การวัดปริมาณรังสีของผู้ป่วยโดยการใช้ฟิล์ม กาฟโครมิกอีบีที3 ในการฉายรังสีทั่วร่างกาย

นางสาววิพาพอร อินพาวง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาฉายาเวชศาสตร์ ภาควิชารังสีวิทยา
คณะแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2559

IN VIVO DOSIMETRY USING GAFCHROMIC EBT3 FILM IN TOTAL BODY IRR ADIATION

Miss Viphaphone Inphavong

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Medical Imaging
Department of Radiology
Faculty of Medicine
Chulalongkorn University
Academic Year 2016

Thesis Title	IN VIVO DOSIMETRY USING GAFCHROMIC EBT3 FILM IN TOTAL BODY IRRADIATION
By	Miss Viphaphone Inphavong
Field of Study	Medical Imaging
Thesis Advisor	Associate Professor Sivalee Suriyapee, M.Eng
Thesis Co-Advisor	Taweap Sanghangthum, Ph.D.

Accepted by the Faculty of Medicine, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

.....Dean of the Faculty of Medicine
(Professor Suttipong Wacharasindhu, M.D.)

THESIS COMMITTEE

.....Chairman
(Associate Professor Kanjana Shotelersuk, M.D.)

.....Thesis Advisor
(Associate Professor Sivalee Suriyapee, M.Eng)

.....Thesis Co-Advisor
(Taweap Sanghangthum, Ph.D.)

.....External Examiner
(Professor Franco Milano, Ph.D.)

วิพาพอร อินพาวง : การวัดปริมาณรังสีของผู้ป่วยโดยการใช้ฟิล์ม กาฟโครมิกอีบีที3 ในการฉายรังสีทั่วร่างกาย (IN VIVO DOSIMETRY USING GAFCHROMIC EBT3 FILM IN TOTAL BODY IRRADIATION) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ศิวลี สุริยาปี, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ดร.ทวีป แสงแห่งธรรม, 58 หน้า.

วัตถุประสงค์ของการศึกษานี้เพื่อวัดปริมาณรังสีในหุ่นจำลองและผู้ป่วยที่ได้รับการฉายรังสีทั่วร่างกายด้วยฟิล์มกาฟโครมิกอีบีที3 การฉายเริ่มต้นด้วยการฉายรังสีด้านข้าง ที่ระยะจากต้นกำเนิดรังสีถึงแนวแกนกลางบริเวณกึ่งกลางผู้ป่วย 5 เมตรให้ปริมาณรังสี 200 cGy ต่อครั้ง ฉายวันละ 2 ครั้ง เป็นเวลา 3 วัน รวม 6 ครั้ง กำหนดปริมาณรังสีที่ บริเวณศรีษะ ขา ให้ได้รับปริมาณรังสี 1200 cGy ส่วนที่ปริมาณรังสียังขาดอยู่บริเวณทรวงอกและช่องท้อง ฉายรังสีเพิ่มด้านหน้า-หลังและหลัง-หน้า ในการฉายครั้งที่ 7 ใช้เทคนิค3 มิติ แบบรังสีล้อมรอบเฉพาะก้อนเนื้อร้าย พร้อมกับปิดบริเวณ ปอด และไต ไม่ให้ได้รับรังสี ทำการวัดปริมาณรังสีในผู้ป่วย 1 แผนการรักษา ในการฉายด้านข้างซ้าย-ขวา รวม 6 ครั้ง วัดในหุ่นจำลอง 4 แผนการรักษา และวัดในผู้ป่วย 5 แผนการรักษา ใช้เทคนิค 3 มิติ ให้รังสีเข้าทางด้านหน้าด้านหลัง สองลำสวนทางกัน วางฟิล์มบนหุ่นจำลองและบนผู้ป่วยในบริเวณ ไหล่ รักแร้ ช่วงอก สะดือ หน้าท้อง ขาหนีบ และ ต้นขา ผลจากการฉายด้านข้างซ้าย-ขวา ค่าความแตกต่างเฉลี่ยของปริมาณรังสีระหว่างการวัดและคำนวณเท่ากับ 0.4±2.7% จากการรักษาใช้เทคนิค 3 มิติ ผลจากหุ่นจำลองได้ค่าความแตกต่างเฉลี่ยของปริมาณรังสีระหว่างการวัดและคำนวณเท่ากับ -2.9±1.2% ความแตกต่างเฉลี่ยในปอด -3.3±3.4% ในไต -3.0±6.0% ผลจากผู้ป่วยได้ค่าความแตกต่างเฉลี่ยระหว่างการวัดและคำนวณเท่ากับ -0.8±1.6% ผลจากการทดลองค่อนข้างสอดคล้องกับ Petra ซึ่งรายงานค่าความแตกต่างในหุ่นจำลองเท่ากับ 0.7±2.1% และ ในผู้ป่วยเท่ากับ 0.5±4.7% งานวิจัยนี้ได้แสดงให้เห็นว่า เครื่องวางแผนการรักษาคำนวณปริมาณรังสีได้ถูกต้องภายใน ±5% จากการวัดปริมาณรังสีในการฉายรังสีทั่วร่างกายด้วยฟิล์มกาฟโครมิกอีบีที3.

ภาควิชา รังสีวิทยา	ลายมือชื่อนิสิต .....
สาขาวิชา ฉายาเวชศาสตร์	ลายมือชื่อ อ.ที่ปรึกษาหลัก .....
ปีการศึกษา 2559	ลายมือชื่อ อ.ที่ปรึกษาร่วม .....

5874104030 : MAJOR MEDICAL IMAGING
KEYWORDS: TOTAL BODY IRRADIATION (TBI) / IN-VIVO DOSIMETRY / GAFCHROMIC EBT3 FILM

VIPHAPHONE INPHAVONG: IN VIVO DOSIMETRY USING GAFCHROMIC EBT3 FILM IN TOTAL BODY IRRADIATION. ADVISOR: ASSOC. PROF. SIVALEE SURIYAPEE, M.Eng, CO-ADVISOR: TAWEAP SANGHANGTHUM, Ph.D., 58 pp.

The purpose of this study is to measure the dose in the phantom and patients during total body irradiation by EBT3 film. The techniques of TBI were two lateral parallel opposing fields at extended SAD of 500 cm for 200 cGy/fraction, 2 fractions per day in 3 days and aimed 1200 cGy at the head and legs. The remainder dose of less than 1200 cGy in chest and abdomen parts were added with AP/PA fields by 3D-CRT with lung and kidney shielded by MLC in the 7^{th} fraction. The dose measurement was performed in 1 plan of patient in lateral fields for 6 fractions and 4 plans in phantom and 5 plans in patient in AP/PA fields using 3D-CRT in Eclipse TPS. The films were placed in phantom and patient of shoulder, armpit, chest, umbilicus, abdomen, groin and thigh. For lateral fields, the average dose difference was 0.4±2.7%. For 3D-CRT in phantom, the average dose difference was -2.9±1.2%. The average dose difference in lung and kidney were -3.3±3.4% and -3.0±6.0%, respectively. For patient, the average dose difference was -0.8±1.6%. The results were agreed with Petra M.H et al who reported 0.7±2.1% and 0.5±4.7% differences between measured and calculated dose in phantom and patient, respectively. The performance of EBT3 film for TBI dosimetry shows reliable for calculation of patient dose with less than ±5% of uncertainties.

Department:	Radiology	Student's Signature	.....
Field of Study:	Medical Imaging	Advisor's Signature	.....
Academic Year:	2016	Co-Advisor's Signature	.....

ACKNOWLEDGEMENTS

First and foremost I offer my sincerest gratitude to my supervisor, Associate Professor Sivalee Suriyapee from Division of Radiation Oncology, Department of Radiology, Faculty of Medicine, Chulalongkorn University, who has supported me a lot throughout my thesis with her patience and knowledge whilst allowing me the room to work in my own way. I am equally grateful to Dr. Taweap Sanghangthum, my co-advisor for his help in the experiment, kind suggestion, and constructive comments in my experiments and English and Thai language proof in this research.

I am deepest appreciation of IAEA sponsorship for 2 years course in Master degree program at Chulalongkorn University.

I am deeply thank Associate Professor Anchali Krisanachinda, for giving me opportunities to attend Master of Science Program in Medical Imaging at Chulalongkorn University and her kindness, support, valuable encouragement and entirely care during the entire course of study.

I would like to greatly thank Associate Professor Kanjana Shotelersuk, Head of Radiation Oncologist in Division of Radiation Oncology, Department of Radiology, Faculty of Medicine, Chulalongkorn University for her kindness comment for my thesis and allowing me for equipment supported.

I would like to thank Professor Franco Milano, Professor of Medical Physics, University of Florence for his kindness in examining this thesis and provide suggestion for the improvement.

I would like to greatly thank Mr. Sornjarod Oonsiri, Mr. Tanawat Tawonwong, all physicist and staff at Division of Radiation Oncology, King Chulalongkorn Memorial Hospital, for their kind support, comments and supply the knowledge for my experiment.

Finally, I would like to thank my family: my parents Bounyok and Nuanyai for giving birth to me and supporting me spiritually throughout my life.

CONTENTS

Page

Page

LIST OF TABLES

LIST OF FIGURE

LIST OF ABBREVIATIONS

Abbreviation	Term
AAA	Analytical Anisotropic Algorithm
AAPM	American Association of Physicists in Medicine
Acuros XB	Acuros XB Algorithm
AP/ PA	Antero-posterior/Postero-anterior
BEV	Beam's Eye View
BMT	Bone Marrow Transplantation
cGy	Centi-Gray
cm	Centimeter
cm^2	Square Centimeter
cm^3	Cubic Centimeter
CT	Computed Tomography
DCF	Distributed Calculation Framework
D_{Cal}	Calibration Dose
D_{max}	Depth Maximum Dose
d_{ref}	Dose at Reference
DRR	Digitally Reconstructed Radiographs
ESTRO	European Society for Therapeutic Radiology and Oncology
FIF	Field-In-Field
HD-TBI	High Dose Total Body Irradiation
HSCT	Hematopoietic Stem Cell Transplant
HU	Hounsfield Unit
IAEA	International Atomic Energy Agency
ICRU	International Commission on Radiation Unit and Measurement
IMRT	Intensity Modulated Radiation Therapy

ISP	International Specialty Products
KCMH	King Chulalongkorn Memorial Hospital
kVp	Kilovoltage Peak
LBTE	Linear Boltzmann Transport Equation
MeV	Mega-electron-Volt
MLC	Multi-Leaf Collimator
MOSFET	Metal-Oxide Semiconductor Field Effect Transistor Dosimeter
MU	Monitor Units
MV	Megavoltage
NTCP	Normal Tissue Complication Probability
OAR	Off-Axis Ratio
OD	Optical Density
OSL	Optically-Stimulated Luminescence Dosimeter
PD	Prescribed Dose
PDD	Percentage Depth Dose
PDD_N	Normalized Percentage Depth Dose
RGB	Red, Green and Blue
RL/LL	Right Lateral/ Left Lateral
RTPS	Radiotherapy Treatment Planning System
SAD	Source-Axis Distance
S_c	Collimator Scatter Factor
SCD	Source to Calibration Point Distance
SD	Standard Deviation
SFOV	Scan Field of View
SNC	Sun Nuclear Corporation
SPD	Source to Point of Interest Distance
S_p	Phantom Scatter Factor
SSD	Source to Surface Distance
TCP	Tumor Control Probability

TF	Tray Factor
TLD	Thermoluminescent Dosimeter
TMR	Tissue-Maximum Ratio
TPR	Tissue-Phantom Ratio
VMAT	Volumetric Modulated Arc Therapy
WF	Wedge Factor
Z_{eff}	Effective Atomic Number
Z^{water}_{eff}	Effective Atomic Number of Water
2D	Two Dimensional
3D/3D-CRT	Three-Dimensional Conformal Radiotherapy

CHAPTER I

INTRODUCTION

1.1 Background and rationale

Radiation therapy is one of the most common methods for treatment cancer by delivering high radiation dose to the tumor while minimize dose to the normal tissues. Total body irradiation is a type of external beam radiotherapy and considered as a special technique aimed to deliver a uniform dose to entire body within ±10% of prescription dose while keeping dose to lung within tolerance level[1]. TBI is used in conjunction with chemotherapy to prepare patients for bone marrow transplantation (BMT) and remains an important component of hematopoietic stem cell transplant (HSCT) with the goal of eradicating residual malignant cells or modulating the immune system of the transplant recipient. Typically treatment of TBI are usually used at extended source to surface distances (SSD) technique because it is the simplest and most prevalent of the TBI technique used nowadays[2], although there are many other difference treatment technique that have been described in AAPM report no. 17 in 1986[1]. The extended SSD technique can be divided into lateral parallel opposing field technique and anterior-posterior/posterior-anterior parallel-opposed technique (AP/PA). For lateral parallel opposing field technique, the treatment is more comfortable to patient if lying supine position on specially designed couch and require longer distance, but patient may have greater variation in body thickness along the path of beams. The AP/PA techniques treat patient in standing or lay down, it can provide a better dose uniformity along the longitudinal body axis and require additional lung blocks to reduce lung dose. The technique has evolved in parallel with an increase in the knowledge of the biologic response to ionizing radiation and improvements in radiation dosimetry and treatment delivery[3].

However, the choose of TBI technique depends on specific clinical situation such as available equipment, maximum field size, treatment distance, dose-rate, photon beam energy, patient dimension and the need to select the shielding in certain body structure[3]. The treatments of TBI are complicated by uncertainty of absolute

dosimetry as well as large dose variation across the target volume, making very difficult to assess clinical efficacy when comparing results from various treatment centers. Furthermore, the actual dose delivered to the patient is often limited by normal tissue tolerance. There are unique dosimetric challenges associated with TBI when compared with conventional radiation therapy. The first is large treatment field sizes irradiation and extended distance for TBI make more complex in scattering conditions. Second, it is difficult to produce uniform dose distributions in the entire body of patient due to variation in body contour along craniocaudal and transverse axes. Third, the large dose fraction size and irradiation volume require special attention to critical normal organ tolerance especially lung limitation because high doses will be collected with radiation pneumonitis, a potentially lethal complication[4].

In the past, TBI at King Chulalongkorn Memorial Hospital (KCMH) were treated by high dose technique with 1200 cGy dose in 6 fractions, 2 fractions per day in 3 days by AP/PA fields and RL/LL lateral parallel opposing fields. For AP/PA fields, patient was positioned on supine and prone on the floor and treated for 6 MV photon beams with lung shielded by Cerrobend blocks and boost the remainder dose on chest wall with 6 MeV electron beams. For the RL/LL lateral parallel opposing fields, patient lied on special design TBI couch at extended source-axis distance (SAD) at 500 cm, maximum field sizes of 40 x 40 cm^2 and irradiated with 6 MV photon beams, after that field size was reduced to cover shoulder and abdomen regions and irradiated with 10 MV photon beams for the reminder doses. Nowadays, the treatment technique have changed to 6 fractions of two lateral parallel opposing fields by manual calculation and boost remainder dose at chest and abdomen part with AP/PA fields by 3D conformal radiotherapy (3D-CRT) with lung and kidney shielded by MLC in the 7^{th} fraction. The dose distribution is calculated by Eclipse treatment planning system (TPS), the advanced Field-in-Field (FIF) technique is used in AP/PA fields to compensate for homogenous dose considering body contour variation.

The purpose of this study is to measure the dose during total body irradiation in boost fraction with AP/PA fields by 3D-CRT calculated in Eclipse TPS. The dose is measured by Gafchromic EBT3 films in phantom and patients and the evaluation is done by percent dose differences between calculated dose and measured dose.

1.2 Objective

To measure the dose in the phantom and patient during total body irradiation of 6 MV photon beams with AP/PA fields by 3D-CRT using Gafchromic EBT3 film.

CHAPTER II

LITERATURE REVIEW

2.1 Theory

2.1.1 Total Body Irradiation

First reports on the use of TBI in treatment of disease appeared in the 1930's. In recent years, there has been revived interest in the use of very large radiation fields for the treatment of a variety of malignant diseases[5]. Total body irradiation (TBI) or whole body irradiation is considered as a special procedure since it differs significantly from the standard treatment techniques. The difference primarily are due to the fact that the fields of treatment for TBI exceed the size of the scattering volume (entire body) in all directions, and the irradiation volume is highly irregular in shape[6]. TBI with megavoltage photon beams is well-established technique used in conjunction with chemotherapy in treatment of systemic malignant diseases[7]. In radiation oncology, radiation is given to prepare for bone marrow or stem cell transplant by reducing the number of viable cells and suppressing the recipient's immune system. There are three main purposes of TBI: immunosuppression to allow engraftment of donor stem cells (e.g. immunologic, diseases, aplastic anemia); eradication of malignant cells (e.g. leukemia, lymphoma and some solid tumor); and eradication of cell populations with genetic disorders (e.g. Fanconi's anemia, thalassemia major)[8].

The categories of TBI can be divided into four types[5]:

a) High dose TBI (HDTBI) with a single fraction is treated for dose range of 750 to 900 cGy or sometime it is up to six fractions with dose of 200 cGy/fraction in 3 days (total dose is 1200 cGy), HDTBI with megavoltage photon beams is frequently used to destroy a bone marrow and leukemia cells, to immunosuppress the patient prior to receiving a bone marrow transplant (BMT), or both.

b) Low dose TBI with megavoltage photon beams employs a larger fraction in 10 to 15 days with a typical dose of 10 to 15 cGy per day. It is used for treatment of

lymphocytic leukemia, lymphomas or neuroblastoma. The lower doses reduce the risk of serious complication.

c) Half body irradiation, aims to give a sufficiently high dose with a typical dose of 8 Gy delivered to upper or lower half-body in a single fraction. This technique has become so successful that it is being used in a number of clinical trials as an adjuvant form of primary therapy for Ewing's sarcoma and bronchogenic carcinoma.

d) Total nodal (lymphoid) irradiation with a typical total dose prescription of 40 Gy delivered in 20 fractions. It has been shown to be a powerful immunosuppressive agent and suggested as an adjunctive therapy for organ transplantation and a number of autoimmune diseases.

2.1.1.1 Treatment Techniques

The goal of the TBI technique is to deliver a uniform dose to entire body with no more than ±10% dose heterogeneity in reference to the dose to the prescription point[1].

TBI treatment techniques are carried out with: dedicated irradiations (i.e., treatment machines specially designed for total body irradiation) and modified conventional megavoltage radiotherapy equipment (treatment at extended source-surface distance (SSD), treatment with a translational beam, and treatment with a sweeping beam)[6].

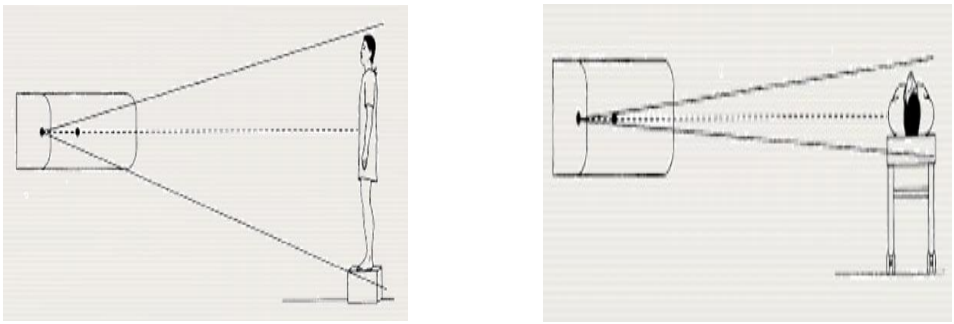
There are three methods that are in used to administer TBI with modified conventional radiotherapy equipment[3]:

1) Treatment at extended source-surface distance (SSDs)

The extended source-to surface distance can be divided into 2 techniques: an anteroposterior (AP) / posteroanterior (PA) technique and bilateral technique[7]:

- AP/PA Total Body Irradiation: patient is irradiated in anterior and posterior parallel-opposing fields while patient positioned in a stands or lay down at the long distance (Figure 2.1 (a)). The technique and the modifications made to it to accommodate shielding of specific organ such as the lungs, kidneys, and brain. The major advantages of this technique are less thickness variation of the body in superior-interior direction and reduced radiation dose to lungs.

- Bilateral Total Body Irradiation: this technique involves left and right lateral opposing fields (Figure 2.1 (b)) with the patient is seated or in supine positioned on a special designed couch which are more comfortable, as the lateral body thickness is quite disparate over the head-to-toe length of a patient, compensators (usually fixed to the gantry head) will often be required to reduce the dose to the head, neck, and legs as the smaller thickness organs. The advantages are natural lung compensation with arms and more comfortable patient position.



(a) (b)

Figure 2.1 The treatment at extended source-surface distance (SSDs) in (a) AP/PA fields and (b) RL/LL lateral field

2) The treatment technique with a translational couch that moves a patient horizontally beneath a vertical beam to achieve a uniform dose distribution (Figure 2.2). In 1997, Chui et al. purposed an arc treatment with gravity-oriented compensator to deliver a uniform dose to a patient lying on the floor. This method can be implemented in a small treatment room, but it also results in a large penumbra around the lung shield area[5].

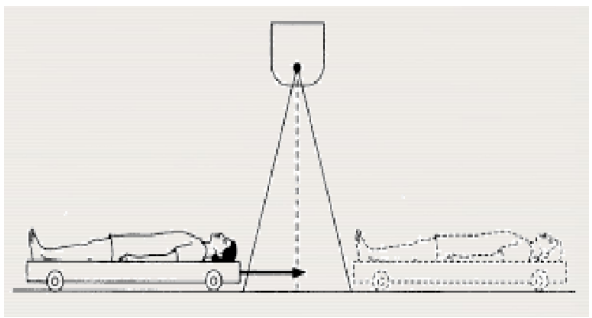


Figure 2.2 The treatment with a translational couch technique with patient moves translational through a stationary beam

3) Treatment with a sweeping beam technique using the head swivel of a column mount (Figure 2.3) and has been in use in clinic in 1986. The patient lies supine or prone on a low couch constructed to allow localization and verification radiographs to be taken in the treatment geometry without having to move the patient[5].

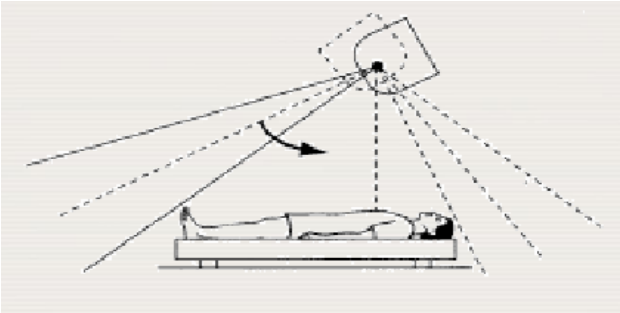


Figure 2.3 The beam sweeps over a stationary patient

Many different techniques were described for the effective irradiation of the entire body. The aim of each technique is to provide as uniformity accurate dose as possible throughout body. A secondary important aim is not to exceed the tolerance of any organ (except for bone marrow). TBI setup represents a very irregular and extended field. It is essential to deliver homogenous radiation dose over whole body, which requires careful setup design to minimize the possible errors. TBI is a complex radiotherapy treatment need for careful treatment planning, accurate localization of organ and strict adherence to quality assurance protocols[8]. For these protocols concern about basic quality assurance protocols related to performance of equipment used for treatment planning and TBI dose delivery; pre-treatment quality assurance protocols dealing with calibration and preparation of equipment immediately preceding the TBI treatment; treatment quality assurance protocols which deal with measurements of the dose delivered to the patient during the TBI procedure[5]. Delivery of homogenous dose distribution through the whole body is very challenging with TBI.

The task for in vivo dosimetry in the case of TBI is three folds: a. Determine the dose specification point (usually taken at mid-pelvis or mid-abdomen); b. Estimate the homogeneity of the midline dose distribution at different loci in cranio-caudal direction; and c. Monitor the dose at the level of organs at risk (lungs, liver, kidneys, etc)[9].

2.1.1.2 Dose Homogeneity for TBI

There are many factors that work to limit dose homogeneity when the total body is the target of irradiation. The thickness of the irradiated volume for TBI tends toward the maximum values encountered for more conventional therapy. This is certainly true if patients are treated with lateral beams, but section thickness is also a problem when AP/PA fields are used. This is because standard techniques for dealing with high-dose regions are not easily applied to TBI. The techniques for shielding critical normal structures (lungs, kidneys, etc) have not been as cleanly developed for lateral field irradiation as they have been for the AP/PA treatment geometry[10].

Dose inhomogeneity in TBI is inevitable because of the following factors: a.) irregular body thickness over the irradiation volume cause the midline dose to differ; b.) variation in the tissue density along the beam axis changes the photon flux at a given point increasing the dose in less dense parts of the body such as lungs; c.) summation of entrance and exit beam dose cause the radiation dose near the skin to be much larger than the midline dose[1]. A thorough understanding of these limitations helps in devising improved methods to reduce dose inhomogeneity[10].

- **Tissue Lateral Effect**

The effect of beam energy on the shape of a single-field depth dose curve and the summed curve for opposed fields can be large. For the opposed field situation, the difference is most dramatic when the thickness of the patient for a particular part of the body is large [11]. For very large separations like the width of the shoulders for an adult patient, the dose near the entry surfaces can be as much as 25% higher than the midline dose for a 6 MV photon energy and 500 cm SAD geometry used as shown in Figure 2.4. This figure also shows that increasing the beam energy from 6 to 15 MV for the same treatment distance bring this dose differential down to about half this amount for the 52 cm section separation[10].

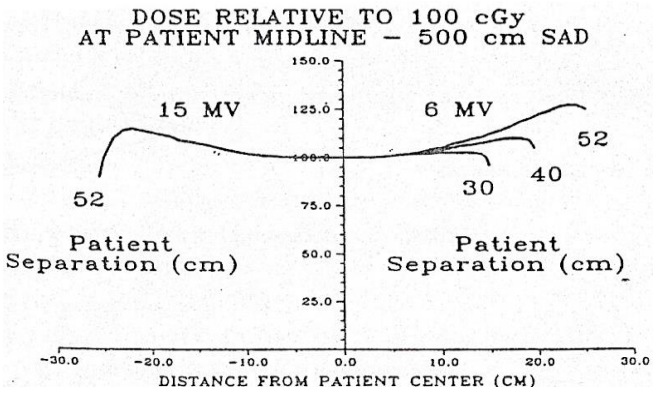


Figure 2.4 The dose at the build-up depth at either beam entry surface increases with the thickness of the body

Figure 2.5 shows the dose increase near the entry surfaces of the opposed beams for two different SADs (300 and 500 cm) and for two photon energies and for a Cobalt-60 beam. Symmetric hot spots will occur very near the d_{max} depths for the individual beams. The Cobalt-60 beams with treatment at short distance are not recommended when the treatment room geometry dictates the use of lateral fields. The large separations for patients at the level of the shoulders can drive the maximum dose very high. For an AP/PA field arrangement, the problem is less serious and might produce an acceptable distribution. However, another problem that has not yet been discussed might make this treatment unacceptable. That is, there may be much thinner parts of the body that cause the high dose to go well above the ±5% limit. The one cause of dose inhomogeneity is the lack of electron equilibrium at the entry surface for any one of the selected treatment fields[10].

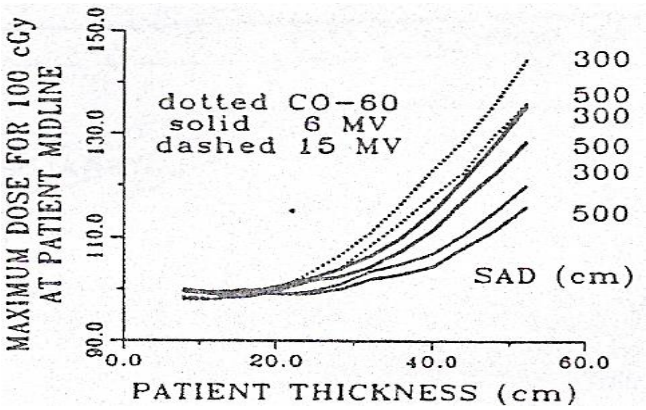


Figure 2.5 The change in the max dose compared to the midline dose as a function of treatment distance

- **Dose Buildup Effect**

Figure 2.5 demonstrates the improvement in dose homogeneity which can be obtained by increasing the photon energy. However, it is well known that the skin dose will decrease as energy increases. The surface dose is particularly important in patients who have a generalized disease such as leukemia, where leukemic blasts cells can be presumed to be circulating in the capillary bed immediately beneath the skin surface. Because of the extended SSD's and field size used, the skin dose for TBI is usually not as low as the measured values for more standard treatment conditions. This difference results from the increased number of electron generated in the air column for longer treatment distances. Figure 2.6 shows an increase in the skin dose as the field size changes from 10x10 cm^2 to 40x40 cm^2. This figure also compares the skin dose from source-to-skin distances of 100, 300 and 500 cm. The buildup curves do not include the contribution from the exit dose for an opposed field and previous measurements have shown that the dose build down on the exit surface is not large. Therefore, the dose will be higher when the contributions from opposing or other fields are included[10].

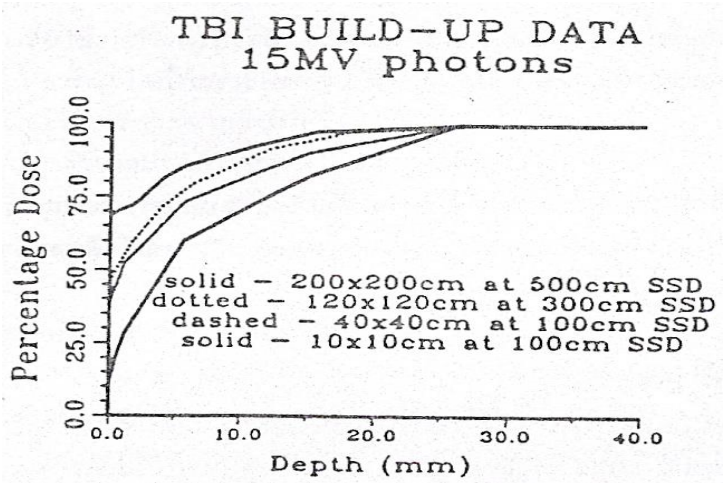


Figure 2.6 The dose buildup as a function of field size and distance for a 15 MV photon beams

When it is not possible to obtain the extended distances needed to increase the skin dose to acceptable limits, a beam spoiler can be used. Figure 2.7 shows the change in skin dose for 10 MV in treatment room where SSD was restricted to 300 cm. A 1 cm plastic sheet was placed in the path of the photon beam to produce

scattered electrons. This figure demonstrates the expected increase in the skin dose which occurs when the plastic spoiler is moved toward the patient's surface[10].

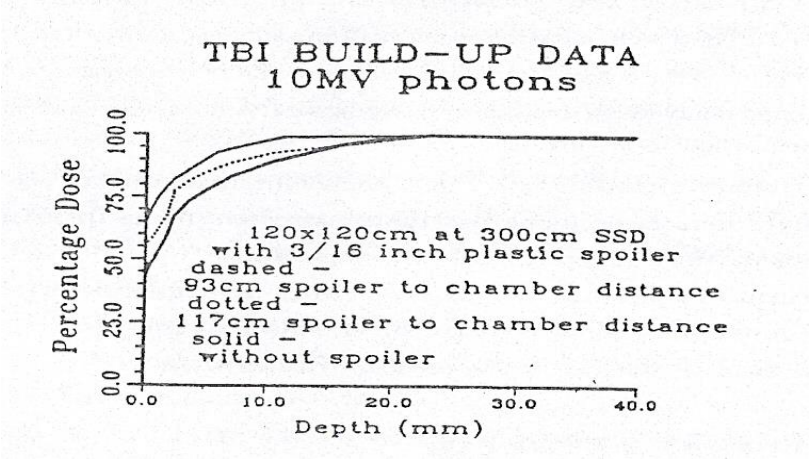


Figure 2.7 The change in dose buildup as a function of the distance of plastic beam spoiler from the phantom surface

- **Field Flatness**

Total body irradiation usually employs the largest available field size. Therefore, the "horns" often seen on the large field beam profiles as measured in air are important. These regions of increased dose can become aligned with thinner body sections such as the neck and lower legs, thus further decreasing the dose homogeneity. For some treatment units the increase in the photon fluence toward the edge of the beam relative to the center axis value can be as much as 13%. This increase must be taken into account in treatment planning and when necessary, steps must be taken to decrease the dose in these areas[10].

2.1.1.3 The use of Tissue Compensators to Adjust Dose Homogeneity

Simple tissue compensators that extend completely across the patient can be used to decrease the dose to thinner body sections like the necks or ankles. If compromised room geometry forces the use of lateral fields, much more extensive compensation will be needed. The ratio of tissue phantom ratios (TPRs) can be used to determine compensator thickness. Some assumptions about the scattering volumes that determine the TPRs must be made to perform the calculation of compensator thickness[10].

2.1.1.4 Shielding Critical Structure

Certain sensitive normal tissues might be limited to a dose that is less than the prescription dose. This might be due to the normal dose limit for that tissue, or the particular organ could be compromised by the previous irradiation or chemotherapy. There are at least two methods for reducing the dose to critical structures. First, it is possible to place strips of absorbing material completely across the patient to shield these regions. This technique is useful when the amount of adjustment is such that the dose to regions surrounding the critical structure will not be reduced to an extent that they fall outside acceptable dose homogeneity limits. A second method provides much more shielding for the lungs by placing Cerrobend blocks between the source of radiation and the patient. The blocks are significantly decreases the dose to the chest wall anterior and posterior to the lungs, the technique uses electron fields to boost the dose for these regions. This technique is common to treat the patient with AP/PA fields seated on a special device designed to control positioning for this treatment[10].

2.1.1.5 Point Measurements

Treatment planning for TBI can stress the capabilities of any RTPS. This is because the sizes and depths of the fields used for irradiation often exceed the limits employed in gathering the data for treatment planning system commissioning. For this reason, point measurements for verifying the prescription dose and the dose distribution are extremely important for TBI. Surface measurements can be taken with appropriate build-up material around the dosimeter. A treatment planning system can be used to generate a percentage depth dose curve for the actual SSD to the patient's surface at the point of measurement, and this information can be used to correct to the midline position[10].

2.1.1.6 Prescription Methods

The generally accepted dose prescription method for TBI uses a single point specification with a statement of the upper and lower dose limits for other parts of the body. Some detailed restrictions for specific critical organs at risk can also be included in the prescription statement. The typical point for dose prescription for TBI

used is the center point (laterally and anterior to posterior) at the level of the umbilicus. It has already been pointed out that TBI offers a significant dosimetric challenge. In most situations, treatment units are not commissioned specifically for TBI. This means that the scattering volume (entire body) will deviate widely from the conditions under which the data used to prepare the treatment planning system was gathered[10].

2.1.2 Calculation of Monitor Units

A manual calculation is used to determine the monitor units required to deliver the prescription dose. The basis of any MU calculation system used for the verification of the delivered dose is the derivation of a dose or dose rate delivered in patient from the known dose rate under the reference conditions. The MUs are determined using a manual calculation process, where the calculate dose were based on water phantom gathered at time of machine commissioning for total body irradiation condition. Manual calculations have become more accurate due to more detailed characterization of dosimetric function. Many manual methods are currently being used to determine MUs. The use of many different approaches increases the probability of calculation errors, either in the misunderstanding of varying nomenclatures or in the absence or misuse of important parameters within the calculation formalism. The clinical application of the formalism has been presented in AAPM task group 114[11]. The MU calculations for field with and without beam modifiers for both isocentric and source to surface distance (SSD) setups. MU calculations for photon beam may be performed using either TPR (isocentric) or PDD (nonisocentric) formalism[12]:

- For SSD technique or nonisocentric field:

Percentage depth dose (PDD) or Normalized percentage depth dose (PDD_N) is a suitable quantity for calculations involving SSD technique as shows in equation (1), the Monitor Units (MUs) are calculated by following:

$$MU = \frac{D}{D_{Cal}.\,S_c(r_c)\,x\,S_p(r).\frac{PDD_N}{100}(d, r_d, x).\,TF.\,OAR(d, x).\left(\frac{SCD}{SSD + d_o}\right)^2} \quad (1)$$

- For SAD technique or isocentric field:

Tissue-Phantom Ratio (TPR) or Tissue-Maximum Ratio (TMR) is the quantity of choice for dosimetric calculations involving isocentric technique as shows in equation (2). The MUs are calculated by following:

$$MU = \frac{D}{D_{Cal}.S_c(r_c).S_p(r_d).TMR(d,r_d).WF(d,r_d,x).TF.OAR(d,x).(\frac{SCD}{SPD})^2} \quad (2)$$

Where, D = dose to be delivered at the point of interest

D_{Cal} = Calibration dose per MU at d_{ref} under reference conditions

$S_c(r_c)$ = Collimator scatter factor for the collimator defined field size r_c,

$S_p(r)$ = Phantom scatter factor at d_{ref} for the field size r at the depth of maximum dose

$S_p(r_d)$ = Phantom scatter factor at d_{ref} for the field size r at the isocentric depth

TF = Tray factor

WF = Wedge factor

$OAR(d,x)$ = off-axis ratio at depth d and off-axis distance x from central axis

SSD = source to surface distance at extended field

SCD = Source to calibration point distance at which D_{Cal} is specified

SPD = Source to point of interest distance at which D is delivered

$d_o = d_{ref}$ for TPR and PDD_N

$t_o = d_{ref}$ of maximum dose for TMR and PDD

The above MU equations assume that:

- The calibration dose per MU (D_{Cal}) is specified at the source-calibration point distance (SCD) for the reference field size and at the reference depth.
- Tray factor (TF) is a transmission factor for the blocking tray, independent of field size and depth.
- Inverse-square law holds good for change in photon energy fluence in air as a function of distance from the source.

2.1.3 The Eclipse™ Treatment Planning System

Eclipse™ is an integrated and comprehensive treatment planning system supporting radiation treatment modalities, it was designed to increase productivity for clinicians using simplified data settings and easy drag and drop functionality. The Eclipse treatment planning system helps to address the time-consuming and challenging aspect of treatment planning contouring[13].

2.1.3.1 Analytical Anisotropic Algorithm

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 photon dose calculation model was developed to meet both of these clinical expectations, providing a fast Monte-Carlo-based 3D convolution/superposition algorithm for accurate heterogeneity-corrected photon dose calculation for all types of external beam treatments and it is comprised of two main components, the configuration algorithm and the actual dose calculation algorithm[13]. This study using AAA algorithm for calculate dose in 3D-CRT in boost fraction in TBI at KCMH.

2.1.3.2 Acuros XB Algorithm

The Acuros XB algorithm has been developed to address two strategic need of external photon beam treatment planning: accuracy and speed. It 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. Acuros XB is fully integrated into the Eclipse distributed calculation framework (DCF) as a new dose calculation algorithm and uses the multiple-source model originally derived for AAA algorithm[14].

2.1.3.3 Three-Dimensional Conformal Radiotherapy

Three-dimensional conformal radiotherapy (3D-CRT) links 3D anatomic information and used dose distribution that conform as closely as possible to the target volume in terms of adequate dose to the tumor and minimum possible dose to normal tissue. The concept of conformal dose distribution has also been extended to include clinical objectives such as maximizing tumor control probability (TCP) and minimizing normal tissue complication probability (NTCP). Thus, the 3D-CRT technique encompasses both the physical and biologic rationales in achieving the desired clinical results. The radiation oncologist draws the target volume in each slice with appropriate margins to include three distinct regions: a) visible tumor; b) a region to account uncertainties in microscopic tumor spread; and c) a region to account for positional uncertainties. Then, the 3D- treatment planning software can be designed fields and beam arrangement. One of most useful features of the system is computer graphics, which allow beam's-eye-view (BEV) visualization of the delineated targets and other structures. Anatomic images of high quality are required to accurately delineate target volumes and normal structure. One of the important features of 3D treatment planning is the ability to reconstruct images in planes other than that of original transverse image called the digitally reconstructed radiographs (DRRs)[15].

Dose calculation algorithms for computerized treatment planning have been evolving since the middle of the 1950s. Terms the algorithms fall into three categories: a) correction: based; b) model based; and c) direct Monte Carlo. Either one of the methods can be used for 3D treatment planning, although with varying degree of accuracy and speed. Direct Monte Carlo is the most accurate method for treatment planning, but currently it is not feasible because it requires prohibitively long computational time[15].

Treatment is delivered using beam shaping with MLC which have multiple leaves or shield which can block part of the radiation beam. The treatment planning process for 3D-CRT included beam data representation, patient data acquisition, definition of treatment portals, dose calculation, dose display and evaluation, and finally the plan documentation. 3D RTP process further involves: a) volumetric target and anatomy definition; b) analysis and merging of several diagnostic imaging data

set; c) unrestricted beam geometry; d) 3-D dose calculations and display; and e) finally 3D plan evaluation.

- **Field-in-Field Technique**

Field in field is a manually based forward intensity modulated radiotherapy (IMRT) plan for which the calculated dose in modified in certain dose distribution areas by creating multiple lower-weighted reduction fields based on the primary field. FIF technique uses a simple method to compensate for body contour variation with lateral beam deliver, it is relative simple and less time consuming method than the inverse planned IMRT technique. The advantages of FIF technique are: 1) reduces the scattered dose to patient; 2) considerably reduce monitor units; 3) less of total time required for treating a patient; 4) avoids hotspots that persist even after the used of wedge in extreme tissue inhomogeneities and contour irregularities; and 5) diminish time required for commissioning the wedge. The used of FIF technique depends of the complexity of the plan. It would be easier to use for few number of beams and when the number of beams exceeds more than three, it becomes relative time consuming for planner. However, the placement of isocenter play important role in FIF technique especially when the plan is normalized with respect to the isocenter[16].

2.1.4 In-Vivo Dosimetry

In vivo dosimetry is very important tool for verification of the actual dose delivered to the target volume and for estimation of dose to organ at risk, there are two different goals: first, the measurement of doses to organs at risk that are difficult to calculate (such as the dose to eyes and gonads) and second, the verification of the delivered dose in order to improve treatment accuracy and to minimize the risk of dose misadministration. In vivo dosimetry is the most direct method for monitoring the dose delivered to the patient receiving radiation therapy[14]. In-vivo dosimetry is of particular relevance in case of TBI before bone marrow transplantation for different reasons (Meeting of LEIDON, 1982; AAPM, 1986; ESTRO, 1987)[9]: difficulties in calculation of dose at the dose at different points in the patient, increased risk of patient movements due to the long duration of treatment and, in single fraction regimen, the necessity to correct the dose before the end of the session. In this respect, the in vivo measurement are to be considered not only as an independent check, but

rather as an integral part of the overall dosimetric approach for this particular treatment technique[17].

ICRU report 24[18] specifies what in vivo dosimetry might include:

- Entrance dose measurements
- Exit dose measurements
- Transmission measurements
- Intracavitary absorbed dose measurements

The first three aims listed above are restricted to the patient's surface. However, it is possible to obtain information on the dose to the tumor or critical structures also by intracavitary measurement or by using the combined information of exit and entrance dose measurements for an estimation of the tumor absorbed dose.

In vivo dosimetry involves the measurement of radiation doses to patients during their radiation treatment in order to ensure the treatment are carried out as they were planned. Dose to the skin of a patient undergoing radiotherapy depends on some parameters that are difficult to take into account. The measurement can be performed using various detector such as silicon diodes, small thermoluminescent dosimeters (TLDs), metal-oxide-semiconductor field effect transistor (MOSFET) dosimeters and radiochromic film.

2.1.4.1 Radiochromic Film

Radiochromic effects involve the direct coloration of material by absorption energetic radiation, without requiring latent chemical, optical, or thermal development or amplification. The radiochrommic process, involves the production of immediate permanent colored images of a radiation expose pattern in a solid, with or without "fixing" of sensor medium against further change (Niroomand AAPM TG-55 Med. Phys 25 1998)[19]. The radiochromic EBT type films have become a standard tool for dosimetry in medical radiation physics, especially for quality assurance with respect to IMRT and for experimental benchmarking of dose calculation algorithm[20].

- The Gafchromic EBT film was released in 2004 by International Specialty Products (ISP, Wayne, NJ), was the first type of radiochromic film suitable for the use with doses as low as the typical doses occurring in radiation therapy. In 2009, the Gafchrommic EBT film was replaced by the Gafchromic EBT2 film that incorporates

a yellow marker dye in the active layer and a synthetic polymer as the binder component. Several works have been published studying some EBT and EBT2 properties, such as film homogeneity, scanning orientation dependence, energy dependence, temperature dependence and ambient light sensitivity. In 2011, Ashland released a new film generation, the Gafchromic EBT3 film. According to producer's note, EBT3 film is made by laminating active layer between two identical polyester layers, which makes the product more robust and allow water immersion. While the active layer composition and response is unchanged, the real EBT3 improvement are: the symmetric structure that will avoid the potential errors in optical density measurement due to scanning side in EBT2, the matte polyester substrate that prevents Newton's Rings formation, and the presence of fiducial marks that allows for the film automatic alignment[21].

- The structure of EBT3 film was comprised of an active layer, nominally 30 μm thick, sandwiched between two 125 μm matte-polyester substrates (Figure 2.8) and scaled by density of 0.0153 g/cm^{3}for the EBT film model. The active layer contains the active component, a marker dye, stabilizers and other components giving the film its low-energy dependence. The active layer of EBT3 radiochromic films consist of H (56.8%), C (27.6%), O (13.3%), Al (1.6%), and Li (0.6%). Therefore, EBT3 film model is near tissue equivalent and high spatial resolution (<0.1 mm) and near tissue equivalent (Z_{eff} =7.26 compared to Z^{water}_{eff} =7.3)[22].

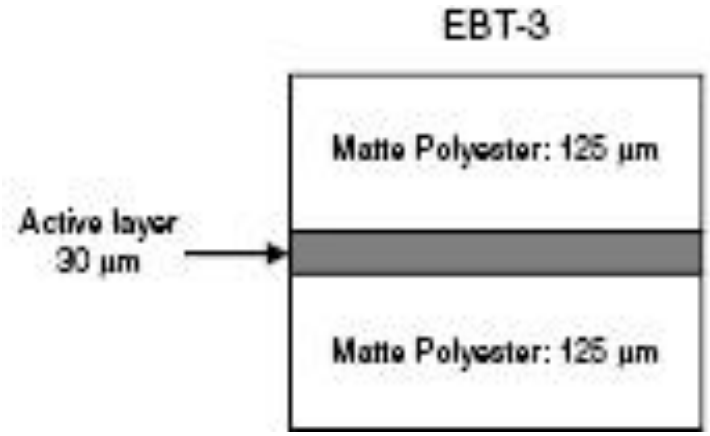


Figure 2.8 The structure of Gafchromic EBT3 model film

The high sensitivity of EBT3 film has been designed for the measurement of absorbed dose of high-energy photon beams and particularly attractive for IMRT dosimetry. It is also has a potential application as an *in vivo* dosimeter in TBI dosimetry. The film was designed for using in the 1 cGy to 100 Gy dose ranges. The EBT3 film model presented some improvements, such as greater uniformity less than 1%. Active layer incorporates a yellow marker dye to decrease UV/light sensitivity and enables all the benefits of multichannel dosimetry, when it's used in conjunction with an RGB (Red, Green and Blue) film scanner. The symmetric structure eliminates the need for keeping track of which side of the film is facing the light source of the scanner. The polyester substrate has a special surface treatment containing microscopic silica particles that maintain a gap between film surface and the glass window in a flatbed scanner. Since the gap nearly ten times the wavelength of visible light, formation of Newton's Ring interference patterns in images acquired using flatbed scanners is prevented. The EBT3 film also can be handle in room light-no need for a darkroom, stable at temperatures up to 60^{o}C, can be cut and shape the film to your need, easy to handle and flexible in shape to fit the patient's body contour[22].

2.2 Review of Related Literatures

Fan-Chi S, et al[2] investigated clinical application of Gafchromic EBT film for in vivo dose measurement of total body irradiation radiotherapy by using Gafchromic EBT film and TLD measurement in phantom and 2 TBI patients. For phantom, the studied were performed in an anthropomorphic phantom and set treatment position according to standard procedure of the lateral TBI technique Films and TLDs were covered by bolus and packed together at the position of head, shoulder, chest, umbilicus, hip and thigh. For patient study, film and TLD were placed at the left and right sides of head, shoulder, chest, umbilicus, hip, thigh, knee, and ankle. Result for phantom studied showed that the measured dose along central axis by Gafchromic EBT film were in a good agreement (differences between -4.1% and 0.6%) with those measured by TLDs. For patient study, the results have demonstrated that Gafchromic EBT film was able to provide accurate results to evaluate the patient dose uniformity with less than ±5% of the prescription dose.

Rui Yao, et al[4] reported the delivering total body irradiation(TBI) with improved dose homogeneity in 9 patients who underwent TBI procedures and patient's anterior-posterior separations: forehead, neck, shoulder, middle of sternum, xyphoid, umbilicus, pelvis, middle of thigh, knee and ankle and their off-axis-distances from the umbilicus were measured in the treatment position. The myeloablative and nonmyeloablative regimens were planned to delivered dose to patient. The myeloablative TBI regimen involved four daily fractions of 300 cGy/fraction using AP/PA beams, for the nonmyeloablative include single 200 cGy fraction of TBI without lung blocking. For both regimens, dose homogeneity due to contour variation along craniocaudal axis was kept to ±10%. The OSL detector was applied to measure entrance doses of 6 and 18 MV beams. The relative deviations from prescription dose of sites excluding the lung doses were within 5% on average. The technique used collimator jaws instead of custom compensators to modulate a beam and achieve the desired midplane dose uniformity. The whole body midplane dose uniformity of ±10% was achieved. For the measurement setup, the predicted midplane lung doses were 5% to 10% higher than measured doses for 6 and 18 MV beams, respectively.

Petra M. Hartl, et al[23] studied total body irradiation in attachment free sweeping beam technique using Oncentra RTPS. The patients were treated with 6 MV photon beams by rotational fields alternating from 310^{o} to 70^{o} clockwise and reverse on a low couch on the floor in supine and prone position. For in vivo with difference total dose of 4 Gy, 8 Gy, 10 Gy and 12 Gy, the measurement was performed in 10 patients on forehead, neck ventral midline, chest midline, ventral and dorsal projection of reference point, abdomen midline, ventral thigh and ankle by using diode detector in combination with a Multidos electrometer and Multisoft software and male Alderson phantom equipped with Gafchromic films was applied for final control of dose distribution. The results of MU calculated by RTPS and measured showed very good agreement within 0.7%±2.1% in Alderson phantom and 0.5%±4.7% in 10 patients but the value of legs dose were not considered due to short scanning length of CT scanner. The mean lung dose was 3% higher in phantom and comparable in the patients due to the lower attenuation of the lung tissue. They also reported that the planning system cannot handle the lung shields because cumulative DVH of real lung dose cannot be presented for patients with 10 Gy total doses or higher.

Lancaster C.M, et al[24] studied in-vivo dosimetry from total body irradiation patients (2000-2006): results and analysis in 86 patients by using semiconductor diodes connected to an electrometer for dosimetry of TBI patients which AP fields were calculated by Plato TPS. The manual calculation in lateral field was used to determine the monitor units (MUs) required to deliver the prescription dose, prescribed to a depth of half the AP separation at the pelvis for the patients prescribed of 12 Gy or to the maximum dose point in the lungs for the patients prescribed of 13.2 Gy. The patients laid on a bed at a distance of 460 cm from source to the skin surface and treated with 18 MV photon beams. The gantry angle of 90^{o} or 270^{o}, opened maximum field sizes of 40x40 cm^2 and collimator angle of 45^{o} were used in this studied. For the measured dose in AP fields, single diodes were attached to the beam exit side of the head, sternal notch, chest, abdomen and pelvis corresponding to the simulator-CT slices used in planning. For the lateral fields, a diode was also placed between the patient's thighs to obtain a dose representative of the mid-pelvis dose. The results in lateral field, agreement of average dose within 3% was found on the

pelvis and thighs. The average exit dose was within 5% of expected dose for the shoulder and abdomen, 6.7% for the chest and 5.7% for the head. In AP fields, the average exit dose showed similar mixture of reasonable and poor agreement between measured and planned dose which average were 3% in shoulder and chest, 5% in head, abdomen, and pelvis region.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Research Design

This study is an observational descriptive study with cross-sectional method.

3.2 Research Question

What are the in vivo doses in phantom and patient in total body irradiation using 3D-CRT?

3.3 Research Design Model

The research design model is shown in Figure 3.1.

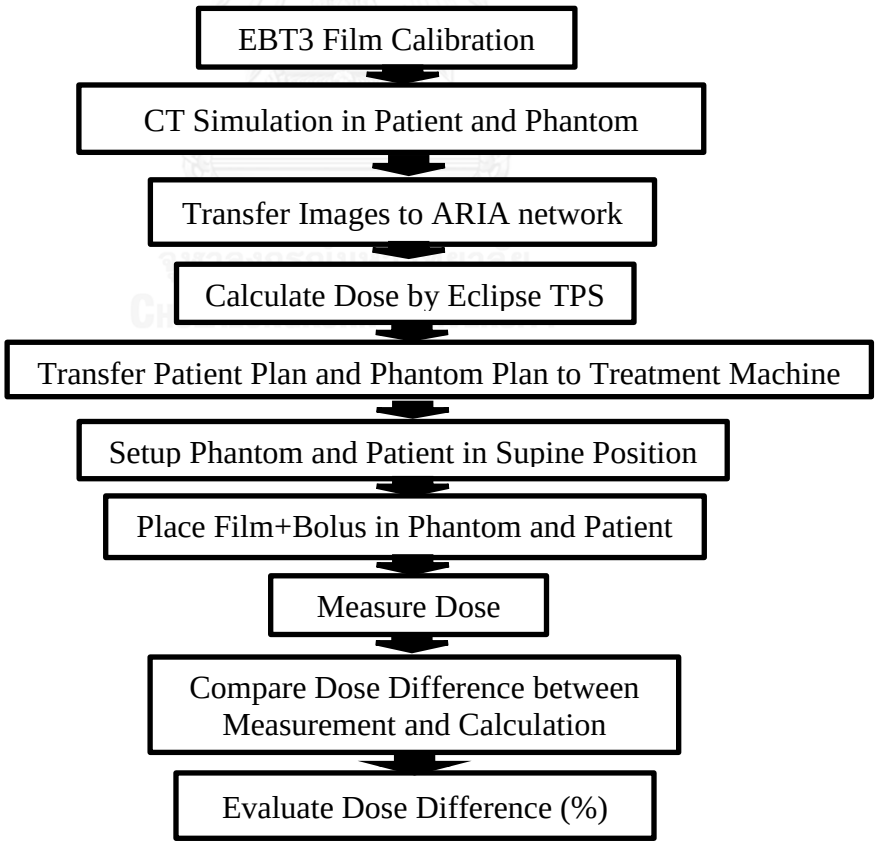


Figure 3.1 The research design model

3.4 Conceptual Framework

The percent dose differences between measured dose by EBT3 film and calculated dose by Eclipse TPS in each site in phantom and patients are influenced by the factors of location and direction of film, patient condition and position, film characteristic, body contour and dose range. The conceptual framework is shown in Figure 3.2.

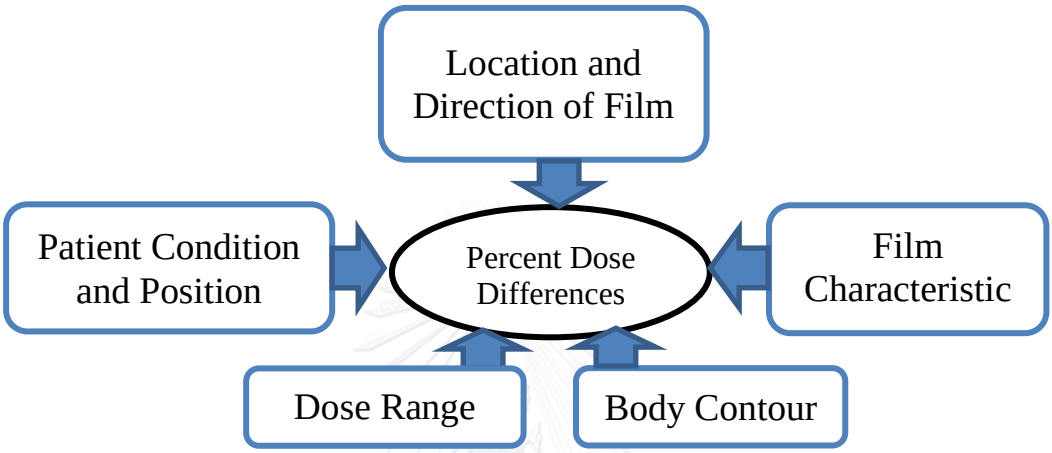


Figure 3.2 The conceptual framework

3.5 Materials

3.5.1 Philips Brilliance Big Bore CT Simulator

The Philips brilliance big bore CT scanner (Philips Health Care, Guildford, UK) which is shown in Figure 3.3, is the 16-slice per revolution with 2.4 cm coverage allows to cover large areas in the fastest time. It has an 85 cm bore size to accommodate patients in immobilization devices or with bulky patient monitoring devices, and 60 cm true Scan Field of View (SFOV) to include all patient skin surfaces with kVp of 90, 120 and 140 kVp.

Figure 3.3 The Philips brilliance big bore 16-slices CT scanner

3.5.2 Clinac iX Linear Accelerator

The Clinac iX linear accelerator (Varian Medical System, Palo Alto, CA, USA), which is shown in Figure 3.4, can be delivered 6 MV and 10 MV photon beams. It can produce five of 6, 9, 12, 15, 18 and 22 MeV electron energies. There are 120 leaves of MLC that can provide conformal shaping of radiotherapy treatment beam to tumor. It can attribute the field size ranging from 0.5x0.5 cm^2 to 40x40 cm^2.

Figure 3.4 The Clinac iX linear accelerator

5.3.3 Clinac 21EX Linear Accelerator

The Clinac 21EX linear accelerator (Varian Medical Systems, Palo Alto, CA, USA), which is shown in Figure 3.5, can be delivered 6 MV and 10 MV photon beams and five of 6, 9, 12, 16, 20 MeV electron beam energies. There are 6 stationary therapy dose rates from 100-600 monitor units per minute. The multi-leaf collimator is mounted below the conventional collimator in the same direction of x-jaws.

Figure 3.5 The Clinac 21EX linear accelerator

3.5.4 Scanning Densitometer System

The Perfection v700 photo scanner (Epson Seiko Corp., Nagano, Japan) applied for EBT3 film scanning is shown in Figure 3.6. The 4800 dpi and 6400 dpi optical resolutions (Epson Dual Lens System) consistently deliver precision color and detail.

Figure 3.6 The Perfection V700 photo scanner

3.5.5 TBI Wood Couch

The in-house special couch for bilateral TBI technique, which is shown in Figure 3.7, is made from wood and can adjust the patient position in various angles. For tall patients, the position could be adjusted for the patient length fitted to field size available. The couch height is special designed made for the patient alignment with the beam covered the total body and the couch can be rotated for another lateral field. This treatment couch is designed for inserting a plastic sheet of 150x150x1 cm^3 as a beam spoiler in both sides to increase the dose at surface and buildup region to the patient.

Figure 3.7 The special TBI couch for bilateral technique

3.5.6 Solid Water Phantom

The solid water phantom material (Gammex, IA, USA), which is shown in Figure 3.8, it has 1.03 g/cm^3 of the density and 5.96 of effective atomic numbers. It made in square slab of 30x30 cm^2 with the various thicknesses of 0.2, 0.3, 0.5, 1.0, 2.0, 3.0, 4.0 and 5.0 cm.

Figure 3.8 The solid water phantom

3.5.7 Male Alderson RANDO Phantom

The male Alderson RANDO phantom (MedTec, IA, USA) shown in Figure 3.9, incorporates materials to simulate various body tissue muscle, bone, lungs and air cavities. It was created from tissue equivalent material with a density of 0.985 g/cm^3 and effective atomic number of 7.3. It is modeled according to the International Commission on Radiation units and Measurement (ICRU) Report No.44. The phantom's size is 188 cm tall and is sectioned transversely into slice of 2.5 cm each containing a matrix of 0.5 cm diameter holes spaced 3 cm apart.

Figure 3.9 The male Alderson RANDO phantom

3.5.8 Gafchromic EBT3 Film

The Gafchromic EBT3 film (Ashland Inc., Wayne, NJ, USA), which is shown in Figure 3.10, is a self-developing film for radiotherapy dosimetry. The fillm responds to radiation exposure forming a blue colored polymer with an absorption peak at 636 nm. The EBT3 film has a good property in dose range of 0.1 Gy to 20 Gy. In this study, the EBT3 film was used for dose measurement in phantom and patient during total body irradiation.

Figure 3.10 The Gafchromic EBT3 film

3.5.9 Eclipse Treatment Planning System (TPS)

The Eclipse treatment planning (Varian Medical System, Palo Alto, CF, and USA) version 11.0.36 (AAA Algorithm) shown in Figure 3.11, is an integrated treatment planning system supporting radiation treatment modalities such as 2D, 3D conformal, IMRT, VMAT and electron beams. The Eclipse is designed to increase productivity for clinicians using leading edge automated tools to create, import an optimize plans across numerous multiple linear accelerators. In this study, it was used to calculate the FIF boost dose in AP/PA TBI technique.

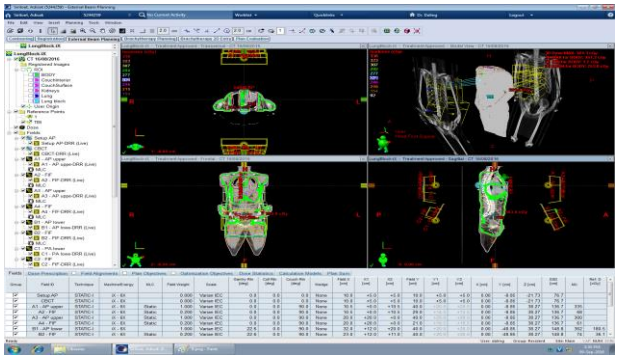


Figure 3.11 The Eclipse treatment planning

3.6 Methods

3.6.1 Film Calibration in the Solid Water Phantom

The sheet of EBT3 film was cut into 2x2 cm^2 and placed at 1.5 cm depth as the depth of maximum dose with 10 cm backscatter and field size of 10x10 cm^2, at 100 cm SSD and calibrated with the ranges of 10-800 cGy from 6 MV photon beams by Clinac iX linear accelerator as shown in Figure 3.12. The films were scanned after 24 hours post-irradiation by using Epson Scanner. The optical density (OD) of the film was read in red channel and generated response curve relationship between OD and pixel value by SNC patient software.

Figure 3.12 The EBT3 films calibration with 6 MV photon beams

3.6.2 Uncertainty Analysis for Gafchromic EBT3 Film Dosimetry

The uncertainties in EBT3 film measurement were recommended by manufacturer's specifications and AAPM TG-55 protocol as reference from Elsa Y, et al study[22]. The summary of dose uncertainties in percentage (%) for EBT3 films measurement is shown in Table 3.1.

Table 3.1 The summary of dose uncertainties of Gafchromic EBT film

Characteristic	Red Channel	Green channel	Blue channel
Response curves and fitting procedure	2.6	4.3	4.1
Dose resolution of the system	1.8	2.3	3.1
Film reproducibility	0.2	0.3	0.3
Film uniformity	0.2	0.3	0.3
Relative orientation of the film	6.2	2.7	3.3
Reproducibility of response of the scanner	0.3	0.3	0.3
Homogeneity on the bed of scanner	2.0	3.0	4.5
Total Uncertainty[a]	3.2	4.9	5.2

[a] without considering relative orientation of the film and homogeneity on the bed of scanner

3.6.3 In Vivo Dosimetry

The TBI technique at King Chulalongkorn Memorial Hospital (KCMH) is normally treated patients with 6 MV photon beams by Clinac iX linear accelerator and Clinac 21EX linear accelerator. This technique is two lateral parallel opposing fields. The patient was supine in positioned on special design TBI couch at extended source axis distance (SAD) of 500 cm with dose of 200 cGy per fraction, two fractions per day in three days by manual calculation aimed 1200 cGy at the head and legs. The remainder dose of less than 1200 cGy in chest and abdomen parts were added with AP/PA fields by 3D-CRT with lung and kidney shielded by MLC to obtain 0% and 50% of prescribed dose, respectively, in the 7^{th} fraction at extended source to surface distance (SSD) of 100 cm on couch. The given dose was calculated by Eclipse TPS (AAA algorithm) with 6 MV photon beams. The Field in Field (FIF) technique was employed to acquire homogenous dose.

3.6.3.1 The Lateral Parallel Opposing Fields

One patient was selected for dose measurement in 6 fractions in lateral parallel opposing fields which processed by following:

1. The thickness in lateral and AP directions at head, neck, shoulder, chest, umbilicus level, hip, groin, thigh, knee, leg and ankle were measured and averages in order to calculate monitor unit by manual calculation in Microsoft excel. The data was loaded into Microsoft excel 2010 to performed MUs calculation by radiation oncologist which manual calculation also considered limitation of lung dose should not greater than 10 Gy as shown in Figure 3.13. The whole body CT images were loaded to Varian Eclipse TPS to performed dose calculation in two lateral parallel opposing fields to obtain the dose in each site of patient as shown in Figure 3.14.
2. Patient was set in supine positioned on special designed TBI couch at extended source-axis distance (SAD) for 500 cm, the gantry was rotated to 270^{o} and maximum field sizes was set to 40x40 cm^2 as shown in Figure 3.15. A beam spoiler of 1 cm thickness was placed beside patient couch to increase the dose in buildup region.
3. Technologist set beam for energy of 6 MV, calculated MUs with dose rate of 400 MU/min was performed.

4. Films covered with bolus were placed on the surface at left side-right side of head, neck, shoulder, armpit, umbilicus, hip, thigh, knee, leg and ankle in 6 fractions of treatment in lateral parallel opposing fields as shown in Figure 3.16.

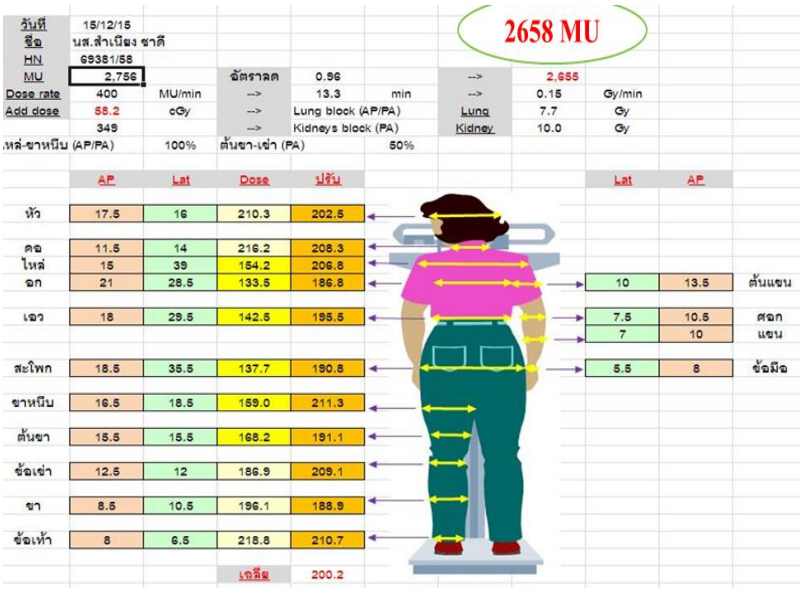


Figure 3.13 The monitor units (MU) calculation

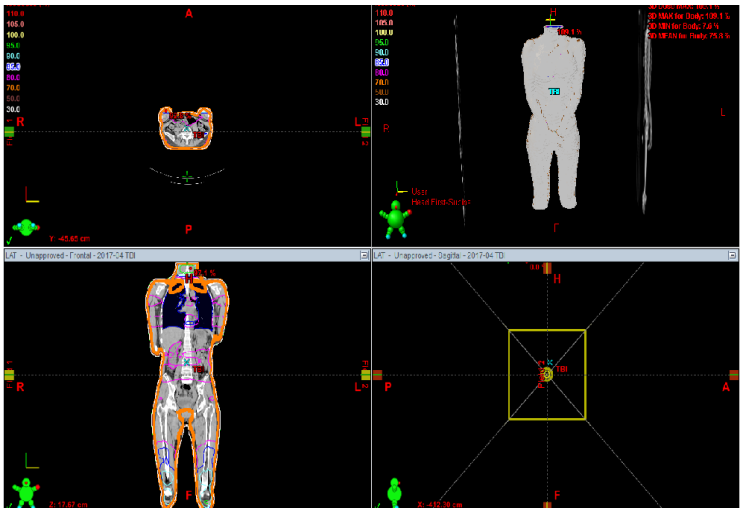


Figure 3.14 The dose calculation in lateral parallel opposing filed in Eclipse TPS

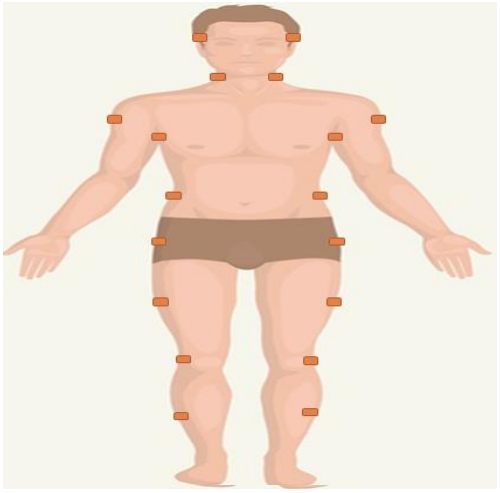


Figure 3.15 The position of film on the surface of patient

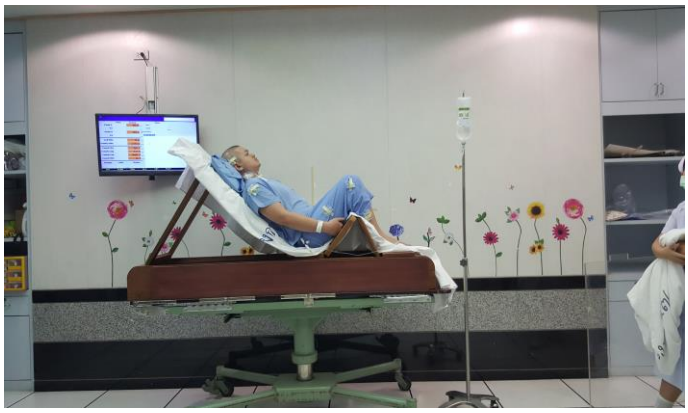


Figure 3.16 The patient in supine position on a special design TBI couch

3.6.3.2 The Boost Fraction in AP/PA Fields

The male Alderson phantom and patient measurement were processed by following:

- **Phantom Study**

1. CT scanning of male Rando phantom was performed by Philip big bore CT simulator and CT images were transferred to the Varian Eclipse TPS via data networking.
2. The CT data were loaded and the contouring of body, lungs and kidneys were created. The four patient plans were transferred to phantom and the doses were calculated by Eclipse TPS in 3D-CRT with remainder dose of 300 cGy prescribed in level of the umbilicus. The lungs and kidneys were shielded by MLC to obtain 0%

and 50% of prescribed dose, respectively. The plans were employed 6 MV photon beams and 400 MU/min dose rate. The plans were exported to Acuity simulator to draw region of lungs and kidneys shielded by MLC as shown in Figure 3.17.

3. The four plans were exported to Clinac iX linear accelerator. Phantom was positioned in supine on a couch and the SSD was set 100 cm at the chest region as the reference point as shown in Figure 3.18. The couch was rotated to 90 degree to irradiate upper AP fields with lung blocks. The lower AP fields were irradiated by moving couch longitudinal and gantry was rotated to 22.6 degree. For PA fields, the couch was moved longitudinal and vertical direction, the gantry was rotated to 157.4 degree to irradiated lower fields and gantry was rotated to 180 degree to irradiate upper fields with lung and kidney blocks. Total treatment field was 4 fields group which each field, the Field-In-Field technique were added to compensate for the variation of body contour as shown in Figure 3.19.

4. One sheet of EBT3 film was cut into 2x2 cm^2 and placed inside the phantom at shoulder, lung and kidney shield, umbilicus, abdomen, and films under bolus (3x3x1.5 cm^3) were placed on the surface of shoulders, middle chest, umbilicus, abdomen, groin and thighs, they are shown in Figure 3.20.

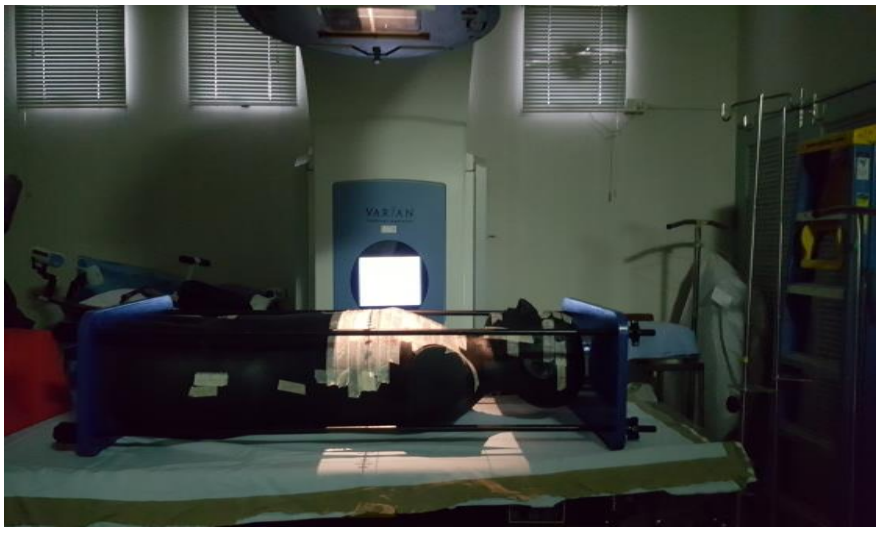


Figure 3.17 The regions of lung and kidney shielded by MLC

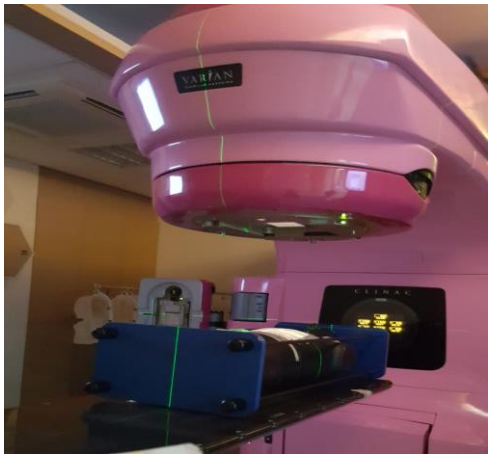


Figure 3.18 The phantom setting at 100 cm SSD on chest region of phantom surface

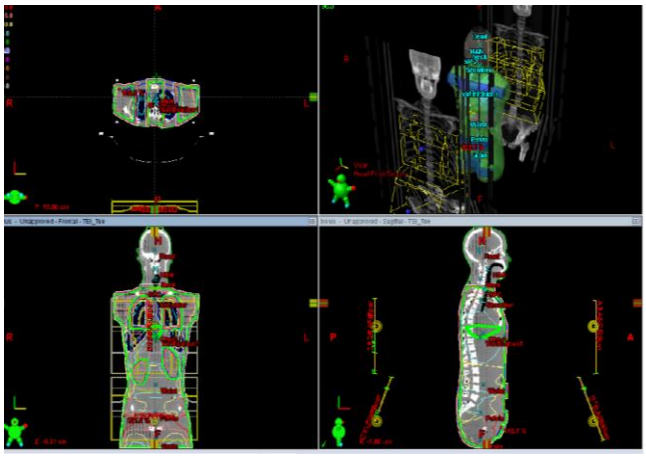


Figure 3.19 The phantom treatment planning

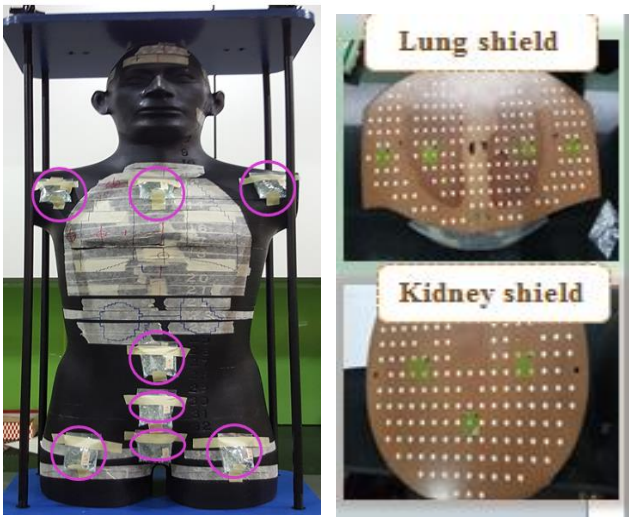


Figure 3.20 The film in the phantom

- **Clinical Study**

1. Five patients were scanned by Philip big bore CT simulator with full scan length of 180 cm from shoulder to knee and CT images were acquired for 5 mm slices thickness and .

2. The acquired CT images were transferred and loaded to the Varian Eclipse TPS via data networking. The contouring of body, lung and kidney were created and treatment was planned by 6 MV photon beams by 3D-CRT in Eclipse TPS with approximate 250 to 350 cGy of prescribed dose in level of umbilicus**.** The lung and kidney were shielded by MLC in order to obtain 0% and 50% of prescribed dose, respectively.

3. The plans were exported to Clinac iX linear accelerator**.** EBT3 film sheet was cut into 2x2 cm^2, 10 films were covered with bolus and placed in AP direction on patient surface for shoulders, armpits, middle chest, umbilicus, abdomen, groin and thighs as shown in Figure 3.21. The films were placed only in AP direction due to difficulty to place in PA direction because the TBI patient weren't in good condition as normal patient and the limitation of time.

4. Patient was positioned in supine on couch and extended source to surface distance (SSD) at 100 cm on couch. For AP fields with lung shield, the couch was moved to 90 degree to irradiate upper fields. For lower AP fields, the gantry was rotated to 22.6 degree and the couch was moved longitudinal as shown in Figure 3.22. For PA fields with lung and kidney shields, the couch was moved longitudinal and vertical direction, the gantry was rotated to 157.4 degree and 180 degree to irradiate upper and lower fields, respectively**.** Total treatment beams of TBI patient were 4 fields group which each field, the FIF were added to compensate for the variation of body contour which was shown in Figure 3.23.

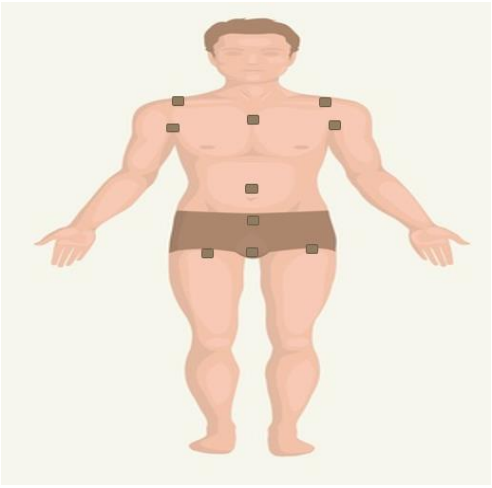


Figure 3.21 The film position along AP direction on surface of patient

Figure 3.22 The patient in supine position for AP fields in boost fraction

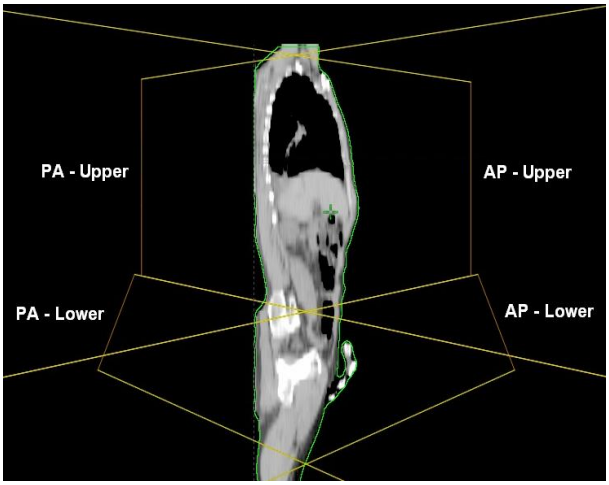


Figure 3.23 The 4 fields group in AP/PA by 3D-CRT in patient

3.6.3.3 Film Analysis

All irradiated films were scanned after 24 hours post irradiation with Epson v700 scanner and absolute doses were determined for each irradiated film by SNC patient software (MapCHECK) as shown in Figure 3.24.

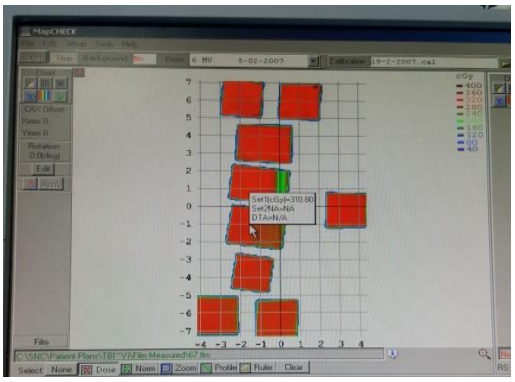


Figure 3.24 The irradiated film scanned by SNC patient software

The dose difference (%) between measurement and calculation in each site of phantom and patient were calculated by following equation:

$$\%\text{Dose diff} = \frac{\text{Dose Calculation} - \text{Dose Measurement}}{\text{Dose Measuresurement}} \text{x}100 \qquad (3)$$

Where, dose calculation represent dose by Eclipse TPS, while dose measurement represents measured dose by EBT3 film.

The acceptable criteria between measured dose and calculated dose in this study were ±10% according to reference from Petra M.H et al[23] and Fan-Chi S et al[2].

3.7 Outcome Measurement

The outcome for dose measurement in phantom and patients were percent dose differences between measured dose by EBT3 film and calculated dose by Eclipse TPS.

3.8 The Target Population

The patient who underwent TBI procedure at King Chulalongkorn Memorial Hospital from December 10th 2016 to April 20th 2017.

3.9 Sample Size

The sample size was determined by using following equation:

$$N = \frac{[Z^2_{\frac{\alpha}{2}} * \sigma^2]}{d^2} = 6.8 \approx 7$$

Total = 7 plans

Where, - z is the reliability coefficient of normal distribution.

For 95 % confident level, $\alpha = 0.05$, $Z_{\alpha/2} = 1.96$

- σ^2 is variance of difference, $\sigma = 0.13$ (From Rui.Y et al[4])
- d =acceptable error = 0.1

We used 9 plans include 4 plans in phantom and 5 plans in patient.

3.10 Measurement

Variable

Independent variable: location and direction of film, patient condition and position, film characteristic, dose range and body contour.

Dependent variable: Prescribed dose.

3.11 Data Collection

3.10.1 The measurement: phantom, patients and films.

3.10.2 Patient Information: CT images and thickness.

Lateral technique: measure in 6 fractions for one patient

AP/PA technique: measure in phantom for four plans and measure in patient for five plans

Using Varian Clinac iX linear accelerator and Varian Eclipse treatment planning system at Division of Radiation Oncology, King Chulalongkorn Memorial Hospital, Bangkok, Thailand.

3.12 Data Analysis

The percent dose differences in phantom and patients were shown as average, standard deviation and range (Max-Min) presented in table and scatter plot.

3.13 Expected Benefit

The patient acquired corrected design doses both in total body and organ at risks, no complication to lung and kidney.

3.14 Ethic Consideration

This study was performed in phantom and TBI patient, the research proposal was submitted and approved by Ethic Committee of Faculty of Medicine, Chulalongkorn University as shown in Figure 3.25

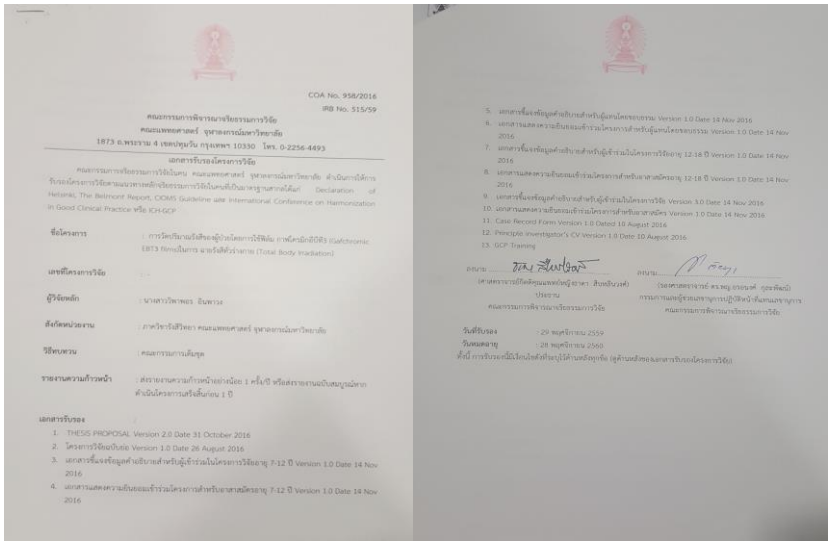


Figure 3.25 The certificate of approval from Ethic Committee of Faculty of Medicine, Chulalongkorn University

CHAPTER IV

RESULTS

4.1 Film Calibration

The calibration curve plotted between pixel value and optical density (OD) was used for film measurement reading, it was exponential shape as shown in Figure 4.1.

The calibration curve was generated from the doses of 10 cGy to 800 cGy. The dose from 10 to 300 cGy was in high dose gradient and from 300 to 800 cGy was in low dose gradient.

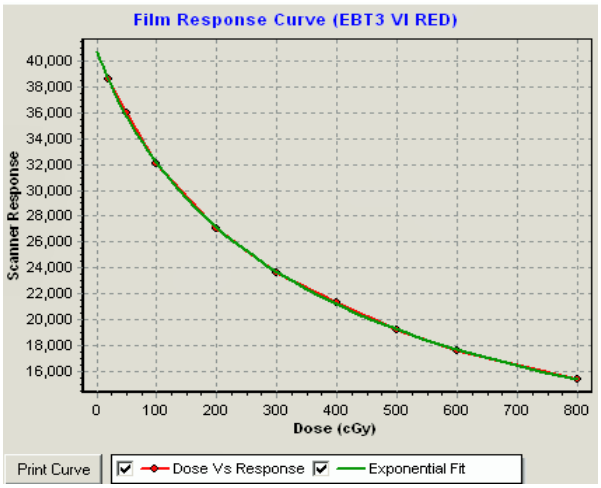


Figure 4.1 The EBT3 film calibration curve

4.2 In-Vivo Dosimetry

4.2.1 The Lateral Parallel Opposing Field

- **Clinical Study**

The results for lateral fields measured in six fractions of one patient are shown in Table 4.1 and Figure 4.2. The detail of dose measurement and calculation for each organ of six fractions is shown in Appendix I. The average of percent dose differences between measured dose on the surface by EBT3 film with bolus and calculated dose by Eclipse TPS were observed for -0.9%, -0.5%, 0.8%, -1.7%, 0.4%, 2.0%, -1.3%, 1.5% and 3.1% in head, neck, shoulder, armpit, umbilicus, hip, thigh, knee and ankle, respectively. The total average percent dose difference was 0.4±2.7%. The highest difference of 3.1% was observed in ankle and the lowest was 0.5% in neck.

Table 4.1 The average of percent dose differences in six fractions for one patient

Anatomical site	Calculate Dose (cGy)	Measure Dose (cGy)	Average
Head	176.2	177.8±9.4	-0.9%
Neck	179.7	180.6±14.8	-0.5%
Shoulder	156.1	154.8±10.2	0.8%
Armpit	157.7	160.1±7.6	-1.7%
Umbilicus	159.3	158.6±9.2	0.4%
Hip	155.1	152.1±12.2	2.0%
Thigh	161.3	163.4±8.9	-1.3%
Knee	167.4	165.0±6.7	1.5%
Ankle	167.4	162.4±6.2	3.1%
Average			0.4±2.7%

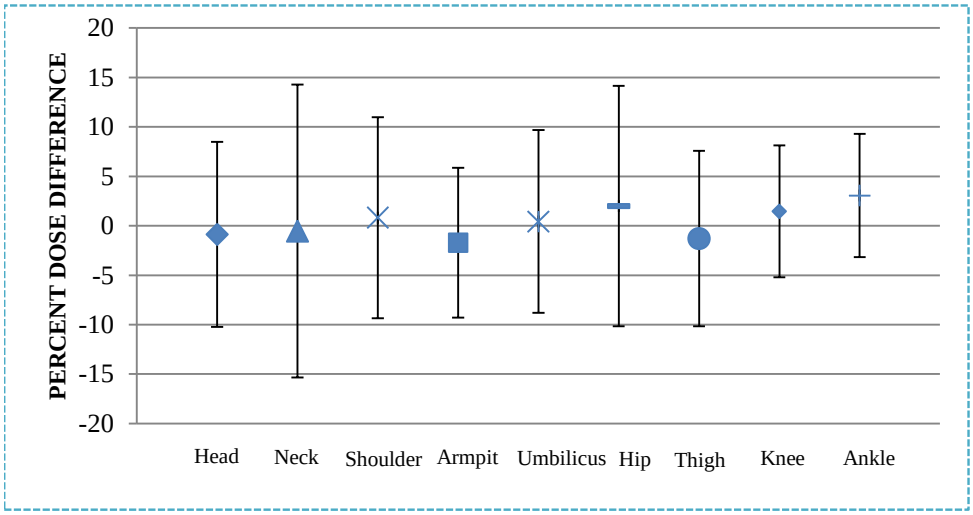


Figure 4.2 The average percent dose differences and SD in 6 fractions for RL/LL lateral parallel opposing fields

4.2.2 The Boost Fraction

- **Phantom Study**

The results of four plans in phantom are shown in Table 4.2 and Figure 4.3. The detail of dose measurement and calculation for the organs in 4 plans are shown in Appendix II. The average and standard deviation of percent dose differences between measured dose by EBT3 film and calculated dose by Eclipse TPS were observed for -2.9±1.2%. The differences were detected for -3.1±5.5%, -3.3±3.4%, -3.0±6.0%, -2.6±6.9%, -3.6±5.5%, -4.6±4.6%, -3.0±4.1% and -0.2±4.9% at shoulder, lung, kidney, chest, umbilicus, abdomen, groin, and thigh, respectively. The total average percent dose difference was -2.9±1.2%. The highest difference was 9.9% in abdomen and the lowest was 0.1% in umbilicus.

Table 4.2 The average and standard deviation of percent dose differences in each site of 4 plans in phantom

Anatomical site	Average±SD	Range
Shoulder	-3.1±5.5%	-6.0 to 4.8
Lung	-3.3±3.4%	-7.4 to -0.2
Kidney	-3.0±6.0%	-8.7 to 5.1
Chest	-2.6±6.9%	-6.5 to 7.8
Umbilicus	-3.6±5.5%	-9.6 to 3.7
Abdomen	-4.6±4.6%	-9.9 to 1.2
Groin	-3.0±4.1%	-8.3 to 1.0
Thigh	-0.2±4.9%	-5.3 to 4.9
Average	-2.9±1.2%	

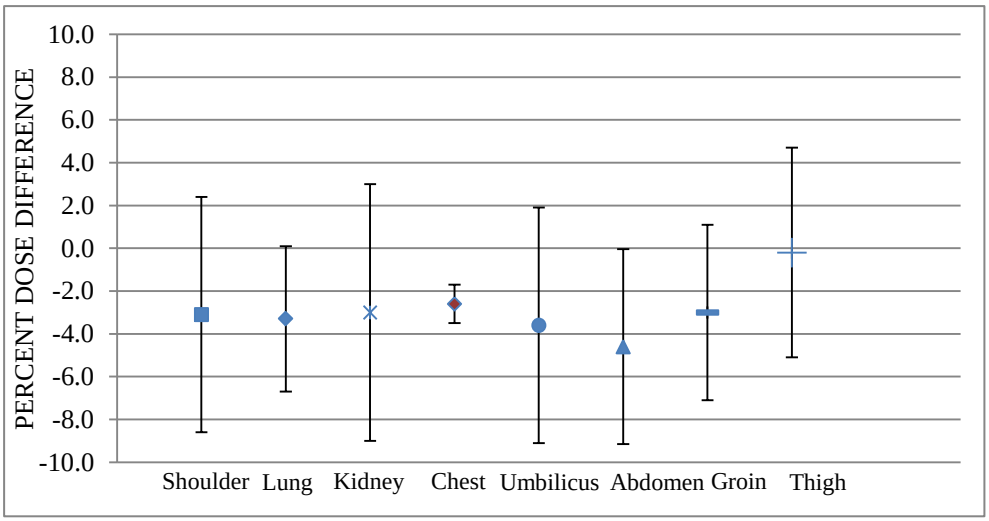


Figure 4.3 The average percent dose differences and standard deviation of 4 plans in phantom study

- **Clinical Study**

The results of five patients are shown in Table 4.3 and Figure 4.4. The detail of dose measurement and calculation for the organs in 5 patients are shown in Appendix III. The average and standard deviation of percent dose differences between measured dose by EBT3 film and calculated dose by Eclipse TPS were observed for 2.1±5.9%, -0.8±2.8%, -1.3±2.5%, 0.9±4.6%, 3.3±4.4%, 0.6±5.5% and 1.0±4.5% at armpit, shoulder, umbilicus, abdomen, groin, and thigh, respectively. The total average percent dose difference was -0.8±1.6%. The highest difference was 10.6% in armpit and the lowest was 1.1% in abdomen.

Table 4.3 The average and standard deviation of percent dose differences in each site of 5 patients at KMCH

Anatomical site	Average±SD	Range
Armpit	2.1±5.9%	-4.6 to 10.6
Shoulder	-0.8±2.8%	-3.7 to 2.1
Chest	-1.3±2.5%	-3.3 to 1.6
Umbilicus	0.9±4.6%	-4.4 to 3.9
Abdomen	3.3±4.4%	-1.1 to 7.6
Groin	0.6±5.5%	-3.3 to 7.0
Thigh	1.0±4.5%	-4.2 to 4.5
Average	-0.8±1.6%	

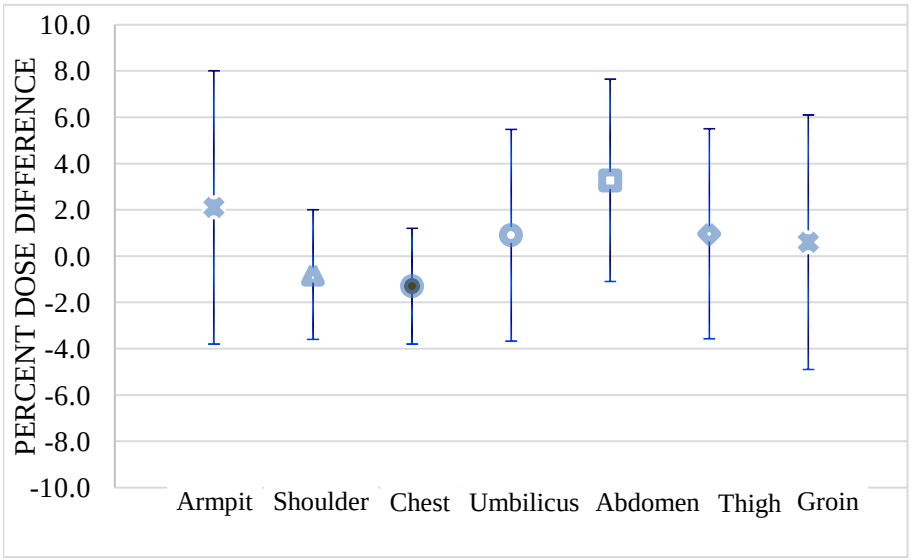


Figure 4.4 The average percent dose differences and standard deviation of 5 patients in clinical study

CHAPTER V

DISCUSSION AND CONCLUSIONS

5.1 Discussion

Total body irradiation was considered as a special technique aimed to deliver ±10% dose uniformity to entire body while keeping lung dose within tolerance limit of less than 10 Gy. The measured dose was performed by EBT3 film which contributed high spatial resolution, near tissue equivalent and low energy dependence, it is suitable for in-vivo dose measurement of total body irradiation (TBI) according to Fan-Chi Su et al[2], who reported that specific characteristic of Gafchromic EBT3 film were accurate, reproducible and linearity, under TBI conditions.

The measured dose by EBT3 film with bolus was performed for one plan in six fraction of one TBI patient, four plans in male Alderson Rando phantom and five plans in TBI patients at KCMH to ensure actual dose delivery in boost fraction.

For doses calculated by Eclipse TPS, lung and kidney shielded by MLC, they were considered to reduce pulmonary toxicity Petra M.H et al[23].

5.1.1 Lateral Parallel Opposing Fields

The dose measurement for lateral parallel opposing fields in six fractions of one patient showed the high standard deviation of 14.8 for neck and 12.2 for hip region may be due to the film placing in different positions for six fractions and difference of patient positions. The curve of body contour in neck and hip made the variation of film reading in each fraction. The doses in head, neck and leg were in the range of 180 - 200 cGy which was in high dose gradient resulting in large dose difference.

The average percent dose difference of 0.4±2.7%. The highest difference was 3.1% in ankle and lowest was 0.5% in neck. Fan-Chi Su et al[2] studied in vivo dose measurement in lateral parallel opposing fields in two patients by using EBT3 film, the average dose difference was 0.9±2.0%. Our study was slightly higher than Fan-

Chi Su et al[2] may due to their studied was performed only one fraction for each patient and difference of film positions.

5.1.2 The Boost Fraction in AP/PA Fields

A. Phantom Analysis

The in vivo dosimetry was performed in four plans in phantom. The EBT3 films with bolus were placed along phantom surface and inserted inside phantom for umbilicus and abdomen including lung and kidney shielded by MLC. The maximum difference was 9.9% in abdomen region which may cause from the overlapping of upper/lower fields (field junction) and the lowest was 0.1% in umbilicus region.

The average percent dose difference of -2.9±1.2% was observed. Petra M.H et al[23] investigated the MU calculated by RTPS and measured dose by using EBT3 film in male Rando phantom, the difference between calculated and measured was 0.7±2.1% considered both lateral and AP/PA fields. Our study was slightly higher difference than Petra M.H et al[23]. For the lung and kidney that was shielded by MLC, the average dose difference was -3.3% and -3.0%, respectively. The results were agreeable with T. Streller et al[25] who recommended the difference in lung dose would be within 5%.

B. Clinical Analysis

The in vivo dosimetry was performed in five plans in TBI patient at KCMH. The EBT3 films with bolus were only placed along patient surface. For the results in five plans in patients, the overall average percent dose difference was slightly lower difference than phantom study. The results illustrated good agreement between calculated and measured dose, the measured dose showed higher than calculated dose which we could observe in most region.

The average percent dose difference of 0.8±1.6% was observed. The highest difference was 10.6% in armpit which may cause from the film position movement during prolong TBI irradiation and the poor patient condition. The lowest difference was 0.7% in shoulder region. Our work was comparable with Petra M.H et al[23] who

presented 0.5±4.7% in 10 patients and better than Rui Yao et al[4] who reported 3.5±5.9% in 19 patients.

The summary of the deviation of measurement from the calculation were:

- Less times to place EBT film firmly in patient before irradiation.
- The film was not tightly cleave on surface of patient (head, neck) due to the curvature of the contour, the difficulty of placing the film due to the barrier on the surface of patient such as catheter wire, hairs, clothes, etc.
- TBI patients were not in good condition as normal case.
- Other reasons (new film package, new calibration curve, dose range in high gradient region).

5.2 Conclusions

The average percent dose differences between measured dose by using EBT3 film and calculated dose by Eclipse TPS in one plan in patient for lateral fields in six fractions, four plans in phantom study and five plans in patients for 3D-CRT in clinical study are within ±5%. The lung and kidney shielded by MLC measured in phantom are within ±3%, it is important to reduce dose in lung to avoid pulmonary toxicity and important to reduce dose in kidney in pediatric patient. However, the measured doses in most anatomical sites are higher than calculated dose by Eclipse TPS.

The EBT3 film can be used to measured dose in the patient during total body irradiation with 5% of the accuracy of delivered dose in total body irradiation.

The percent dose differences depend on location and direction of film, patient condition and position, film characteristic, dose range and body contour.

REFERENCES

1. Van Dyk, J., M.Galvin, G.Glasgow and E.B.Podgorsak, The physical aspects of total and a half body photon irradiation. AAPM, 1986. **17**: p. 1-45.

2. Sua, F.-C., C. Shia, and N. Papanikolaoua, Clinical application of GAFCHROMIC EBT film for in vivo dose measurements of total body irradiation radiotherapy. Applied Radiation and Isotopes, 2008. **66**: p. 389–394.

3. Khan, F.M., The Physics of Radiation Therapy. Fifth ed. Chapter 18 TOTAL BODY IRRADIATION. 2014.

4. R, Y., et al., A simplified technique for delivering total body irradiation with improved dose homogeneity. Med. Phys, 2012. **39**(4): p. 2239–2248.

5. B.Shank, Total body irradiation. Elsevier, in TECHNIQUES AND MODALITIES, L. Gunderson and J. Tepper, Editors. 2011. p. 1660.

6. Oliveira, F.F., et al., In vivo dosimetry with silicon diodes in total body irradiation. ELSEVIER, 2014. **94**: p. 374-378.

7. Patel, R.P., et al., In vivo dosimetry for total body irradiation: five year results and technique comparison. Med Phys, 2014. **15**(4): p. 306-315.

8. Chie, E.K., et al., Dose homogeneity of the total body irradiation in vivo and in vitro confirmed with thermoluminescent dosimeter. IAEA/NIS, 2000. **17**(4): p. 7-65.

9. Dam, J.V. and G. Marinello, Methods for in vivo dosimetry in external radiotherapy. ESTRO, 2006. **83**(2): p. 60-61.

10. Galvin, J.M., Total body irradiation dosimetry and practical considerations. AAPM, 2012: p. 1-9.

11. Stern, R.L., et al., Task group report. Verification of monitor unit calculations for non-IMRT clinical radiotherapy. Vol. 38. 2011: AAPM. 504-530.

12. Diode in vivo dosimetry for patients receiving external beam radiation therapy. AAPM 2005. **87**: p. 44-57.

13. Sievinen, J., W. Ulmer, and W. Kaissl. AAA photon dose calculation model in EclipseTM. . 2013.

14. failla, g.A., et al. Acuros XB advanced dose calculation for Eclipse treatment planning system. 2015.

15. Starkschall, G., A Practical Guide to 3D Planning and Conformal Radiation Therapy. What is 3D Radiation Therapy Treatment Planning 1999, Advanced Medical

16. Prabhakar, R., P.K. Julka, and G.K.R.e. al, Can field-in-field technique replace wedge filter in radiotherapy treatment planning: a comparative analysis in various treatment sites. Australasian Physical & Engineering Sciences in Medicine, 2008. **31**(317): p. 4.

17. Kron, T., Dose Measuring Tools, in The modern technology of radiation oncology, J.V. Dyk, Editor. 1999, Medical Physics: Med Phys. p. 752.

18. Bethesda, Determination of Absorbed Dose in a Patient Irradiated by Beams of X or Gamma Rays in Radiotherapy Procedures. ICRU, 1976. **24**: p. 65.

19. Azam Niroomand-Rad, C., et al., Radiochromic Film Dosimetry, Niroomand-Rad, Editor. 1998: AAPM. p. 2094-2103.

20. Ganapathy, K., et al., Patient dose analysis in total body irradiation through in vivo dosimetry. Med. Physics, 2012. **37**(4): p. 214-218.

21. Borca, C., et al., Dosimetric characterization and use of gafchromic EBT3 film for IMRT dose verification. applied clinical Med. Phys, 2013. **14**(2): p. 158-164.

22. EY, L.M., et al., Evaluation of the uncertainty in an EBT3 film dosimetry system utilizing net optical density. Med. Phys, 2016. **17**(5): p. 62.

23. Härtl, P.M., et al., Total body irradiation-an attachment free sweeping beam technique. Radiation Oncology, 2016. **11**(81): p. 1181-1186.

24. Lancaster, C.M., J.C. Crosbie, and S.R. Davis, In-vivo dosimetry from total body irradiation patients (2000-2006): results and analysis. Australas Phys Eng Sci Med, 2008. **31**(3): p. 191-195.

25. Streller, T., et al., In vivo lung dose estimation during total body irradiation with Gafchromic EBT3 films. ESTRO, 2014. **33**(164).

APPENDIX

APPENDIX I

The measured and calculated dose in six fractions of one patient for the lateral parallel opposing fields

Anatomical site		Calculated dose by Eclipse (cGy)	Measured dose (cGy)	Percent dose difference (%)
Head	Right	176.2	180.6±10.6	-2.4
	Left		174.9±7.8	0.7
Neck	Right	179.7	183.0±12.6	-1.9
	Left		178.2±17.6	0.8
Shoulder	Right	156.1	152.1±10.0	2.6
	Left		157.5±10.5	-0.9
Armpit	Right	157.7	160.5±9.8	-1.8
	Left		160.2±5.5	-1.6
Umbilicus	Right	159.3	157.5±11.3	1.1
	Left		159.8±7.0	-0.4
Hip	Right	155.1	151.7±14.6	2.2
	Left		152.5±10.1	1.7
Thigh	Right	161.3	163.3±9.9	-1.2
	Left		163.5±8.6	-1.4
Knee	Right	167.4	164.9±8.6	1.5
	Left		165.0±4.9	1.4
Ankle	Right	167.4	162.5±4.3	3.0
	Left		162.3±8.9	3.1
Average±SD				0.4±1.8

APPENDIX II

The measured and calculated dose of four plans in phantom for 3D-CRT in AP/PA boost fraction

Phantom 1

Anatomical site	Calculated (cGy)	Measured (cGy)	%Diff
Surface with bolus			
Shoulder R	304.9	327.8	-7.0
Shoulder L	301.2	320.9	-6.1
Chest	297.5	316.2	-5.9
Umbilicus	302.7	308.6	-1.9
Abdomen	311.0	328.1	-5.2
Groin	316.2	322.8	-2.1
Thigh R	301.8	310.5	-2.8
Thigh L	304.2	316.6	-3.9
Inside phantom			
Shoulder R	293.7	288.3	1.9
Shoulder L	298.3	306.0	-2.5
Lung R	107.4	108.2	-0.8
Lung L	110.1	110.5	-0.4
Kidney R	203.0	110.5	-3.1
Kidney L	207.8	209.5	-3.6
Umbilucus	296.3	215.5	-6.1
Abdomen	283.3	315.7	-1.8
Average±SD			-3.2±2.4

Phantom 2

Anatomical site	Calculated (cGy)	Measured (cGy)	%Diff
Surface with bolus			
Shoulder R	331.9	359.0	-7.8
Shoulder L	334.0	348.4	-4.1
Chest	325.4	344.9	-5.6
Umbilicus	335.0	351.4	-4.7
Abdomen	353.9	380.5	-7.0
Groin	365.7	377.9	-3.3
Thigh R	351.7	354.2	-0.7
Thigh L	349.9	354.8	-1.4
Inside phantom			
Shoulder R	335.8	375.4	-10.6
Shoulder L	331.2	357.9	-7.5
Lung R	58.8	62.1	-5.4
Lung L	57.9	54.8	5.6
Kidney R	180.7	195.3	-7.5
Kidney L	174.3	182.3	-4.4
Umbilucus	299.0	312.0	-4.2
Abdomen	304.0	319.4	-4.8
Average±SD			-4.5±3.6

Phantom 3

Anatomical site	Calculated (cGy)	Measured (cGy)	%Diff
Surface with bolus			
Shoulder R	295.3	284.1	3.9
Shoulder L	279.0	259.8	7.4
Chest	292.2	271.1	7.8
Umbilicus	284.0	283.6	0.1
Abdomen	270.6	276.9	-2.3
Groin	237.0	233.3	1.5
Thigh R	247.7	230.6	7.4
Thigh L	248.0	241.9	2.5
Inside phantom			
Shoulder R	296.4	285.0	4.0
Shoulder L	299.8	287.0	4.5
Lung R	60.0	65.0	-7.7
Lung L	60.4	65.0	-7.1
Kidney R	256.0	249.0	2.8
Kidney L	147.0	134.5	9.2
Umbilucus	293.3	272.7	7.5
Abdomen	285.0	272.0	4.8
Average±SD			2.9±5.1

Phantom 4

Anatomical site	Calculated (cGy)	Measured (cGy)	%Diff
Surface with bolus			
Shoulder R	336.4	319.2	5.4
Shoulder L	336.9	320.4	5.1
Chest	331.5	307.8	7.6
Umbilicus	284.3	305.1	-6.8
Abdomen	253	228.8	10.5
Groin	265.5	269.0	-1.3
Thigh R	293.9	271.5	8.2
Thigh L	298.9	272.1	9.8
Inside phantom			
Shoulder R	333.9	321.3	3.9
Shoulder L	328.8	339.7	-3.2
Lung R	65.0	60.5	7.3
Lung L	67.2	62.2	7.9
Kidney R	170.9	185.0	-7.6
Kidney L	293.7	299.0	-1.7
Umbilucus	280.3	251.7	11.3
Abdomen	242.0	222.4	8.8
Average±SD			4.1±6.2

APPENDIX III

The measured and calculated dose of five plans in patient for 3D-CRT in AP/PA boost fraction

Patient 1

Anatomical site	Calculated (cGy)	Measured (cGy)	%Diff
Right armpit	319.8	310.8	2.9
Left armpit	321.8	317.8	1.3
Groin	210.9	204.8	3.0
Average±SD			2.4±0.9

Patient 2

Anatomical site	Calculated (cGy)	Measured (cGy)	%Diff
Right armpit	315.4	337.1	-6.4
Left armpit	316.2	318.8	-0.8
Groin	234.1	227.2	3.0
Average±SD			-1.4±4.7

Patient 3

Anatomical site	Calculated (cGy)	Measured (cGy)	%Diff
Right shoulder	320.6	323.9	-1.0
Left shoulder	321.9	327.0	-1.5
Right armpit	315.1	317.7	-0.8
Left armpit	303.7	304.2	-0.2
Chest	290.2	296.8	-2.2
Umbilicus	326.4	341.5	-4.4
Abdomen	326.0	315.5	3.3
Groin	320.7	327.0	-1.9
Right thigh	331.5	312.3	6.1
Left thigh	333.8	324.4	2.9
Average±SD			0.03±3.1

Patient 4

Anatomical site	Calculated (cGy)	Measured (cGy)	%Diff
Right shoulder	303.8	309.5	-1.8
Left shoulder	300.7	316.4	-4.9
Right armpit	289.8	315.2	-8.1
Left armpit	297.7	307.2	-3.1
Chest	257.9	266.8	-3.3
Umbilicus	291.2	282.5	3.1
Abdomen	297.9	301.3	-1.1
Groin	277.2	286.6	-3.3
Right thigh	264.4	269.2	-1.8
Left thigh	263.3	281.8	-6.6
Average±SD			-3.1±3.1

Patient 5

Anatomical site	Calculated (cGy)	Measured (cGy)	%Diff
Right shoulder	282.7	280.6	0.7
Left shoulder	281.0	271.7	3.4
Right lung	41.5	45.2	-8.1
Left lung	43.6	47.2	-7.7
Right armpit	312.5	283.7	10.4
Left armpit	305.0	277.4	10.1
Chest	269.6	265.3	1.6
Umbilicus	279.5	269.1	3.9
Abdomen	273.9	254.5	7.6
Groin	246.3	230.1	7.0
Right thigh	195.2	192.8	1.2
Left thigh	148.2	142.8	3.8
Average±SD			2.8±5.9

VITA

NAME: Miss Viphaphone Inphavong

SEX: Female

NATIONALITY: Lao

DATE OF BIRTH: 7 August 1991

PLACE OF BIRTH: Bokeo province, Laos

INSTITUTIONS ATTENDED: Bachelor of Science(General Physic)
National University of Laos,
Vientiane Capital, Laos: 2014
Master of Science
(Medical Imaging)
Chulalongkorn University
Bangkok, Thailand

PERMANENT ADDRESS: Hauixai Tai Yai Village, Hauixai District,
Bokeo Province, Laos

E-Mail: Viphaphone_pp@hotmail.com