การเปรียบเทียบปริมาณรังสีที่ผิวระหว่างการคำนวณด้วย Acuros XB และ
Anisotropic Analytical Algorithm ในการรักษามะเร็งเต้านมด้วยรังสี

นางสาวซุย ซุย ลิน

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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Surface dose comparison between Acuros XB and Anisotropic Analytical Algorithm

for breast cancer radiotherapy

Miss Swe Swe Lin

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ซุย ซุย ลิน : การเปรียบเทียบปริมาณรังสีที่ผิวระหว่างการคำนวณด้วย Acuros XB และ Anisotropic Analytical Algorithm ในการรักษามะเร็งเต้านมด้วยรังสี (Surface dose comparison between Acuros XB and Anisotropic Analytical Algorithm for breast cancer radiotherapy) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ศิวลี สุริยาปี, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ดร. ทวีป แสงแห่งธรรม, 71 หน้า.

เครื่องวางแผนการรักษา *Eclipse* ได้เสนออการคำนวณปริมาณรังสีแบบใหม่ คือ *Acuros XB* อัลกอริทึมที่ใช้สมการ *Linear Boltzmann transport* ในการแก้ค่าผลของความไม่สม่ำเสมอของเนื้อเยื่อในร่างกายผู้ป่วย วัตถุประสงค์ของงานวิจัยครั้งนี้ เพื่อเปรียบเทียบความแตกต่างของปริมาณรังสีที่ผิวในการฉายรังสีผู้ป่วยมะเร็งเต้านมระหว่างการคำนวณปริมาณรังสีโดยใช้ *AAA* และ *Acuros XB* อัลกอริทึม เริ่มต้นจากทำการตรวจสอบความถูกต้องของปริมาณรังสีที่ผิวในหุ่นจำลองที่มีความหนาแน่นอิเล็กตรอนใกล้เคียงน้ำและหุ่นจำลองที่มีโครงสร้างคล้ายช่วงทรวงอกมนุษย์ *(CIRS)* จากนั้นทำการศึกษาในผู้ป่วยมะเร็งเต้านมที่ไม่ได้ผ่าเต้านมออกจำนวน *12* ราย ทำการวางแผนในเทคนิค *open field, standard wedged tangent (SWT), electronic compensator (E Comp), field-in-field (FF), tangential intensity modulated radiation therapy (T IMRT), coplanar intensity modulated radiation therapy (CP IMRT), non-coplanar intensity modulated radiation therapy (NCP IMRT) and volumetric modulated arc therapy (VMAT)* จากเครื่องวางแผนการรักษา *Eclipse* โดยใช้ *AAA* และ *Acuros XB* อัลกอริทึมในการคำนวณปริมาณรังสี ทำการอ่านค่าปริมาณรังสีที่ผิว ที่ความลึก *4* และ *6* มม ที่ตำแหน่งยอด ข้างด้านใน และข้างด้านนอกในแนวแกนกลางลำรังสี จากการทดลองพบว่า ปริมาณรังสีที่ผิวในหุ่นจำลองที่มีความหนาแน่นอิเล็กตรอนใกล้เคียงน้ำระหว่างการคำนวณด้วย *AAA* และ *Acuros XB* อัลกอริทึม มีค่าสูงกว่าค่าจากการวัดจริงด้วยฟิล์มที่ *33.32%* และ *12.31%* ตามลำดับ การตรวจสอบความถูกต้องของปริมาณรังสีในหุ่นจำลองที่มีโครงสร้างคล้ายช่วงทรวงอกมนุษย์ *(CIRS)* ที่ผิวแสดงค่าปริมาณสูงกว่าการวัดด้วยฟิล์มที่ *28.96%* และ *14.31%* สำหรับ *AAA* และ *Acuros XB* อัลกอริทึม ตามลำดับ ในส่วนของผู้ป่วยจริงปริมาณรังสีที่ผิวจากการคำนวณด้วย *2* อัลกอริทึมมีความแตกต่างและความแปรปรวนของข้อมูลค่อนข้างสูง ที่ *20.69±10.45%* ที่ตำแหน่งข้างด้านในและข้างด้านนอกของเต้านมความแตกต่างของปริมาณรังสีจาก *2* อัลกอริทึมไม่สูง ที่ความลึก *6* มม ปริมาณรังสีจากทั้ง *2* อัลกอริทึม มีความแตกต่างกันเพียงเล็กน้อย โดยความแตกต่างอยู่ภายใน *6%* ซึ่งผลคล้ายคลึงกับงานวิจัยของ *Akino* สามารถสรุปได้ว่าโปรแกรมการคำนวณปริมาณจากทั้ง *2* อัลกอริทึม ไม่ถูกต้องบริเวณที่ผิวเมื่อทำการตรวจสอบปริมาณรังสีด้วยฟิล์ม *EBT2* ในทั้งหุ่นจำลองที่มีความหนาแน่นอิเล็กตรอนใกล้เคียงน้ำและหุ่นจำลองที่มีโครงสร้างคล้ายช่วงทรวงอกมนุษย์ และพบว่าการคำนวณปริมาณรังสีจากทั้ง *2* อัลกอริทึมมีความแตกต่างกันสูงที่ผิว โดยเฉพาะในเทคนิคการรักษาแบบ *CP IMRT* และ *VMAT* แต่ที่ความลึกตั้งแต่ *6* มม ขึ้นไปปริมาณรังสีที่คำนวณได้จากทั้ง *2* อัลกอริทึมมีความแตกต่างกันเพียงเล็กน้อย โดยจะเห็นว่าปริมาณรังสีที่ผิวในการฉายรังสีผู้ป่วยมะเร็งเต้านมขึ้นกับรูปร่างของเต้านมและเทคนิคการรักษาที่ใช้

ภาควิชา รังสีวิทยา	ลายมือชื่อนิสิต ....
สาขาวิชา ฉายาเวชศาสตร์	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....
ปีการศึกษา 2557	ลายมือชื่อ อ.ที่ปรึกษาร่วม ....

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KEYWORDS: SURFACE DOSE / AAA / ACUROS XB / IMRT / VMAT

SWE SWE LIN: Surface dose comparison between Acuros XB and Anisotropic Analytical Algorithmfor breast cancer radiotherapy. ADVISOR: ASSOC. PROF. SIVALEE SURIYAPEE, CO-ADVISOR: TAWEAP SANGHANGTHUM, Ph.D., 71 pp.

A new algorithm for photon dose calculation, Acuros XB, has been recently introduced in the new version of Eclipse treatment planning, it employs a sophisticated Linear Boltzmann transport equation (LBTE) to account for the effects of heterogeneities in patient dose calculation. The purpose of this research is to compare the surface dose between AAA and the new algorithm Acuros XB in breast cancer radiotherapy techniques. The study was performed for surface dose verification in the homogenous solid water phantom and non-homogeneous CIRS thorax phantom. Moreover, the surface doses of 12 breast conserving surgery cases were investigated with 8 treatment planning techniques, i.e. open field, standard wedged tangent (SWT), electronic compensator (E Comp), field-in-field (FF), tangential intensity modulated radiation therapy (T IMRT), coplanar intensity modulated radiation therapy (CP IMRT), non-coplanar intensity modulated radiation therapy (NCP IMRT) and volumetric modulated arc therapy (VMAT) in Eclipse treatment planning system (TPS) using AAA and Acuros XB. The surface point doses were recorded at tip, medial and lateral sides of the breast at the surface, 4mm, 6mm depth and compared in both algorithms. The surface dose verification in homogeneous phantom showed AAA and Acuros XB calculation were higher than film measurement of 33.32% and 12.31%, respectively. The verification in CIRS phantom illustrated that AAA and Acuros XB were 28.96% and 14.31%, respectively, underestimated dose than film measurement at the surface. For the patient analysis, the tip of the breast showed the highest differences for surface between two algorithms, especially CP IMRT and VMAT techniques. The surface dose differences of the lateral side was much higher than the medial side of the breast. At the deeper depth start from 6mm, both calculation algorithms showed the good agreement approximately 6% for all techniques, which agreed with Akino et al study. It is concluded that the treatment planning system cannot give the accurate dose for surface dose calculation, as verified with the EBT2 film on homogeneous slab phantom and non-homogeneous CIRS thorax IMRT phantom. Acuros XB contributes very high dose differences to the AAA at the surface, especially CP IMRT and VMAT, but comparable at the deeper depth starting from 6 mm. The surface dose for breast radiotherapy depends on the geometry of the structure and treatment techniques used.

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

Abbreviation	Terms
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
TPS	Treatment Planning System
TLD	Thermoluminescent Dosimeter
2D	Two-Dimensional
3D/3DCRT	Three-Dimensional Conformal Radiotherapy
IMRT	Intensity Modulated Radiation Therapy
VMAT	Volumetric Modulated Arc Therapy
AAA	Analytical Anisotropic Algorithm
Acuros XB	Acuros XB Algorithm
BTE	Boltzmann Transport Equation
LBTE	Linear Boltzmann Transport Equation
T/N	Tumor Extent/ Nodal Involvement
SWT	Standard Wedge Tangent
E Comp/eComp	Electronic Compensator
FF	Field-in-Field
T IMRT	Tangential Intensity Modulated Radiation Therapy
CP IMRT	Coplanar Intensity Modulated Radiation Therapy
NCP IMRT	Non-Coplanar Intensity Modulated Radiation Therapy

TCP	Tumor Control Probability
NTCP	Normal Tissue Complication Probability
CT	Computed Tomography
MRI	Magnetic Resonance Imaging
PET	Positron Emission Tomography
MLC	Multi-Leaf Collimator
MU	Monitor Unit
DSAR	Differential Scatter Air Ratio
TERMA	Total Energy Released Per Mass
D_W	Dose-to-Water
D_M	Dose-to-Medium
PDD	Percent Depth Dose
CIRS	Computerized Imaging Reference Systems
DTA	Distance to Agreement
MV	Mega Voltage
DRR	Digitally Reconstructed Radiograph
PA	Posterior Anterior
SSD	Source to Surface Distance
Dmax	the Depth of Dose Maximum
CTV	Clinical Target Volume
PTV	Planning Target Volume
AAPM	American Association of Physicists in Medicine
HU	Hounsfield Unit

CHAPTER 1

INTRODUCTION

1.1 Background and Rationale

Radiotherapy is the standard treatment of breast cancer after complete surgery.[1] The common rationale for post-operative radiotherapy is to reduce local recurrence but radiation therapy contribute to late toxicities and poor cosmetic outcomes.[2] The superficial dose coverage is important if the tumor has extension close to the skin. Therefore, the skin dose accuracy in radiation treatment of breast cancer is important for the cosmetic outcomes. According to the ICRP and ICRU recommendations, skin dose should be accessed at a depth of 70 µm, which corresponds to the boundary between the dermis and epidermis layers of the skin.[3, 4] The term "skin dose" is a clinical term and refers to the dose to the radiation sensitive epithelial layer, while the term "surface dose" is used to describe the dose to an infinitesimal mass at the very surface of a phantom.[5] Determination of surface dose by measurement is difficult and also the surface dose calculation from advanced radiotherapy treatment planning systems (TPS) are not accurate because electronic equilibrium is not established in that region. The surface dose can be measured with extrapolation chambers, plane parallel chambers, TLD and films.[6]

The breast is the special organ, it lies on the chest wall and very close to the critical organs like heart and lung. To reduce the radiation dose to that critical organs, the tangential beams are normally employed for the breast radiotherapy. The dose delivered to the breast, which is non-uniform geometry structure, is not homogeneous. Therefore, treatment techniques for the breast radiotherapy have to be considered for the dose reduction to the critical organs and also the correction for difference depth. The skin dose assessment for breast also becomes more complicated. There are many kinds of techniques to treat the breast cancer; conventional radiotherapy (2D), conformal radiotherapy (3DCRT), intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT).[7] Treatment plan for the radiotherapy is obtained by using the advanced treatment planning system. The advanced dose calculation in the Eclipse Treatment planning is undertaken by the dose calculation algorithm like Analytical Anisotropic Algorithm (AAA) and Acuros XB. The AAA dose calculation model is a 3D pencil beam convolution-superposition algorithm that has separated modeling for primary photons, scattered extra-focal photons and electrons scattered from the beam limiting devices. In AAA, the clinical broad beam is divided into small, finite-sized beamlets to which the convolutions are applied.[8] The new algorithm, Acuros XB uses a sophisticated technique to solve the Linear Boltzmann transport equation (LBTE) and directly accounts for the effects of heterogeneities in patient dose calculation. To calculate dose with Acuros XB, it needs

to have a material map of the imaged patient. Unlike convolution/superposition algorithms, where heterogeneities are generally handled as density based corrections applied to dose kernels calculated in water, Acuros XB explicitly models the physical interaction of radiation with matter.[9]

The purpose of this study is to investigate the surface doses of eight treatment techniques, to monitor and to guarantee for the consistency between Acuros XB and analytical anisotropic algorithm (AAA) planning systems with the dose delivery. Finally, comparison for surface dose and dose in build-up region between Acuros XB and analytical anisotropic algorithm (AAA) is evaluated.

1.2 Objective

To compare the surface dose difference between Acuros XB and analytical anisotropic algorithm (AAA) in breast cancer radiotherapy techniques.

CHAPTER 2
REVIEW OF RELATED LITERATURE

2.1 Theory

2.1.1 Breast Cancer

Breast cancer is the term given to a variety of malignant tumors that forms in tissues of the breast. The most common type of breast cancer is ductal carcinoma, which begins in the lining of the thin tubes that carry milk from the lobules of the breast. Another type of breast cancer is lobular carcinoma, which begins in the lobules of the breast. Invasive breast cancer is the breast cancer that has spread from where it began in the breast ducts or lobules to surrounding normal tissue.[10]

2.1.2 Treatment and Clinical Trials

Invasive breast cancer usually requires surgical treatment, as well as treatment after surgery, including radiation. Two options exist for breast surgery; mastectomy (removal of the entire breast) and breast conserving surgery (removal of the cancerous area and a small amount of surrounding tissue). Clinical T1, T2 less than 3cm, N0 invasive breast cancers are treated by wide local excision (conservative surgery) followed by radiotherapy. Patients with operable tumors which are 3-4 cm or more in diameter have a higher local recurrence rate with conservative surgery and radiotherapy, and may be offered primary chemotherapy. All patients who have microscopic tumor present at a resection margin should be considered for tumor bed boost radiotherapy. Post-mastectomy radiotherapy is recommended for patients with T3, T4 tumors and with 4 or more positive axillary nodes. For inoperable T3 and T4 tumors, primary systemic therapy is given before combined local treatment. If no axillary surgery has been performed, axillary radiotherapy may not be indicated. Lymph node irradiation is a little more complicated and some parts is still in clinical trials. Palliative radiotherapy is a major role for the locally advanced and fungating breast tumors with symptomatic metastases sites.[1]

2.1.3 Treatment Techniques for Breast Radiotherapy

There are two kinds of radiotherapy treatment, external and internal (brachytherapy) radiotherapy for the breast cancer. The external beam radiotherapy is the standard treatment for breast cancer. There are many techniques for external beam treatment. They are roughly named as conventional radiotherapy (2D), conformal radiotherapy (3DCRT), intensity modulated radiation therapy (IMRT) and volumetric

modulated arc therapy (VMAT). The treatment technique chosen depends on the staging, prognosis and the other factors.

2.1.3.1 Conventional Radiotherapy

Two-dimensional (2-D) treatment planning is a standardized treatment techniques applied mostly to palliative cases. In this technique, a single patient contour using lead wire or plaster strips is transcribed on to a sheet of graph paper with identify reference points, manual or a 2-D computer treatment planning system used for calculation of dose distributions for X-rays and electron treatment. Nowadays, computed tomography is used for contouring the surface and organ at risk in the central slice to calculate the dose for 2D conventional radiotherapy.[6]

(a) Open Field

This technique is a standard 2D conventional radiotherapy for breast cancer. In this technique, two parallel opposing tangential beams are used without any beam modifiers. This technique cannot account for the different depth of the non-uniform breast geometry. Therefore, some of the breast area get the high isodose distribution called hot spot area, especially at the tip of the breast. (Fig 2.1)
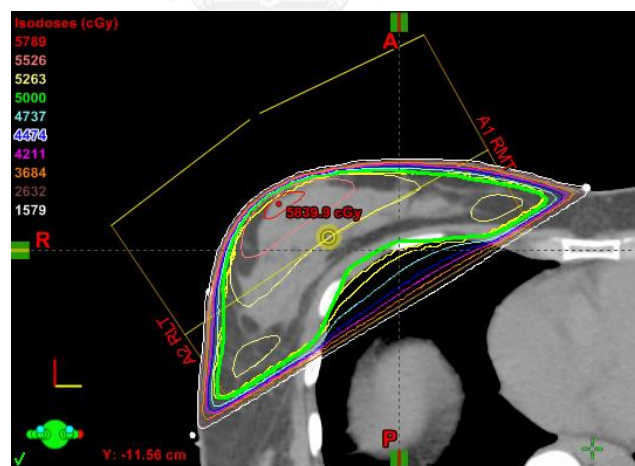
Figure 2.1 Breast treatment plan for Open Field technique

(b) Standard Wedge Tangent (SWT)

This technique is also a 2D conventional radiotherapy for breast cancer and the radiation beam is arranged as tangential beam. However, the beam-modifying devices called wedge filter is used to get the dose homogeneity on the breast organ. In this technique, the thick and thin part of the wedge filter cannot fully compensate the depth

effect of the non-uniform breast structure and the hot spot area is observed on some part of breast. (Fig 2.2)[7]
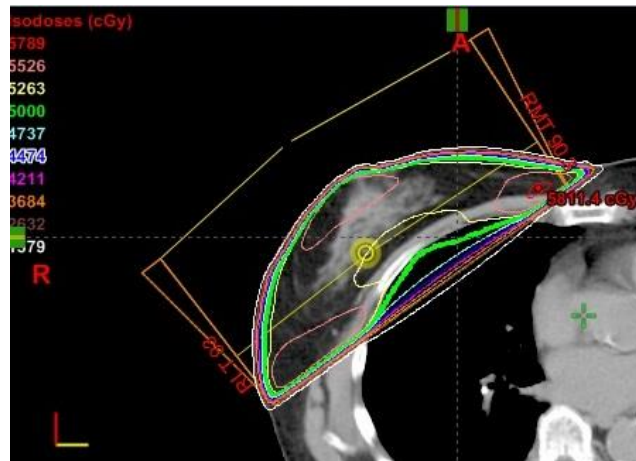
Figure 2.2 Breast treatment plan for Standard Wedged Tangent technique

2.1.3.2 Three- Dimensional Conformal Radiotherapy

Three-dimensional conformal radiation therapy (3DCRT) is based on 3D anatomic information and employed dose distributions that conform as closely as possible to the target volume in terms of adequate dose to the tumor and minimized possible dose to normal tissue. The concept of conformal dose distribution has been extended to include clinical objectives such as maximizing tumor control probability (TCP) and minimizing normal tissue complication probability (NTCP). In 3D CRT, modern imaging modalities such as computed tomography (CT), magnetic resonance imaging (MRI) and positron emission tomography (PET) are used to accurately delineate target volume and normal structure in computer based treatment planning system.[11]

(a) Field-in-Field (FF)

This technique is a three-dimensional conformal radiotherapy for breast radiotherapy. In this technique, radiation beam is arranged by giving the additional fields placing within the existing field to get the dose homogeneity of the breast. This isodose distribution can account for the depth effect of the breast. (Fig 2.3)[12]
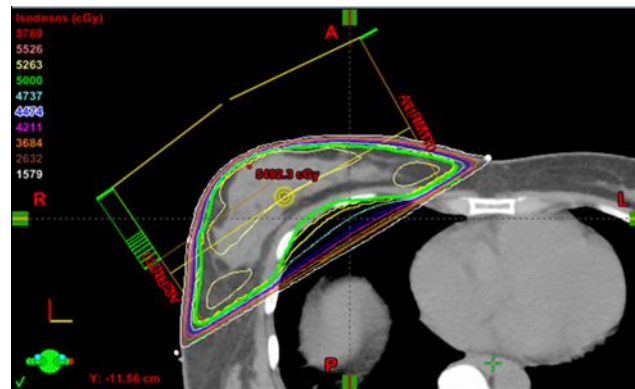
Figure 2.3 Breast treatment plan for Field-in-Field technique

(b) Electronic Compensator (E Comp)

This is a three dimensional conformal radiotherapy technique that multi-leaf collimator (MLC) is used as tissue compensator. In this technique, MLC is moved dynamically during the treatment to compensate the dose to the curved surface area of the breast. (Fig 2.4)[7]
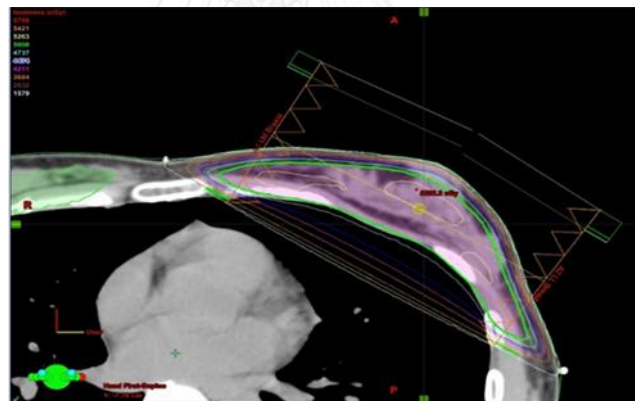
Figure 2.4 Breast treatment plan for Electronic Compensator technique

2.1.3.3 Intensity Modulated Radiation Therapy

The term intensity modulated radiation therapy (IMRT) refers to the radiation therapy technique in which non uniform fluence is delivered to the patient at any given position of the treatment beam to optimize the composite dose distribution. The treatment criteria for plan optimization are specified by the planner and the optimal fluence profiles for a given set of beam direction are determined through inverse planning. The fluence files generated are electronically transmitted to the linear accelerator, which is computer control, that is, equipped with the required software and hardware to deliver the intensity modulated beams as calculated.[11]

(a) Tangential Intensity Modulated Radiation Therapy (T IMRT)

This is an intensity modulated radiation therapy technique that two tangential beams arrangement is employed. An inverse planning technique are employed with the optimization dose to obtain the conformal dose in the target and minimum dose to the critical organ. (Fig 2.5)[7]
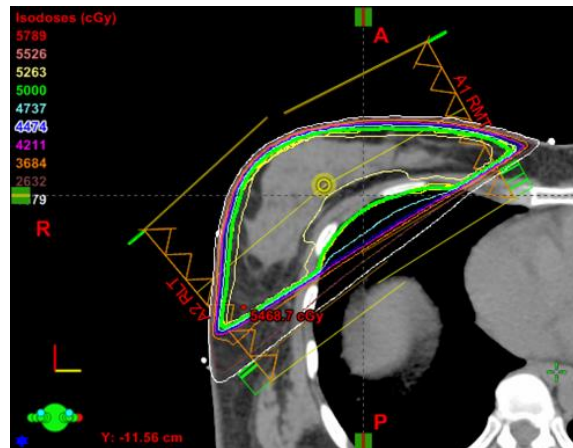
Figure 2.5 Breast treatment plan for Tangential Intensity Modulated Radiation Therapy technique

(b) Coplanar Intensity Modulated Radiation Therapy (CP IMRT)

This is an intensity modulated radiation therapy technique that uses multiple fields' arrangement in coplanar plane. An inverse planning technique is undertaken using optimization dose constraints to optimize the lower dose to the critical organ. (Fig 2.6)[7]
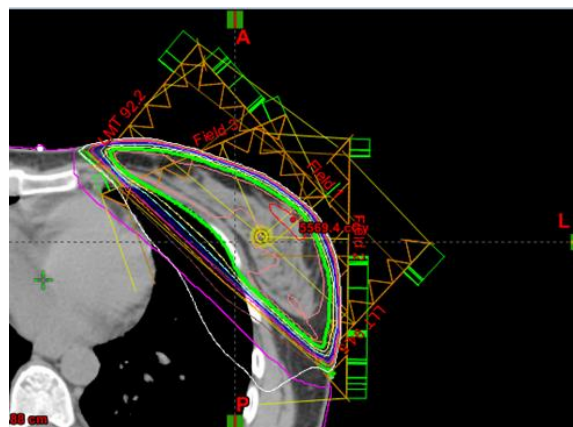
Figure 2.6 Breast treatment plan for Coplanar Intensity Modulated Radiation Therapy technique

(c) Non-Coplanar Intensity Modulated Radiation Therapy (NCP IMRT)

This is an intensity modulated radiation therapy technique that uses multiple field arrangement in non-coplanar plane. An inverse planning technique is undertaken using optimization dose constraints to optimize the dose to the critical organ. This technique is suitable for irregular target volume. (Fig 2.7)[7]
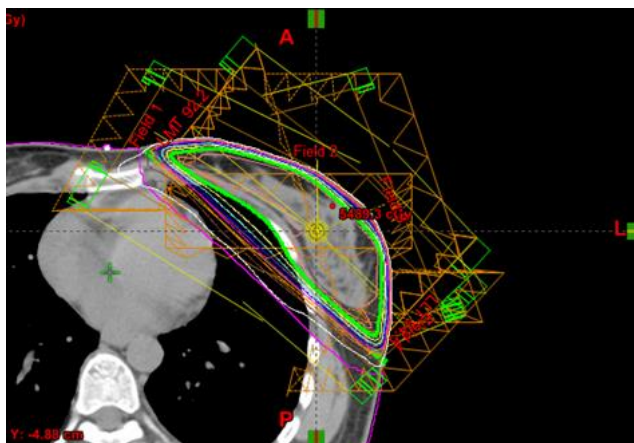
Figure 2.7 Breast treatment plan for Non-Coplanar Intensity Modulated Radiation Therapy technique

(d) Volumetric Modulated Arc Therapy (VMAT)

Volumetric modulated arc therapy is the advanced technique of the intensity modulated radiation therapy that delivers the arc beam. During the gantry move like arc beam therapy, MLC will move, MU and dose rate also can vary dynamically in this technique. (Fig 2.8)
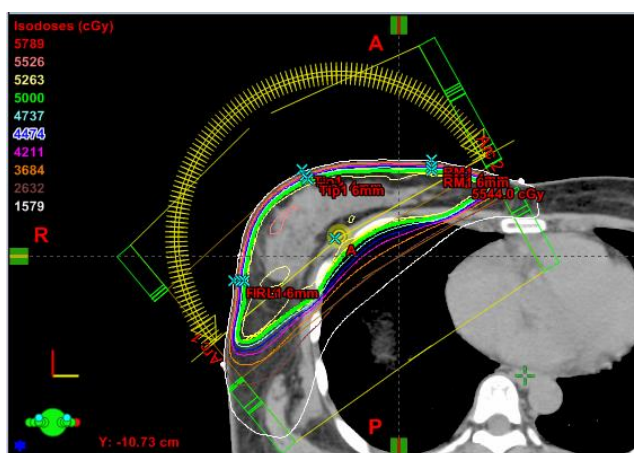
Figure 2.8 Breast treatment plan for Volumetric Modulated Arc Therapy technique

2.1.4 Surface Dose

The surface dose is defined as the dose deposited at the boundary between the air and the phantom.[13] For megavoltage photon beams the surface dose is generally much lower than maximum dose. The surface dose depends on beam energy and field size. The surface dose represents contributions of the dose from photons scattered from the collimators, flattening filter and air, photons backscattered from the patient, high energy electrons produced by photon interactions in air and any shielding structures in the vicinity of the patient.[6] The charged particles released in the treatment machine head and the air column between the head and the irradiated medium contaminate the primary beam and that contribute the dose in the surface and buildup region.[14]

The surface dose is very difficult to measure due to electronic equilibrium is not establish in that region. Therefore, the choice of the measurement device is very important. The variety of dosimeters can be used such as extrapolation ionization chamber, fixed-separation parallel-plate ionization chambers, TLDs, diodes and films. The reference against which surface dose measurements are usually compared is the extrapolation chamber. However, measurements with the extrapolation chamber are time consuming, as each dose value is obtained by extrapolating several measurements to the zero volume.[13] The dose gradient as the surface is very steep at approximately 2% for every 2.1 mm so that the true depth at which the surface is reported becomes critical. It should also be noted that the surface dose depends on field size and bolus effect.[5] For curved structure such as the breast, chest, as well as head and neck, surface dose assessment become more complicated. Surface doses are increasingly being measured with radiochromic film, which has several advantageous features for dosimetry, such as its high planner spatial resolution, low sensitivity, tissue equivalent, self-development, and concise usage.[15]

2.1.5 Radiochromic Dosimetry Film

Because of the standard surface dose measurement dosimeter, extrapolation chamber, is not suitable for the clinical usage, the radiochromic film models are introduced for the surface dose measurement. The high spatial resolution and low spectral sensitivity of radiochromic films make them ideal for the measurement of dose distributions in regions of a high dose gradient in radiation fields. In radiochromic film, the image formation is occurred as a dye-forming or a polymerization process. The energy is transferred from photon or particle to the receptive part of leuko-dye or colorless photo monomer molecule. The radiochromic film does not need the wet developing process. Many radiochromic film models, the MD-55, XR-T, HS, have been extensively used for surface and skin dose measurements in various clinical situations. The new radiochromic film, the EBT GAFCHROMIC® dosimetry film model has been commercially introduced by Internal Specialty Products in 2004 and has been used in many researches for clinical surface dose measurement. The EBT model has two

sensitive layers, which is designed for two dimensional dose measurements in high energy photon beams (above 1 MeV). The structure of the EBT film model consists of two sensitive layers, each having a thickness of 17 μm and separated by a 6 μm thick surface layer, all sandwiched between two 97 μm clear polyester sheets. (Fig 2.9) The effective point of measurement in the case of radiochromic film is assumed to be at the center of the sensitive layer of the film, and scaled by density 0.0153 g/cm^2 for the EBT GAFCHROMIC® film model.[13] The EBT model is a nearly tissue equivalent, the effective atomic number is 6.98. The EBT model does not need the chemical processing and the flat-bed scanner especially in red channel is used for film reading. The response of the scanner is that the pixel value changes are less when the net optical density is more than 1.0. The speed of EBT film development is stabilized about 4 hours after irradiation. The effect of EBT film polarization depends on the quantity of doses, that high dose has less effect than low dose. The variation due to dose dependent is about 5% for 400 cGy to 24% for 50 cGy. Moreover, at the higher dose give more non-uniformity to the film, which is due to the effect of light scattering in a CCD film scanner. The EBT model film is the less field size dependency. For EBT model film, the suitable dose range should not be greater than 400 cGy, according to the sensitometric curve of the film. Nowadays, the new EBT model, the EBT2 and EBT3 were introduced in clinical use.
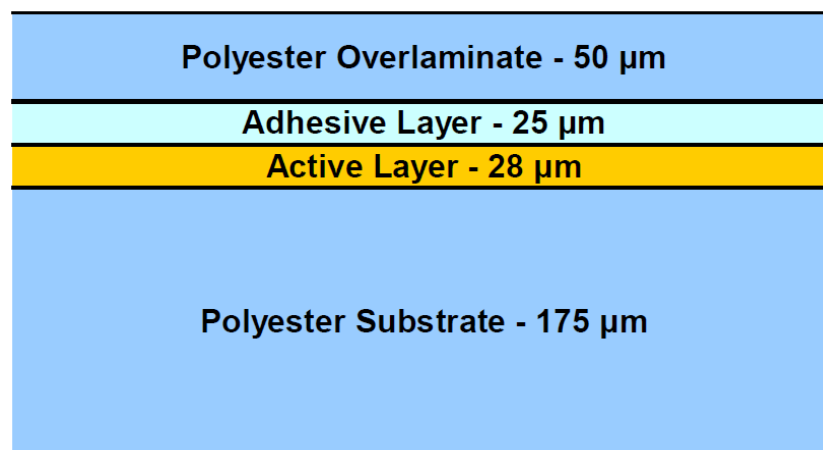
Figure 2.9 Structure of GACHROMIC® EBT2 model film

2.1.6 Dose Calculation Algorithm

Treatment plan for the radiotherapy is acquired by using the advanced treatment planning system which the dose calculation algorithm is employed. The dose algorithms in external beam treatment planning are often classified as correction-based and model-based.

2.1.6.1 Correction-Based Algorithms

The correction-based algorithms calculate the dose in a patient by correcting the measured distribution in the water phantom to account for beam geometries, beam modifiers, patient contours, beam aperture opening, and tissue heterogeneities.[16] The dose algorithms for high energy photon beams were first developed for the ultimate homogeneous patient, the patient completely consisting of water. Measurements of a set of generic dose functions, e.g., tissue air ratios, tissue phantom ratios, output factors, and off-axis ratios are performed in a water phantom for a set of regular treatment fields under reference conditions. The dose within a patient is then calculated by extrapolating this measurements to the specific chosen treatment fields and by the application of various correction algorithms. The advantage of this algorithm is very fast calculation, however, it usually assume electronic equilibrium and inaccurate near heterogeneities.[17] Correction-based dose calculation algorithms are based on broad-beam measured data and are not suited for use in IMRT.

2.1.6.2 Model-Based Algorithms

The model-based algorithms compute the dose in a patient using with the model of radiation transport. It is created to account directly for the underlying physical processes responsible for the energy deposition within the patient.[17] The models are created as the radiation field provided by the linear accelerator and the subsequent energy transported by photons and electrons in the patient. There are three different approaches, namely the differential scatter air ratio, the delta volume method and the kernel based method.[14]

(1)   Differential Scatter Air Ratio Model (DSAR)[14]

The first method to address the 3D problem of dose to heterogeneous phantoms by scaling first and higher order scatter as first scatter was the differential scatter a ratio method which proposed by Beaudoin (1968). These describe contributions to dose at appoint in water from photons scatter in surrounding volume elements as a function of the distance to that point. Scatter dose contributions (dSAR /dV) medium at point r in an inhomogeneous medium from a volume element at r' are expressed in the DSAR method as shown in equation (2.1)

$$\left(\frac{dSAR}{dV}\right)_{medium} = \left(\frac{dSAR}{dV}\right)_{water} \rho_e(r') f_1(r') f_2(r, r') \qquad (2.1)$$

Where,

$\rho_e(r')$ = electron density relative to water at a scattering site

f_1 = factor describing the attenuation of the beam relative to water between source to volume element

f_2 = factor describing the attenuation of secondary photon fluence relative to water along the path between volume and dose calculation point

(2) Delta Volume Model[14]

The delta volume method is the work by Wong and Henkelman (1983). Dose at a point in a heterogeneous medium is calculated as a sum of the primary dose, an augmented first-scatter dose component and an approximate residual multiple- scatter component. Relative primary dose is obtained similarly to the DSAR method from the knowledge of the primary intensity in air and the density along the path of the primary photons.

(3) Kernel Based Models (Convolution/Superposition)

Kernel based convolution/superposition models are a family of models with roots in the imaging world. Analogous to image formation, the dose deposition is viewed as a superposition of appropriately weighted responses (kernels) to point irradiations. The kernels are representing the energy transport and dose deposition of secondary particles stemming from a point irradiation.[14] It is common to use two elementary dose kernels for model-based algorithms, point-spread kernel and pencil-beam kernel.[18]

3(a) Point-Spread Kernel Models[14]

The calculation of dose from point kernels can be described as a two-step procedure. In the first step the energy released in the patient through attenuation of the primary photons is calculated by ray-tracing primary photon trajectories, including beam modulators, etc. In the second step, dose is calculated by superposition of appropriately weighted kernels. The dose equation (2.2) is as follow.

$$D(r) = \iiint_V T(r-s)h(s)d^3s \qquad\qquad (2.2)$$

Where,

T(s) = TERMA (total energy released per mass) from the primary photon fluence $\Psi(s)$

3(b) Pencil-Beam Kernel Models[14]

A pencil kernel describes the energy deposited in a semi-infinite medium from a point monodirectional beam (Fig 2.10). For the purpose of treatment optimization, Gustafsson et al (1994) used a very general formulation of the radiotherapy dose calculation problem in equation (2.3).

$$D(r) = \iint_S \int_E \iint_\Omega \sum_m \Psi_{E,\Omega}^m(S) \frac{P^m}{\rho}(E, \Omega, s, r) d^2\Omega dE d^2s \qquad (2.3)$$

Where,

$\Psi_{E,\Omega}^m(S)$ = energy fluence differential in energy E and direction Ω for beam modality m

$P^m/\rho (E, \Omega, s, r)$ = corresponding pencil kernel for energy deposition per unit mass at r due to primary particles entering the patient at s
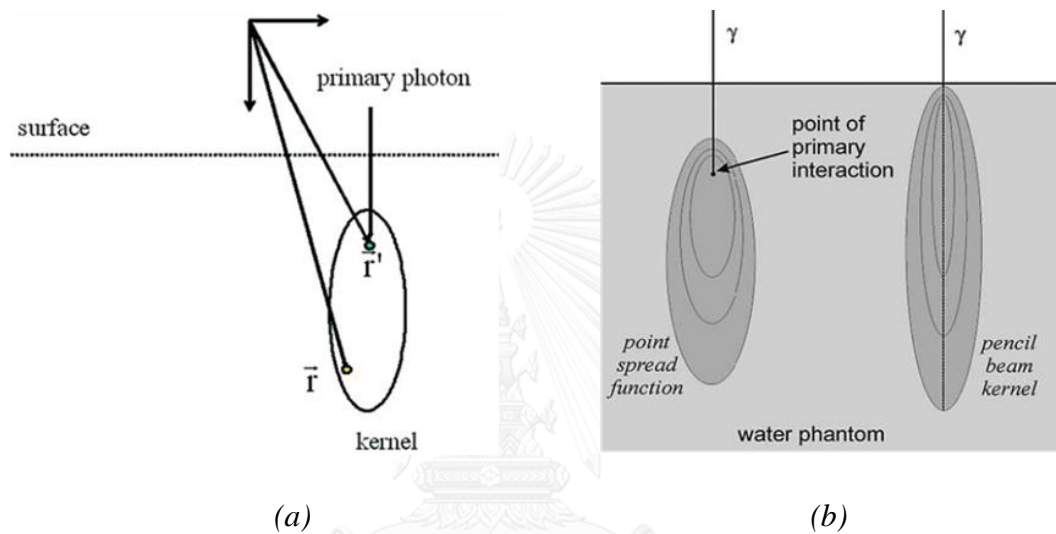
Figure 2.10 (a) Point kernels and (b) pencil-beam kernels[17]

The advanced dose calculation in the Varian Eclipse Treatment planning system is undertaken by the dose calculation algorithm like anisotropic analytical algorithm (AAA) and Acuros XB. AAA and Acuros XB are the model-based algorithms.

2.1.7 Anisotropic Analytical Algorithm (AAA)[8]

The AAA dose calculation model is a 3D pencil beam convolution-superposition algorithm that has separate modeling for primary photons, scattered extra-focal photons, and electrons scattered from the beam limiting devices. The AAA dose calculation model has two main components, the configuration algorithm and the actual dose calculation algorithm. The configuration algorithm is used to determine the basic physical parameters used to characterize the fluence and energy spectra of the photons and electrons present in the clinical beam and their fundamental scattering properties in water equivalent medium. In actual dose calculation, the clinical broad beam is divided into small, finite-sized beamlets to which the convolutions are applied. Tissue heterogeneities are accounted for anisotropically in the full 3D neighborhood of an interaction site by the use of 13 lateral photon scatter kernels. This is performed by

the use of radiological scaling of the dose deposition functions and the electron density based scaling of the photon scatter kernels independently in four lateral directions. The final dose calculation is obtained by superposition of the doses from the photon and electron convolutions. The dose distribution resulting from an arbitrary beamlet β due to photons in a sufficiently large homogenous neighborhood is calculated by the following convolution:

$$D_{\beta,ph}(X^{\sim}, Y^{\sim}, Z^{\sim}) = \Phi_\beta \times I_\beta(Z, \rho) \times \iint_{(u,v)\in Area(\beta)} K_\beta(U - X, V - Y, Z; \rho)dudv$$

(2.4)

Where,
The photon beam attenuation is modeled with an energy deposition density function $I_\beta(Z, \rho)$.
The photon scatter is modeled with a scatter kernel $K_\beta(X, Y, Z, \rho)$ = the lateral dose scattering.
The calculation point $(X^{\sim}, Y^{\sim}, Z^{\sim})$ is represented by (X, Y, Z) relative to the origin of the beamlet coordinate system.
Φ_β = photon fluence

The dose distribution resulting from an arbitrary beamlet β due to the contaminating electrons is calculated by the following convolution:

$$D_{cont,\beta}(X^{\sim}, Y^{\sim}, Z^{\sim}) = \Phi_{cont,\beta} \times I_{cont,\beta}(Z, \rho) \times \iint_{(u,v)\in Area(\beta)} K_{cont,\beta}(U - X, V - Y, Z; \rho)dudv$$

(2.5)

Where,

$\Phi_{cont,\beta}$ = electron fluence

The final dose $D(X^{\sim}, Y^{\sim}, Z^{\sim})$ at an arbitrary calculation point in the patient is obtained by a superposition of the separate dose contributions from the primary photons (ph1) (Equation 2.4), extra-focal photons (ph2) (Equation 2.4), and contaminating electrons (Equation 2.5) from all individual beamlets;

$$D(X^{\sim}, Y^{\sim}, Z^{\sim}) = \sum_\beta (D_{ph1,\beta}(X^{\sim}, Y^{\sim}, Z^{\sim}) + D_{ph2,\beta}(X^{\sim}, Y^{\sim}, Z^{\sim}) + D_{cont,\beta}(X^{\sim}, Y^{\sim}, Z^{\sim}))$$

(2.6)

In AAA, the basic physical parameters are predefined by Monte Carlo simulations and adapted to the available beam data measured in a water equivalent

medium. The beam data required to configure the Pencil Beam Convolution model in Eclipse is sufficient for the configuration of the AAA model.

2.1.8 Acuros XB Algorithm (Acuros XB)[9]

In external beam radiotherapy, heterogeneities introduced by materials such as lung, bone, air and non-biological implants may significantly affect patient dose fields. Acuros XB uses a sophisticated technique to solve the Linear Boltzmann transport equation (LBTE) and directly accounts for the effects of these heterogeneities in patient dose calculations. The Boltzmann transport equation (BTE) is the governing equation which describes the macroscopic behavior of radiation particles (neutrons, photons, electrons, etc.) as they travel through and interact with matter. The LBTE is the linearized form of the BTE, which assume that radiation particles only interact with the matter they are passing through, and not with each other, and is valid for conditions without external magnetic fields. The source model for Acuros XB in eclipse use the existing AAA machine source model. This model consists of four components, such as primary source, extra focal source, electron contamination, photons scattered from wedge. The Acuros XB patient transport consists of four discrete steps, which are performed:

1. Transportation of source model fluence into the patient
2. Calculation of scattered photon fluence in the patient
3. Calculation of scattered electron fluence in the patient
4. Calculation of dose distribution in the patient

Steps 1 to 3 are performed to calculate the electron fluence in every voxel of the patient. After the energy dependence, electron fluence is solved, the desire dose quantity (dose-to-medium or dose-to-water) is computed in step 4. Step 1 is the only step repeated for each beam, and steps 2 to 4 are performed once. In step 1, the machine sources are modeled as external sources and ray tracing is performed to calculate the uncollided photon and electron fluence distributions in the patient. In steps 2 and 3 Acuros XB discretizes in space, angle, and energy, and iteratively solves the LBTE. In step 4, the dose in any voxel of the problem is obtained through applying and energy dependent fluence-to-dose response function to the local energy dependent electron fluence in that voxel. Acuros XB supports to dose reporting options, dose-to-water (D_W) and dose-to-medium (D_M). Therefore, to calculate dose, Acuros XB must have a material map of the imaged patient. Unlike convolution/superposition algorithms, where heterogeneities are generally handled as density based corrections applied to dose kernels calculated in water, Acuros XB explicitly models the physical interaction of radiation with matter. Acuros XB requires the chemical composition of each material in which particles are transported through, not only the density. For dose calculation in Acuros XB use following equation;

$$D_i = \int_0^\infty dE \int_{4\pi} d\,\Omega^\wedge \frac{\sigma_{ED}^e(\vec{r},E)}{\rho(\vec{r})} \Psi^e(\vec{r},E,\Omega^\wedge) \qquad (2.7)$$

Where,

σ_{ED}^e = Macroscopic electron energy deposition across sections in units of MeV/cm
ρ = Material density in g/cm^3

2.2 Related Literatures

Akino Y. et al evaluated surface dosimetry between treatment planning system and measurement by using dose calculation algorithm software AAA version 10 and phantom measurement with GAFCHROMIC EBT2 film. This study investigated various treatment techniques such as tangential wedges, field-in-field (FF), electronic compensator (eComp), and intensity-modulated radiotherapy (IMRT). Surface dose measurement was performed with EBT2 film at different depths. At deeper depths, film dosimetry showed good agreement with the TPS calculation. At the shallower depth, the measured dose was higher than TPS calculation by 15%-30% for all techniques. In general, TPS even with advanced algorithms (AAA) do not provide accurate dosimetry in the buildup region, as verified by EBT2 film for all treatment techniques.[19]

Devic S. et al determined a correction procedure for radiochromic film in order to obtain an accurate skin dose measurement using Attix parallel-plate ionization chamber, extrapolation chamber, four types of Gafchromic films (HD-810, EBT, HS and XR-T) and TLDs. To illustrate this correction, the measurement of PDD at effective point, buildup region, build-down region, considered field size effect and also the calculation with Monte Carlo simulation were performed. The data of measurement suggested that within the first millimeter of the skin region, the PDD for a 6 MV photon beam and field size of 10x10 cm^2 increased from 14% to 43%.The correction factors for the exit skin dose due to the build-down region were negligible. The skin dose correction for the effective point of measurement in the build-down region was the order of 0.3% for all Gafchromic film models. Different dosimeters used for the surface dose estimates should be properly calibrated and necessary corrections applied in order to estimate accurately the skin dose. For the three GAFCHROMIC dosimetry film models, the 6MV beam entrance skin dose measurement corrections due to their effective point of measurement were 15% for the EBT, 15% for the HS, and 16% for the XR-T model GAFCHROMIC films.[13]

Nakano M. et al studied about the surface dosimetry for the breast radiotherapy treatments by using GAFCHROMIC EBT2 film and Attix parallel-plate ionization chamber. The measurements were performed with four types of phantoms; homogenous phantom, lung equivalent material phantom, cylindrical CT phantom and chest-simulated phantom. Surface dose measurement using EBT2 film showed good agreement with Attix chamber with the uncertainty of 3.3%.On chest phantom, the case

of two opposed tangential fields, without and with bolus, the surface dose ranged from 48.3% (67.5˚) to 55.2% (45˚) and from 89.1% (67.5˚) to 96.6% (0˚), respectively. This study also demonstrated the suitability of Gafchromic EBT2 film for surface dose measurements in megavoltage photon beams.[15]

Hoffmann L. et al investigated the accuracy of Acuros XB photon dose calculation algorithm in both homogeneous and heterogeneous media compared with AAA and measurement by using test plan of 6MV and 15MV photon which created on CIRS thorax phantom. Moreover, this study investigated the output factors, depth dose curves and profiles of symmetric fields and asymmetric fields. The results showed good agreement with AAA. For the plans calculated on the CIRS phantom, the number of meeting the gamma criterion of 3% in dose and 3 mm in DTA was higher with Acuros XB (98% for 6MV, 100% for 15MV) than with AAA (94% for 6MV, 96% for 15MV). Dose calculation with Acuros XB in homogeneous media are in good agreement with both measurements and AAA. However, in heterogeneous media, Acuros XB is more accurate than AAA in both lung and bony materials.[20]
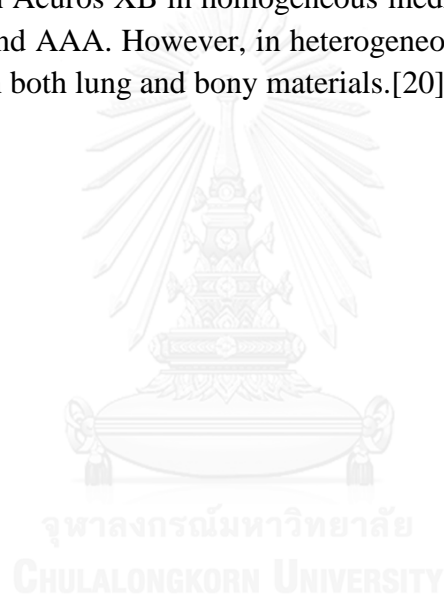
CHAPTER 3

RESEARCH METHODOLOGY

3.1 Research Design

This study is an observational analytical study.

3.2 Research Question

What are the surface dose difference between Acuros XB and analytical anisotropic algorithm (AAA) in breast cancer radiotherapy techniques?

3.3 Research Design Model

This study is separated into two main parts, the phantom study and the clinical application.
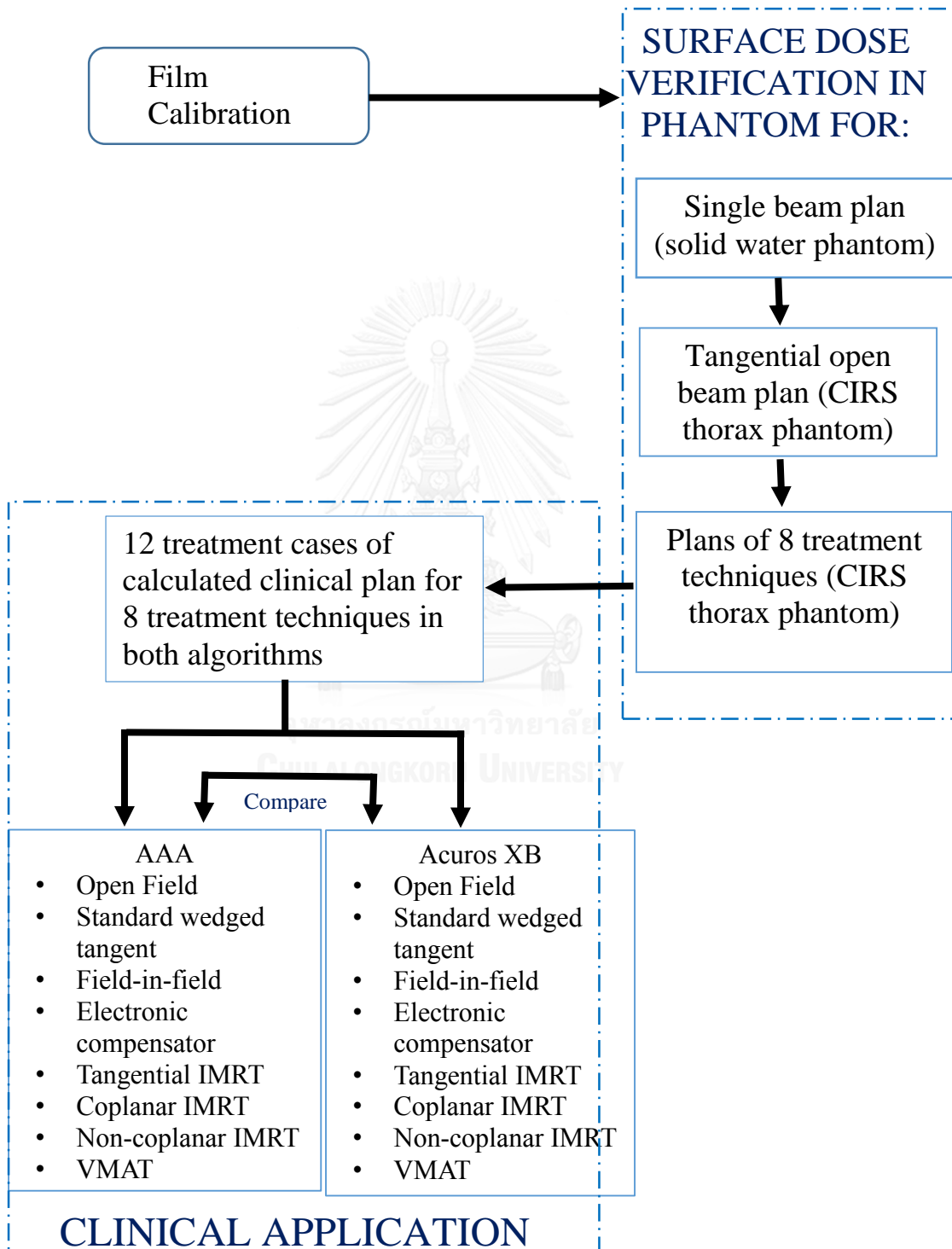
Figure 3.1 Research Design Model

3.4 Conceptual Framework

The surface dose for the patient in radiotherapy is affected by the treatment techniques, dose calculation algorithm of the TPS,and others factors like beam energy and field sizes. Moreover, the surface dose for breast radiotherapy is affected by the shape and size of the breast.[6]
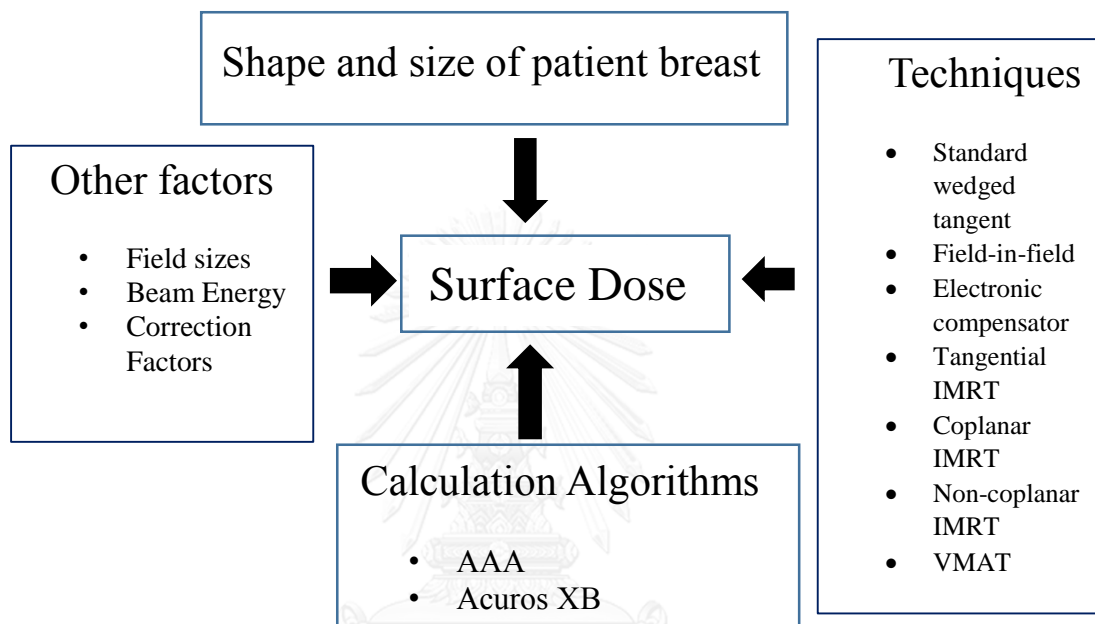
Figure 3.2 Conceptual Framework

3.5 Materials

The materials used in this study are from the Department of Therapeutic Radiology and Oncology, King Chulalongkorn Memorial Hospital.

3.5.1 Varian ClinaciX linear accelerators

Varian ClinaciX linear accelerators (Varian medical Systems, Palo Alto, USA), that can deliver 6 and 10 MV photon beam with 120 multi-leaf collimators and cone beam CT. This model can deliver arc beam therapy. (Fig 3.3)

Figure 3.3 Varian ClinaciX

3.5.2 GE Lightspeed RT: 4 Slices, 80 cm CT scanner

The 4 slices CT scanner (Lightspeed RT GE: Medical system, Waukesha. WI, USA) has the ability to simultaneously collecting 4 rows of scan data (Fig 3.4). Additional software for treatment planning is virtual simulation which can reconstructed raw image into 3D image and can generate DRR (digital reconstructed radiograph) in many directions. Furthermore, this software allow radiation oncologist to plan treatment and mark point on patient via moving laser in CT room directly.

Figure 3.4 GE Lightspeed RT CT scanner

3.5.3 Solid Water Phantom

The solid water phantom (Gammex, WI, USA) which the density of 1.02 g/cm^3, and atomic number of 5.95 is made in square slab of 30 x 30 cm^2 with the thickness of 0.2, 0.3, 0.5, 1.0, 2.0, 3.0, 4.0 and 5.0 cm. Solid water phantoms are shown in (Fig 3.5).
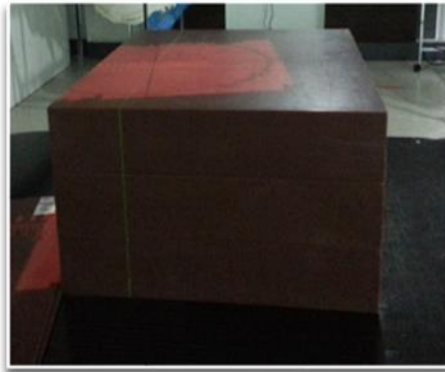
Figure 3.5 Solid water phantom

3.5.4 CIRS IMRT Thorax Phantom[21]

The CIRS Model 002LFC IMRT Thorax Phantom for film and ionization chamber dosimetry (Tissue Simulation and Phantom Technology, CIRS, Virginia, USA) (Fig 3.6) is designed for the complex tissues surrounding for commissioning and comparison of treatment planning systems while providing a simple reliable method for verification of individual patient plans. It is elliptical in shape. It properly represents human anatomy in size and proportion. It is 30 cm long x 30 cm wide x 20 cm thick (PA). The phantom is constructed of proprietary tissue equivalent epoxy materials. Linear attenuations of the simulated tissues are within 1% of actual attenuation for bone and water from 50 keV to 25 MeV.

Model 002LFC Includes

Qty	Description
1	Thorax section drilled to accommodate rod inserts
12	1 cm thorax sections
1	3 cm end section
1	Alignment base
1	Holding device
1	Water equivalent insert with ion chamber cavity
1	Bone equivalent insert with ion chamber cavity
1	Lung equivalent insert with ion chamber cavity
5	Water equivalent solid rod inserts
1	Bone equivalent solid rod insert
4	Lung equivalent solid rod inserts
1	Set of CT to film fiducial markers

(a) (b)
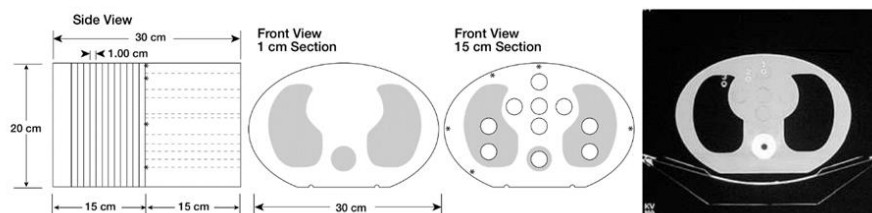
(c)

Figure 3.6 (a) CIRS Model002LFC IMRT Thorax Phantom, (b) the composition of CIRS phantom and (c) the structure of CIRS phantom

3.5.5 Tissue Mimicking Bolus

The tissue mimicking bolus gives the thicknesses which provides maximum dose buildup for relevant photon energies. It can conform to patient's contour and it is made with tissue equivalent material. The bolus is made with a synthetic oil gel with a specific gravity of 1.02 g/cm^3. It is based on vinyl plastic containing a large amount of diisodecyl phthalate. It is 0.5 cm to 1 cm thick and 30 cm square shape. (Fig 3.7)

Figure 3.7 Tissue mimicking bolus

3.5.6 Gafchromic EBT2 Films

GAFCHROMIC EBT2 (Fig 3.8) is a radiochromic dosimetry film that has been developed specifically to quantitative dose measurement application in external beam radiotherapy. The EBT2 film is a self-developing (develops in real time without post exposure treatment), energy independent, near tissue equivalent, water resistant, high spatial resolution and can handle in room light. The wide dose range of Gafchromic EBT2 film is 1 cGy to 800 cGy. The size of EBT2 film is 20 x 25 cm^2 and 25 sheets in one package.
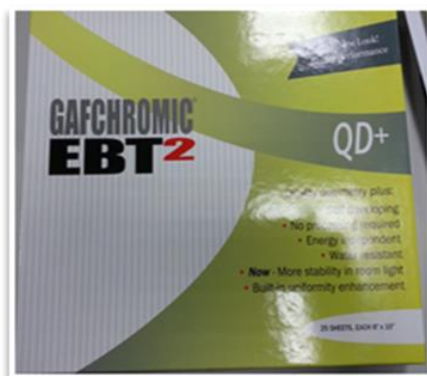
(a)   *(b)*

Figure 3.8 (a) Gafchromic EBT2 film, (b) Small pieces of Gafchromis EBT2 films

3.5.7 Flat-Bed CCD Scanner

The Epson perfection V700 flat-bed color CCD (model V700; Epson Seiko Corp., Nagano, Japan) for EBT film digitization is used as a scanner densitometer. The maximum scanning media size is 22 x30 cm^2. The color depth of scanner is 48-bit color. The optical resolution of scanner is 6400 dpi x 9600 dpi and the maximum resolution is 12800 dpi x 12800 dpi of interpolated resolution. It is shown in Fig 3.9.

Figure 3.9 Epson Perfection flat-bed CCD scanner

3.5.8 Eclipse Treatment Planning System Version 11.0.31

Eclipse treatment planning system version 11.0.31 (Varian medical Systems, CA, USA) is a treatment planning for all treatment techniques such as 3D conformal, IMRT, VMAT, electron and brachytherapy. Eclipse version 11.0.31 provides the two photon dose calculation algorithms, Analytical Anisotropic Algorithm (AAA) and the new algorithm Acuros XB. Eclipse helps dosimetrists, physicists, and physicians efficiently create, select and verify the best treatment plans for the patients. The Eclipse planning system is shown in Fig 3.10.

Figure 3.10 Varian Eclipse treatment planning system

3.6 Methods

3.6.1 Film Calibration in the Solid Water Phantom

EBT2 films were placed at the 1.5 cm depth (Dmax) in solid water phantom, 10x10 cm^2 field size, 100 SSD and irradiated with 6 MV photon beam of varying dose from 0 to 800 cGy. The films were scanned using a Flat-Bed CCD Scanner 24 hours after irradiation to get the good performance of the EBT2 film. The signal of the films were read, the calibration curve between dose and scanner response signal for the EBT2 film was obtained.

3.6.2 Uncertainty Analysis for GAFCHROMIC EBT2 Film Dosimetry

The uncertainties in EBT2 film measurements were derived in accordance with the ISO methodology as described in the IAEA TRS-398 dosimetry protocol as reference from Masahiro et al. study. The measurement uncertainties are estimated as relative standard uncertainties, and the sources of uncertainties are arranged into type A and type B. The sources of uncertainties for EBT2 film measurement is shown in (Table 3.1).[13]

Table 3.1 Standard uncertainty in the measurement of surface or near surface dose using Gafchromic EBT2 film

Source of Uncertainty	Uncertainty Type	Standard Uncertainty (%)
1. Signal measurement over pixels	A	0.7
2. Signal measurement over multiple film pieces	A	1.8
3. Linac X-ray output reproducibility	B	0.2
4. EBT2 film best-fit calibration curve	B	1.7
5. Setup repeatability of the phantom and film pieces	B	0.1
6. Dose output accuracy	B	0.6
7. Film Homogeneity	B	1.9
Total Uncertainty		3.3%

3.6.3 Verification of Single Beam Plan in the Homogeneous Solid Water Slab Phantom

For the basic verification of the surface dose, the EBT2 film which was cut into 3x3 cm^2 were placed on the homogeneous solid water slab phantom at the 0 (surface), 2, 4, 6, 15, 30, 50 and 100 mm depth. The dose measurement was performed with the conventional single beam 10x10 cm2 field size, 100 cm SSD, 500 MU, 400 MU/min, 6 MV photon beam by using ClinaciX (Varian Medical Systems, Palo Alto, CA). (Fig 3.11)The doses were normalized to the dose at Dmax. After irradiation, the dose measurement and the calculation from Eclipse TPS (Varian Medical Systems, CA) in both AAA (version 11.0.31) and Acuros XB (version 11.0.31) algorithms were compared.

(a)   *(b)*

Figure 3.11 Dose measurement for single beam plan in the homogeneous solid water slab phantom; (a) Films set up, (b) Field set up with solid water phantom

3.6.4 Verification of Tangential Open Beam Plan in the CIRS Thorax Phantom

For the non-homogeneous phantom and curve surface measurement, EBT2 films were cut as the long sheets and sandwiched between the slices of the tissue mimicking bolus at the surface, 5-mm, 10-mm and 15-mm (Dmax) depth on the CIRS IMRT Thorax Phantom. (Fig 3.12) The tangential parallel opposing fields (54.2° and 238° gantry angle) of 6 MV photon beam, 10x10 cm^2 field size, 300 MU for each field, 400 MU/min were irradiated. Then the films were scanned and the point doses of every 1 cm apart in each depth were measured. The doses were normalized to the dose at Dmax at the central axis of the beam. The calculated dose of the phantom with Eclipse TPS in both AAA and Acuros XB algorithms were recorded and compared with the measurement.

Figure 3.12 Dose measurement for tangential open beam plan in the CIRS thorax phantom

3.6.5 Verification of Plans in Eight Treatment Technique in the CIRS Thorax Phantom

CT scanning of CIRS thorax phantom was performed by using GE lightspeed CT simulator. (Fig 3.13) CT data were acquired for 3 mm slice thickness with abdominal protocol. The acquired CT images were exported to the Varian Eclipse treatment planning system (TPS) via the data networking. The target volume of the breast clinical target volume (CTV), planning target volume (PTV) and critical structures such as lung and heart were created on the CT images. And then, the plan with eight treatment techniques for 6 MV photon beams were undertaken in the TPS for both AAA and Acuros XB algorithms. The eight treatment techniques were;

(1) Open field, two tangential beams
(2) Standard wedge tangent (SWT), two tangential beams with dynamic wedge
(3) Electronic compensator (E Comp), two tangential beams with dynamic MLC compensator
(4) Field-in-field (FF), two tangential beams with subfields
(5) Tangential intensity modulated radiation therapy (T IMRT), two tangential beams
(6) Coplanar intensity modulated radiation therapy (CP IMRT), five beams
(7) Non-coplanar intensity modulated radiation therapy (NCP IMRT), two coplanar and four non-coplanar beams
(8) Volumetric modulated arc therapy (VMAT), two arc beams

For the plan verification, EBT2 films were cut as the long sheets and placed on the chest wall of the CIRS IMRT Thorax Phantom. The two sheets of EBT2 films were

placed on the surface of breast of CIRS phantom. (Fig 3.14) Irradiation was performed with the eight treatment techniques and the dose was calculated with both AAA and Acuros XB algorithm. For Acuros XB calculation, an organ had to create for assign the CT number of specific material. After irradiation, the films were scanned and the point doses were measured. The measured point doses on the surface were normalized to the dose in the chest wall (prescribed dose). And then, the measured point doses and calculated point doses were compared for both algorithms.

(a)   *(b)*
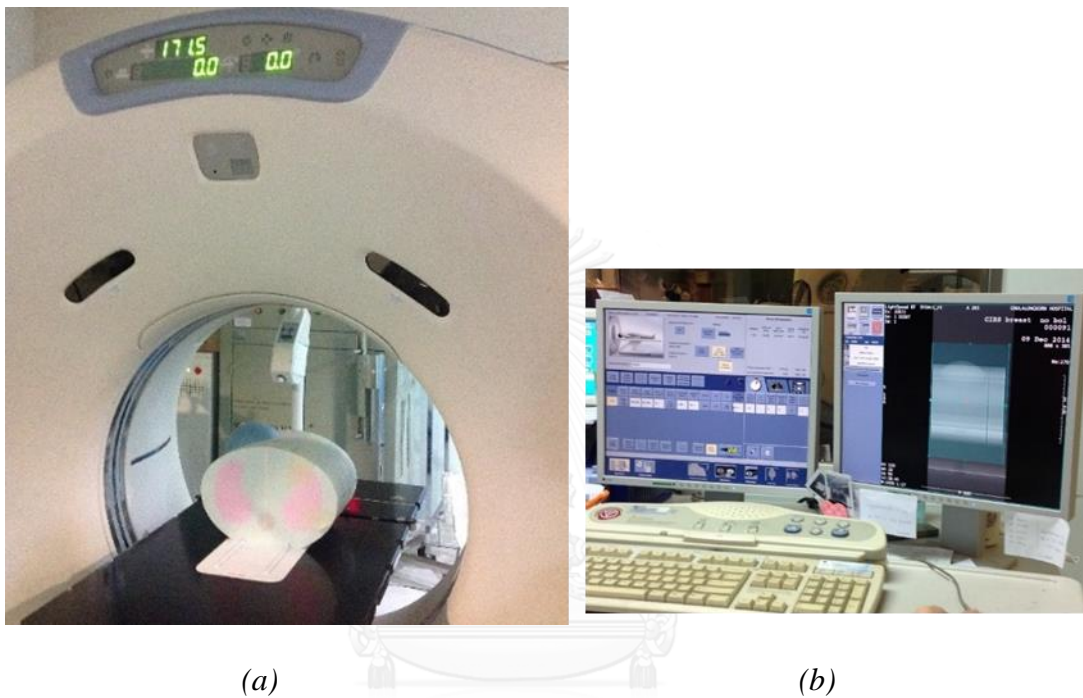
Figure 3.13 CT scanning of CIRS thorax phantom; (a) phantom set up inside the CT machine, (b) CT scanner console + the CT protocol and scout view of CIRS phantom
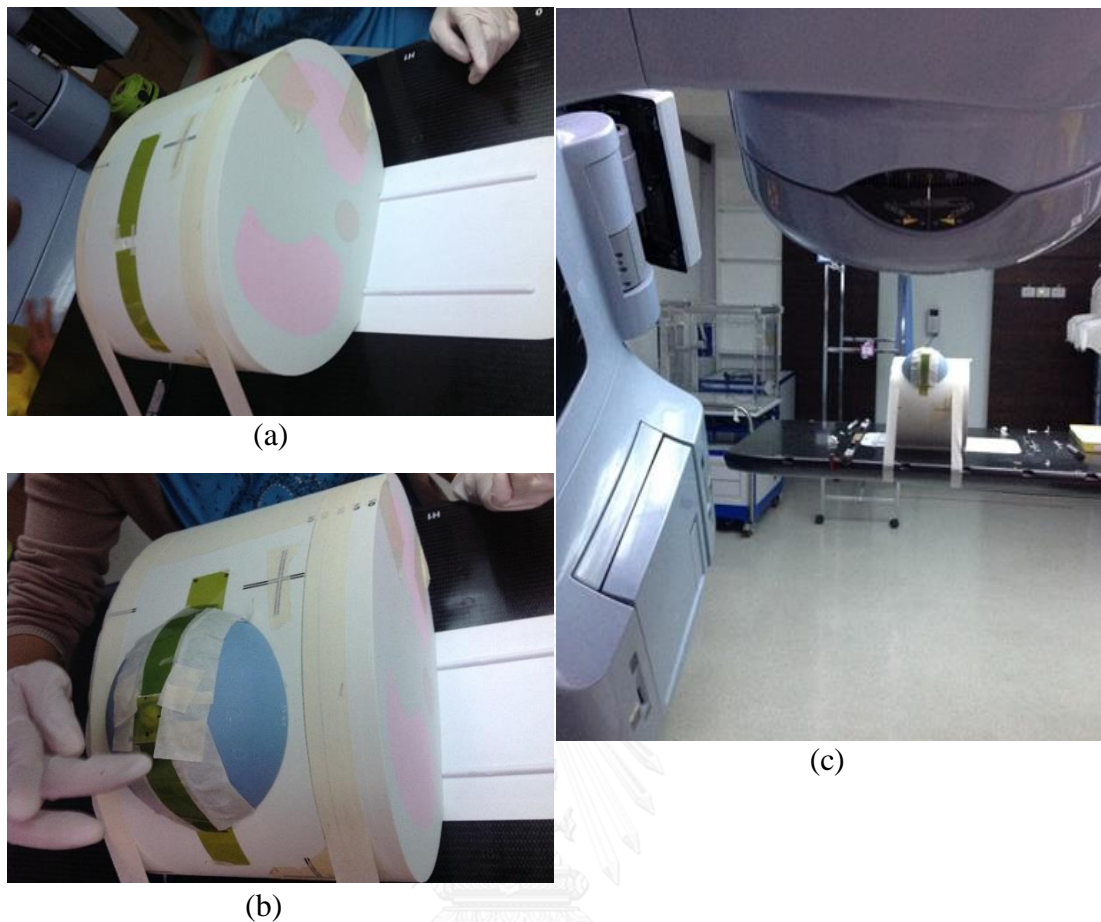
Figure 3.14 Placement position of the EBT2 films and set up position of CIRS thorax phantom; (a) the placement position of EBT2 films on the chest wall, (b) the placement position of EBT2 films on the surface of breast and (c) set up position and beam arrangement of CIRS phantom with films

3.6.6 Patient Analysis

The surface dose calculation comparison of AAA and Acuros XB algorithm was performed in TPS by using 12 cases of breast conservative surgery patients who were breast cancer and were treated with radiation from the Therapeutic Radiology and Oncology Division at King Chulalongkorn Memorial Hospital, Bangkok, Thailand. The retrospective CT images with PTV volume from the database were planned in the TPS with the eight treatment techniques, i.e. Open Field, SWT, E Comp, FF, T IMRT, CP IMRT, NCP IMRT, and VMAT. For the IMRT and VMAT the same optimization dose constraints were employed according to Chulalongkorn Hospital routine protocol. (Table 3.2) For all treatment techniques, the prescribed dose of 5000 cGy to PTV was delivered. The prescribed dose was defined at 95% isodose line. The surface doses were calculated in the Eclipse TPS by using AAA and Acuros XB algorithm. The calculated surface doses were recorded at the tip, medial and lateral side of the breast: 0 (surface),

4, and 6 mm depth and then the recorded doses of the two algorithms were compared. (Fig 3.15)

Table 3.2 The optimization dose constraints for IMRT and VMAT

Organ	Volume	Dose
PTV	0 %	51 Gy
	100 %	50 Gy
Organ 90	0 %	50 Gy
Organ 80	0 %	45 Gy
Heart	0 %	45 Gy
	3 %	30 Gy
	10 %	5 Gy
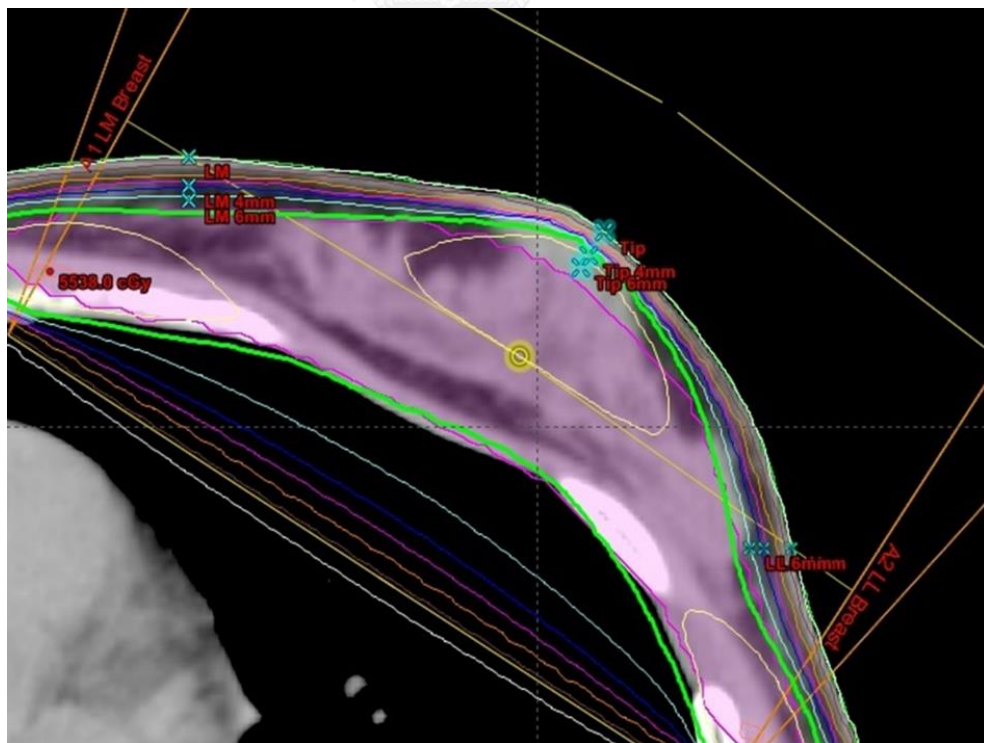
Figure 3.15 The calculated surface doses recorded at the tip, medial and lateral side of the breast (0 (surface), 4, and 6 mm) depth of SWT

3.7 Outcome to be Measured

The outcome for the surface dose calculation in patient was the percent difference of dose calculation between AAA and Acuros XB algorithm in TPS, for the clinical cases of breast cancer radiation therapy with the eight treatment techniques (Open, SWT, FF, E-comp, T-IMRT, CP-IMRT, NCP-IMRT, and VMAT).

3.8 Sample Size

The sample size was determined such that the mean difference between AAA and Acuros XB was at least 70% with the 95% confidence interval (Variance of difference = 69%) by using following equation,

$$n = \frac{\left(z\alpha_{/2} + z_\beta\right)^2 \sigma^2}{d^2} = 10.199 \approx 12 \text{ cases}$$

Total = 12 cases

Where, z is the reliability coefficient of normal distribution
$\alpha = 0.05$, $z\_(\alpha/2) = 1.96$
$\beta = 0.10$, $z\_\beta = 1.28$
σ = Variance of difference = 0.69 (from previous study)[22]
d = Difference of mean = 0.7

3.9 Measurement

Variable

Independent variables: machine output, film uncertainty, and film calibration

Dependent variables: prescribed dose, plan parameters

3.10 Data Collection

3.10.1 The Measurement: used phantoms and films

3.10.2 Patient Information: CT images and size of breast

The data was collected at Varian ClinaciX linear accelerator system and Varian Eclipse treatment planning system at Division of Therapeutic Radiology and Oncology, King Chulalongkorn Memorial Hospital, Bangkok, Thailand.

3.11 Data Analysis

The surface doses for plan verification were collected as in mean, standard deviation and ranges presented in the form of table and graph.

The percent difference of AAA and Acuros XB algorithms for clinical cases were presented in the form of table and graph.

3.12 Expected Benefit and Application

This study assisted to determine which treatment technique and which algorithm can reduce the surface dose for the breast cancer radiotherapy treatment.

3.13 Ethic Consideration

Although this study was performed in phantom and CT images from the database, the research proposal was submitted and approved by Ethics Committee of Faculty of Medicine, Chulalongkorn University. (Fig 3.16)

Figure 3.16 Certificate of Approval from Ethic Committee of Faculty of Medicine, Chulalongkorn University

CHAPTER 4
RESULTS

4.1 Film Calibration

The calibration curve was used for film measurement reading, it showed exponential shape. (Fig 4.1)
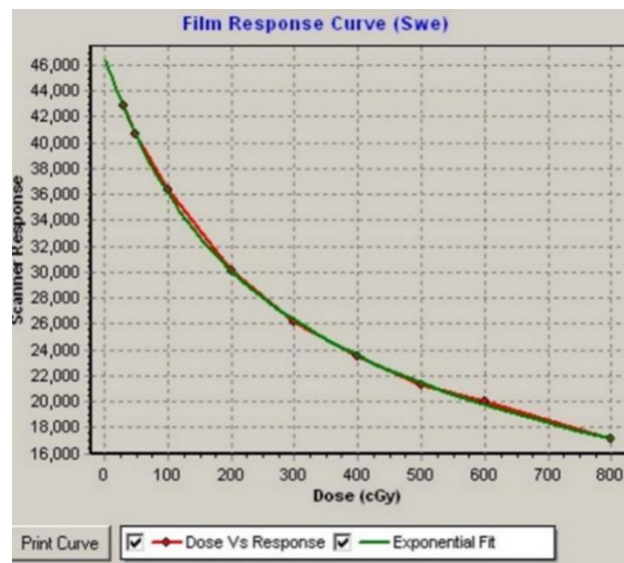
Figure 4.1 Film calibration curve between dose and scanner response

4.2 Verification of Single Beam Plan in the Homogeneous Solid Water Slab Phantom

The comparison of surface and buildup region dose measurement with the film in the homogeneous solid water slab phantom and TPS calculation in AAA and Acuros XB are shown in Table 4.1 and Fig 4.2. The dose at the surface (0 mm depth) showed Acuros and AAA were higher than film measurement of 12.31% and 33.32%, respectively. The percent difference between AAA and Acuros XB at the surface was 15.76%. Beyond the surface, the calculated dose became lower than measurement. After depth of maximum dose, calculated dose turned to be higher than measurement. At the deeper depth of 4- and 6-mm the film measurement was within 10.87% higher than calculation. However, dose calculated by AAA and Acuros XB showed good agreement after depth of maximum dose. The percent difference was calculated by this equation;

$$\% \text{ difference} = \frac{AAA/Acuros\ XB - measurement}{measurement} \times 100 \qquad (4.1)$$

Table 4.1 The surface and buildup region dose comparisons of Film, AAA and Acuros XB in solid water phantom

Position of films	Film Measurement (cGy)	Dose (%)			Dose Difference (%)	
		Film	AAA	Acuros XB	Film & AAA	Film & Acuros XB
Surface	97.28	19.37	25.82	21.75	33.33	12.31
2 mm	331.16	65.93	57.51	55.77	-12.77	-15.41
4 mm	430.86	85.77	76.49	76.45	-10.82	-10.87
6 mm	488.74	97.30	87.65	87.52	-9.92	-10.05
15 mm	502.32	100.00	100.00	100.00	0.00	0.00
30 mm	471.33	93.83	94.82	95.14	1.05	1.40
50 mm	406.53	80.93	86.34	86.74	6.68	7.18
100 mm	321.07	63.92	66.72	67.11	4.39	4.99
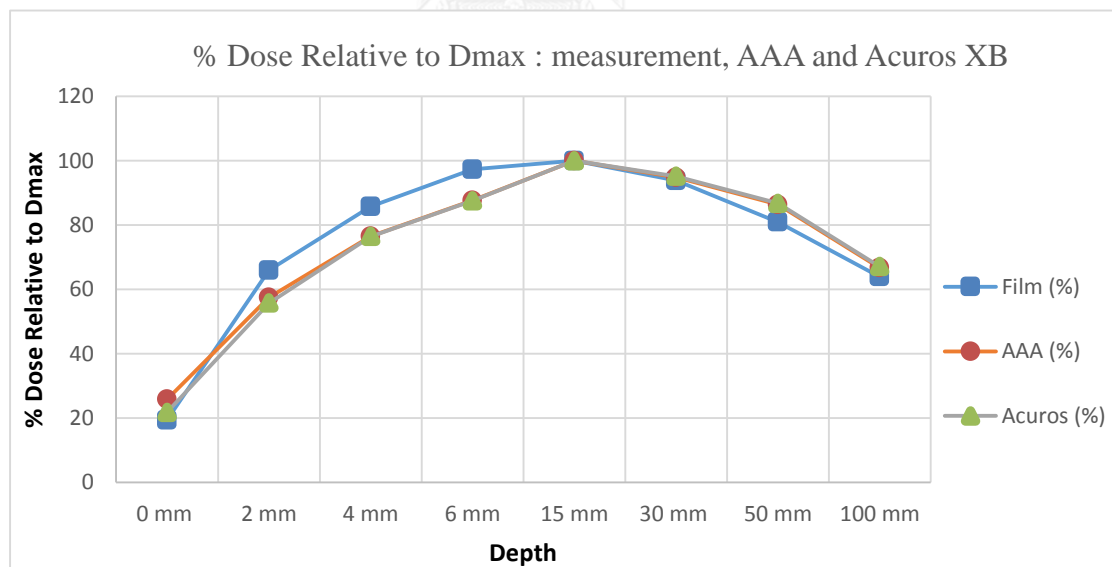
Figure 4.2 The surface and buildup region dose measurement with the film in the homogeneous solid water slab phantom and TPS calculation in AAA and Acuros XB

4.3 Verification of Tangential Open Field Plan in the CIRS Thorax Phantom

The average relative dose (normalized to the dose at 1.5 cm depth of the central axis) over the curved surface and buildup region of the measurement with EBT2 film in CIRS Thorax Phantom and Eclipse TPS calculation with AAA and Acuros XB are shown in Table 4.2 and Fig 4.3. In this graph, AAA showed 28.96% underestimated dose than film measurement at the surface. However, the dose at the surface in Acuros XB, which 14.31% underestimated, was closer to the measurement than AAA. The percent difference between AAA and Acuros XB at the surface was 20.62%. At the deeper depth, 5-, 10-, and 15-mm, both algorithms contributed nearly good agreement with the film measurement and also showed the excellent agreement between both calculation algorithms. At the shallow depth, the calculated dose was lower than measurement, but it was contrary after depth of maximum dose.

Table 4.2 The surface and buildup region dose comparisons of Film, AAA and Acuros XB in CIRS thorax phantom

Position of films	Dose (%)			Dose Difference (%)	
	Film	AAA	Acuros XB	Film & AAA	Film & Acuros XB
surface	48.93	34.76	41.93	-28.96	-14.31
5 mm	99.70	100.58	101.89	0.88	2.20
10 mm	103.34	106.24	105.63	2.80	2.21
15 mm	103.33	106.32	105.39	2.90	2.00
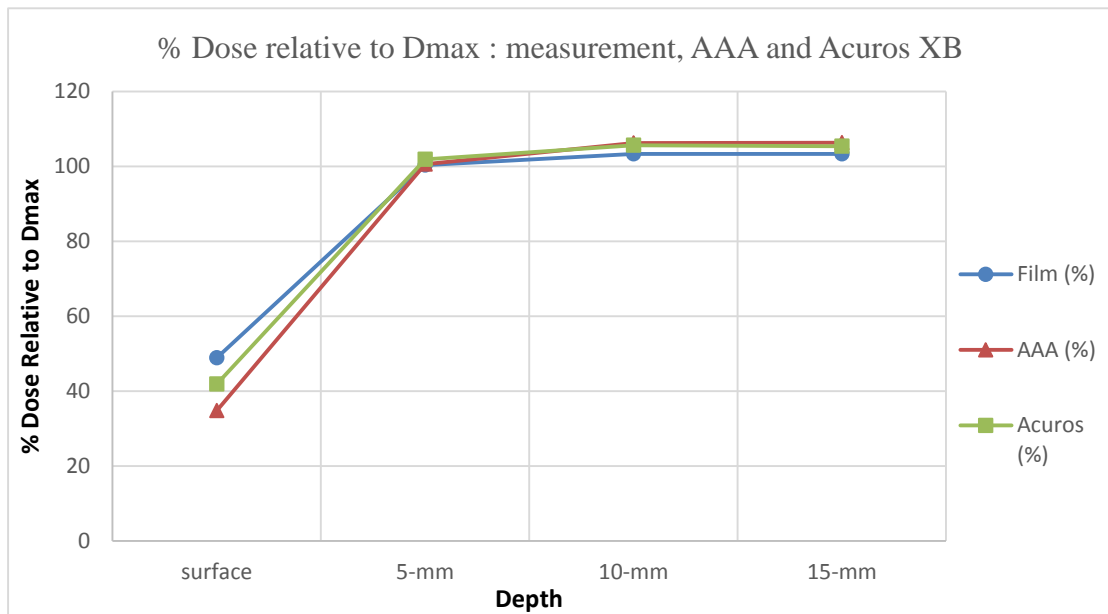
Figure 4.3 The dose at surface and buildup region measured with the film in the CIRS Thorax IMRT Phantom and TPS calculated in AAA and Acuros XB

4.4 Verification of Plans in Eight Treatment Techniques in the CIRS Thorax Phantom

The film measurement of the eight treatment techniques for both AAA and Acuros XB are shown in Fig 4.4 and 4.5, respectively. In these graphs both techniques demonstrated the same pattern. The Tip of the breast illustrated the highest surface dose in almost all eight treatment techniques except VMAT, the surface doses at the tip were ranged from 49.57% in VMAT and 75.72% in FF for AAA (mean 65.30±8.17%) and ranged from 40.01% in VMAT and 69.61% in Open field for Acuros XB (mean 59.91±9.91%). The surface doses for Medial and Lateral sides of the breast were very close to each other in both algorithms for almost all treatment techniques. The doses at the medial for AAA were ranged from 40.12% in NCP IMRT and 66.49% in CP IMRT (mean 51.47±8.12%) and for Acuros XB were ranged from 34.19% in NCP IMRT and 61.65% in CP IMRT (mean 47.66±9.56%). For lateral side, the doses were ranged from 43.85% in E Comp and 59.06% in Open field for AAA (mean 50.38±5.14%) and were ranged from 35.20% in VMAT and 52.31% in NCP IMRT for Acuros XB (mean 47.14±5.59%). The surface dose for the VMAT technique was similar for Tip, Medial and Lateral side of the breast in both algorithms.
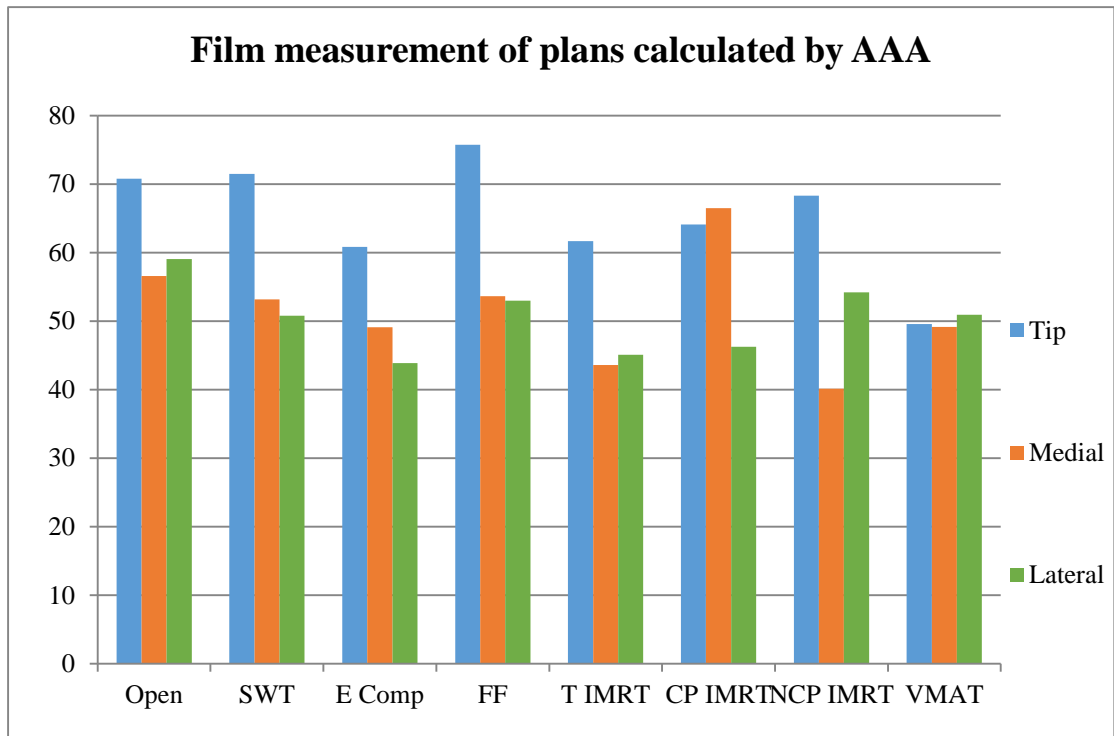
Figure 4.4 The surface dose of film measurement for eight treatment plans calculated by AAA algorithm
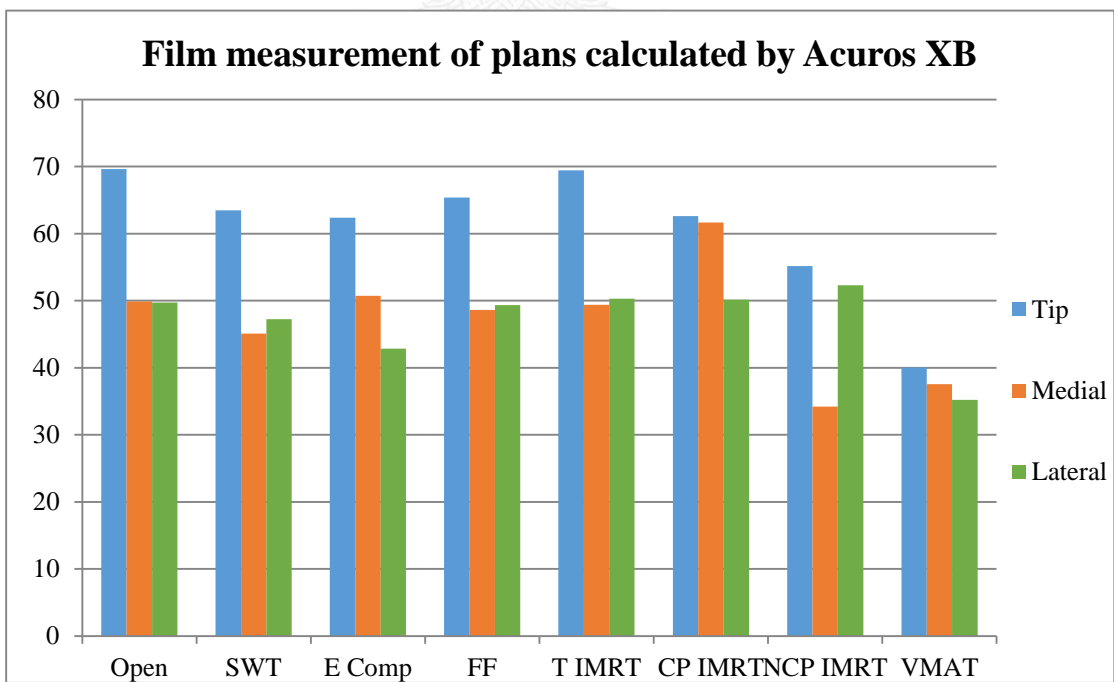
Figure 4.5 The surface dose of film measurement for eight treatment plans calculated by Acuros XB algorithm

The comparison between film measurement with AAA calculation, and film with Acuros XB calculation are shown in Table 4.3 and 4.4. In AAA plan, for all techniques, the average surface dose of film measurement was higher than TPS calculation 41.29% at the Tip, 40.17% at the medial and 41.39% at the lateral for eight techniques. In Acuros XB plan, TPS calculation was underestimated than film measurement 19.59% at the Tip, 6.55% at the medial and 12.04% at the lateral for eight techniques.

Table 4.3 Surface dose comparisons between film measurement and AAA calculation

Techniques	AAA (%)			Film (%)			Difference (%)		
	Tip	Medial	Lateral	Tip	Medial	Lateral	Tip	Medial	Lateral
Open	45.45	30.87	30.18	70.77	56.55	59.06	-35.79	-45.41	-48.90
SWT	37.20	29.83	30.73	71.47	53.18	50.76	-47.95	-43.92	-39.46
E Comp	31.44	25.49	27.11	60.84	49.08	43.85	-48.32	-48.07	-38.19
FF	41.78	31.95	27.15	75.72	53.62	52.98	-44.82	-40.40	-48.76
T IMRT	41.06	24.28	25.58	61.65	43.58	45.09	-33.41	-44.30	-43.27
CP IMRT	42.19	36.51	34.18	64.11	66.49	46.24	-34.19	-45.08	-26.07
NCP IMRT	38.27	35.00	34.30	68.30	40.12	54.18	-43.96	-12.74	-36.69
VMAT	28.81	28.76	25.58	49.57	49.13	50.92	-41.88	-41.47	-49.77
Mean	38.27	30.34	29.35	65.30	51.47	50.38	-41.29	-40.17	-41.39
SD	5.66	4.24	3.56	8.17	8.12	5.14	6.05	11.33	8.07

Table 4.4 Surface dose comparisons between film measurement and Acuros XB calculation

Techniques	Acuros XB (%)			Film (%)			Difference (%)		
	Tip	Medial	Lateral	Tip	Medial	Lateral	Tip	Medial	Lateral
Open	56.79	42.47	41.35	69.61	49.85	49.73	-18.41	-14.81	-16.86
SWT	48.92	41.72	39.82	63.47	45.06	47.25	-22.93	-7.42	-15.73
E Comp	40.42	39.94	37.93	62.35	50.71	42.82	-35.17	-21.24	-11.43
FF	52.66	42.67	40.01	65.36	48.64	49.33	-19.43	-12.28	-18.89
T IMRT	50.69	42.64	42.51	69.44	49.41	50.30	-27.00	-13.70	-15.48
CP IMRT	55.85	52.38	48.99	62.59	61.65	50.16	-10.76	-15.08	-2.34
NCP IMRT	48.79	47.02	47.26	55.16	34.19	52.31	-11.55	37.53	-9.66
VMAT	35.43	35.49	33.12	40.01	37.55	35.20	-11.46	5.48	-5.91
Mean	48.69	43.04	41.37	59.91	47.66	47.14	-19.59	-6.55	-12.04
SD	7.38	4.96	5.04	9.91	9.56	5.59	8.61	18.46	5.77

4.5 Patient Analysis

Table 4.5 displays the calculated surface dose of AAA and Acuros XB which point doses were recorded at the tip, lateral and medial side of the breast of eight treatment techniques. In this table, the Open, SWT and FF contributed the highest surface dose than other techniques at the tip of the breast in both algorithms. The techniques, E Comp, T IMRT, CP IMRT and NCP IMRT illustrated very similar and VMAT showed minimum surface dose at the tip of the breast. The lateral and medial side of the breast showed the same trend for the surface dose in both algorithms.

Table 4.5 Surface dose recorded from TPS for the tip, lateral and medial side of the breast

Plan	Algorithms	Relative surface dose (%)		
		Tip	Lateral	Medial
Open	AAA	46.60±3.06	32.28±4.25	33.03±2.78
	Acuros XB	49.76±4.06	36.62±5.81	34.96±3.85
SWT	AAA	44.84±3.06	32.94±4.60	33.21±2.80
	Acuros XB	47.40±3.03	35.92±5.64	35.10±3.73
E Comp	AAA	35.26±4.38	30.84±4.31	31.32±2.79
	Acuros XB	37.18±4.70	36.00±5.86	34.28±3.45
FF	AAA	43.16±2.68	31.43±3.94	32.46±2.53
	Acuros XB	46.32±3.79	36.92±5.94	34.49±3.66
T IMRT	AAA	37.79±5.39	29.75±3.89	30.32±2.73
	Acuros XB	38.32±5.21	35.15±5.96	33.66±3.51
CP IMRT	AAA	30.90±3.05	34.13±4.93	32.26±3.35
	Acuros XB	37.16±3.81	37.05±7.37	33.93±2.91
NCP IMRT	AAA	35.03±4.34	29.42±5.15	29.59±4.30
	Acuros XB	36.84±4.35	35.45±5.90	33.18±3.78
VMAT	AAA	24.17±2.07	30.94±5.51	29.02±2.39
	Acuros XB	29.96±3.39	31.99±4.98	29.09±3.49

Table 4.6 displays the calculated percent dose difference between AAA and Acuros XB of point dose recorded at 0-mm (surface), 4-mm, 6-mm depth at the tip, lateral and medial side of the breast of eight treatment techniques. The percent dose difference was calculated by using following equation (4.2)

$$\% \text{ difference} = \frac{Acuros\ XB - AAA}{AAA} \times 100 \qquad (4.2)$$

Table 4.6 The percent dose difference of surface and buildup region calculation in the Eclipse TPS by AAA and Acuros XB for eight treatment techniques

Point Position		Dose differences between AAA and Acuros XB (%)							
		Open	SWT	E Comp	FF	T IMRT	CP IMRT	NCP IMRT	VMAT
Tip	0 mm	7.08±9.87	6.10±9.14	5.85±9.60	7.64±10.29	2.49±14.09	20.69±10.45	5.98±12.53	24.50±15.60
	4 mm	2.63±1.29	2.42±1.27	1.96±1.60	2.99±3.04	2.60±8.90	4.76±2.31	2.76±1.47	6.15±3.95
	6 mm	1.91±0.88	2.01±0.85	1.34±1.12	2.29±2.46	1.64±4.08	1.59±1.10	1.26±0.71	2.69±2.68
Lateral	0 mm	16.81±31.27	12.81±32.56	20.55±33.53	20.58±31.30	21.49±31.99	11.20±29.26	24.79±33.50	7.92±31.14
	4 mm	9.66±5.27	9.87±5.85	9.63±5.50	7.23±8.07	9.31±5.69	5.78±4.74	9.64±5.39	2.31±5.38
	6 mm	6.89±1.94	6.22±1.75	6.60±2.03	5.42±4.47	5.99±1.95	3.99±1.85	5.89±2.59	2.07±3.11
Medial	0 mm	6.49±14.66	6.35±14.18	10.35±15.68	6.88±14.52	11.95±16.41	6.45±16.32	13.79±17.38	1.09±16.44
	4 mm	10.30±7.23	10.87±7.44	11.53±7.30	9.08±8.40	10.90±7.67	8.22±6.13	11.14±7.66	5.09±8.39
	6 mm	6.02±3.47	6.25±3.43	6.63±3.41	4.78±5.04	6.09±3.36	4.36±2.50	5.92±3.17	3.02±2.98

Figure 4.6 shows the diagram of mean percent difference of AAA and Acuros XB recorded dose at the Tip (0-, 4-, 6-mm depth) of the breast. The surface doses gave the result of high difference between the two algorithms, especially the CP IMRT and VMAT techniques, the highest was 24.50±15.60% and the standard deviation of the result was also high. At the 4-mm depth, nearly all techniques except VMAT showed comparable to each other. The dose differences at that depth were 2.63±1.29%, 2.42±1.27%, 1.96±1.60%, 2.99±3.04%, 2.60±8.90%, 4.76±2.31%, 2.76±1.47%, and 6.15±3.95% for Open, SWT, E Comp, FF, T IMRT, CP IMRT, NCPIMRT and VMAT, respectively. At the deeper depth (6-mm), all techniques showed less percent difference than 4-mm, the highest difference was only 2.69±2.68% for VMAT technique.
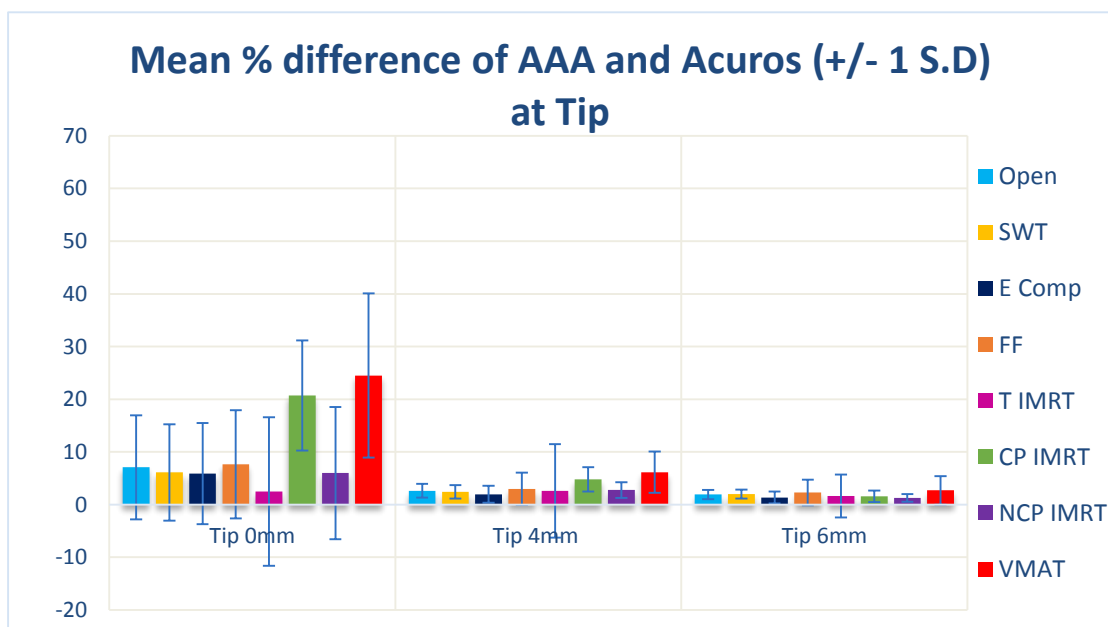
Figure 4.6 The mean percent dose differences at surface and buildup region between AAA and Acuros XB for eight treatment techniques at the Tip of the breast

Figure 4.7 shows the mean percent difference of AAA and Acuros XB dose at the Lateral side (0-, 4-, 6-mm depth) of the breast. The surface dose differences were comparable between techniques, the highest was 24.79±33.50%. The dose differences were lower between two algorithms, when the depth was deeper. The highest dose differences for 4- and 6-mm depth were 9.87±5.85% and 6.89±1.94%, respectively.
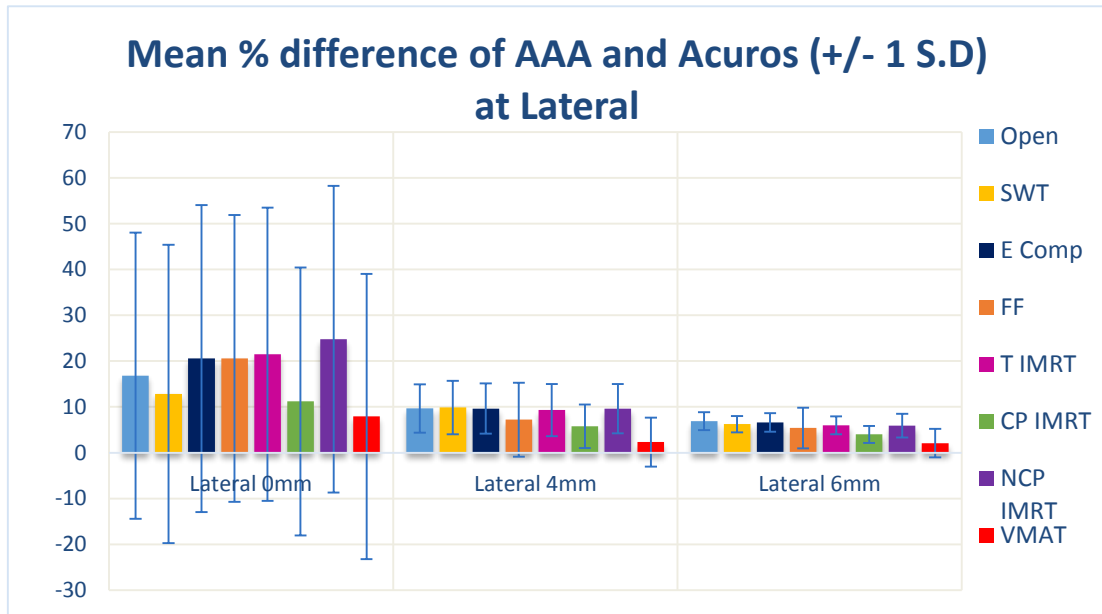
Figure 4.7 The mean percent dose differences at surface and buildup region between AAA and Acuros XB for eight treatment techniques at the Lateral of the breast

Figure 4.8 shows the mean percent difference of AAA and Acuros XB recorded dose at the Medial side (0-, 4-, 6-mm depth) of the breast. They showed the same trend as the lateral side in all depths and techniques. The highest dose differences for surface, 4-, and 6-mm were $13.79\pm17.38\%$, $11.53\pm7.30\%$ and $6.63\pm3.41\%$, respectively. The deeper depth showed good agreement in both algorithms than shallower depth.
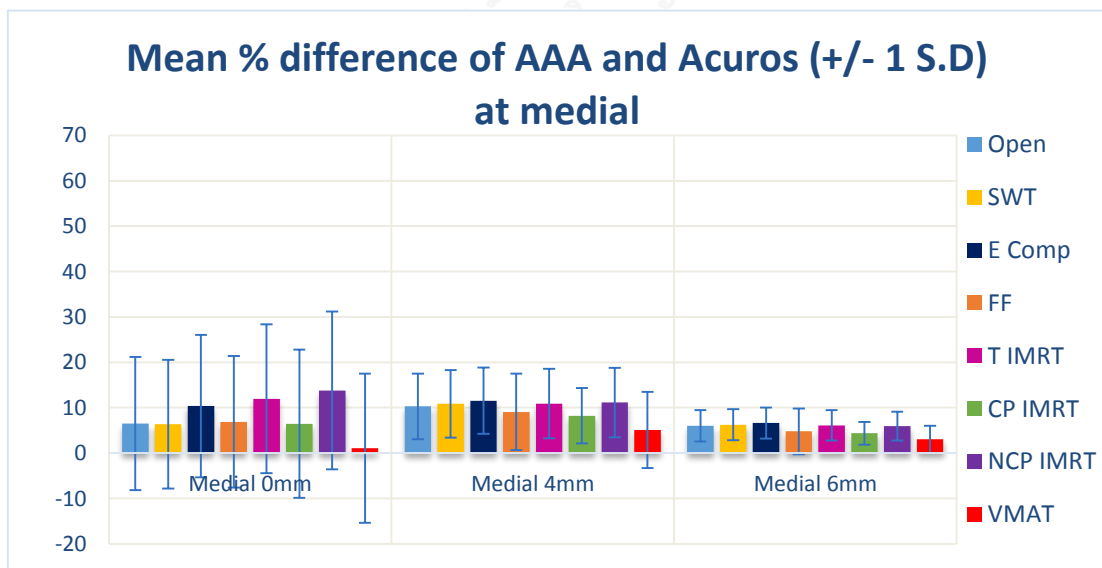
Figure 4.8 The mean percent dose differences at surface and buildup region between AAA and Acuros XB for eight treatment techniques at the Medial of the breast

CHAPTER 5

DISCUSSION AND CONCLUSIONS

5.1 Discussion

The surface dose can be defined as the energy deposited within an infinitesimally small mass of tissue at the surface of the phantom. However, there is no dosimeter that has an infinitesimally small sensitive volume and the surface dose is difficult to measure. An extrapolation chamber is almost ideal dosimeter for surface dose measurement but it is not practical use in general hospital. Therefore, in this study, the surface dose measurement was performed by using the EBT2 film which is suitable for surface dose measurement according to Devic S. et al study, who reported that EBT model GAFCHROMIC® film by ignoring the skin dose correction factors, the skin dose based on a single film piece measurement would overestimate the skin dose by 5%, and small field size dependence.[13] The surface and buildup region dose verification measurement was performed on the homogeneous slab phantom and non-homogeneous CIRS phantom to get the accurate surface dose for clinical application. We used grid size 2.5x2.5 mm^2 for TPS calculation for the surface dose. For the TPS calculation, contour of the body also have to be considered, we found actual body and body contour is highly difference in some points of the CT images of the phantom due to the automatic contouring of setting the HU value. This makes the uncertainty dose at the surface.

5.1.1 Verification of Single Beam Plan in the Homogeneous Solid Water Slab Phantom

The surface and buildup region dose verification measurement were investigated on the homogeneous slab phantom with the beam perpendicular to the surface of the phantom. The surface dose measurement on the phantom is 19.37% of Dmax which agree with the Nakano M et al. study, who reported that the surface dose measurement with EBT2 film on a homogeneous phantom was 19.4% of Dmax.[15] The difference between the measurement and TPS show AAA algorithm overestimate than film measurement 33.33% at the surface. Acuros XB shows closer surface dose to the measurement than AAA, however, it is still higher than film measurement 12.31%. These large differences are due to the incorrect dose calculation of treatment planning in the disequilibrium region. In the built-up region TPS calculation is underestimated than measurement approximately 10.87%, which agree with the AAPM tolerance that allowed up to 20% in built-up region of depth dose curves between measurements and calculation.

5.1.2 Verification of Tangential Open Beam Plan in the CIRS Thorax Phantom

The surface and buildup region dose verification with nonhomogeneous material was investigated on the CIRS nonhomogeneous Thorax phantom. The surface dose for this measurement is 48.93% (ranged from 41.6% − 59.5%) of Dmax which agree with the Nakano M. et al. study, who reported that the surface dose measurement with EBT2 film on a chest phantom was 51.75% (ranged from 48.3% - 55.2%) of Dmax.[15] In our investigation, the surface dose measurement for two tangential parallel opposing fields illustrate 28.96% and 14.31% higher than AAA and Acuros XB calculation, respectively, but at the buildup region, start from 5-mm depth, TPS calculation is very close to the film measurement in both algorithms which agree with the Akino Y. et al, who reported that at deeper depths mainly (6-11 mm), film dosimetry showed good agreement with the TPS calculation.[19]

Moreover, Acuros XB shows more closer dose to measurement than AAA at the surface, but still underestimates than measurement 14.31% ; that is because of the capability of Acuros XB, it accounts for the specific elemental compositions of human tissue and calculates the dose to proper medium, that is not available in AAA and also Acuros XB can account more scatter dose than AAA.[23] However, we cannot believe the TPS for surface dose calculation. At 15-mm depth, Acuros XB is good agreement than AAA when compare with film. Therefore, after 5-mm depth, at the built-up region, the TPS calculation can be trusted.

5.1.3 Verification of Plans in Eight Treatment Techniques in the CIRS Thorax Phantom

For film measurement, the surface dose at the Tip of the breast is the highest, it ranges from 50% - 75% of prescribed dose in all techniques but the Medial and Lateral sides of the breast are comparable to each other, they range from 40% - 66% of prescribed dose that agreed with the Akino Y. et al, who reported that the wedge, FF, and ecomp techniques showed the surface dose around the medial region of approximately 45% - 50% of the prescribed dose while the dose increased in the lateral direction with highest around the nipple to 70% - 75% of the prescribed dose.[19] However, in our study, VMAT shows the same surface dose in all three locations because gantry rotates around the patient and contribute the uniform dose in this technique. The surface dose at the tip is the highest and medial and lateral side are the same distribution that is because the more curved shape of the tip and the medial and lateral are the same curved shape in the phantom breast, but in actual patient the lateral side which is more moveable than medial side of the breast and the shape may contribute the difference dose.

In treatment plan verification between measurement and calculation, the surface dose of film measurement is higher than TPS for 40% in AAA algorithm and 19% at

the Tip, 12% at the Lateral and Medial side in Acuros XB algorithm. The result is agreed with the phantom verification measurement in this study. In table 4.4, the film measurement result for NCP IMRT shown film measurement is lower dose than TPS calculation. That is due to the machine MLC movement problem which occurred during the measurement. Normally, in all eight treatment techniques, the surface dose from TPS is underestimated than film measurement.

5.1.4 Patient Analysis

For clinical cases from Table 4.5, the algorithms play the important role in various planning techniques, the surface dose illustrate high difference of more than 20% between AAA and Acuros XB at the tip of the breast for VMAT and IMRT plans, while the other techniques of both surface and build up region show difference within 10% at 4mm and 6% at 6mm depth. The Acuros XB can calculate more accurate than AAA in a curve surface such as the tip of the breast. Surface dose calculation using imaging based TPS is depended on the grid size and body contour. If the grid size is reduced, the difference of calculation from the measurement would expect to be less.

5.2 Conclusions

For the surface dose measurement of breast radiotherapy, Open field, SWT and FF show the same trend in high surface dose especially at tip of the breast. E Comp and T IMRT contribute the relatively low surface dose than other techniques. CP and NCP IMRT deliver the reasonable surface dose, but higher than E Comp and T IMRT. VMAT contributes the lowest and homogeneous surface dose for the breast radiotherapy in eight treatment techniques.

In breast measurement, the tip of the breast receives the highest surface dose in almost all techniques, especially Open field and FF. The lateral and medial sides of the breast obtain the similar dose distribution for the surface dose in almost all techniques. However, in CP IMRT, medial side is higher than lateral and in NCP IMRT show vice versa for the surface dose.

For the patient analysis using the calculation of both algorithms, the tip of the breast shows the highest differences for surface between two algorithms. The surface dose of lateral side shows the higher dose differences than medial side of the breast. However, the calculation of the both algorithms show under dose at the tip than measurement, which is due to the less consideration of the curved surface.

It is concluded that the treatment planning system cannot give the accurate dose for surface dose calculation, as verified with the EBT2 film on homogeneous slab phantom and non-homogeneous CIRS thorax IMRT phantom. Calculation by Acuros XB contributes high dose difference to AAA at the surface of CP IMRT and VMAT plan, but comparable at the deeper depth starting from 6 mm. The calculated surface

dose for breast depends on the geometry of the structure, treatment techniques and the algorithms.

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APPENDIX

APPENDIX I

Figure I. Open Field treatment plan of CIRS Thorax phantom

Figure II. SWT treatment plan of CIRS Thorax phantom

Figure III. E Comp treatment plan of CIRS Thorax phantom

y	MLC	Field Weight	Scale	Gantry Rtn [deg]	Coll Rtn [deg]	Couch Rtn [deg]	Wedge	Field X [cm]	X1 [cm]	X2 [cm]	Field Y [cm]	Y1 [cm]	Y2 [cm]	X [cm]	Y [cm]	Z [cm]	SSD [cm]	MU	Ref. D [cGy]
X	Dose Dynamic	1.000	Varian IEC	67.7	0.0	0.0	None	10.0	+6.0	+4.0	14.0	+7.0	+7.0	-9.19	5.56	9.69	94.6	386	
X	Dose Dynamic	1.000	Varian IEC	242.9	0.0	0.0	None	10.0	+4.0	+6.0	14.0	+7.0	+7.0	-9.19	5.56	9.69	94.4	371	

Figure IV. FF treatment plan of CIRS Thorax phantom

ergy	MLC	Field Weight	Scale	Gantry Rtn [deg]	Coll Rtn [deg]	Couch Rtn [deg]	Wedge	Field X [cm]	X1 [cm]	X2 [cm]	Field Y [cm]	Y1 [cm]	Y2 [cm]	X [cm]	Y [cm]	Z [cm]	SSD [cm]	MU	Ref. D [cGy]
- 6X	Static	0.948	Varian IEC	67.7	0.0	0.0	None	10.0	+6.0	+4.0	14.0	+7.0	+7.0	-9.19	5.56	9.69	94.6	267	295.2
- 6X	Static	0.948	Varian IEC	242.9	0.0	0.0	None	10.0	+4.0	+6.0	14.0	+7.0	+7.0	-9.19	5.56	9.69	94.4	271	300.1
- 6X	Static	0.052	Varian IEC	67.7	0.0	0.0	None	10.0	+6.0	+4.0	14.0	+7.0	+7.0	-9.19	5.56	9.69	94.6	16	16.7
- 6X	Static	0.052	Varian IEC	242.9	0.0	0.0	None	10.0	+4.0	+6.0	14.0	+7.0	+7.0	-9.19	5.56	9.69	94.4	18	17.3

Figure V. T IMRT treatment plan of CIRS Thorax phantom
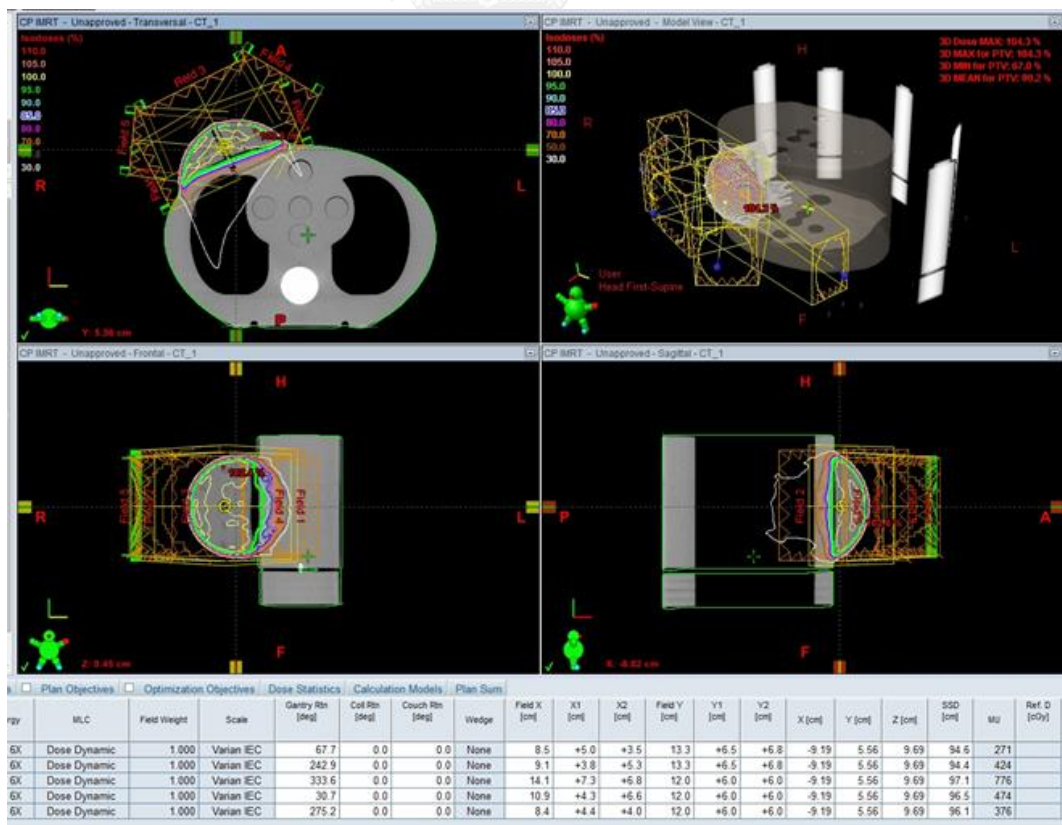
Figure VI. CP IMRT treatment plan of CIRS Thorax phantom

Figure VII. NCP IMRT treatment plan of CIRS Thorax phantom
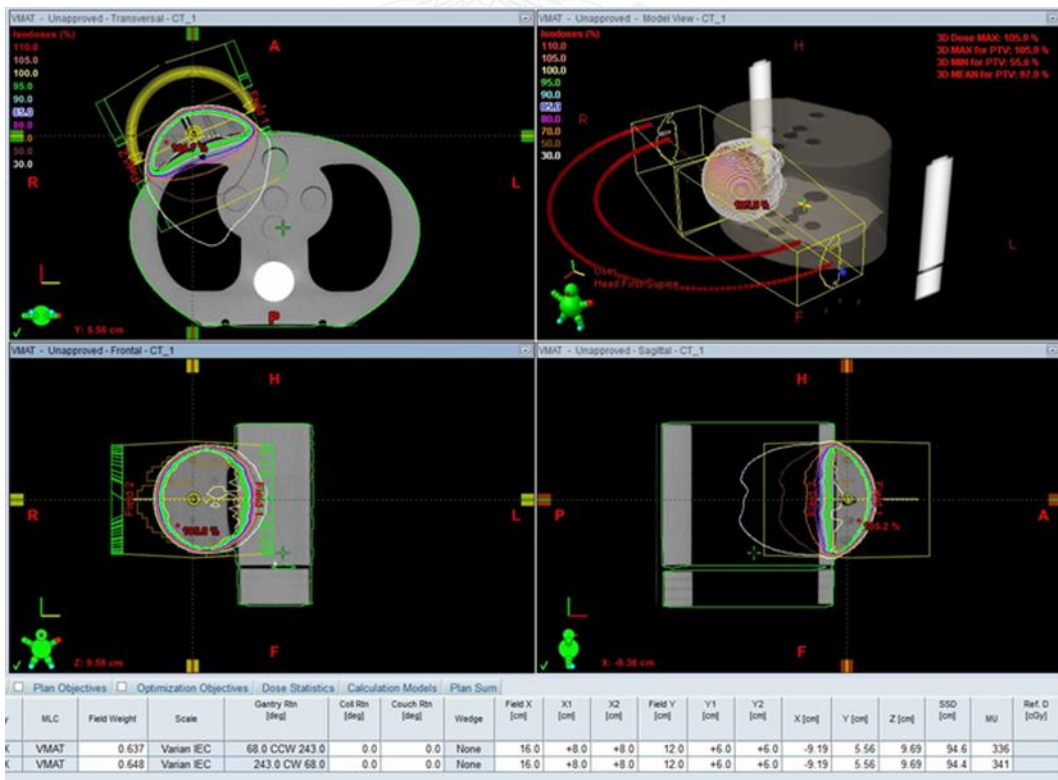
Figure VIII. VMAT treatment plan of CIRS Thorax phantom

APPENDIX II

Table I: Recorded point doses data for Open Field

Patient ID		Tip	Tip 4mm	Tip 6mm	Lateral	Lateral 4mm	Lateral 6mm	Medial	Medial 4mm	Medial 6mm
Patient 1	AAA	45.09	109.00	110.37	33.27	86.95	94.60	33.99	86.96	93.68
	Acuros	52.78	112.45	111.96	27.63	93.59	97.71	37.99	91.74	96.74
	% Diff	17.05	3.17	1.44	-16.95	7.64	3.29	11.77	5.50	3.27
Patient 2	AAA	42.88	104.75	106.96	27.92	85.95	93.68	33.41	90.43	99.82
	Acuros	44.56	107.24	107.95	42.09	91.34	98.12	31.02	96.72	101.63
	% Diff	3.92	2.38	0.93	50.75	6.27	4.74	-7.15	6.96	1.81
Patient 3	AAA	46.55	111.55	112.88	29.09	80.08	88.32	27.10	80.42	88.49
	Acuros	47.97	112.14	114.58	37.74	84.75	95.09	34.41	84.42	90.69
	% Diff	3.05	0.53	1.51	29.74	5.83	7.67	26.97	4.97	2.49
Patient 4	AAA	49.71	110.69	112.27	28.24	80.72	89.14	31.56	83.95	91.20
	Acuros	51.67	113.08	113.95	37.34	83.12	93.91	32.22	87.36	94.86
	% Diff	3.94	2.16	1.50	32.22	2.97	5.35	2.09	4.06	4.01
Patient 5	AAA	48.05	112.64	115.51	30.15	83.24	89.57	34.00	84.01	92.86
	Acuros	46.64	114.99	116.19	40.01	85.9	96.40	29.19	90.50	96.14
	% Diff	-2.93	2.09	0.59	32.70	3.20	7.62	-14.14	7.73	3.53
Patient 6	AAA	42.08	108.58	110.05	34.85	73.63	86.13	33.86	75.1	85.36
	Acuros	47.06	109.64	111.82	34.43	84.51	91.63	32.59	85.23	93.11
	% Diff	11.83	0.98	1.61	-1.21	14.78	6.39	-3.75	13.49	9.08
Patient 7	AAA	52.07	111.29	113.29	32.31	77.15	90.53	39.48	81.48	89.68
	Acuros	46.91	115.12	116.62	34.97	92.20	99.16	37.39	89.13	94.65
	% Diff	-9.91	3.44	2.94	8.23	19.51	9.53	-5.29	9.39	5.54
Patient 8	AAA	43.13	113.84	115.82	34.50	76.77	89.05	32.63	71.19	81.01
	Acuros	54.42	117.02	118.83	31.19	89.24	94.61	41.22	80.53	91.96
	% Diff	26.18	2.79	2.60	-9.59	16.24	6.24	26.32	13.12	13.52

Patient 9	AAA	47.03	111.43	113.68	39.51	82.91	90.33	31.57	69.49	84.78
	Acuros	48.37	113.16	115.89	29.73	90.10	96.37	38.23	91.14	92.29
	% Diff	2.85	1.55	1.94	-24.75	8.67	6.69	21.10	31.16	8.86
Patient 10	AAA	49.08	109.90	112.97	32.61	79.38	86.13	32.70	74.43	85.05
	Acuros	57.79	113.83	114.66	44.67	87.20	95.06	31.95	80.87	88.66
	% Diff	17.75	3.58	1.50	36.98	9.85	10.37	-2.29	8.65	4.25
Patient 11	AAA	48.59	109.61	112.22	25.97	83.51	92.06	32.26	83.69	92.25
	Acuros	53.02	115.23	115.90	46.02	89.67	98.71	39.90	93.22	99.90
	% Diff	9.12	5.13	3.28	77.20	7.38	7.22	23.68	11.39	8.29
Patient 12	AAA	44.99	108.58	110.10	38.92	78.72	90.85	33.82	81.31	90.02
	Acuros	45.95	112.64	113.55	33.60	89.46	97.68	33.35	87.17	96.82
	% Diff	2.13	3.74	3.13	-13.66	13.64	7.52	-1.39	7.21	7.55

Table II: Recorded point doses data for Standard Wedged Tangent (SWT)

Patient ID		Tip	Tip 4mm	Tip 6mm	Lateral	Lateral 4mm	Lateral 6mm	Medial	Medial 4mm	Medial 6mm
Patient 1	AAA	44.17	106.87	108.33	33.34	87.38	95.25	34.08	87.30	94.16
	Acuros	50.81	109.76	110.08	27.28	92.28	97.94	37.91	92.11	97.29
	% Diff	15.03	2.70	1.62	-18.17	5.61	2.82	11.24	5.51	3.32
Patient 2	AAA	42.01	102.85	105.18	28.11	87.19	95.32	33.53	90.06	99.39
	Acuros	42.66	105.21	106.41	44.47	91.60	98.52	31.01	96.36	101.24
	% Diff	1.55	2.30	1.17	58.20	5.06	3.36	-7.52	7.00	1.86
Patient 3	AAA	44.07	105.67	107.10	29.26	80.38	88.61	27.33	80.93	88.99
	Acuros	45.37	106.29	108.80	37.88	84.97	95.30	34.63	84.78	91.06
	% Diff	2.95	0.59	1.59	29.46	5.71	7.55	26.71	4.76	2.33
Patient 4	AAA	47.64	106.19	107.87	28.41	80.86	89.17	31.85	84.76	92.11
	Acuros	49.43	108.48	109.50	37.40	83.04	93.73	32.48	88.08	95.67
	% Diff	3.76	2.16	1.48	31.64	2.70	5.11	1.98	3.92	3.87
Patient 5	AAA	45.28	106.17	109.04	30.39	83.74	90.06	34.26	84.47	93.32
	Acuros	43.86	108.37	109.66	40.21	86.25	96.75	29.29	90.75	96.41
	% Diff	-3.14	2.07	0.57	32.31	3.00	7.43	-14.51	7.44	3.31
Patient 6	AAA	41.21	106.31	107.87	35.06	73.91	86.40	34.11	75.48	85.74
	Acuros	45.97	107.29	109.56	34.55	84.69	91.81	32.72	85.47	93.33
	% Diff	11.55	0.92	1.57	-1.46	14.59	6.26	-4.08	13.23	8.85
Patient 7	AAA	50.83	108.51	110.54	32.47	76.20	88.97	39.79	83.13	91.93
	Acuros	45.65	112.15	113.71	34.50	90.35	96.88	37.66	90.99	96.97
	% Diff	-10.19	3.36	2.868	6.252	18.57	8.89	-5.35	9.46	5.48
Patient 8	AAA	39.62	104.81	107.10	34.84	77.38	89.65	32.88	71.86	81.75
	Acuros	49.8	107.73	109.87	31.38	89.71	95.07	41.61	81.12	92.55
	% Diff	25.69	2.79	2.59	-9.93	15.93	6.05	26.55	12.89	13.21
Patient 9	AAA	45.70	108.32	110.63	39.69	83.16	90.57	31.77	69.83	85.14
	Acuros	48.18	109.79	112.82	29.71	90.38	96.33	37.05	91.48	92.81
	% Diff	5.43	1.36	1.98	-25.14	8.68	6.36	16.62	31.00	9.01

Patient 10	AAA	46.24	108.79	110.6	38.49	76.43	89.53	32.54	74.56	86.86
	Acuros	50.73	110.88	113.05	33.77	90.05	95.11	33.46	87.19	93.91
	% Diff	9.71	1.92	2.18	-12.26	17.82	6.23	2.83	16.94	8.12
Patient 11	AAA	47.27	106.52	109.15	26.12	83.79	92.32	32.40	83.92	92.47
	Acuros	51.48	112.05	112.82	46.16	89.87	98.90	39.99	93.39	100.06
	% Diff	8.91	5.19	3.38	76.72	7.26	7.13	23.43	11.29	8.21
Patient 12	AAA	43.98	106.07	107.68	39.10	78.94	91.04	33.99	81.54	90.24
	Acuros	44.82	110.04	111.07	33.68	89.61	97.86	33.42	87.31	96.97
	% Diff	1.91	3.74	3.15	-13.86	13.52	7.49	-1.68	7.08	7.46

Table III: Recorded point doses data for Electronic Compensator (E Comp)

Patient ID		Tip	Tip 4mm	Tip 6mm	Lateral	Lateral 4mm	Lateral 6mm	Medial	Medial 4mm	Medial 6mm
Patient 1	AAA	29.98	90.31	98.29	31.38	86.72	95.35	32.03	86.71	94.61
	Acuros	33.42	90.81	98.63	26.82	92.13	98.29	36.85	91.97	97.84
	% Diff	11.47	0.554	0.35	-14.53	6.24	3.08	15.05	6.07	3.41
Patient 2	AAA	30.31	87.73	96.72	26.12	84.88	93.50	31.29	87.55	96.71
	Acuros	28.36	87.46	96.08	42.82	89.23	96.24	30.32	95.01	99.31
	% Diff	-6.43	-0.31	-0.66	63.94	5.13	2.93	-3.10	8.52	2.69
Patient 3	AAA	38.71	97.93	100.22	27.67	78.38	87.13	25.42	80.04	88.93
	Acuros	39.21	98.11	102.05	36.83	82.91	93.18	34.60	85.84	92.74
	% Diff	1.29	0.18	1.83	33.10	5.78	6.94	36.11	7.25	4.28
Patient 4	AAA	38.87	93.02	98.88	27.15	79.79	88.67	29.67	82.49	90.03
	Acuros	39.79	94.70	99.51	36.67	82.55	93.59	31.43	85.85	93.52
	% Diff	2.37	1.81	0.64	35.06	3.46	5.55	5.93	4.07	3.88
Patient 5	AAA	35.60	92.05	98.90	28.22	81.88	88.88	31.78	81.96	91.44
	Acuros	34.34	93.29	99.01	39.32	85.34	96.14	28.36	88.63	94.54
	% Diff	-3.53	1.35	0.11	39.33	4.23	8.17	-10.76	8.14	3.39
Patient 6	AAA	32.84	92.25	97.98	33.33	72.93	85.93	32.65	74.30	84.94
	Acuros	37.32	93.41	99.23	34.27	84.28	91.76	32.40	84.98	92.97
	% Diff	13.64	1.26	1.28	2.82	15.56	6.79	-0.77	14.37	9.45
Patient 7	AAA	39.13	91.13	97.77	31.64	76.17	89.36	37.56	80.19	89.18
	Acuros	35.80	94.52	100.31	34.32	90.51	97.44	36.20	88.40	94.55
	% Diff	-8.51	3.72	2.60	8.47	18.83	9.04	-3.62	10.24	6.02
Patient 8	AAA	26.84	85.74	95.10	33.01	75.82	88.96	29.96	68.89	79.27
	Acuros	32.89	87.79	97.26	30.84	89.33	94.86	40.35	79.30	90.69
	% Diff	22.54	2.39	2.27	-6.57	17.82	6.63	34.68	15.11	14.41
Patient 9	AAA	39.01	95.38	99.40	38.15	82.10	89.82	30.41	68.11	83.82
	Acuros	40.60	96.11	100.76	28.52	88.01	94.63	36.68	89.85	90.05
	% Diff	4.08	0.77	1.37	-25.24	7.20	5.36	20.62	31.92	7.43

Patient 10	AAA	38.32	90.57	97.07	31.26	78.86	85.82	32.33	75.05	86.15
	Acuros	45.27	93.58	97.87	43.96	85.52	93.13	33.30	85.37	94.08
	% Diff	18.13	3.32	0.82	40.63	8.45	8.52	3.00	13.75	9.21
Patient 11	AAA	39.41	96.08	101.15	24.54	81.08	89.89	30.20	80.62	89.74
	Acuros	43.01	100.44	103.80	44.63	87.89	97.27	37.87	90.08	97.02
	% Diff	9.14	4.54	2.62	81.87	8.40	8.21	25.40	11.73	8.11
Patient 12	AAA	34.13	89.19	95.39	37.64	77.34	89.80	32.51	81.03	90.23
	Acuros	36.19	92.71	98.08	33.02	88.54	96.93	33.05	86.86	96.78
	% Diff	6.04	3.95	2.82	-12.27	14.48	7.94	1.66	7.20	7.26

Table IV: Recorded point doses data for Field-in-Field (FF)

Patient ID		Tip	Tip 4mm	Tip 6mm	Lateral	Lateral 4mm	Lateral 6mm	Medial	Medial 4mm	Medial 6mm
Patient 1	AAA	40.97	99.33	100.62	32.55	86.57	94.41	33.90	86.91	93.59
	Acuros	47.61	102.81	102.98	27.01	91.45	96.94	37.45	91.56	96.75
	% Diff	16.20	3.50	2.35	-17.02	5.64	2.68	10.47	5.35	3.38
Patient 2	AAA	40.94	99.94	102.06	27.70	86.67	94.73	33.28	89.00	97.30
	Acuros	42.75	104.31	104.72	44.18	90.61	97.20	30.64	95.35	99.88
	% Diff	4.42	4.37	2.61	59.50	4.55	2.61	-7.93	7.14	2.65
Patient 3	AAA	41.76	100.82	102.06	28.58	79.53	87.99	27.12	80.52	88.60
	Acuros	43.07	101.08	103.36	37.42	84.36	94.78	34.41	84.46	90.75
	% Diff	3.14	0.26	1.27	30.93	6.07	7.72	26.88	4.89	2.43
Patient 4	AAA	46.42	103.43	104.92	27.19	78.80	87.47	30.66	83.02	90.42
	Acuros	49.29	107.14	107.59	36.35	81.52	92.43	31.59	86.13	93.91
	% Diff	6.18	3.59	2.55	33.69	3.45	5.67	3.03	3.75	3.86
Patient 5	AAA	43.88	102.63	105.24	29.87	83.24	89.7	33.49	83.85	92.94
	Acuros	42.86	105.75	106.72	39.91	85.89	96.46	29.07	90.27	95.98
	% Diff	-2.32	3.04	1.41	33.61	3.19	7.54	-13.20	7.66	3.27
Patient 6	AAA	39.18	100.92	102.32	34.79	73.96	86.65	33.57	74.75	85.03
	Acuros	43.92	102.25	104.31	34.53	84.86	92.13	32.40	84.75	92.59
	% Diff	12.09	1.32	1.95	-0.75	14.74	6.32	-3.49	13.38	8.89
Patient 7	AAA	47.91	102.44	104.32	31.79	77.02	90.76	37.83	78.77	86.95
	Acuros	44.06	107.86	109.06	34.56	91.70	98.82	36.35	86.86	92.47
	% Diff	-8.03	5.29	4.54	8.71	19.06	8.88	-3.91	10.27	6.35
Patient 8	AAA	39.80	104.80	106.63	34.30	76.82	89.29	32.28	71.30	81.32
	Acuros	51.12	109.47	110.98	31.24	89.57	94.90	41.22	80.75	92.23
	% Diff	28.44	4.46	4.08	-8.92	16.60	6.28	27.70	13.25	13.42
Patient 9	AAA	43.90	103.82	105.92	39.30	83.54	91.10	31.61	70.28	86.02
	Acuros	46.03	108.35	110.91	29.67	90.43	96.97	37.63	90.81	92.36
	% Diff	4.85	4.36	4.71	-24.50	8.25	6.44	19.05	29.21	7.37

Patient 10	AAA	45.44	101.94	104.85	32.56	79.48	86.27	32.44	74.37	85.13
	Acuros	53.89	106.21	107.06	44.63	87.19	95.09	31.84	80.75	88.60
	% Diff	18.59	4.19	2.11	37.07	9.70	10.22	-1.85	8.58	4.08
Patient 11	AAA	43.85	99.42	101.85	25.12	82.36	91.23	30.47	80.41	89.20
	Acuros	48.83	105.99	106.37	45.33	88.80	98.01	38.23	90.36	97.18
	% Diff	11.35	6.61	4.44	80.45	7.82	7.43	25.47	12.37	8.95
Patient 12	AAA	43.90	107.55	108.37	33.43	88.95	97.01	32.92	86.25	96.00
	Acuros	42.46	102.08	103.53	38.17	77.98	90.40	33.05	80.27	89.02
	% Diff	-3.28	-5.09	-4.47	14.18	-12.33	-6.81	0.40	-6.93	-7.27

Table V: Recorded point doses data for Tangential Intensity Modulated Radiation Therapy (T IMRT)

Patient ID		Tip	Tip 4mm	Tip 6mm	Lateral	Lateral 4mm	Lateral 6mm	Medial	Medial 4mm	Medial 6mm
Patient 1	AAA	24.40	71.82	88.09	30.44	84.74	93.26	31.47	86.35	93.41
	Acuros	33.20	93.32	100.69	26.27	90.21	95.96	37.10	91.53	96.74
	% Diff	36.07	29.94	14.30	-13.69	6.46	2.90	17.89	6.00	3.57
Patient 2	AAA	36.24	98.26	102.88	26.68	85.43	93.12	30.97	86.77	95.71
	Acuros	34.85	98.10	102.59	43.16	89.09	95.23	29.86	93.60	97.73
	% Diff	-3.84	-0.16	-0.28	61.77	4.28	2.27	-3.58	7.87	2.11
Patient 3	AAA	38.62	100.37	102.99	27.41	78.45	87.21	25.18	80.05	88.70
	Acuros	41.87	101.38	104.46	36.29	82.22	92.56	33.81	84.57	91.72
	% Diff	8.42	1.01	1.43	32.40	4.81	6.14	34.27	5.65	3.41
Patient 4	AAA	35.24	88.79	95.81	25.42	76.47	85.66	27.95	80.00	87.71
	Acuros	34.84	89.83	96.54	35.29	80.00	90.90	30.74	83.95	91.52
	% Diff	-1.14	1.17	0.76	38.83	4.62	6.12	9.98	4.94	4.34
Patient 5	AAA	40.11	99.21	103.11	27.93	80.75	87.55	31.51	80.96	90.22
	Acuros	37.29	99.65	102.38	38.71	84.13	94.80	27.97	87.28	93.02
	% Diff	-7.03	0.44	-0.71	38.60	4.19	8.28	-11.24	7.81	3.10
Patient 6	AAA	35.18	99.90	102.41	32.08	72.15	85.58	30.57	72.82	83.78
	Acuros	34.94	97.11	103.11	33.94	83.69	91.32	31.61	83.52	91.76
	% Diff	-0.68	-2.79	0.67	5.80	15.99	6.71	3.40	14.69	9.53
Patient 7	AAA	45.04	99.15	101.85	29.03	74.06	87.75	36.18	78.60	87.70
	Acuros	39.76	101.77	104.12	33.80	88.81	95.16	35.27	86.34	92.31
	% Diff	-11.72	2.64	2.23	15.36	19.92	8.44	-2.52	9.85	5.26
Patient 8	AAA	38.27	99.47	101.88	32.64	75.13	88.02	28.43	69.47	79.76
	Acuros	43.53	99.63	103.04	31.05	88.71	93.79	40.63	79.31	90.53
	% Diff	13.74	0.16	1.14	-4.87	18.08	6.56	42.91	14.16	13.50
Patient 9	AAA	38.83	95.35	98.68	35.40	77.86	85.73	28.80	65.28	80.95
	Acuros	31.34	91.98	98.83	27.58	84.55	90.85	35.62	86.41	87.84
	% Diff	-19.28	-3.53	0.15	-22.09	8.59	5.97	23.68	32.37	8.51

Patient 10	AAA	45.06	96.68	99.55	30.21	81.59	87.45	31.95	76.86	87.39
	Acuros	49.11	99.86	99.00	45.62	87.31	94.30	35.07	87.88	95.21
	% Diff	8.99	3.29	-0.55	51.01	7.01	7.83	9.77	14.34	8.95
Patient 11	AAA	40.58	100.44	103.75	23.29	75.05	84.13	28.98	77.26	85.93
	Acuros	43.17	102.72	104.37	39.91	80.22	89.43	34.94	83.49	90.13
	% Diff	6.38	2.27	0.60	71.36	6.25	6.30	20.57	8.06	4.89
Patient 12	AAA	35.93	99.90	102.38	36.19	74.43	87.07	31.84	76.70	83.89
	Acuros	35.91	96.71	102.26	30.21	83.05	90.84	31.28	80.61	88.88
	% Diff	-0.06	-3.19	-0.12	-16.52	11.58	4.33	-1.76	5.10	5.95

Table VI: Recorded point doses data for Coplanar Intensity Modulated Radiation Therapy (CP IMRT)

Patient ID		Tip	Tip 4mm	Tip 6mm	Lateral	Lateral 4mm	Lateral 6mm	Medial	Medial 4mm	Medial 6mm
Patient 1	AAA	27.48	84.99	92.24	30.50	86.09	94.61	35.65	88.84	95.53
	Acuros	35.81	88.72	94.60	27.61	95.97	102.00	37.29	92.44	98.11
	% Diff	30.31	4.39	2.56	-9.48	11.48	7.81	4.60	4.05	2.70
Patient 2	AAA	29.97	94.86	101.60	32.99	94.72	99.97	37.22	94.80	100.89
	Acuros	35.50	101.69	103.35	50.62	97.62	101.11	32.66	100.58	102.70
	% Diff	18.45	7.20	1.72	53.44	3.06	1.14	-12.25	6.10	1.79
Patient 3	AAA	35.80	100.42	104.04	28.14	78.32	87.04	24.97	79.11	86.25
	Acuros	39.70	102.10	104.90	36.11	81.14	91.32	34.72	83.47	88.72
	% Diff	10.89	1.67	0.83	28.32	3.60	4.92	39.05	5.51	2.86
Patient 4	AAA	25.65	80.02	92.26	28.76	81.00	88.62	31.74	86.33	92.28
	Acuros	31.87	85.16	93.35	36.12	80.73	91.13	32.58	86.36	92.51
	% Diff	24.25	6.42	1.18	25.59	-0.33	2.83	2.65	0.04	0.25
Patient 5	AAA	34.43	96.14	102.73	28.83	76.69	81.78	31.32	79.32	87.88
	Acuros	34.75	97.78	102.45	35.78	76.50	85.95	28.07	84.64	89.46
	% Diff	0.93	1.71	-0.27	24.11	-0.25	5.10	-10.38	6.71	1.80
Patient 6	AAA	28.55	95.27	99.94	37.09	75.23	86.86	34.03	77.30	87.87
	Acuros	37.12	99.25	103.25	34.08	83.39	90.45	32.86	85.54	93.03
	% Diff	30.02	4.18	3.31	-8.12	10.85	4.13	-3.44	10.66	5.87
Patient 7	AAA	31.13	91.96	99.22	34.21	78.93	90.98	35.35	79.41	89.23
	Acuros	34.67	96.50	101.07	33.25	87.83	94.04	33.68	86.28	93.00
	% Diff	11.37	4.94	1.87	-2.81	11.28	3.36	-4.72	8.65	4.23
Patient 8	AAA	29.21	94.01	100.74	41.03	85.97	96.82	29.07	70.95	81.63
	Acuros	38.58	96.53	101.71	32.25	93.70	98.05	38.14	76.34	88.60
	% Diff	32.08	2.68	0.96	-21.39	8.99	1.27	31.20	7.60	8.54
Patient 9	AAA	30.65	89.14	94.91	40.05	84.15	90.71	29.50	65.15	79.33
	Acuros	34.36	95.29	98.25	30.17	90.54	96.06	33.21	81.82	83.66
	% Diff	12.10	6.90	3.52	-24.66	7.59	5.90	12.58	25.59	5.46

Patient 10	AAA	33.90	91.13	99.42	35.19	81.52	87.04	33.81	75.94	85.35
	Acuros	45.81	99.01	100.94	43.15	82.82	90.21	32.28	82.70	91.47
	% Diff	35.13	8.65	1.53	22.62	1.60	3.64	-4.53	8.90	7.17
Patient 11	AAA	33.69	93.39	99.91	31.02	95.17	100.43	31.89	83.18	91.30
	Acuros	41.89	98.90	100.71	50.67	96.29	104.38	38.50	90.61	96.99
	% Diff	24.34	5.90	0.80	63.35	1.18	3.93	20.73	8.93	6.23
Patient 12	AAA	30.29	93.05	98.45	41.71	83.94	95.76	32.59	81.15	89.15
	Acuros	35.87	95.37	99.50	34.80	92.60	99.42	33.22	85.96	94.00
	% Diff	18.42	2.49	1.07	-16.56	10.32	3.82	1.93	5.93	5.44

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Table VII: Recorded point doses data for Non-coplanar Intensity Modulated Radiation Therapy (NCP IMRT)

Patient ID		Tip	Tip 4mm	Tip 6mm	Lateral	Lateral 4mm	Lateral 6mm	Medial	Medial 4mm	Medial 6mm
Patient 1	AAA	28.24	87.21	96.15	30.00	90.42	99.76	35.35	91.67	97.26
	Acuros	34.78	91.32	97.63	27.23	95.20	101.77	40.76	95.48	98.80
	% Diff	23.16	4.71	1.54	-9.23	5.29	2.02	15.30	4.16	1.58
Patient 2	AAA	35.06	95.12	100.28	29.25	89.42	95.36	32.28	90.97	98.20
	Acuros	32.97	97.23	101.55	46.77	92.39	96.32	30.87	98.42	101.00
	% Diff	-5.96	2.22	1.27	59.90	3.32	1.01	-4.37	8.19	2.85
Patient 3	AAA	38.01	98.80	102.21	29.14	80.98	88.81	24.76	81.18	90.63
	Acuros	40.22	99.65	103.19	40.17	86.57	95.98	34.83	87.47	94.09
	% Diff	5.81	0.86	0.96	37.85	6.90	8.07	40.67	7.75	3.82
Patient 4	AAA	28.63	82.42	94.87	24.58	76.52	86.43	22.24	73.52	84.24
	Acuros	31.62	86.14	95.16	34.69	79.33	90.33	27.86	78.43	87.72
	% Diff	10.44	4.51	0.31	41.13	3.67	4.51	25.27	6.68	4.13
Patient 5	AAA	38.16	96.60	101.81	24.77	71.93	79.38	29.58	79.21	89.26
	Acuros	33.01	97.81	102.03	35.45	77.11	87.51	27.23	87.51	93.61
	% Diff	-13.49	1.25	0.22	43.12	7.20	10.24	-7.95	10.48	4.87
Patient 6	AAA	32.32	94.34	99.92	30.64	71.45	84.58	33.48	78.91	89.43
	Acuros	34.34	94.97	101.35	33.77	82.60	90.24	33.68	89.08	97.22
	% Diff	6.25	0.67	1.43	10.22	15.61	6.69	0.60	12.89	8.71
Patient 7	AAA	40.59	95.80	100.03	26.89	72.02	86.52	36.37	80.83	90.25
	Acuros	36.08	97.73	101.08	31.89	85.49	92.86	33.92	85.78	93.22
	% Diff	-11.11	2.02	1.05	18.60	18.70	7.33	-6.74	6.12	3.29
Patient 8	AAA	31.88	93.15	98.92	30.13	72.14	85.99	26.49	64.47	74.67
	Acuros	40.56	97.02	101.58	28.57	84.75	90.43	37.29	73.49	84.23
	% Diff	27.23	4.16	2.69	-5.18	17.48	5.16	40.77	13.99	12.80
Patient 9	AAA	35.52	93.95	97.97	40.07	83.23	89.50	25.86	61.19	77.76
	Acuros	36.17	95.81	99.78	30.97	90.18	94.40	32.94	81.71	83.82
	% Diff	1.83	1.98	1.85	-22.71	8.35	5.48	27.38	33.54	7.79

Patient 10	AAA	42.02	95.71	100.81	29.12	76.64	83.14	30.39	73.37	83.41
	Acuros	47.47	99.74	102.13	42.75	82.70	89.78	31.85	82.51	90.65
	% Diff	12.97	4.21	1.31	46.81	7.91	7.99	4.80	12.46	8.68
Patient 11	AAA	33.52	91.92	98.72	21.33	75.97	87.29	29.33	79.50	88.72
	Acuros	38.03	95.45	99.27	40.11	81.34	91.87	35.47	87.73	94.39
	% Diff	13.46	3.84	0.56	88.05	7.07	5.25	20.93	10.35	6.39
Patient 12	AAA	36.39	93.24	97.98	37.10	75.23	85.83	28.92	78.57	87.73
	Acuros	36.80	95.78	99.84	32.98	85.90	91.74	31.46	84.16	93.11
	% Diff	1.13	2.72	1.90	-11.10	14.18	6.89	8.78	7.12	6.13

Table VIII: Recorded point doses data for Volumetric Modulated Arc Therapy (VMAT)

Patient ID		Tip	Tip 4mm	Tip 6mm	Lateral	Lateral 4mm	Lateral 6mm	Medial	Medial 4mm	Medial 6mm
Patient 1	AAA	21.94	79.71	91.25	33.45	92.74	100.76	28.32	81.74	89.56
	Acuros	31.63	88.84	97.06	24.29	88.61	96.03	26.66	82.77	92.36
	% Diff	44.16	11.45	6.36	-27.38	-4.45	-4.69	-5.86	1.26	3.12
Patient 2	AAA	23.60	86.41	98.79	27.61	88.99	97.09	33.97	88.05	94.89
	Acuros	28.79	92.65	100.24	37.35	85.97	96.07	29.41	96.72	101.48
	% Diff	21.99	7.22	1.46	35.27	-3.39	-1.05	-13.42	9.84	6.94
Patient 3	AAA	23.57	79.82	89.18	23.63	73.84	85.59	28.98	84.20	90.54
	Acuros	30.23	87.94	95.83	30.96	76.81	89.79	35.03	82.83	88.87
	% Diff	28.25	10.17	7.45	31.02	4.02	4.90	20.87	-1.62	-1.84
Patient 4	AAA	25.63	84.39	94.75	27.53	80.13	88.65	25.63	81.80	90.83
	Acuros	28.62	85.74	93.85	32.27	77.52	89.65	27.33	80.74	91.19
	% Diff	11.66	1.60	-0.95	17.2	-3.25	1.12	6.63	-1.29	0.39
Patient 5	AAA	25.29	81.38	92.95	27.01	75.97	82.24	30.95	78.70	88.01
	Acuros	26.61	87.89	95.04	32.56	75.24	87.05	24.70	79.16	87.07
	% Diff	5.21	8.00	2.24	20.54	-0.96	5.84	-20.19	0.58	-1.06
Patient 6	AAA	21.82	81.46	90.87	35.59	73.34	84.35	27.03	70.87	83.78
	Acuros	25.38	80.64	90.47	31.09	76.86	85.15	25.95	75.81	87.16
	% Diff	16.31	-1.00	-0.44	-12.64	4.80	0.94	-3.99	6.97	4.034
Patient 7	AAA	26.15	85.60	94.47	31.52	77.85	91.34	30.75	76.50	88.04
	Acuros	27.96	88.52	97.29	31.38	86.77	94.31	26.77	78.18	89.43
	% Diff	6.92	3.41	2.98	-0.44	11.45	3.25	-12.94	2.19	1.57
Patient 8	AAA	22.83	85.86	96.33	39.91	86.01	97.80	25.80	68.29	79.71
	Acuros	36.24	93.29	100.64	29.49	91.72	97.14	34.81	70.88	83.63
	% Diff	58.73	8.65	4.47	-26.10	6.63	-0.675	34.922	3.79	4.91
Patient 9	AAA	23.63	81.53	91.93	37.40	82.85	91.04	27.68	63.29	80.01
	Acuros	29.03	87.84	95.89	26.05	86.49	95.92	31.04	81.70	86.05
	% Diff	22.85	7.73	4.30	-30.34	4.39	5.36	12.13	29.08	7.54

Patient 10	AAA	25.48	81.37	94.21	23.98	73.40	80.91	30.57	66.64	75.17
	Acuros	34.68	89.68	96.47	35.26	73.30	83.79	25.62	66.91	77.39
	% Diff	36.10	10.21	2.39	47.03	-0.13	3.56	-16.19	0.40	2.95
Patient 11	AAA	28.47	88.64	97.69	27.23	86.70	92.96	28.56	79.59	89.89
	Acuros	33.49	91.81	96.90	43.22	85.37	94.95	30.78	86.00	94.93
	% Diff	17.63	3.57	-0.80	58.72	-1.53	2.14	7.77	8.05	5.60
Patient 12	AAA	21.67	81.76	91.91	36.43	75.67	88.63	29.99	81.04	89.78
	Acuros	26.91	84.06	94.5	29.91	83.35	92.32	31.01	82.54	91.59
	% Diff	24.18	2.81	2.81	-17.89	10.14	4.16	3.40	1.85	2.02

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