tomography (CT) or magnetic resonance (MRI) images of the patient in conjunction with computerized dose calculations to determine the dose intensity pattern that will best conform to the tumor shape. Typically, combinations of multiple intensity-modulated fields coming from different beam directions produce a custom tailored radiation dose that maximizes tumor dose while also minimizing the dose to adjacent normal tissues. The treatment plan of IMRT is shown in Figure 2.1.

Because the ratio of normal tissue dose to tumor dose is reduced to a minimum with the IMRT approach, higher and more effective radiation doses can safely be delivered to tumors with fewer side effects compared with conventional radiotherapy techniques. IMRT also has the potential to reduce treatment toxicity, even when doses are not increased. Due to its complexity, IMRT does require slightly longer daily treatment times and additional planning and safety checks before the patient can start the treatment.

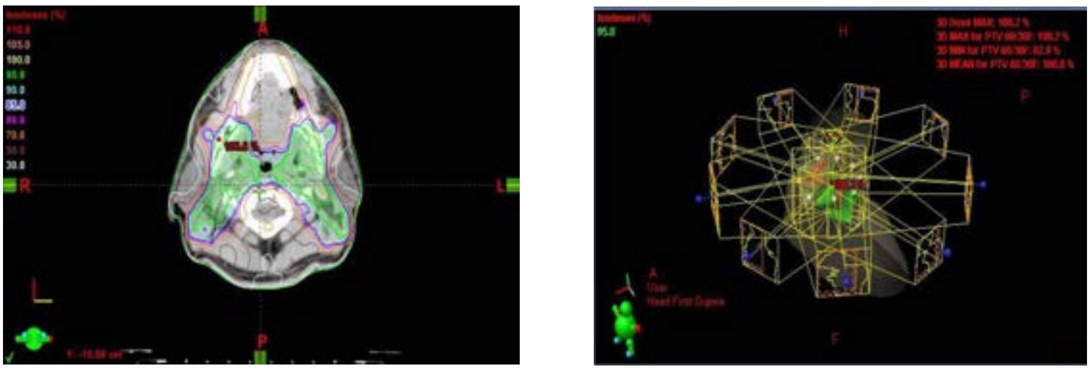


Figure 2.1 Treatments planning of IMRT

2.1.2 Volumetric modulated radiotherapy [9]

VMAT delivers radiation by rotating the gantry of a LINAC through one or more arcs with the radiation continuously on. As it does so, a number of parameters can be varied. These include: MLC aperture shape, the fluence output rate, the gantry rotation speed and the MLC orientation. It is undisputed that VMAT can deliver highly conformal dose distributions similar to those created by other forms of IMRT. As such, it becomes a valued member of the IMRT delivery arsenal. The treatment plan of VMAT is shown in Figure 2.2. VMAT most operate by creating some form of fixed-field modulated beams, decomposing these into MLC components, redistributing those over small arcs and re-optimizing the outcome. In doing so, VMAT can take advantage of the above mentioned four variable parameters, but must do so while respecting the physical constraints of the LINAC and MLC such as the maximum gantry speed, maximum leaf speed, the MLC orientation constraints and the available subdivisions of fluence output rate.

Provided that the gantry speed can be varied continuously, it does not require a continuous variation of fluence output rate to obtain a continuous variability of fluence output rate per degree. The minimum fluence output rate and the maximum gantry speed determine the constraining minimum fluence output rate per degree. Where there is a maximum fluence output rate and minimum gantry speed, there will be a constraining maximum fluence output rate per degree. VMAT can generate equivalently conformal dose distributions with fewer MU in a faster time. To have that is clearly advantageous these include: shorter treatments; better for patients in discomfort; less susceptibility to intra fraction motion; possibly less induced secondary cancers; quicker overall treatment slots.

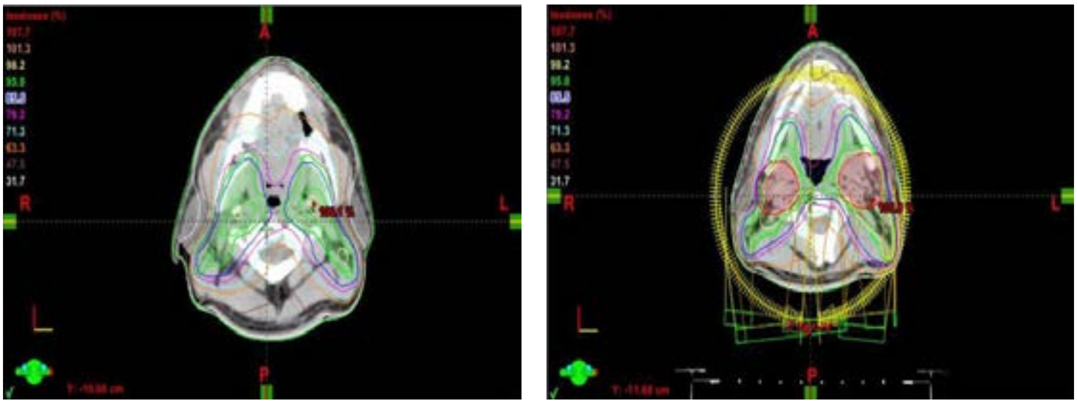


Figure 2.2 Treatment planning of VMAT

2.1.3 Treatment planning [10]

Computerized TPS are used in external beam radiotherapy to generate beam shape and dose distributions with the intent to maximize tumor control and minimize normal tissue complications. Patient anatomy and tumor targets can be represented as 3D models. The medical physicist is responsible for the overall integrity of the computerized TPS to accurately and reliably produce dose distributions and associated calculations for external beam radiotherapy. The simultaneous development of CT, along with the advent of readily accessible computing power, led to the development of CT based computerized treatment planning, providing the ability to view dose distributions directly superimposed upon a patient's axial anatomy. The entire treatment planning process involves many steps, beginning from beam data acquisition and entry into the computerized TPS, through patient data acquisition, to treatment plan generation and the final transfer of data to the treatment machine.

2.1.3.1 Inverse treatment planning [11]

Traditional forward based treatment planning, which is based on a trial and error approach by experienced professionals, is giving way to inverse planning, which makes use of dose optimization techniques to satisfy the user specified criteria for the dose to the target and critical structures. Dose optimization is possible by making use of dose volume histograms (DVH) based on CT, MRI or other digital imaging techniques. These optimized plans make use of IMRT and VMAT to deliver the required dose to the target organ while respecting dose constraint criteria for critical organs.

In IMRT and VMAT, the objective function is a function of the beamlet weights. The number of beamlet for a given case varies from a few hundred to several thousands, depending on the tumor size and beamlet size. A given objective function can be optimized using many different optimization algorithms, such as iterative methods, simulated annealing, filtered back projection, genetic algorithm, maximum likelihood approach, linear programming, etc. For all their complexity, the algorithms to optimize a multidimensional function are routine mathematical procedures. An iterative method is a widely used technique to optimize a multidimensional objective function by starting with an initial approximate solution and generating a sequence of solutions that converge to the optimal solution of the system. In addition to the prescription doses, the current planning system requires the user to pre-select the angular variables (gantry, couch, and collimator angles) and the relative importance factors of the involved structures. These variables and parameters constitute an additional multi-dimensional space, which is coupled to the beam profiles in complicated fashion.

2.1.4 Treatment planning verification [3]

The goal of radiation therapy is to achieve the greatest possible local and regional tumor control. To minimize the variability of tissue response, the ICRU has recommended that the uncertainty in dose delivery be maintained below approximately 5%. During radiation delivery for IMRT and VMAT techniques the MLC leaves are moving so the dosimetric verification of IMRT and VMAT before treatment is necessary due to the complexity of delivery beams**.** To ensure that the intensity map pattern matches that intended by the treatment planning system and that the MUs specified by the treatment planning system will in fact deliver the intended dose.

2.1.4.1 Patient specific dose verification [12]

The ASTRO/ACR guidelines for treatment delivery specify "the dose delivery must be documented for each course of treatment by irradiating a phantom that contains either calibrated film to sample the dose distribution, or an equivalent measurement system to verify that the dose delivered is the dose planned." This guideline implies that each and every plan must be verified by measuring the dose delivered. There are several techniques available to accomplish this task, including point dose, 2D dose measurements for individual fields and for all fields and 3D dose measurement.

2.1.4.1.1 Point dose measurements for a single field can be measured using ion chamber, or diodes. Ion chamber measurements in a phantom are generally acquired at a single specified point such as the isocenter. Diode measurements can be done directly on the patient, as is common in external beam treatment. One must be careful when measuring the dose for a single field since high dose gradients may exist.

2.1.4.1.2 Point dose measurement for all fields. The measurement determines the dose at point other than the location where the dose was prescribed. An ion chamber may be used for point dose measurement.

2.1.4.1.3 2D dose measurement for a single field. In the individual beam, the relative dose distribution is measured on a plane perpendicular to the central axis of each beam in flat measurement devices. Dose is computed at a specified depth in the phantom. It may be measured using film or an array of diode e.g. MapCHECK. Dose profiles or isodose lines may be compared quantitatively using specialized software to scan and analyze the film.

2.1.4.1.4 2D dose measurement for multiple fields. Integrated dosimetry consists of measuring the relative composite dose distribution in one or more selected planes of a measurement device. The integrated dose approach provides direct information on the composite dose distribution and is more efficient. On the other hand, the individual beam approach allows for a more comprehensive analysis and can lead to a better understanding of the sources of error in the planning and delivery process.These are typically measured using film or an array of diode e.g. MapCHECK. Dose profiles or isodose lines may be compared to the treatment plan, which is shown in figure 2.3

2.1.4.1.5 3D dose measurement. The pretreatment verification should be performed in arc mode due to its associated time-varying parameters. An ideal dose measurement device for dosimetric verification under these situations would be an isotropic detector having minimal energy dependence and capable of sampling absolute dose distribution in full three-dimensional space. At the end of measurement, time-resolved beam dosimetry should be available for off-line analysis to identify potential source of errors in the planning and delivery stage. These 3D dose measurement may be measured using film or a cylindrical array of diode e.g. ArcCHECK by rotating the gantry. Dose is computed at a specified depth in the phantom. Dose profiles or isodose lines may be compared quantitatively using specialized software and compared to the treatment plan, which is shown in figure 2.4

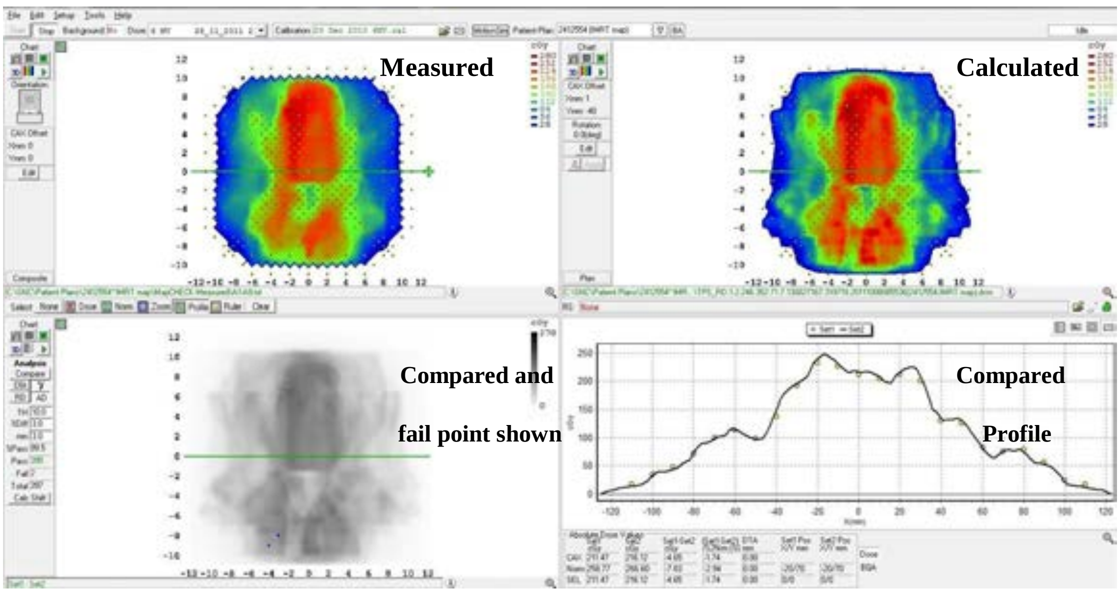


Figure 2.3 2D dose measurements for multiple fields

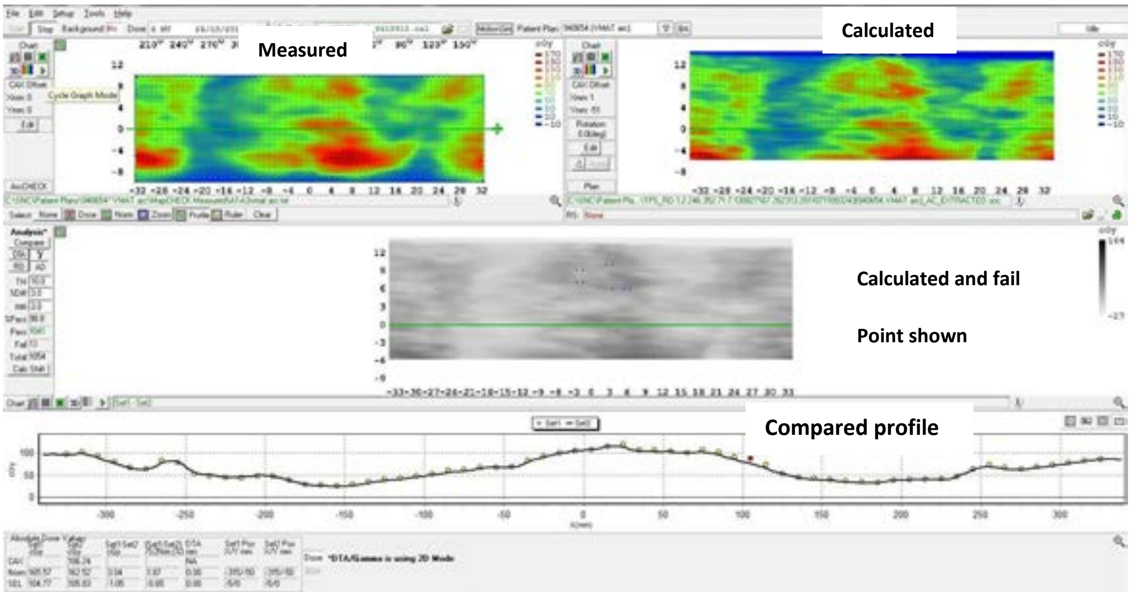


Figure 2.4 3D dose measurements

2.1.5 Silicon diode [1]

Silicon p-n junction diodes are often used for relative dosimetry. Their higher sensitivity, instantaneous response, small size and ruggedness offer special advantages over ionization chamber. They are particularly well suited for relative measurements in electron beams, output constancy checks and in vivo patient dose monitoring. Their major limitations as dosimeters include energy dependence in photon beams, directional dependence, thermal effects, and radiation induced damage. Modern diodes for dosimetry have been designed to minimize these effects.

2.1.5.1 Theory

A dosimetry diode consists of a silicon crystal which is mixed or doped with impurities to make p- and n-type silicon. The p-type silicon is made by introducing a small amount of an element from group III of the periodic table (e.g., boron), making it into an electron receptor. When silicon is mixed with a material from group V (e.g., phosphorus) it receives atoms that are carriers of negative charge, thus making it into an electron donor or n –type silicon. A p-n junction diode is designed with one part of a p-silicon disc doped with an n-type material. The p-region of the diode is deficient in electrons while the n-region has an excess of electrons. The p- and n- type silicon diode are shown in figure 2.5.

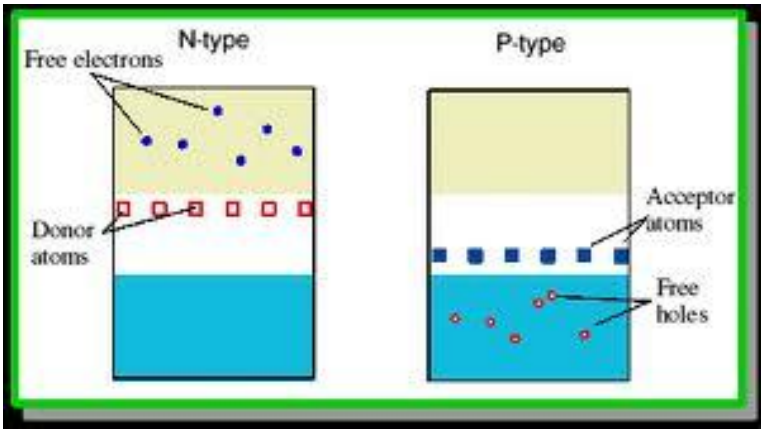


Figure 2.5 The n- and p- type silicon diode

At the interface between p- and n-type materials, a small region called the depletion zone is created because of initial diffusions of electrons from the n-region and holes from the p-region across the junction, until equilibrium is established. The depletion zone develops an electric field which opposes further diffusion of majority carriers once equilibrium has been achieved. When a diode is irradiated electron-hole pairs are produced within the depletion zone. They are immediately separated and swept out by the existing electric field in the depletion zone. This gives rise to radiation induced outside the depletion zone within a diffusion length. The direction of electronic current flow is from the n-to the p-region) Diodes are far more sensitive than ion chambers. Since the energy required producing an electron-hole pair in Si is 3.5eV compared to 34eV required to produce an ion pair in air and because the density of Si is 1800 times that of air, the current produced per unit volume is about 18000 times larger in a diode than in an ion chamber. Thus, a diode, even with a small collecting volume, can provide an adequate signal.

2.1.5.2 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 (59), 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 change significantly, for example, profile measurements in small fields, dose constancy checks. In electron beams, however, the diodes do not show energy dependence as the stopping power ratio of silicon to water does not vary significantly with electron energy or depth. Thus diodes are qualitatively similar to films so far as their energy dependence is concerned. Some diodes exhibit greater stability and less energy dependence than others. It is therefore incumbent upon the user to establish dosimetric accuracy of a diode by comparative measurements with an ion chamber.

2.1.5.3 Angular dependence

Diodes exhibit angular dependence, which must be taken into account if the angle of beam incidence is changed significantly. Again these effects should be ascertained in comparative measurements with a detector which does not show angular dependence.

2.1.5.4 Temperature dependence

Diodes show a small temperature dependence that may by 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. Moreover, their response is independent of pressure and humidity.

2.1.5.5 Radiation damage

A diode can suffer permanent damage when irradiated by ultrahigh doses of ionizing radiation. The damage is most probably caused by displacement of silicon atoms from their lattice positions. The extent of damage will depend upon the type of radiation, energy and total dose. Because of the possible of radiation damage, especially after prolonged use, diode sensitivity should be checked routinely to assure stability and accuracy of calibration.

2.1.5.6 Clinical applications

Diodes are becoming increasingly popular with regard to their use in patient dose monitoring. Since diodes do not require high voltage bias, they can be taped directly onto the patient at suitable points to measure dose. The diodes are carefully calibrated to provide a check of patient dose at a reference point (e.g., dose at d_{max}). Calibration factors are applied to convert the diode reading into expected dose at the reference point, taking into account source to detector distance, field size, and other parameters used in the calculation of monitor units

2.1.6 Gamma evaluation [13]

Although ionization chamber, TLD, diode array and diode cylindrical measurements provide accurate dosimetric data, they are incomplete for treatment planning quality assurance because they only yield the dose in a single point or along one line. Regardless of the measurement technique, what is essential to the QA of the intensity modulated dose delivery is the efficient and accurate comparison of the measured versus calculated dose distribution. A simple qualitative evaluation is made by superimposing the isodose distributions. Provided the relevant isodose lines have been chosen to plot, this evaluation can highlight areas of disagreement, but a more quantitative assessment for final approval is desirable. The extraction and comparison of line profiles provides a more detailed print of the dose correspondence, but because of the limited selection important disagreements can be overlooked. In selecting the most critical and relevant line profiles, adequate experience of the physicist is imperative. Furthermore, the above methods demand a lot of manual analysis and are therefore, time consuming. A higher level of automation and a more quantitative evaluation is desirable to accomplish full integration into daily clinical routine. A first attempt to define a quantitative evaluation method was the use of the dose difference as acceptance criterion. This criterion can be used in low gradient areas but is inadequate to evaluate high gradient areas where a small spatial shift of physical origin or related to the calculation will result in a large dose difference a priori. Van Dyk et al. 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. Visualization of the dose difference distribution identifies regions of disagreement. Because the dose difference in high dose gradient regions may be misleading, Van Dyk et al. used the concept of DTA. The DTA is the distance between a reference data point and the nearest point in the compared dose distribution that exhibits the same dose. The evaluation images displaying the dose difference and DTA are complementary in determining the acceptability of dose calculation versus delivery. In order to merge both evaluation images into a single image, a composite analysis used by Harms et al. uses a pass–fail criterion of both the dose difference and DTA: points that fail both criteria are identified on a composite distribution. The dose difference is displayed with the binary composite distribution highlighting regions of disagreement. A limitation of this technique is that the display of the dose difference may accentuate the impression of failure in high dose gradient regions. Also, it provides no quantitative measure of the magnitude of disagreement. The method presented by Low et al. to simultaneously incorporate the dose and distance criteria. This method provides a numerical quality index referred to as the gamma value that serves as a measure of disagreement in the regions that fail the acceptance criteria and indicates the calculation quality in regions that pass.

2.1.6.1 Gamma evaluation theoretical concept

The gamma method is designed for the comparison of two dose distributions: one is defined to be the reference information $D_r(r_r)$ and the other is queried for evaluation $D_c(r_c)$. A schematic representation of the gamma analysis tool for two dimensional dose distribution evaluations is shown in figure 2.6. The acceptance criteria are denoted by ΔD_M for the dose difference and Δd_M for the distance to agreement. For a reference point at position r_r, receiving dose D_r, the surface representing these

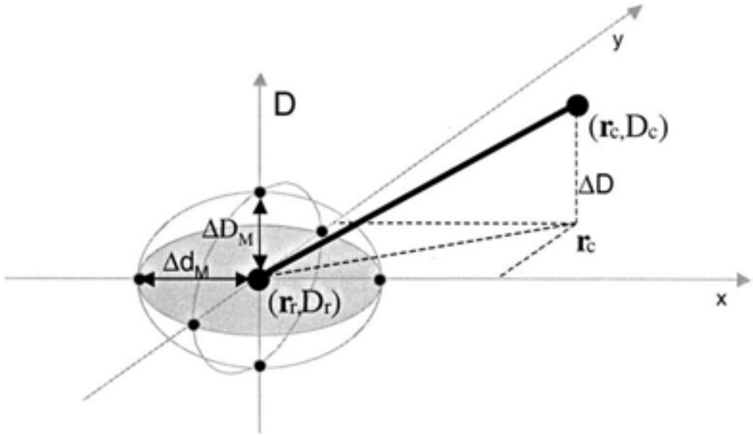


Figure 2.6 Schematic representation of the theoretical concept of the gamma evaluation method.

Acceptance criteria are an ellipsoid defined by:

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

Where

$\Delta r = |r_r - r_c|$

Is the distance between the reference and compared point and

$\Delta D = D_c(r_c) - D_r(r_r)$

Is the dose difference at the position r_c relative to the reference dose D_r in r_r. For the compared distribution to match the reference dose in rr, it need to contain at least one point (r_c, D_c) lying within the ellipsoid of acceptance, i.e. one point for which:

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

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 $\gamma_r(r_c, D_c)$ is minimal. This minimal value is referred to as the quality index $\gamma(r_r)$ of the reference point. The pass–fail criterion therefore becomes

$\gamma(r_r) \leq 1$, correspondence is within the specified acceptance criteria,
$\gamma(r_r) > 1$, correspondence is not within specified acceptance criteria.

An implicit assumption is made that once the passing criteria are selected, the dose difference and DTA analyses have equivalent significance when determining calculation quality.

2.2 Review of related literature

2.2.1 Daniel Le´tourneau et al. [14] evaluated the dosimetric characteristics of MapCheck and assess the role it can play in routine IMRT QA. Fundamental properties of the MapCheck were studied. The diode array were used for verify both conventional and IMRT treatment planning against film and ion chamber. The study showed that the diode array response was linear with dose up to 295 cGy. All diodes were calibrated to within ±1% of each other, and mostly within ±0.5%. The MapCheck readings were reproducible to within a maximum SD of ±0.15%. A temperature dependence of 0.57%/°C was noted and should be taken into account for absolute dosimetric measurement. Clinical performance of the MapCheck for relative and absolute dosimetry was demonstrated with seven beam (6 MV) head and neck IMRT plans, and compared well with film and ion chamber measurements. The study suggests that MapCheck offers the dosimetric characteristics required for performing both relative and absolute dose measurements. Its use in the clinic can simplify and reduce the IMRT QA workload.

2.2.2 R Noble et al. [15] evaluated the use of the ArcCHECK in term of its calibration, stability of calibration with time, reproducibility, linearity with dose and dose rate and consistency of chamber response with orientation using static fields. Existing tolerances for IMRT QA were also assessed. The IMRT patients plan were re-planned with RapidArc and fluences were compared by gamma analysis with measured values. The results showed that the reproducibility of response, linearity with dose and linearity with dose rate yielded coefficients of variation (COV) for the central diodes of <0.3%, <0.3% and <0.6% respectively for both energies. Over a time period of 120 minutes the calibration remained stable with a COV of 0.2% for both 6 and 10 MV. All clinical plans delivered passed the gamma analysis (3%/3mm) with a pixel pass rate of >95%. The study concluded that ArcCHECK is an accurate and efficient tool for IMRTpre-treatment verification and the initial results support the use of established gamma analysis tolerances.

2.2.3 Aime M. et al. [16] devised a patient-specific quality assurance procedure for RapidArc radiotherapy using the MapCHECK detector array. MapCHECK system and a Solid Water phantom with an embedded ion chamber to develop a quality assurance procedure for RapidArc treatment after commissioning; the ion chamber used to measure the absolute dose was surrounded by 6 cm layers of solid water on the anterior and posterior sides. Partial arcs derived from the treatment planning system were used with MapCHECK to determine the actual shape of the dose and correct for the angular dependence. The result showed that the ion chamber measurements were within 1% of the absolute doses predicted by the Eclipse treatment system. When using a partial arc from 60° to 300° on the MapCHECK array and 17 patient plans obtain A 97.52% average passing rate , gamma index <1 using 3%, 3 mm, 10% threshold. The study suggests that MapCHECK system can be used for quality assurance of RapidArc therapies.

2.2.4 Ehua Fan et al.[17] evaluated the performance of ArcCHECK for IMRT patient plan verification, thus to update the conventional 2D planar dose method under the fixed linac gantry angle to a 3D volumetric dose method with actual beam angles as in patient treatment. 36 patient plans were tested on ArcCHECK. Actual beam angles were used for ArcCHECK QA plan delivery, compared with 0 degree delivery for MapCHECK. Gamma criteria of 3%/3mm were use for analysis with the default threshold, where was also used as the criteria in the MapCHECK measurement analysis. The results showed that the QA results were very similar between ArcCHECK with and without the insert. The point measurements were matched closely for different phantoms. For IMRT plan, the values of percentage pass were lower for ArcCHECK than for MapCHECK. Ehua Fan found that ArcCHECK can produce comparable passing rate as MapCHECK by increasing the percentage of dose differences and DTA thresholds gradually.

2.2.5 Jonathan G Li et al. [18] used MapCHECK and Matrixx for verifying IMRT patient plan. The dependence of the response of detectors on the field size, dose rate, and radiation energy were investigated and compared with reference measurements using a Farmer-type ionization chamber. The linearity of the detector response, short-term and long-term reproducibility, statistical uncertainty as a function of delivered dose, and the validity of the array calibration were also examined. The result showed that no field size or SSD dependence were observed at both 6 MV and 18 MV photon energies. MapCHECK showed a stable short-term reproducibility to within the measurement errors; the MatriXX showed a slow but continuously increase in reading during the one-hour period (about 0.8%). The MapCHECK also showed a slightly better array sensitivity correction with all the detectors having less than 1% discrepancy and more than 90% of the detectors within 0.5% variation, whereas about 60% of the MatriXX detectors showed a less than 0.5% variation and ~8% exhibited a larger than 1% discrepancy. MatriXX detectors also displayed a volume-averaging effect consistent with its detector size of ~ 4.5 mm in diameter. Excellent passing rates were obtained for both detector arrays when compared with the planar dose distributions from the treatment planning system for three 6 MV IMRT fields and three 18 MV IMRT fields after the volume-averaging effect of the MatriXX was taken into account.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Research design

This study is an observational descriptive study.

3.2 Research design model

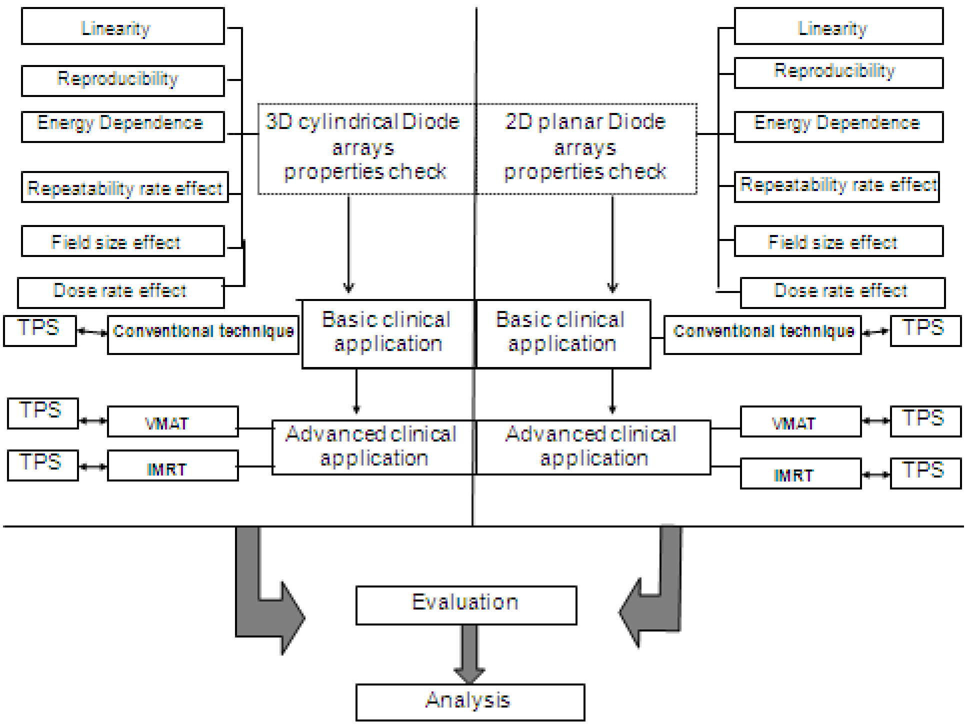


Figure 3.1 Research design model

3.3 Conceptual frameworks

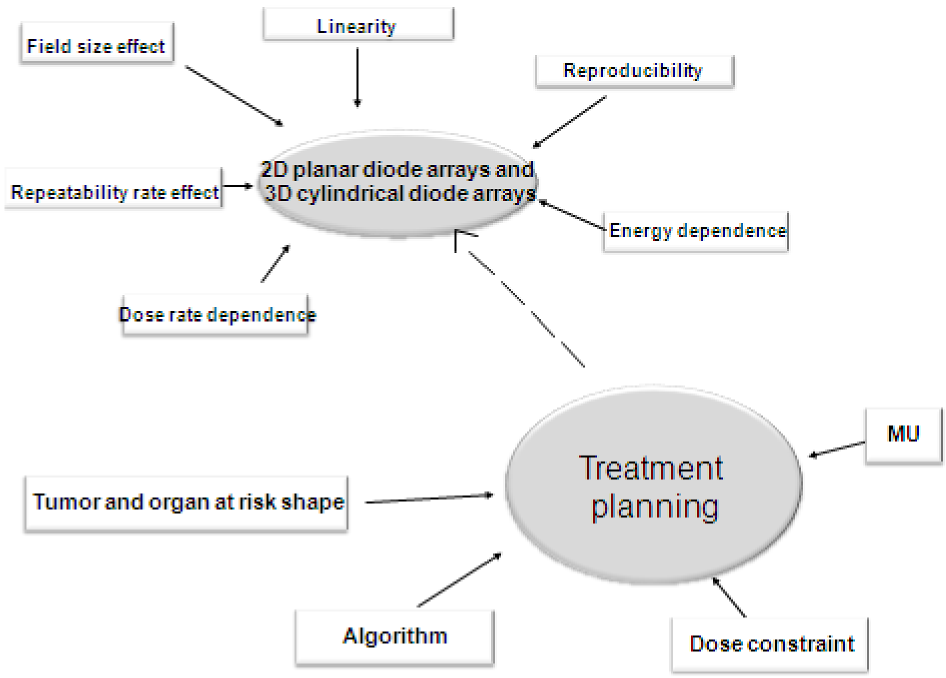


Figure 3.2 Conceptual frameworks.

3.4 Key words

- IMRT
- VMAT
- MapCHECK
- ArcCHECK
- Treatment verification

3.5 Research question

What are the difference of dosimetric verification resulting in patient planning using 2D planar diode arrays and 3D cylindrical diode arrays in IMRT and VMAT?

3.6 Materials

3.6.1 Two dimensional diode arrays device

MapCHECK (Sun Nuclear Corp., Melbourne, Florida, USA) which is shown in figure 3.3 contains 445 n-type solid state diode detectors. The inner 221 detectors cover the central 10×10 cm^2 and are arranged in a zigzag pattern so that the diagonal spacing between detectors is 0.707 cm. The outer 224 detectors are arranged in a similar pattern, but with a diagonal spacing between detectors of 1.414 cm. The array covers an area of 22.0×22.0 cm^2. The active detector area of each diode is 0.8×0.8 mm^2. The relative sensitivity differences between the detectors were obtained through a manufacturer specified procedure. No warm-up time is given for the MapCHECK. The depth of detector is 1.35 cm which is 2 cm water equivalent.

Figure 3.3 MapCHECK (Sun Nuclear Corp., Melbourne, Florida, USA)

3.6.2 Three dimensional diode arrays

ArcCHECK (Sun Nuclear Corp., Melbourne, Florida, USA) Model 1220, which is shown in figure 3.4, is a cylindrical water equivalent phantom with a three dimensional array of 1386 diode detectors, arranged in a spiral pattern, with 10 mm sensor spacing. The center of the phantom is 15 cm diameter. The depth of detector is 2.85 cm which is 3.28 cm water equivalent.

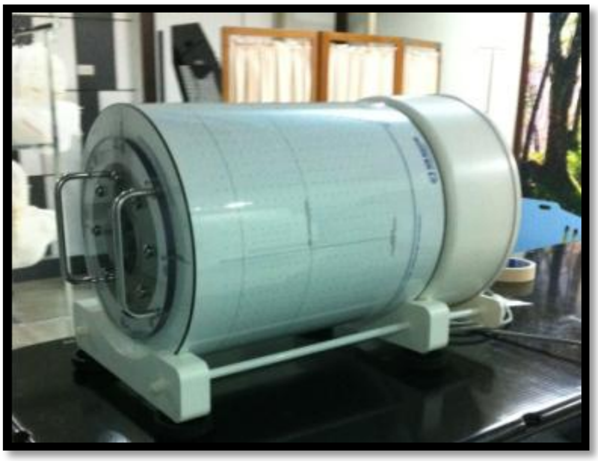


Figure 3.4 ArcCHECK (Sun Nuclear Corp., Melbourne, Florida, USA)

3.6.3 Solid water phantom

The solid water phantom made from epoxy resin based mixture which has similar mass density and electron density to water (1.00g/cm^3 and 3.34x10^{23}electrons/g, respectively). A set of solid water phantom in this study is consisted of 30x30 cm^2 solid water phantom of 3 and 5 cm thicknesses, which is shown in figure 3.5.

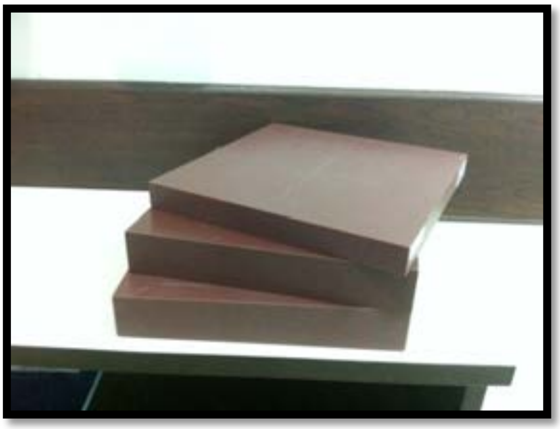


Figure 3.5 Solid water phantoms

3.6.4 CC13 Ionization chamber

The ionization chamber CC13 (Scanditronix, Wellhofer Dosimetries, Schwarzenbruck, Germany) which is shown in figure 3.6 was used for output factor measurement and scan beam profiles, the compact chamber can measure absolute and relative dosimetry of photon and electron beams in solid phantom or in water phantoms. The active volume and the sensitivity of CC13 are 0.13 cm^3 and 2.647x10^8 Gy/C, respectively

Figure 3.6 The CC13 ionization chamber (Scanditronix, Wellhofer Dosimetries, Schwarzenbruck, Germany)

3.6.5 Electrometer

The DOSE-1 (Scanditronix, Wellhofer Dosimetries, Schwarzenbruck,Germany) is a high precision reference class electrometer that significantly exceeds the recommendations of the IEC 60731 and the AAPM ADCLs, it is shown in figure 3.7. It is suitable for using with ionization chamber, semiconductors and diamond probe. The standard DOSE-1 connects to either TNC or BNC connector types. This electrometer is set at 300V and could be used with both CC13 and FC65-P. Maximum charge per pulse is approximate ±40 nc/pulse.

Figure 3.7 The DOSE-1 (Scanditronix, Wellhofer Dosimetries, Schwarzenbruck,Germany).

3.6.6 CT simulator scanner

The 4 slice CT scanner (LightSpeed RT, GE Medical system, Waukesha, WI, USA.), which is shown in Figure 3.8, has the ability to simultaneous collecting 4 rows of scan data. The distance from tube to isocenter is 606 mm. the distance from the tube to detector focus is 1062 mm. Bore diameter is 800 mm which allows images to be reconstructed with a larger field of view than a standard CT system. Additional, raw image into 3D image can generate digital reconstructed radiograph (DRR) in many directions.

Figure 3.8 The 4 slice CT scanner (LightSpeed RT GE Medical system, Waukesha, WI, USA.)

3.6.7 Eclipse treatment planning

Eclipse treatment planning version 8.9.17 (Varian Medical System, Palo Alto, CF, and USA.), which is shown in figure 3.9, is a treatment planning for all modalities such as 2D, 3D conformal, IMRT, VMAT and electron beam. The IMRT and VMAT are planned by inverse planning using analytical and isotopic algorithm (AAA). Eclipse helps dosimetrists, physicists, and physicians efficiently create, select, and verify the best treatment plans for their patients.

Figure 3.9 Eclipse treatment planning: version 8.9.17 (Varian Medical System, Palo Alto, CF, and USA.)

3.6.8 Linear accelerator

Varian Clinic iX (Varian Oncology systems, Palo Alto, CA, USA) , which is shown in figure 3.10, delivers dual photon beams of 6 MV and 10 MV, and six electron beam energies of 4, 6, 9, 12, 16 and 20 MeV. Photo field sizes are ranged from 0.5x0.5 cm^2 to 40x40 cm^2 at isocenter. The distance from the target to isocenter is 100 cm. These are six stationary therapy dose rates range from 100-600 monitor units per minute. The MLC is mounted below the conventional collimator in the same direction of x-jaws. There are 120 leaves that can move as the dynamic movement.

Figure 3.10 Varian Clinic iX linear accelerator (Varian Oncology systems, Palo Alto, CA, USA)

3.6.9 Patient plan

Fifteen head and neck patient plans were undertaken for IMRT and VMAT, the example of VMAT plan is shown in figure 3.11.

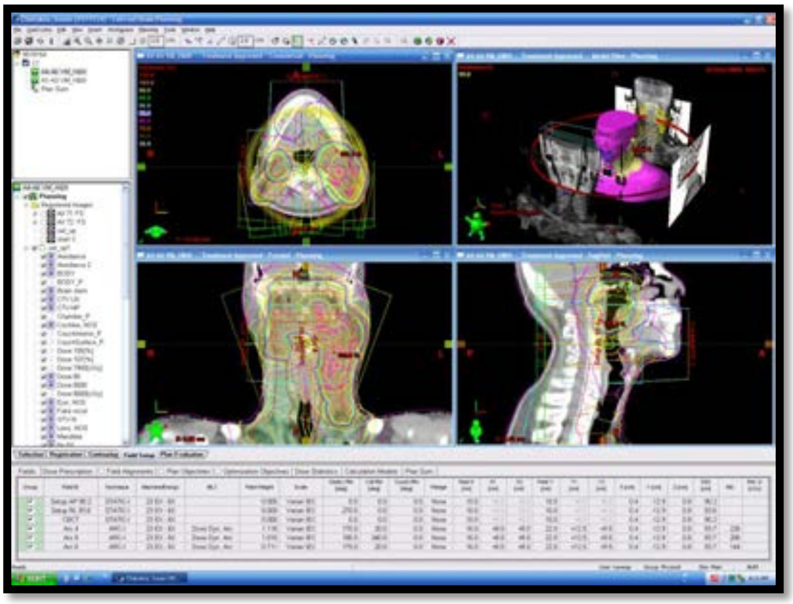


Figure 3.11 Head and neck patient plan

3.7 Methods

3.7.1 Study of detector properties

The measurements of the detector properties for both MapCHECK and ArcCHECK were made only with the central diode of the devices using photon beams. The MapCHECK measurements set up throughout this work is shown in Figure 3.12. The solid water phantom thickness of build up was 3 cm whereas the backscatter material was 5cm thick. The source to surface distance was set at 98.65 cm. The point measurement was then located at 100 cm from the radiation source. For ArcCHECK measurement set up, an acrylic insert with an ionization chamber holder was plugged into ArcCHECK to 26.6 cm diameter cylindrical phantom. The laser was aligned at the reference line of ArcCHECK as shown in Figure 3.13. The source to surface distance was set at 86.5 cm. The point measurement was then located at 100 cm from the radiation source. The devices required two calibration types. One was the dose calibration, which was performed before every MapCHECK and ArcCHECK session. The dose calibration is a procedure to convert the dose measurement relative dose value to absolute dose values by applying a single factor to all detectors. Dose calibration is performed in the central diode with10x10 field at the depth where the dose is known, which minimized the effect of daily LINAC output variation. The other calibration was the array calibration, which determined the ratio of each diode's reading to the central diode reading. These means array calibration measures relative sensitivity difference between the detectors in the measurement devices. For MapCHECK array calibration, the field size, dose and SSD must remain constant. The rotation must be clockwise and the crosshairs must be accurately positioned. Turn on the beam and deliver radiation every 90 degrees of rotation. For this process of ArcCHECK, a factory default array calibration file is provide with each ArcCHECK device, and is associated with ArcCHECK serial number.

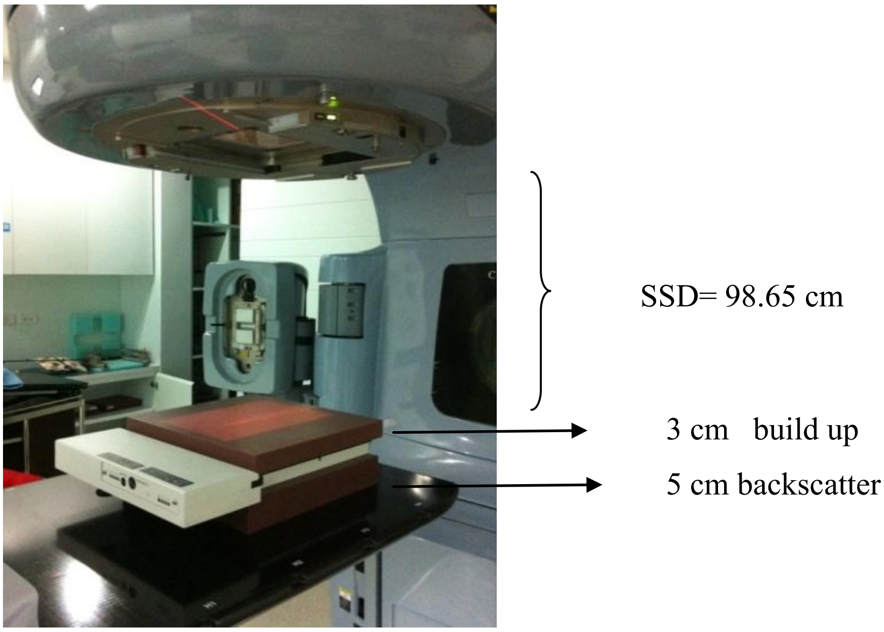


Figure 3.12 MapCHECK set up

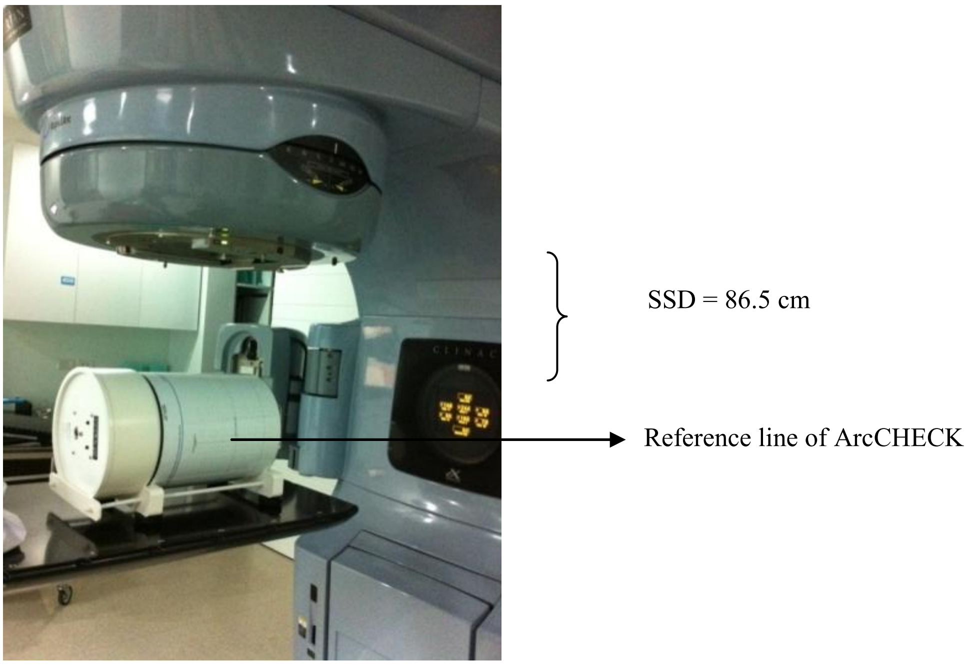


Figure 3.13 ArcCHECK set up

3.7.1.1 Linearity

Measurements were made using 6 MV photon beams. The dose linearity response of the diode were evaluated by measuring its output for beam delivered of 3–300 cGy with repetition rate 400 MU/min and 10x10 cm^2 field size.

3.7.1.2 Reproducibility

The performance of the diode was checked over a period of few months. The measurement evaluated using 6 MV photon beams at a constant machine repetition rate of 400 MU/min, output of 100 MU and 10x10 cm^2 field size. Short-term and long reproducibility were evaluated by repeating the same measurement every 10 minutes over 90 minutes for short reproducibility term and every week over 3 months for long term reproducibility.

3.7.1.3 Energy dependence

The measurement evaluated using 6 MV photon beams at a constant machine repetition rate of 400 MU/min, output of 100 MU and field size of 10x10 cm^2. The difference response for 6 and 10 MV was evaluated as dependence on beam energy.

3.7.1.4 Repeatability rate effect

The pulse rate dependence of the diode were determined by measuring its response using 6 MV photon beams ,at a constant dose 100 MU delivered and 10x10 cm^2 field size with repetition rate ranging from 100 to 600 MU/min.

3.7.1.5 Field size effect

The diode were used to measure the relative dose output for various square field sizes ranging from 2 x 2 to 20 x 20 cm^2 for 6 MV beams at 400 MU/min constant repetition rate. The relative output factors derived from these measurements were compared to the measurements made with an ionization chamber in the same conditions.

3.7.1.6 Dose rate effect

The dose rate effect measurements using 6 MV photon beams. The dose rate effect of the diode were evaluated by measuring its dose rate of 220–630 MU/min with 100 MU and 10x10 cm^2 field size.

3.7.2 Clinical application

3.7.2.1 Basic clinical application

The performance of the diode, when measuring clinical dose maps, was also investigated. Dose profiles of 5x5cm^2, 10x10 cm^2 and 20x20 cm^2 open, static and dynamic wedge of 30° modulated fields have been measured with MapCHECK and ArcCHECK for 6 MV photon beam.

3.7.2.2 Advance clinical application

For advance clinical application, a CT scan of the patient to be treated was done. Then information from the CT scan was used to precisely locate the tumor and organ at risk. The physician designed the treatment plan and estimated dose to the tumor and organ at risk. The physicists optimize the plan by treatment planning software. IMRT and VMAT are inverse treatment planning which have the objective function of the beamlet weights. The number of beamlet for a given case varies from a few hundred to several thousands, depending on the tumor size and beamlet size. Many small beamlet of a plan is intensity map. The leaf sequence will generate the intensity map as desire from inverse treatment planning by its software then the software provides the intensity map for TPS. After optimization of the plan and accepted by the radiation oncologist, the details from the procedure were forwarded to treatment machine (linear accelerator) and both kind of detectors, MapCHECK and ArcCHECK to verify the intensity map provided by treatment machine [3]. The methods are shown in the flow chart figure 3.14.

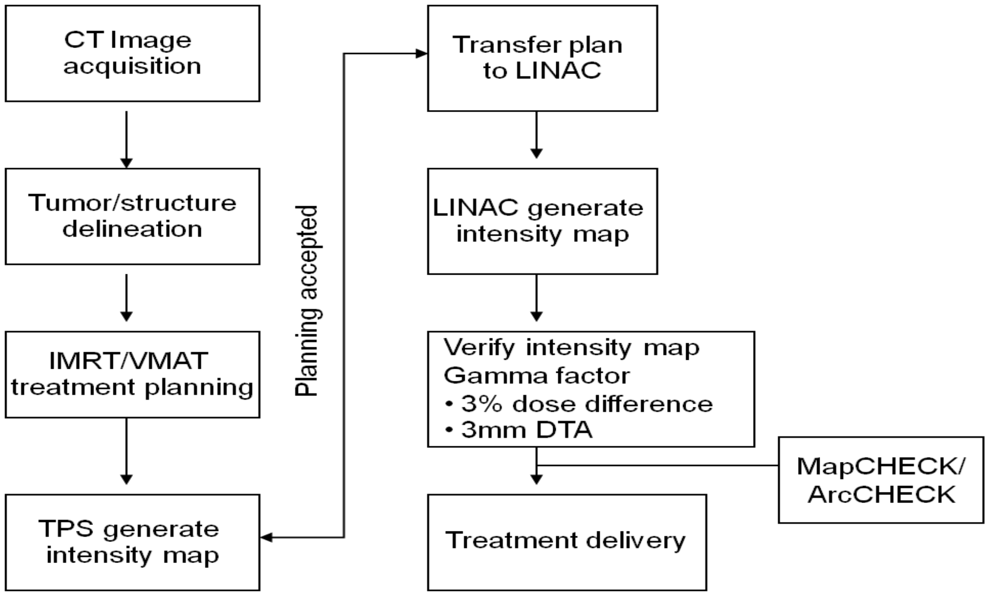


Figure 3.14 Flow chart of treatment in IMRT and VMAT

Treatment planning verification, the detector abilities were evaluated by measuring dose distribution of IMRT plans and VMAT plans from the same patient. Fifteen plans for each type of treatment were selected for head and neck cases.

To verify the treatment plan

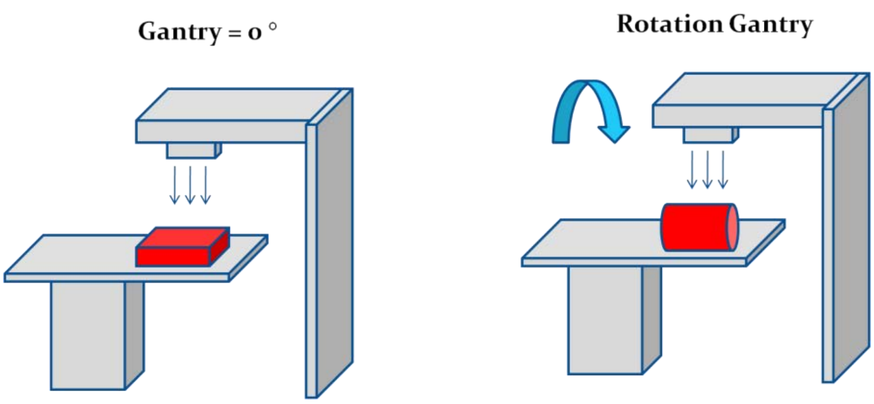
- First performed CT scan for MapCHECK and ArcCHECK which is shown in figure 3.15.

a) b)

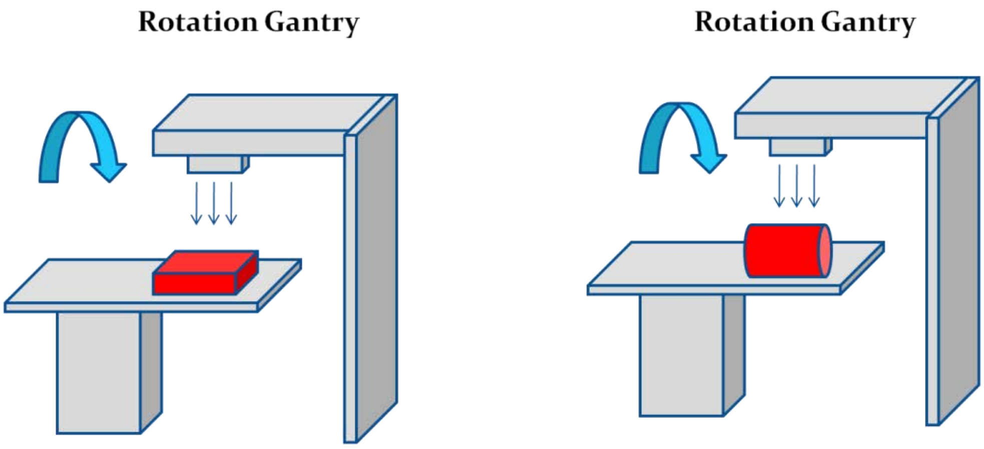
Figure 3.15 CT scan of a) ArcCHECK and b) MapCHECK

- Then created verification plan to the measurement devices by transferring the treatment plan to MapCHECK and ArcCHECK so the measurement device had the same parameters as in the patient plans these included beam energy, field size , dose, dose rate, MLC movement and monitor units

- Then delivered radiation to the measurement devices which were placed on the table at a SSD 95.65 cm for MapCHECK and 86.5 cm for ArcCHECK. For IMRT technique, the radiation delivered to MapCHECK by fixing the gantry at 0 degrees and rotated the gantry for ArcCHECK. For VMAT technique, the radiation delivered to MapCHECK and ArcCHECK by rotating the gantry for all arcs. The set up of MapCHECK and ArcCHECK for QA process is shown in figure 3.16. Patients' cases of IMRT and VMAT plan verification which were measured by MapCHECK and ArcCHECK and compared with the calculation from treatment planning were demonstrated by focusing on the fluence map, the absolute dose distribution, beams profile and gamma value.



(a) MapCHECK and ArcCHECK setup for IMRT QA process



(b) MapCHECK and ArcCHECK setup for VMAT QA process

Figure 3.16 MapCHECK and ArcCHECK setup for IMRT and VMAT QA process

3.8 Outcome Measurement

Independent variable = diode dose response, geometry of measurement device, photon energy, treatment technique

Dependent variable = measurement dose

3.9 Data collection

After study the characteristic of diode, MapCHECK and ArcCHECK were evaluated for IMRT and VMAT pre treatment verification in term of the percent pass between measured and calculated dose. The percent pass, mean gamma value and SD gamma value were record.

3.10 Data analysis

The gamma evaluation of 3% dose difference and 3mm distance to DTA were used for agreement between measured and calculated dose.

3.11 Benefit of the study

1 The characteristics of both detectors are studied and can be used properly and efficiency in the clinic

2 The type of detector for each treatment technique could be selected.

3. If one type of detector is suitable for both treatment techniques, the chance of buying only one detector would be safe for the institute who is going to use these two techniques

3.12 Ethical consideration

Although this study used only planning from patient not directly operated to the patient, however, the proposal was approved by the Ethics Committee of Faculty of Medicine, Chulalongkorn University.

CHAPTER IV

RESULTS

4.1 Study of detector properties

4.1.1 Linearity

The data of MapCHECK dose response over 3 to 300 cGy delivered dose are shown in table 4.1. The collected signals were averaged for 3 times measurements. The graph plotted between dose response measured by MapCHECK and delivered dose is shown in figure 4.1.The diode response was linear with the dose for 6 MV photon beam with regression coefficients of 1.00. The average % CV was 0.13 (0.01-0.49). At the small dose, the % CV was high which mean that MapCHECK had uncertainty in the measurement at low dose (less than 40 cGy) and rather stable at the dose ranged from 60-300 cGy.

Table 4.1 The dose response of the MapCHECK with delivered dose from 3 to 300 cGy for 6 MV photon beam with 10x10 cm^2.

Delivered dose (cGy)	Collected signal			Ave. collected Signal	SD	%CV
	No. of delivered					
	1	2	3			
3	204	203	205	204.00	1.00	0.49
10	749	752	748	749.67	2.08	0.28
20	1435	1434	1432	1433.67	1.53	0.11
40	2875	2866	2870	2870.33	4.51	0.16
60	4304	4304	4306	4304.67	1.15	0.03
80	5745	5742	5752	5746.33	5.13	0.09
100	7258	7249	7261	7256.00	6.24	0.09
150	10813	10822	10815	10816.67	4.73	0.04
200	14444	14443	14431	14439.33	7.23	0.05
250	18074	18069	18071	18071.33	2.52	0.01
300	21710	21719	21700	21709.67	9.50	0.04

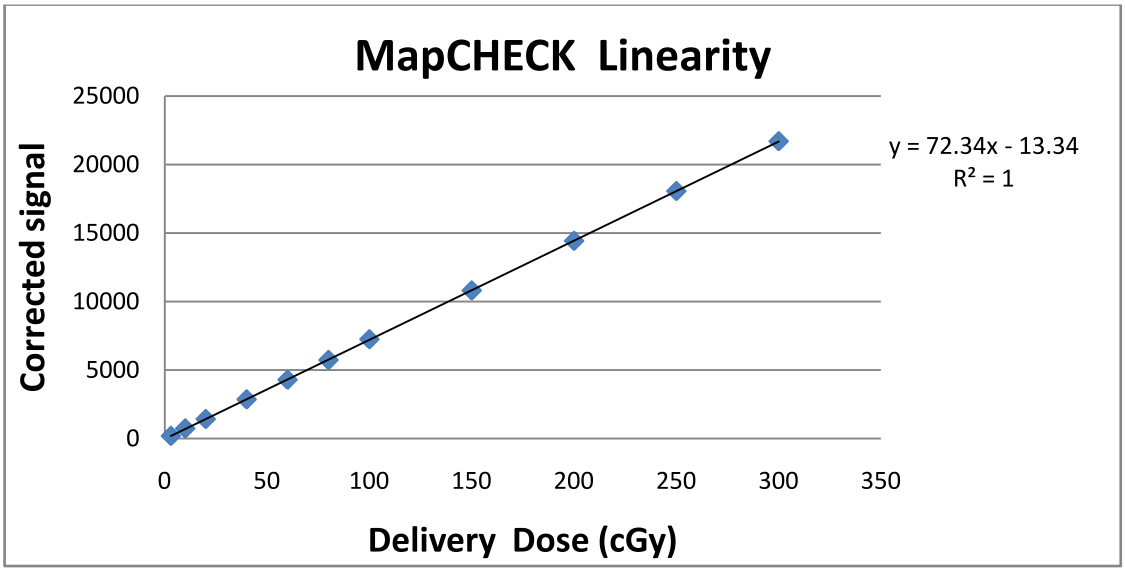


Figure 4.1 MapCHECK response at 6 MV photon beam as function of delivered dose from 3 - 300 cGy.

The data of ArcCHECK dose response over 3 to 300 cGy delivered dose are shown in table 4.2. The collected signals were averaged for 3 times measurements. The graph plotted between dose measured by ArcCHECK and delivered dose is shown in figure 4.2. The diode response was linear with the dose for 6 MV photon beam with regression coefficients of 1.00. The average % CV is 0.09 (0.03-0.35). ArcCHECK showed high %CV at the lower dose (less than 20 cGy) and decreased at the dose ranged from 40-300 cGy which mean that ArcCHECK had higher uncertainty in the measurement at low dose and decreased when the dose become higher.

Table 4.2 The dose response of the ArcCHECK with delivered dost from 3 to 300 cGy for 6 MV photon beam with 10x10 cm^2.

Delivered dose (cGy)	Collected signal			Ave. collected signal	SD	%CV
	No. of delivered					
	1	2	3			
3	6166	6159	6125	6150.00	21.93	0.36
10	24764	24699	24796	24753.00	49.43	0.20
20	49407	49394	49485	49428.67	49.22	0.10
40	102084	102071	101943	102032.67	77.93	0.08
60	151105	151310	151308	151241.00	117.78	0.08
80	200407	200564	200430	200467.00	84.79	0.04
100	253153	253078	253019	253083.33	67.16	0.03
150	376583	376376	376380	376446.33	118.37	0.03
200	503580	503380	503590	503516.67	118.46	0.02
250	630084	629958	629639	629893.67	229.37	0.04
300	756491	756906	756536	756644.33	227.72	0.03

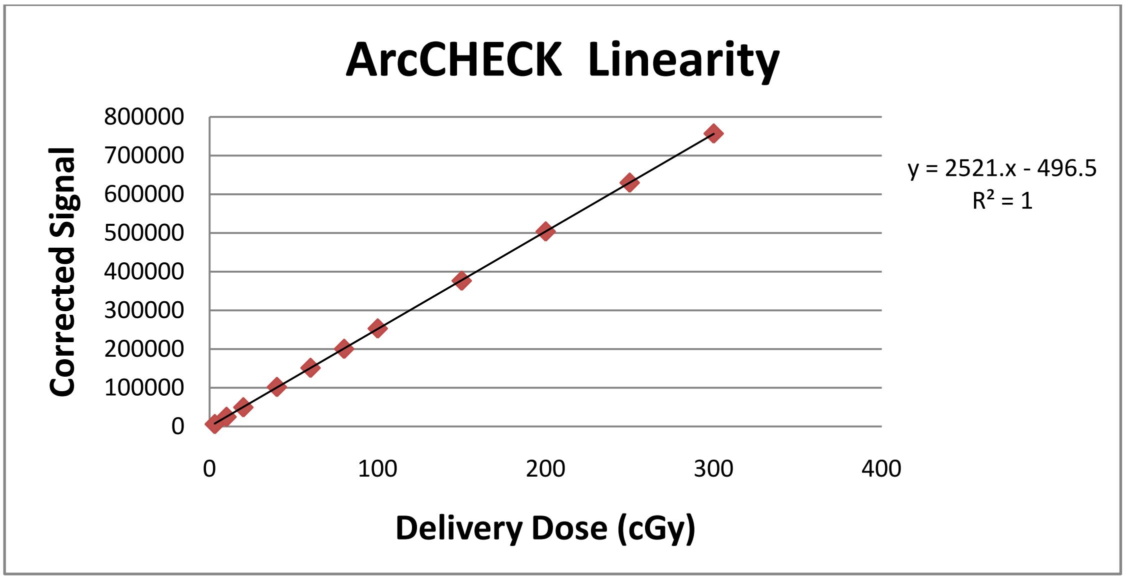


Figure 4.2 ArcCHECK response at 6 MV photon beam as function of delivered dose from 3-300 cGy.

4.1.2 Short term reproducibility

The short term reproducibility of MapCHECK and ArcCHECK were evaluated by repeated measuring every 10 minutes over a period of 90 minutes. The results are shown in table 4.3 for MapCHECK and table 4.4 for ArcCHECK. The collected signals were averaged for 3 times measurements. The graph is shown in figure 4.3. MapCHECK data represented in blue dot and ArcCHECK data represented in red dot. The average collected signal values of both detectors were normalized to average signal of 10 time measurements. The short term reproducibility of MapCHECK and ArcCHECK were within ±0.2% with the SD of 0.1% and 0.04%, respectively.

Table 4.3 The short term reproducibility of MapCHECK over a period of 90 minute. The measurement were made for 6 MV photon beam with 100 MU and 10x10 cm^2.

Minute	Collected signal			Ave. collected	Normalized to average signal of 10 time measurements
	No. of measurement				
	1	2	3	signal	
0	6891	6820	6812	6841.00	1.0019
10	6822	6817	6826	6821.67	0.9991
20	6823	6824	6821	6822.67	0.9992
30	6829	6822	6824	6825.00	0.9996
40	6827	6830	6821	6826.00	0.9997
50	6829	6828	6823	6826.67	0.9998
60	6828	6832	6826	6828.67	1.0001
70	6833	6828	6818	6826.33	0.9998
80	6831	6828	6825	6828.00	1.0000
90	6834	6838	6826	6832.67	1.0007
Average collected signal over 90 minute ± SD = 6827.87±7.35					

Table 4.4 The short term reproducibility of ArcCHECK over a period of 90 minute. The measurement were made for 6 MV photon beam with 100 MU and 10x10 cm^2.

Minute	Collected signal			Ave. collected signal	Normalized to average signal of 10 time measurements
	No. of measurement				
	1	2	3		
0	306635	306652	306717	306668.00	0.9982
10	307089	307328	307068	307161.67	0.9998
20	307421	307387	307106	307304.67	1.0003
30	307162	307371	307176	307236.33	1.0001
40	307330	307002	307255	307195.67	0.9999
50	307246	307249	307547	307347.33	1.0004
60	307485	307472	307570	307509.00	1.0010
70	307080	307224	307573	307292.33	1.0003
80	307380	306983	307182	307181.67	0.9999
90	307049	307398	307255	307234.00	1.0001
Average collected signal over 90 minute ± SD = 307213.07± 150.29					

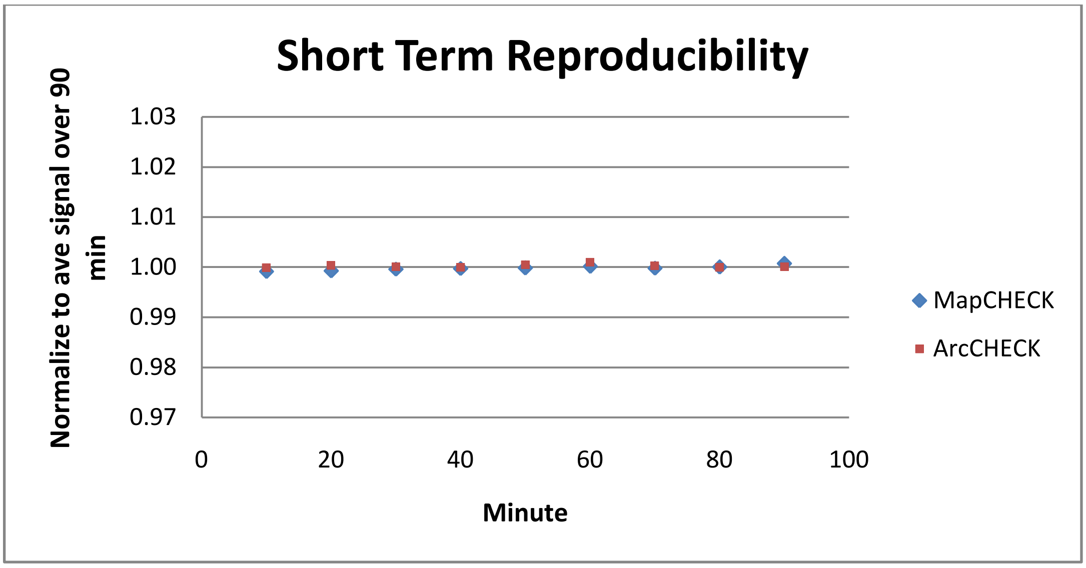


Figure 4.3 The short term reproducibility of MapCHECK and ArcCHECK, the average collected signal were normalized to 10 time measurements.

4.1.3 Long term reproducibility

The long term reproducibility of MapCHECK and ArcCHECK were evaluated by repeated measuring every week over a period of 3 months. The results are shown in table 4.5 for MapCHECK and table 4.6 for ArcCHECK. The collected signals were averaged for 3 times measurements. The graph is shown in figure 4.4. MapCHECK data represented in blue dot and ArcCHECK data represented in red dot. The average collected signal values were normalized to average signal over 3 months. The long term reproducibility of MapCHECK and ArcCHECK were within ±1% and ±2%, with the SD of 0.05% and 0.04%, respectively.

Table 4.5 The long term reproducibility of MapCHECK over a period of 3 months. The measurements were made for 6 MV photon beam with 100 MU and 10x10 cm^2.

Week	Collected signal			Ave. collected signal	Normalized to average signal over 3 months
	No. of measurement				
	1	2	3		
1	6816	6825	6809	6816.67	0.9999
2	6829	6828	6828	6828.33	1.0016
3	6817	6824	6827	6822.67	1.0008
4	6837	6847	6847	6843.67	1.0039
5	6874	6878	6876	6876.00	1.0086
6	6846	6841	6840	6842.33	1.0037
7	6867	6878	6878	6874.33	1.0084
8	6729	6736	6732	6732.33	0.9875
9	6722	6719	6716	6719.00	0.9856
10	6728	6732	6730	6730.00	0.9872
11	6771	6775	6774	6773.33	0.9936
12	6748	6757	6758	6754.33	0.9908
Average collected signal over 3 months ± SD = 6817.26± 3.93					

Table 4.6 The long term reproducibility of ArcCHECK over a period of 3 months. The measurements were made for 6 MV photon beam with 100 MU and 10x10 cm^2.

Week	Collected signal			Ave. collected signal	Normalized to average signal over 3 months
	No. of measurement				
	1	2	3		
1	306200	306072	306091	306121.00	0.9971
2	306722	306903	306607	306744.00	0.9992
3	308339	308183	308274	308265.33	1.0041
4	308531	308291	308498	308440.00	1.0047
5	309945	309389	309764	309699.33	1.0088
6	309486	309853	309828	309722.33	1.0089
7	313962	313930	313676	313856.00	1.0223
8	296740	296773	296751	296754.67	0.9666
9	303288	303617	303182	303362.33	0.9882
10	304334	304386	304124	304281.33	0.9912
11	307359	307301	307354	307338.00	1.0011
12	303055	302732	303037	302941.33	0.9868
Average collected signal over 3 months ± SD =				306996.11±139.01	

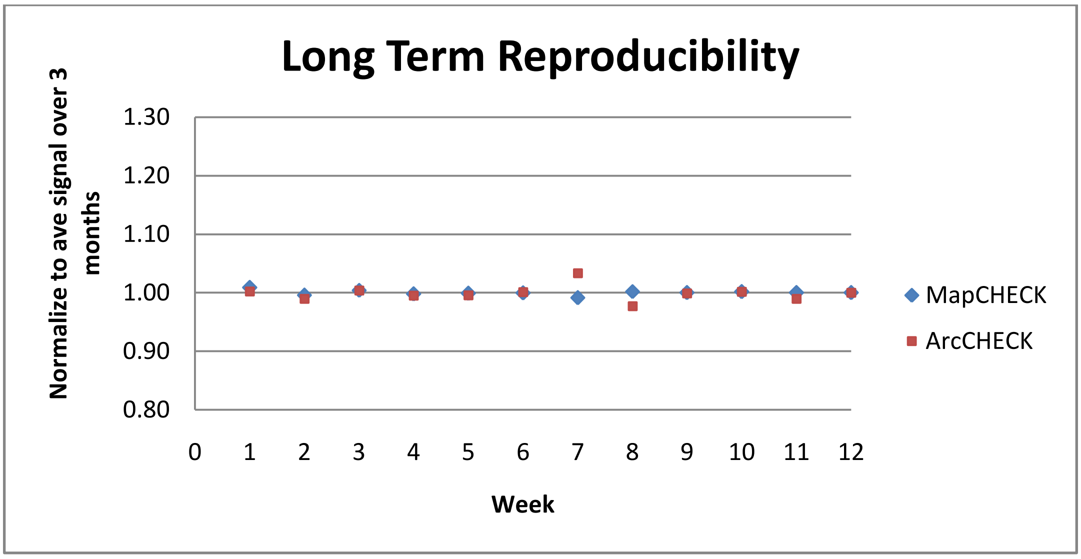


Figure 4.4 The long term reproducibility of MapCHECK and ArcCHECK, the average collected signal were normalized to average signal over 3 months.

4.1.4 Energy dependence

The energy dependence of MapCHECK in 6 and 10 MV photon beams are shown in table 4.7. The collected signals were averaged for 3 time measurement. The result showed that MapCHECK energy dependence was within 4%. The graph is shown in figure 4.5.

Table 4.7 The energy dependence of MapCHECK, the measurements were made for 6 and 10 MV photon beam delivered dose form 50 to 300 cGy with 10x10 cm^2.

cGy	6 MV				10 MV				6 and 10 MV ratio
	No. of measurement			Ave collected signal ± SD	No. of measurement			Ave collected signal	
	1	2	3		1	2	3		
50	3618	3617	3620	3618.33 ± 1.53	3779	3775	3775	3776.33±2.31	1.04
100	7237	7247	7247	7243.67 ± 5.77	7484	7482	7484	7483.33±1.15	1.03
200	14416	14417	14422	14418.33 ± 3.21	15034	15037	15039	15036.67±2.52	1.04
300	21655	21660	21664	21659.67 ± 4.51	22516	22518	22517	22517±1.00	1.04

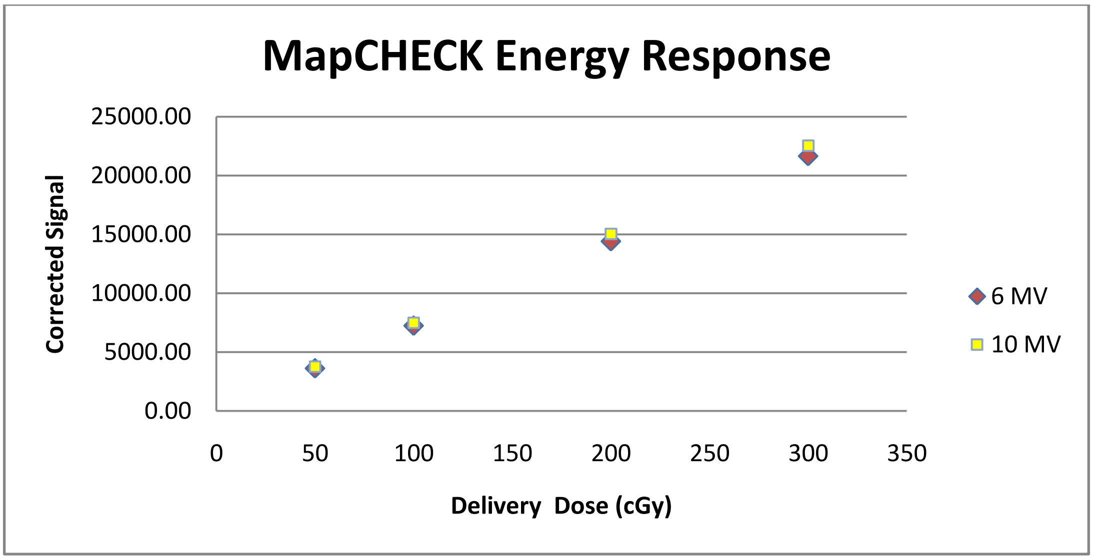


Figure 4.5 The Energy dependence of MapCHECK in 6 and 10 MV photon beams.

The Energy dependence of ArcCHECK in 6 and 10 MV photon beams are shown in table 4.8. The collected signals were averaged for 3 time measurement. The result showed that ArcCHECK energy dependence was within 2%. The graph is shown in figure 4.6.

Table 4.8 The energy dependence of ArcCHECK. The measurements were made for 6 and 10 MV photon beam delivered dose form 50 to 300 cGy with 10x10 cm^2.

cGy	6 MV				10 MV				6 and 10 MV ratio
	No. of measurement			Ave collected signal ± SD	No. of measurement			Ave collected signal	
	1	2	3		1	2	3		
50	125734	125857	126008	125866.33 ± 137.24	128120	128291	128216	128209 ± 80.71	1.02
100	252437	251951	251867	252085 ± 307.72	256740	256598	256697	256678.33 ± 72.82	1.02
200	500953	501032	500882	500955.67 ± 75.04	509566	509775	509502	509614.33 ± 142.77	1.02
300	753275	753299	753190	753254.67 ± 57.27	765689	765910	766434	766011 ± 382.63	1.02

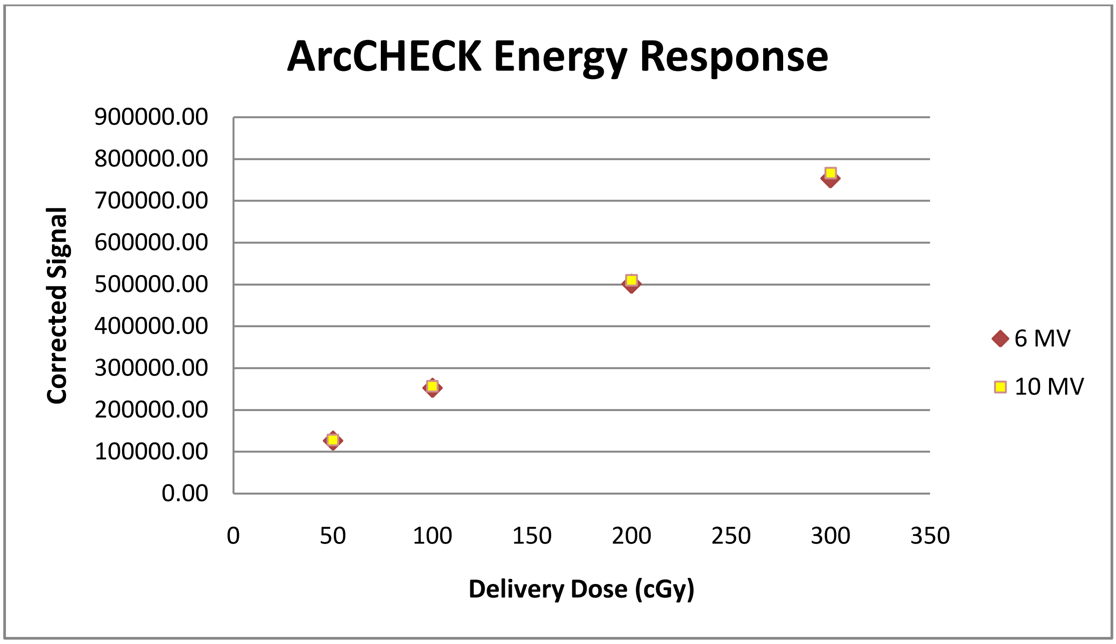


Figure 4.6 The Energy dependence of ArcCHECK in 6 and 10 MV photon beams.

4.1.5 Repeatability rate effect

The repeatability rate effect of MapCHECK and ArcCHECK were normalized to 400 MU/min. The results are shown in table 4.9 for MapCHECK and table 4.10 for ArcCHECK. The graph plotted between the relative repeatability rate effect and dose rate is shown in figure 4.7. MapCHECK data represented in blue dot and ArcCHECK data represented in red dot. The repeatability rate effect was within ±0.1% for MapCHECK and within ±0.25% for ArcCHECK with the SD of 0.05% and 0.12%, respectively.

Table 4.9 The repeatability rate effect of MapCHECK. The measurements were made for 6 MV photon beam delivered repeatability rate from 100 to 600 MU/min with 10x10 cm^2 and 100 MU dose delivered.

MU/min	Collected signal No. of measurement 1	2	3	Ave. collected signal ± SD	Normalized to 400 MU/min
100	6814	6824	6813	6817.00 ± 6.08	1.0000
200	6818	6812	6814	6814.67 ± 3.06	0.9997
300	6809	6809	6814	6810.67 ± 2.89	0.9991
400	6816	6825	6809	6816.67 ± 8.02	1.0000
500	6814	6824	6816	6818.00 ± 5.29	1.0002
600	6822	6818	6820	6820.00 ± 2.00	1.0005

Table 4.10 The repeatability rate effect of ArcCHECK. The measurements were made for 6 MV photon beam delivered repeatability rate from 100 to 600 MU/min with 10x10 $cm^2$and 100 MU dose delivered.

MU/min	Collected signal No. of measurement 1	2	3	Ave. collected signal ± SD	Normalized to 400MU/min
100	306530	306422	306539	306497.00 ± 65.11	1.0012
200	306048	305801	306202	306017.00 ± 202.29	0.9997
300	306062	305860	306199	306040.33 ± 170.54	0.9997
400	306200	306072	306091	306121.00 ± 69.07	1.0000
500	306589	306546	306684	306606.33 ± 70.61	1.0016
600	306657	306954	307092	306901.00 ± 222.29	1.0025

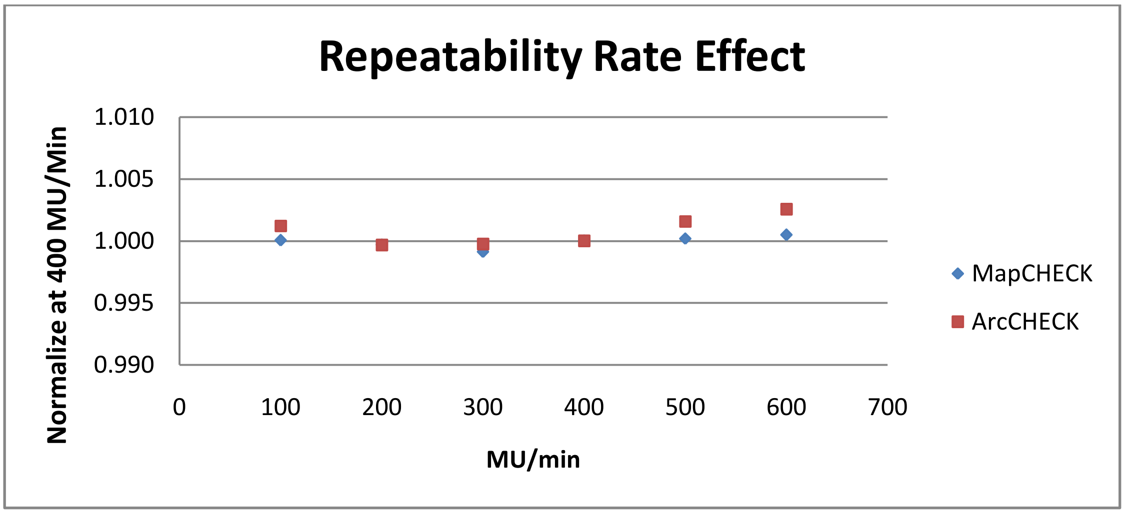


Figure 4.7 The repeatability rate effect of MapCHECK and ArcCHECK.

4.1.6 Field size effect

The response of MapCHECK and CC13 ionization chamber for field size effect, field size varying from 3x3 to 20x20 cm^2 are shown in table 4.11. The collected signals were averaged for 3 time measurement. The graph plotted is shown in figure 4.8, MapCHECK data represented in blue dot and ionization chamber data represented in yellow dot. The value of MapCHECK measurement was normalized to a 10x10 cm^2. The result showed that the MapCHECK agreed with the ionization chamber. At small field size, the signal from MapCHECK is slightly lower than the signal from ionization chamber and increase at large field size. The maximum percentage difference is 1.39 at 3x3 cm^2 field.

Table 4.11 The field size effect of MapCHECK. The measurements were made for 6 MV photon beam delivered dose form 3x3 to 20x20 cm^2 normalized to 10x10 cm^2

Field size (cm^2)	MapCHECK		IC		% diff
	Ave. collected signal ± SD	Normalize to 10x10 cm^2	Ave. IC charge(nC) ± SD	Normalize to 10x10 cm^2	
3x3	5874.67 ± 2.08	0.8621	3.11 ± 0.001	0.8743	1.39
4x4	6094.00 ± 5.00	0.8942	3.21 ± 0.002	0.9019	0.84
6x6	6410.00 ± 6.08	0.9406	3.36 ± 0.002	0.9437	0.32
8x8	6641.67 ± 1.53	0.9746	3.48 ± 0.001	0.9859	0.13
10x10	6814.67 ± 2.31	1.0000	3.56 ± 0.000	1.0000	0.00
12x12	6951.33 ± 4.93	1.0201	3.63 ± 0.003	1.0181	-0.20
15x15	7120.33 ± 3.21	1.0449	3.70 ± 0.001	1.0390	-0.56
20x20	7297.67 ± 1.15	1.0709	3.79 ± 0.003	1.0647	-0.58

% diff = 100-((Map/IC)*100)

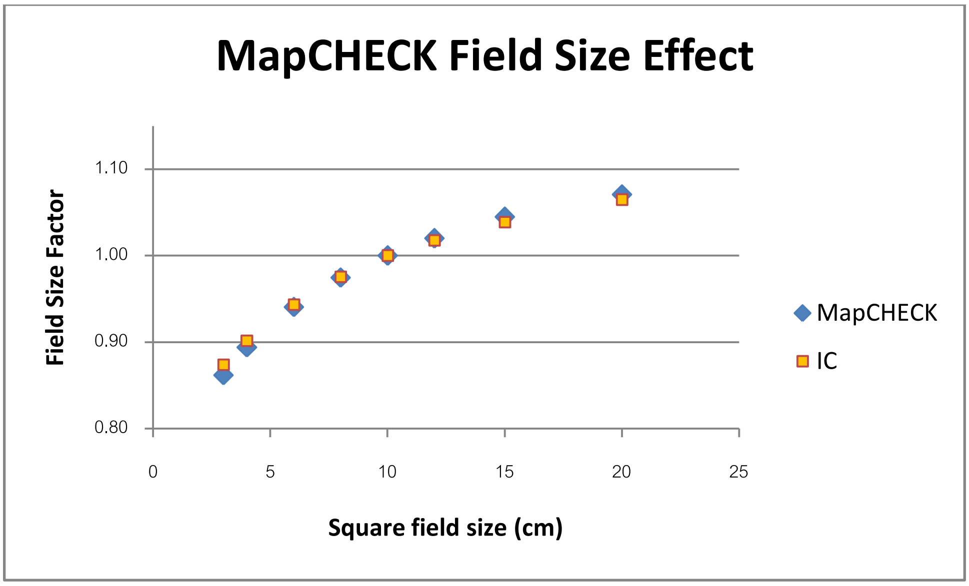


Figure 4.8 The field size effect of MapCHECK , CC13 ionization chamber the results were normalized to 10x10 cm^2

The response of ArcCHECK and CC13 ionization chamber for field size effect, field size varying from 3x3 to 20x20 cm^2 are shown in table 4.12. The collected signals were averaged for 3 time measurement. The graph plotted is shown in figure 4.9. ArcCHECK data represented in red dot and ionization chamber data represented in yellow dot. The value of ArcCHECK measurement was normalizeed to a 10x10 cm^2. The result showed that the ArcCHECK agreed with the ionization chamber. The maximum percentage difference is 1.48 at 3x3 cm^2 field

Table 4.12 The field size effect of ArcCHECK. The measurements were made for 6 MV photon beam delivered dose form 3x3 to 20x20 cm^2 with 10x10 cm^2

Field size (cm^2)	ArcCHECK		IC		% diff
	Ave. collected signal ± SD	Normalize to 10x10 cm^2	Ave. IC charge(nC) ± SD	Normalize to 10x10 cm^2	
3x3	273280.33 ± 267.97	0.8765	4.11 ± 0.002	0.8932	1.48
4x4	281889.67 ± 157.01	0.9141	4.22 ± 0.002	0.9221	-0.47
6x6	293616.33 ± 163.27	0.9623	4.39 ± 0.001	0.9529	-0.60
8x8	301447.00 ± 431.02	0.9856	4.51 ± 0.002	0.9894	-0.50
10x10	306273.00 ± 50.74	1.0000	4.60 ± 0.001	1.0000	0.00
12x12	310561.33 ± 183.14	1.0186	4.68 ± 0.004	1.0166	0.25
15x15	316085.67 ± 92.83	1.0316	4.76 ± 0.002	1.0349	0.28
20x20	321807.00 ± 201.12	1.0680	4.87 ± 0.001	1.0573	0.62

% diff = 100-((Arc/IC)*100)

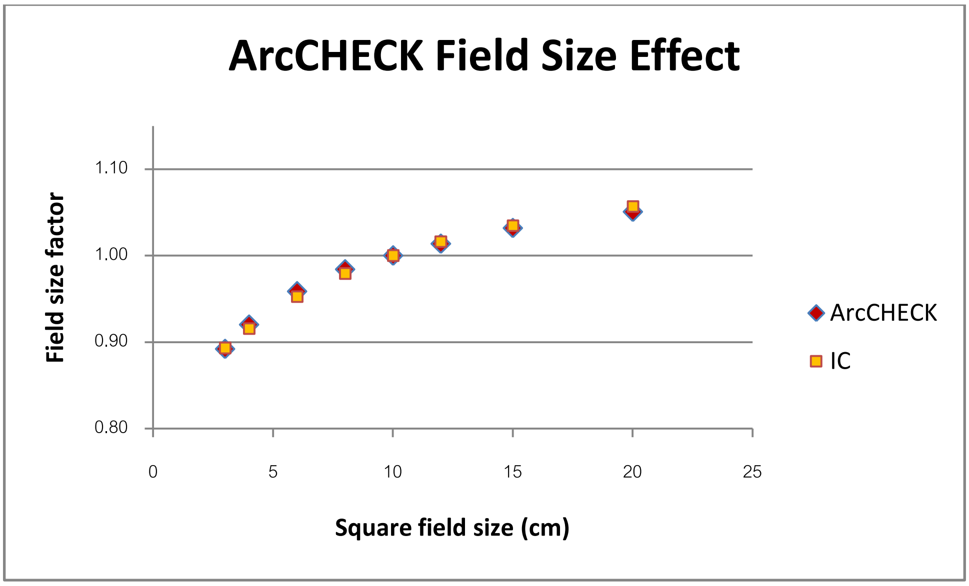


Figure 4.9 The field size effect of ArcCHECK , CC13 ionization chamber the results are normalized to 10x10 cm^2

4.1.7 Dose rate effect

The dose rate response of MapCHECK and ArcCHECK were normalized to 400 MU/min. at 100 cm SAD with 100 cGy dose delivered. The results are shown in table 4.13 for MapCHECK and table 4.14 for ArcCHECK and the graph plotted between the relative dose rate and dose rate is shown in figure 4.10. MapCHECK data represented in blue dot and ArcCHECK data represented in red dot. The dose rate response was within ±1% for both detectors.

Table 4.13 The dose rate effect of MapCHECK, The measurements were made for 6 MV photon beam delivered dose rate from 277 to 625 MU/min and varied SAD from 20 to 120 cm with 10x10 cm^2

MU	MU/min (dose rate)	SAD (cm)	Collected signal No. of delivered			Ave. collected signal ± SD	Relative dose
			1	2	3		
69	625.00	80	7348	7343	7350	7347.00 ± 3.67	1.005
87	493.82	90	7326	7330	7327	7327.67 ± 2.08	1.002
107	400.00	100	7313	7308	7309	7310.00 ± 2.63	1.000
129	330.57	110	7303	7311	7304	7306.00 ± 4.36	0.999
153	277.77	120	7298	7300	7297	7298.33 ± 1.53	0.998

Table 4.14 The dose rate effect of ArcCHECK, The measurements were made for 6 MV photon beam delivered dose rate from 277 to 625 MU/min and varied SAD from 20 to 120 cm with 10x10 cm^2

MU	Mu/min (dose rate)	SAD	Collected signal No. of delivered			Ave. collected signal ± SD	Relative dose
			1	2	3		
65	625.00	80	249983	249993	249910	249962.00 ± 45.31	1.007
82	493.82	90	248652	248354	248431	248479.00 ± 154.62	1.001
101	400.00	100	248200	248276	248246	248240.67 ± 38.28	1.000
122	330.57	110	247237	247402	247484	247374.33 ± 125.80	0.997
145	277.77	120	247044	246682	246791	246839.00 ± 180.71	0.994

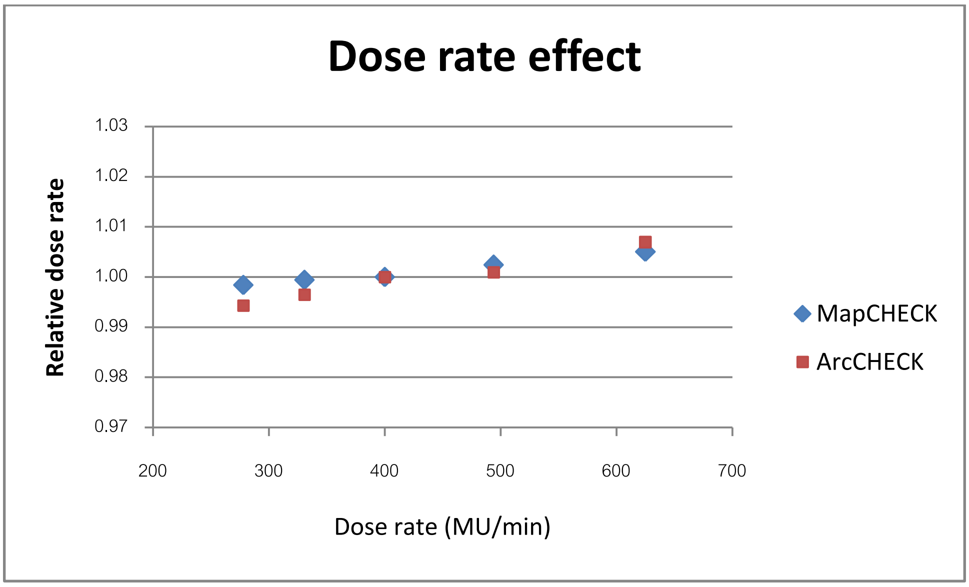
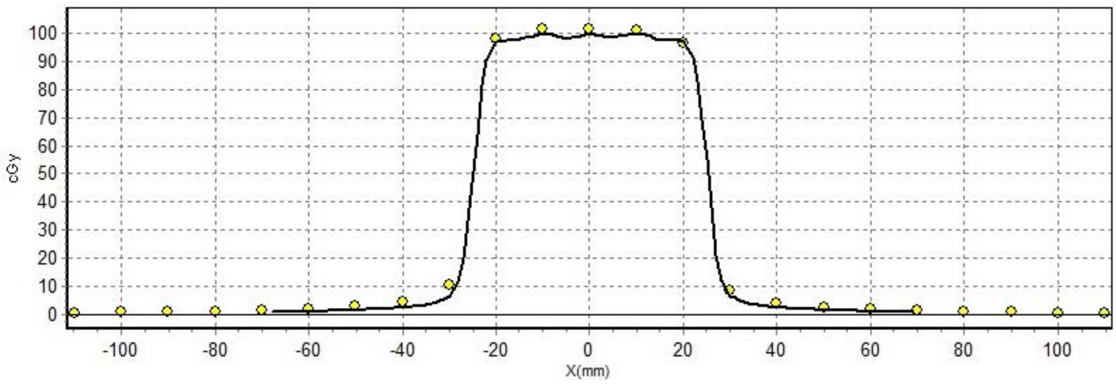


Figure 4.10 The dose rate effect of MapCHECK and ArcCHECK

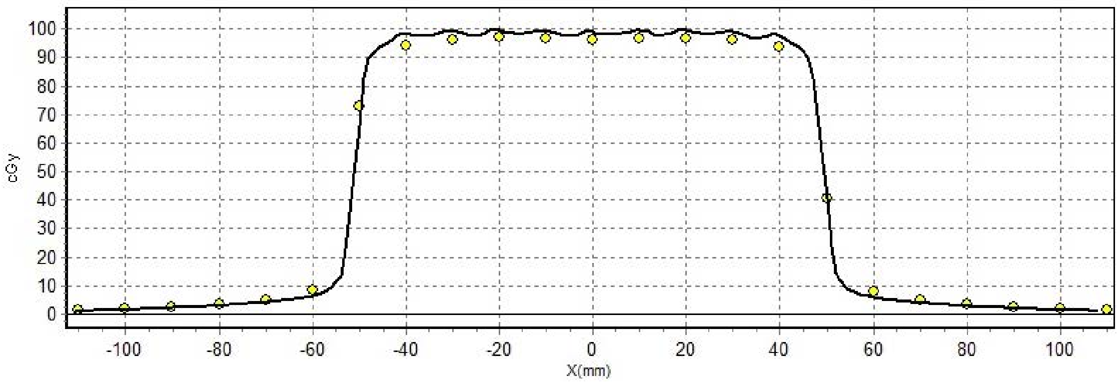
4.2 Clinical application

4.2.1 Basic clinical application

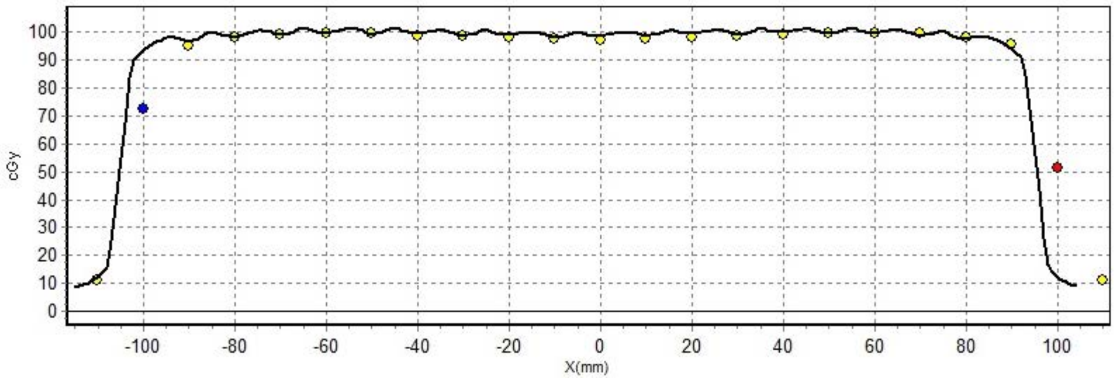
MapCHECK and ArcCHECK were evaluated for basic clinical application in term of the percent pass between measured and calculated dose. The gamma evaluation of 1% dose difference and 1 mm distance to agreement were used for agreement between measured and calculated dose. The measurement were made for 6 MV photon beam. The comparison of beam profile measured by the measurement devices and calculated from Eclipse treatment planning for 5x5 cm^2, 10x10 cm^2 and 20x20 cm^2 open field are shown in figure 4.11 for MapCHECK and figure 4.12 for ArcCHECK. The measurement devices measurements data represented in yellow dot and the calculated dose represented in black line. MapCHECK showed good agreement with the calculated dose for 20x20 cm^2, for 5x5 cm^2 MapCHECK showed slightly higher response than calculated dose and for 10x10 cm^2 MapCHECK showed slightly lower response than calculated dose. ArcCHECK showed good agreement with calculated dose for 5x5 cm^2 and 20x20cm^2, but for 10x10 cm^2 ArcCHECK showed slightly lower response than calculated dose. The beam profile with static wedge of 30° for 10x10 cm^2 field size is shown in figure 4.13 for MapCHECK and figure 4.14 for ArcCHECK. MapCHECK and ArcCHECK illustrated good agreement with calculated dose. The beam profile with dynamic wedge of 30° for 10x10 cm^2 field size is shown in figure 4.15 for MapCHECK and figure 4.16 for ArcCHECK. MapCHECK presented good agreement with calculated dose. ArcCHECK displayed slightly lower response than the calculated dose from TPS. However, all beam profiles of both open and wedge fields demonstrated the percentage passing rate more than 90%.



(A) Field size of 5x5 cm^2

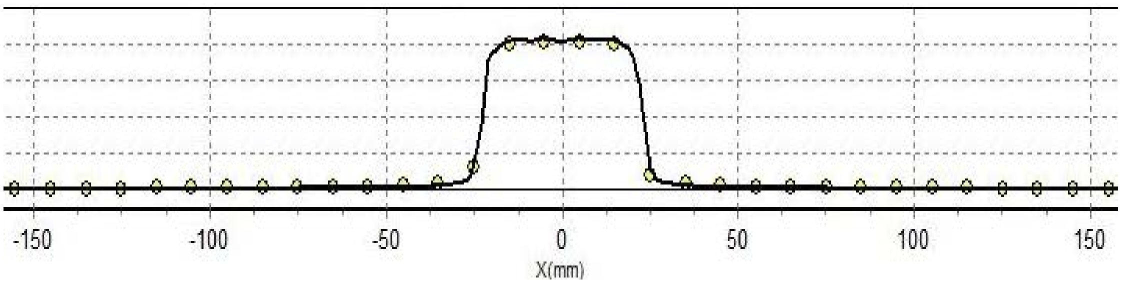


(B) Field size of 10x10 cm^2

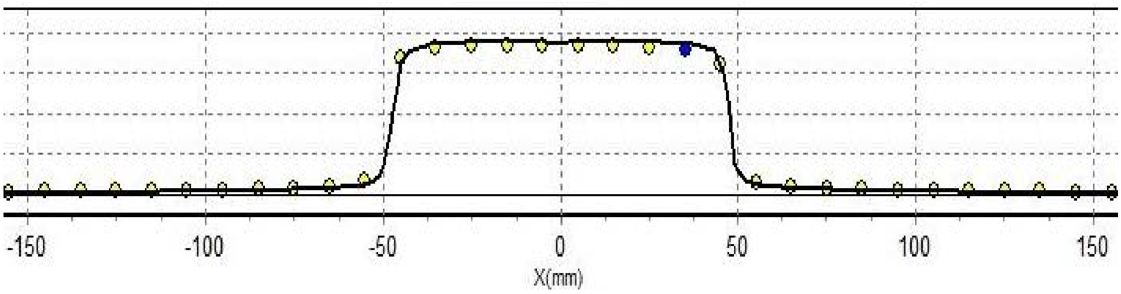


(C) Field size of 20x20 cm^2

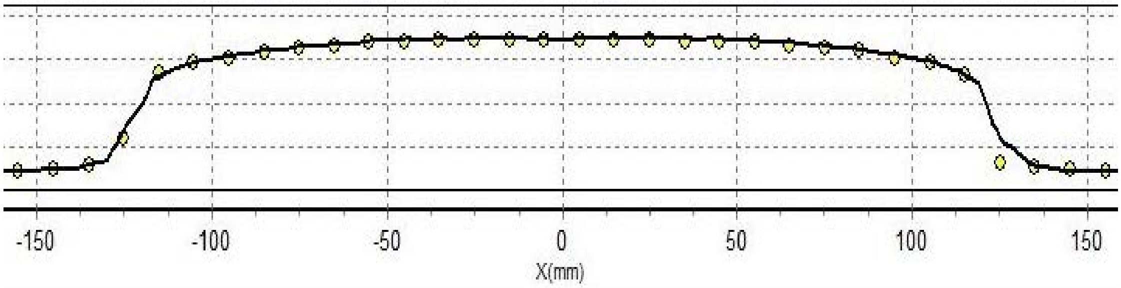
Figure 4.11 The comparison of beam profile measured by MapCHECK and calculated from Eclipse treatment planning for 5x5 cm^2, 10x10 cm^2 and 20x20 cm^2 open field.



(A) Field size of 5x5 cm^2



(B) Field size of 10x10 cm^2



(C) Field size of 20x20 cm^2

Figure 4.12 The comparison of beam profile measured by ArcCHECK and calculated from Eclipse treatment planning for 5x5 cm^2, 10x10 cm^2 and 20x20 cm^2 open field.

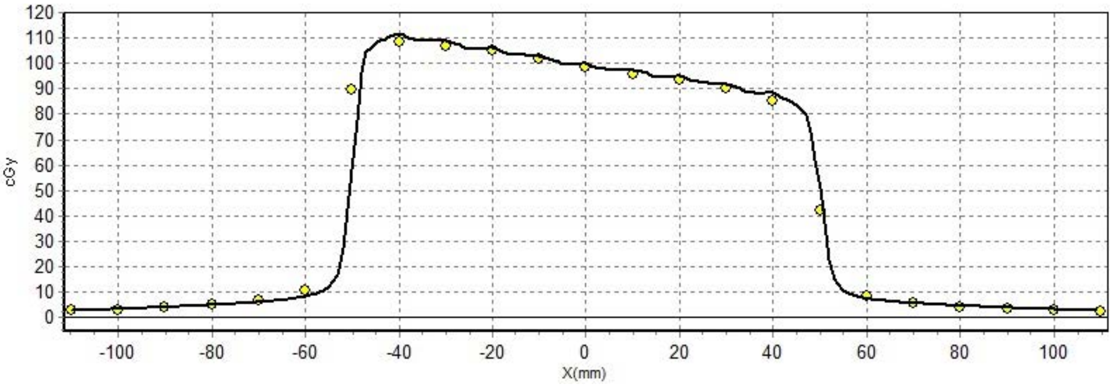


Figure 4.13 The comparison of beam profile with static wedge of 30° measured by MapCHECK and calculated from Eclipse treatment planning for 10x10 cm^2

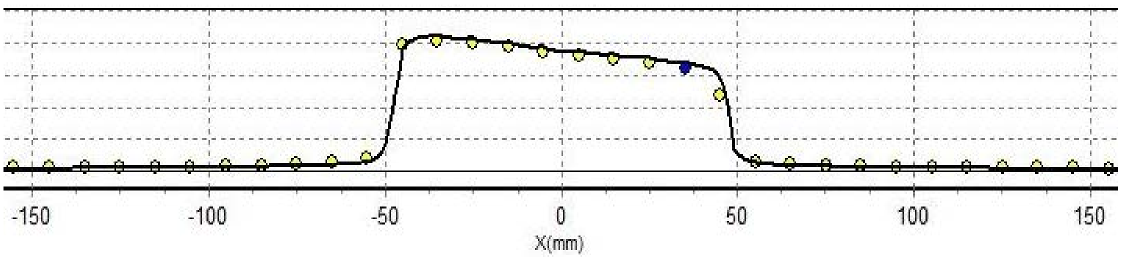


Figure 4.14 The comparison of beam profile with static wedge of 30° measured by ArcCHECK and calculated from Eclipse treatment planning for 10x10 cm^2

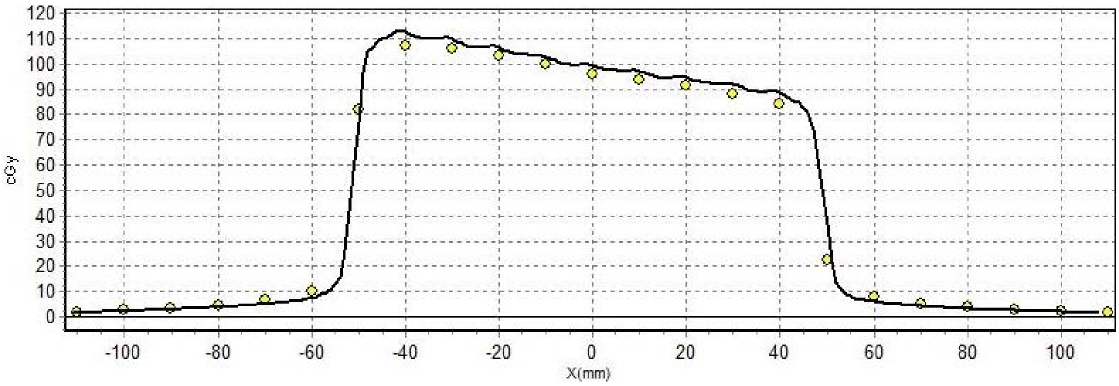


Figure 4.15 The comparison of beam profile with dynamic wedge of 30° measured by MapCHECK and calculated from Eclipse treatment planning for 10x10 cm^2

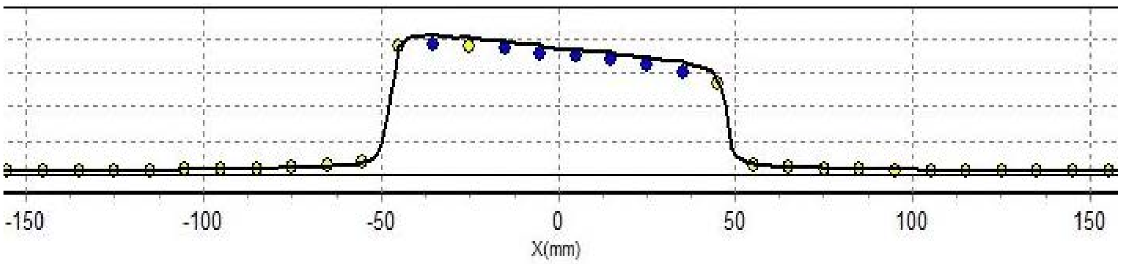
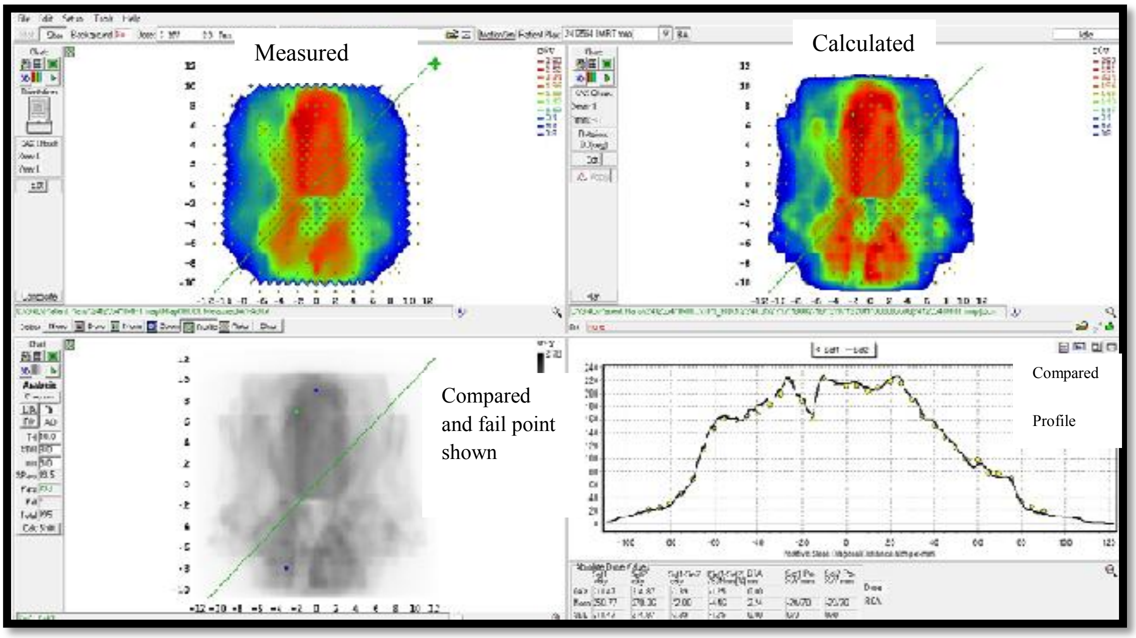


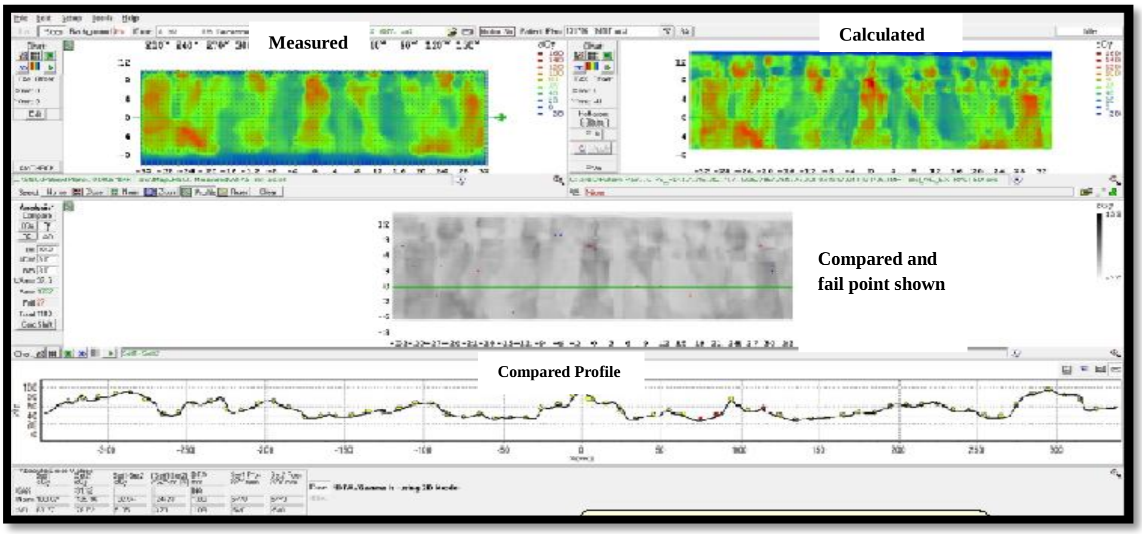
Figure 4.16 The comparison of beam profile with dynamic wedge of 30° measured by ArcCHECK and calculated from Eclipse treatment planning for 10x10 cm^2

4.2.2 Advance clinical application

MapCHECK and ArcCHECK were used for advance clinical application for IMRT and VMAT pre treatment verification. Fifteen IMRT and VMAT plans were selected for head and neck cases. A sample comparison between measured dose by the measurement devices and calculated dose is shown in figure 4.17 for MapCHECK and 4.18 for ArcCHECK.

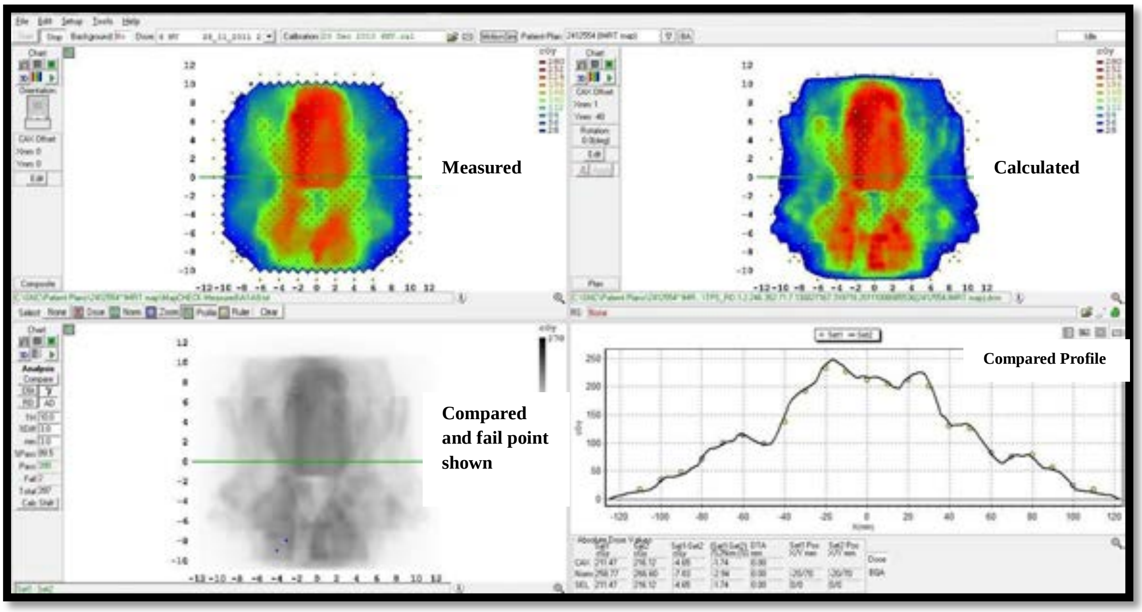


(a) IMRT plan verified by MapCHECK

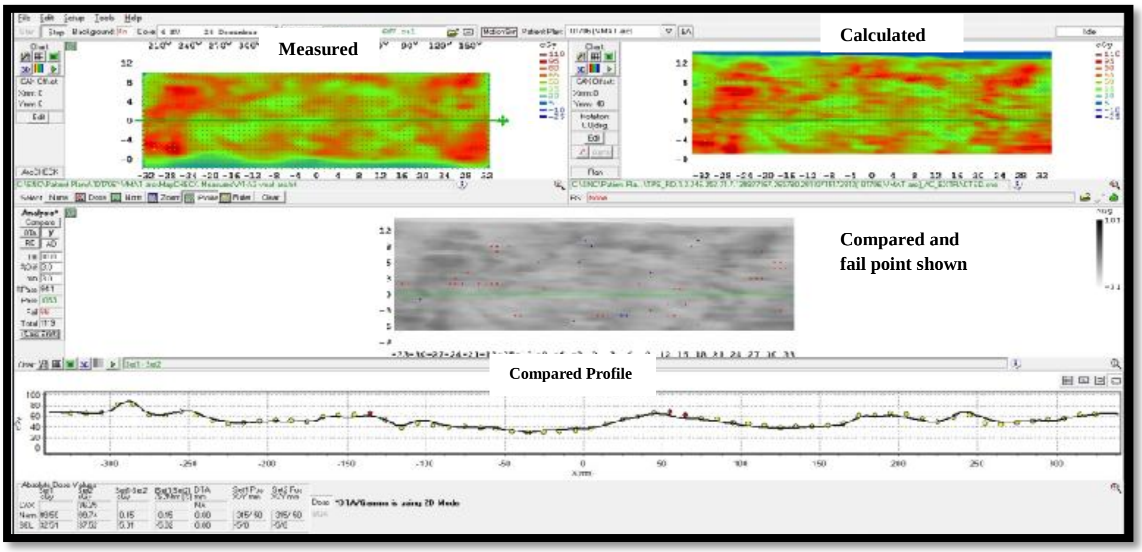


(b) VMAT plan verified by MapCHECK.

Figure 4.17 The example of MapCHECK data compared with TPS agreement shown here is within clinical acceptable criteria of 3 % or 3mm.



(a) IMRT plan verified by ArcCHECK.



VMAT plan verified by ArcCHECK.

Figure 4.18 The examples of ArcCHECK data compare with TPS agreement shown here is within clinical acceptable criteria of 3 % or 3mm.

For MapCHECK screen capture, the measured dose distribution is at the upper left and the calculated dose distributions are at the upper right. The comparison of fluence map between measured and calculated is at the lower left, if the dose and distance exceed the criteria the fail point will be shown, and the comparison between measured and calculated dose can also illustrate as profile as shown at the lower right. For ArcCHECK screen capture, the unrolling measured dose distribution is at the upper left and the calculated dose distributions are at the upper right. The fluence map between measured and calculated is at the middle part of the picture and the comparison between measured and calculated dose can also illustrate as profile as shown at the lower part of the picture.

The agreement between the measurement devices with treatment planning fluence maps were evaluated by gamma value which should not be greater than 1 for dose difference within 3% and DTA within 3mm. The failed diodes are shown in blue or red color dots when gamma value was more than 1. The red color dots mean that the measured dose is higher than the calculated dose and the blue color dots mean that the measured dose is lower than the calculated dose. The percentage passing of the diodes agreement with calculation from the treatment planning of more than 95% was set to be acceptable criteria for IMRT/VMAT verification.

- Verification of IMRT plan by MapCHECK and ArcCHECK

The percentage passing for fifteen IMRT cases verify by MapCHECK and ArcCHECK is shown in table 4.15. For MapCHECK, the percentage passing ranged from 94.00 to 97.70, the average percentage passing was 97.31 ± 1.49. The average number of detector was 344.80 ± 56.50. For ArcCHECK, the percentage passing ranged from 94.00 to 99.20, the average percentage passing was 97.21 ± 2.21. The average number of detector was 1049.31 ± 124. The bar graph is shown in figure 4.19. The results showed that, the percentage passing of MapCHECK was slightly higher than ArcCHECK.

Table 4.15 The percentage passing and the number of detectors for fifteen IMRT cases verify by MapCHECK and ArcCHECK

Case No.	IMRT			
	MapCHECK		ArcCHECK	
	No. of Detector	% Pass	No. of Detector	% Pass
1	307.00	94.00	1185.00	99.20
2	365.00	97.80	988.00	94.40
3	329.00	97.30	988.00	94.00
4	345.00	96.50	988.00	98.30
5	380.00	98.00	1119.00	98.40
6	354.00	97.50	1081.00	96.60
7	379.00	95.80	1119.00	98.80
8	428.00	98.80	988.00	99.60
9	254.00	96.40	931.00	98.60
10	299.00	96.40	1110.00	98.80
11	241.00	97.00	891.00	97.40
12	395.00	99.50	1120.00	97.80
13	435.00	98.40	1252.00	93.00
14	353.00	96.50	1186.00	99.00
15	308.00	99.70	791.00	94.20
Average ± SD	344.80 ± 56.50	97.31 ± 1.49	1049.13 ± 124	97.21 ± 2.21

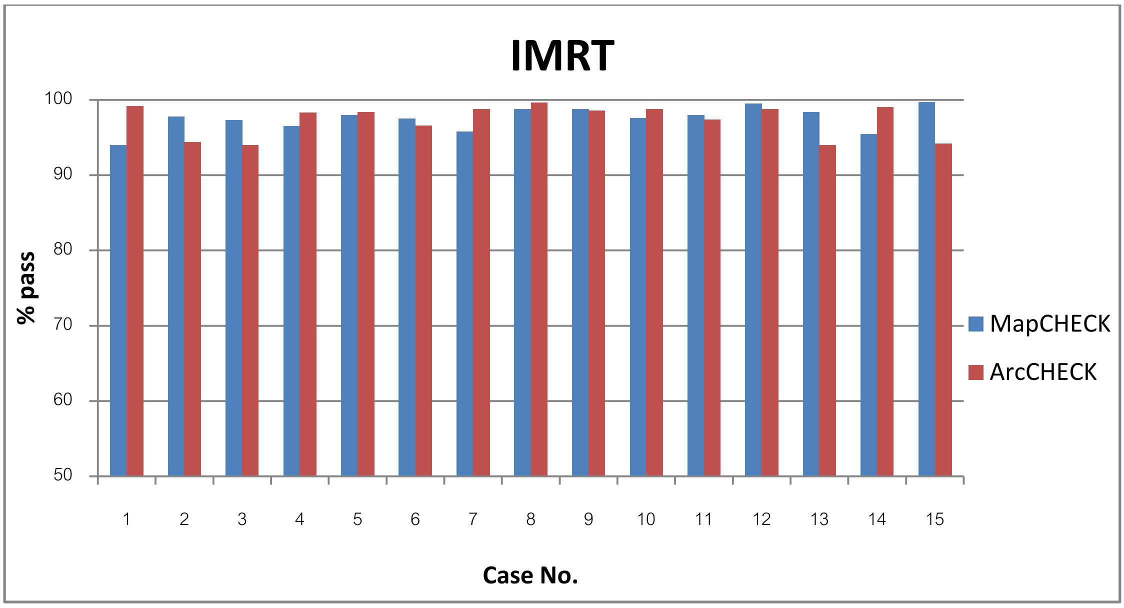


Figure 4.19 Comparison of the percentage passing for MapCHECK and ArcCHECK in IMRT pretreatment verification.

The mean gamma value and the standard deviation (SD) illustrated the distribution of gamma value in IMRT QA plan. The mean gamma value should be less than 0.5. The results are shown in table 4.16. The average of mean gamma was 0.45 ± 0.05 and 0.46 ± 0.06 for MapCHECK and ArcCHECK, respectively. The mean gamma value ranged from 0.35 to 0.53 and 0.35 to 0.56 for MapCHECK and ArcCHECK, respectively. The mean gamma value of ArcCHECK was higher than MapCHECK. The average standard deviations were 0.28 ± 0.02 and 0.30 ± 0.03 for MapCHECK and ArcCHECK, respectively. The standard deviation of gamma value ranged from 0.23 to 0.32 and 0.26 to 0.34 for MapCHECK and ArcCHECK, respectively. This study illustrated that the mean gamma value were agreed with percentage passing, if the percentage passing was higher the mean gamma value would be lower.

Table 4.16 The comparison of mean gamma value and standard deviation between MapCHECK and ArcCHECK of IMRT technique.

Case No.	IMRT			
	MapCHECK		ArcCHECK	
	Mean Y	SD Y	Mean Y	SD Y
1	0.43	0.23	0.36	0.28
2	0.46	0.29	0.56	0.34
3	0.51	0.29	0.46	0.29
4	0.50	0.30	0.48	0.29
5	0.49	0.29	0.44	0.29
6	0.45	0.28	0.49	0.31
7	0.53	0.32	0.41	0.28
8	0.45	0.30	0.35	0.25
9	0.37	0.26	0.52	0.27
10	0.42	0.30	0.42	0.27
11	0.48	0.28	0.49	0.26
12	0.40	0.28	0.44	0.35
13	0.38	0.28	0.55	0.36
14	0.48	0.28	0.42	0.28
15	0.35	0.24	0.49	0.34
Average ± SD	0.45 ± 0.05	0.28 ± 0.02	0.46 ± 0.06	0.30 ± 0.03

- Verification of VMAT plan by MapCHECK and ArcCHECK

The same cases as IMRT were replaned to VMAT. The result for fifteen VMAT cases verify by MapCHECK and ArcCHECK is shown in table 4.17. For MapCHECK, the percentage passing ranged from 96.00 to 100, the average percentage passing was 98.55 ± 1.12. The average number of detector was 410 ± 35.22. For ArcCHECK, the percentage passing ranged from 94.00 to 99.30, the average percentage passing was 97.04 ± 2.13. The average number of detector was 1064.53 ± 134. The bar graph is shown in figure 4.20. The results showed that, the percentage passing of MapCHECK was slightly higher than ArcCHECK.

Table 4.17 The percentage passing and the number of detectors for fifteen VMAT cases verify by MapCHECK and ArcCHECK

Case No.	VMAT			
	MapCHECK		ArcCHECK	
	No. of Detector	% Pass	No. of Detector	% Pass
1	416.00	96.60	1185.00	98.10
2	435.00	97.20	1054.00	94.60
3	434.00	99.50	1185.00	98.70
4	421.00	100.00	988.00	99.30
5	435.00	99.10	1054.00	99.00
6	435.00	98.20	1119.00	94.10
7	424.00	98.60	988.00	98.30
8	408.00	100.00	922.00	97.80
9	343.00	99.40	1040.00	98.10
10	389.00	99.20	1323.00	99.20
11	333.00	98.20	962.00	98.40
12	423.00	99.80	988.00	97.60
13	445.00	97.50	1185.00	94.70
14	438.00	97.30	1185.00	94.00
15	371.00	97.60	790.00	93.70
Average ± SD	410.00 ± 35.22	98.55 ± 1.12	1064.53 ± 134	97.04 ± 2.13

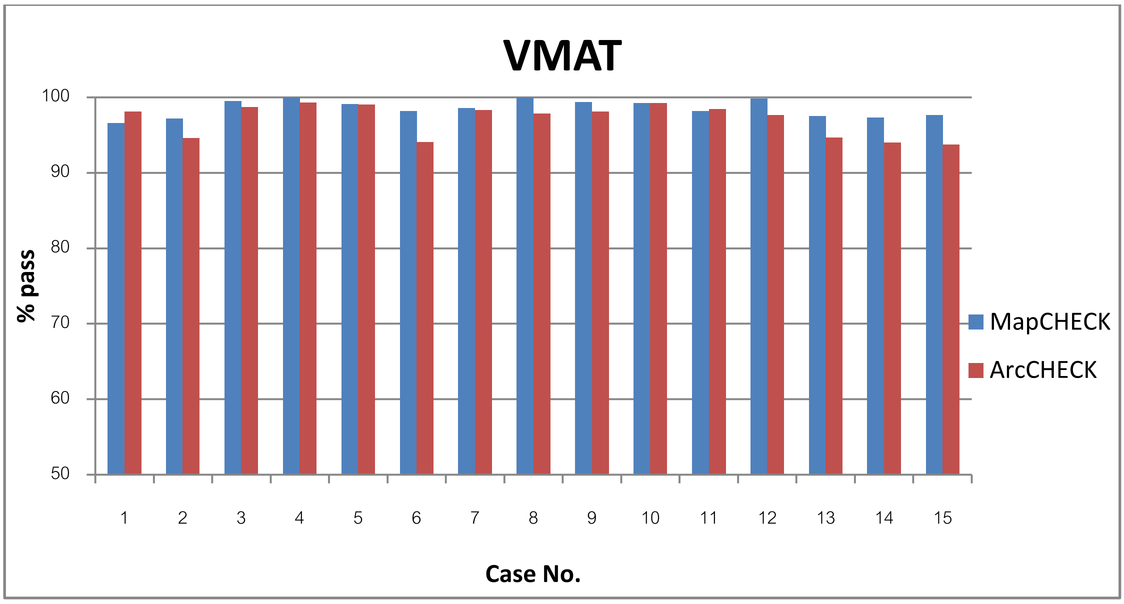


Figure 4.20 Comparison of the percentage passing for MapCHECK and ArcCHECK in VMAT pretreatment verification.

The mean gamma value and the standard deviation illustrated the distribution of gamma values in VMAT QA plan. The mean gamma value should be less than 0.5. The results are shown in table 4.18. The average of mean gamma was 0.37± 0.05 and 0.43 ± 0.06 for MapCHECK and ArcCHECK, respectively. The mean gamma value ranged from 0.30 to 0.47 and 0.36 to 0.56 for MapCHECK and ArcCHECK, respectively. The mean gamma value of ArcCHECK was higher than MapCHECK. The average standard deviations were 0.27 ± 0.03 and 0.30 ± 0.05 for MapCHECK and ArcCHECK, respectively. The standard deviation of gamma value ranged from 0.22 to 0.31 and 0.20 to 0.37 for MapCHECK and ArcCHECK, respectively.

Table 4.18 The comparison of mean gamma value and SD gamma value between MapCHECK and ArcCHECK of VMAT technique.

Case No.	VMAT			
	MapCHECK		ArcCHECK	
	Mean γ	SD γ	Mean γ	SD γ
1	0.38	0.29	0.38	0.28
2	0.40	0.31	0.45	0.36
3	0.38	0.27	0.42	0.29
4	0.30	0.22	0.36	0.20
5	0.38	0.25	0.40	0.27
6	0.47	0.29	0.53	0.33
7	0.39	0.29	0.40	0.29
8	0.36	0.23	0.36	0.30
9	0.33	0.25	0.41	0.26
10	0.32	0.24	0.35	0.26
11	0.31	0.24	0.42	0.25
12	0.32	0.23	0.43	0.32
13	0.38	0.30	0.49	0.36
14	0.41	0.30	0.50	0.37
15	0.39	0.28	0.56	0.37
Average ± SD	0.37 ± 0.05	0.27 ± 0.03	0.43 ± 0.06	0.30 ± 0.05

CHAPTER V

DISCUSSION AND CONCLUSIONS

5.1 Discussion

5.1.1 Study of detector properties

Linearity

The response of both detectors show linearity with the dose varying from 3-300 cGy corresponding to the others studies [14,15] the repeated 3 measurements illustrate the maximum %CV at low dose of 3 cGy, they are 0.49% and 0.36%CV for MapCHECK and ArcCHECK, respectively. The %CV decreases when the dose is higher and the % CV of ArcCHECK is lower and quite stable than MapCHECK.

Reproducibility

The 10 consecutive measurements over 90 minute for short term reproducibility are within ± 0.2% for both MapCHECK and ArcCHECK. These measurements include not only reproducibility of the detector but also the reproducibility of the beam output between measurements. For long term reproducibility, 12 measurements over 3 months are within ±1% for MapCHECK and ±2% ArcCHECK. There is more variation in diode response at week 7^{th} to week 8^{th} due to output adjustment. The graph plot of long term reproducibility of MapCHECK and ArcCHECK shown in figure 4.4 is already corrected for output variation.

Energy response

MapCHECK is more energy dependence; the diode response for 6 MV is lower than 10 MV. The 6 and 10 MV ratios reveal that the difference of the response for 6 and 10 MV is within 4% independence to the dose. ArcCHECK is also energy dependence; the diode response for 6 MV is lower than 10 MV The 6 and 10 MV ratios show that the difference of the response for 6 and 10 MV is within 2% independence to the dose. The energy response of MapCHECK is higher than ArcCHECK. Our MapCHECK is the old version since 2004, while ArcCHECK is the new version of 2010. The construction of diode in ArcCHECK would be made less energy dependence than MapCHECK.

Repeatability rate effect

The MapCHECK and ArcCHECK exhibit increasing sensitivity variation of 0.1% and 0.25% with increasing repetition rate, respectively. For this result, repeatability rate dependence of diode should not be concerned, especially for IMRT QA because all treatment is generally delivered with the same repetition rate.

Field size effect

The output factor for different field sizes with MapCHECK and ArcCHECK are also examined. For field size equal to 10x10 cm^2 and larger, MapCHEKC and ArcCHECK results agree generally to with 0.5% and 0.6%, respectively. At 3x3 cm^2 where the MapCHECK and ArcCHECK underestimate the output factor by 1.39% and 1.48 %, respectively. For small field size, the CC13 ionization chamber overestimates the output factor due to the volume averaging effect. For large field size the diode response overestimates resulting from the scatter dose [1]. This study shows similar result with Jonathan G. Li et al [11]

Dose rate effect

The diode dependence on dose rate is also examined by considering the ratios of the relative doses measured with MapCHECK and ArcCHECK for SSD of 80 to 120 cm. This change in SSD corresponds to a change in dose rate from 277.77 to 625 MU/min. The response of both detectors is within ±1% for dose rate effect. The dose rate response trends to be higher when the dose rate increase, the effect is small in MapCHECK. The dose rate dependence is related to radiation damage of the detectors so the detectors should be checked regularly in the pulsed beam of a LINAC, especially older high-resistivity diodes that have accumulated dose from high-energy photon beams [19].

5.1.2 Clinical application

The measurement devices are studied in basic clinical application in open and wedge field as demonstrated in figure 4.12-4.16. The measurements show good agreement with calculated dose for TPS using gamma evaluation in the criteria of 1% dose difference and 1 mm DTA. The percentage passing over 90% confirms the clinical used of these detectors in advance technique.

For advance clinical application in this study, we investigated differences between MapCHECK and ArcCHECK in IMRT and VMAT plan specific QA. The 15 head and neck IMRT and VMAT plans are measured using MapCHECK and ArcCHECK phantom and compare with the dose form TPS using gamma evaluation in the criteria of 3% dose difference and 3 mm DTA with 95% percentage passing.

In IMRT technique, the radiation delivered to MapCHECK are fixed to the gantry of 0 degree for all beams and rotating the gantry according to clinical used for ArcCHECK measurement. To confirm that there is no dose difference between the QA plan of fix gantry at 0 degree and rotating gantry, we select several cases form 15 plans to deliver the dose by rotating the gantry to MapCHECK and we find that there are no statistical significant different result between fixed and rotated the gantry to MapCHECK in IMRT technique when compared with the treatment planning.

For 15 IMRT head and neck cases, we find that MapCHECK can produce comparable percentage passing as ArcCHECK. The average percentage passing is 97.31± 1.49 with the mean gamma of 0.45 ± 0.05 for MapCHECK. The average percentage passing is 97.21± 2.21 with the mean gamma of 0.46 ± 0.06 for ArcCHECK. The average no. of detector of MapCHECK is 344.80 and ArcCHECK is 1049.13.

The same patients as IMRT are created to VMAT plan. VMAT plans are measured using MapCHECK and ArcCHECK phantom by rotating the gantry to both measurement devices with the same angle as treated patient. The QA results are comparable between MapCHECK and ArcCHECK. The average percentage passing is 98.55 ± 1.12 with the mean gamma of 0.37 ± 0.05 for MapCHECK and the average percentage passing is 97.40 ± 2.13 with the mean gamma of 0.43 ± 0.05 for ArcCHECK. The average number of detector of MapCHECK is 410 and ArcCHECK is 1064.

The percentage passing of MapCHECK is slightly higher than ArcCHECK and the mean gamma value of MapCHECK is slightly lower than ArcCHECK for both treatment techniques. These are due to the more dose measurement point that increases the chance of dose difference, and also the geometry of the detector. MapCHECK is a planar geometry which cannot detect high dose gradient in the sensitive area in some gantry angle, while ArcCHECK detector geometry is a cylindrical shape, where the detector spiral down the cylinder. It can maximize detector distribution for each beam angle, so less point missing attribute to more dose difference.

5.1.3 Comparison to previous works

There were other studies reporting the results of patient specific QA similar to our study as shown in table 5.1

Table 5.1 The average percentage passing compared with other studies

	IMRT		VMAT	
	MapCHECK	ArcCHECK	MapCHECK	ArcCHECK
Daniel et al.	96.40	–	–	–
R. Nobel et al.	–	–	–	>95
Aime et al.	–	–	97.52	–
This study	97.31	97.21	98.55	97.40

Danial et al. [12] evaluated MapCHECK for IMRT QA. Their study showed a 96.4 % average passing rate compare to 97.31 of our study. The study suggested that, the ability of MapCHECK to simultaneously both relative and absolute dose measurement can simplify and reduce IMRT QA work load

R Nobel et al. [13] evaluated ArcCHECK for RapicArc QA. All plans delivered the pass of the gamma analysis (3%/3mm) with the pass rate of >95%. Our percentage average passing rate is 97.40.

Aime M. et al. [14] reported that MapCHECK obtained a 97.52% average passing rate for QA of RapidArc therapies, using criteria of 3%3mm. These results are similar to our MapCHECK results of 98.55% average passing rate for VMAT.

5.2 Conclusions

The difference of dosimetric verification result in IMRT and VMAT patient planning in this study are evaluated by using MapCHECK and ArcCHECK. The performances of devices are studied before clinical used.

The diode response is linear for both detectors. The MapCHECK and ArcCHECK reading are reproducible to within ± 0.02 % for short term reproducibility and ± 2% for long term reproducibility. The Energy dependence of MapCHECK and ArcCHECK in 6 and 10 MV is within ± 4% and ± 2%, respectively. The repeatability rate effect is within ±0.1% for MapCHECK and within ±0.25% for ArcCHECK. The field size effect of the measurement devices agree within ±1% to the ionization chamber for field size larger than 3x3 cm^2. The dose rate response is within ±1% for both detectors.

For clinical application, MapCHECK and ArcCHECK illustrate good agreement with TPS for open and wedge field. IMRT and VMAT of 15 plans are verified by MapCHECK and ArcCHECK, The agreement between TPS with measurement dose is evaluated by gamma analysis for the dose different of 3% and the DTA of 3 mm, the criteria of the percentage passing is 95%.

We found that the IMRT and VMAT verification result are comparable for MapCHECK and ArcCHECK. The statistical analyze of the agreement of MapCHECK and ArcCHECK for treatment plan QA results show no statistical significantly differences between 2 kinds of the measurement devices. The study concludes that, the performances of devices should be studied before clinical used.The both detectors have excellent performance. MapCHECK and ArcCHECK are suitable for IMRT and VMAT pre treatment verifications.

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