SET-UP VERIFICATION DURING PELVIC RADIATION THERAPY USING ELECTRONIC PORTAL IMAGING DEVICE (EPID)

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SET-UP VERIFICATION DURING PELVIC RADIATION THERAPY USING ELECTRONIC PORTAL IMAGING DEVICE (EPID).

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ABSTRACT

In advanced technology radiation therapy, a small CTV-to-PTV margin may result in geometrical misses during the treatment fractions. This study used matching anatomy software to compare electronic portal images (EPI) with the simulation images and measured the set-up errors in X, Y and Z directions. Methods of selecting bony anatomy to do the matching were studied. Then, the set-up error in AP and Lat pelvic images were measured. The sample group was 34 patients treated with pelvic radiotherapy in Siriraj hospital from January 2005 - October 2006. Individual and population systematic and random errors were calculated. Then the adequate CTV-to-PTV margin was calculated. The factors that influenced patient set-up error were also studied: age(<70,≥70), sex (male, female), weight (<65 ,≥65kg) and immobilization (Vac- Lok group and no Vac- Lok group). Results showed that the three anatomic landmarks were adequate for bony anatomy matching of AP and Lat pelvis images as long as the pubic symphysis was included. The results showed that the set-up error ranged from -0.61cm to 0.44 cm in L–R direction (X),-0.84 to 0.77 cm in A-P direction (Y) and -0.46 to 0.51cm in the S-I direction (Z). The individual systematic errors (Σ_{ind}) and random error were both highest in the A-P direction (Y). The population systematic errors (Σ_{pop}) in X,Y and Z were 0.13 cm, 0.24 cm and 0.12 cm. The population random errors (σ_{pop}) were 0.19 cm, 0.20 cm and 0.17 cm in X ,Y and Z directions, respectively. There was no statistical significance between sex and age group ($p>0.05$). However, there was a statistical significance in the the Y direction between the immobilization groups ($p=0.002$), and in the X direction between the weight (<65, ≥65kg) groups ($p=0.01$).The calculated adequate CTV-to-PTV margin in X, Y and Z direction were 0.46 cm, 0.74 cm and 0.42 cm, respectively. In conclusion, the calculated maximum CTV-to PTV margin for pelvic radiation therapy was 0.74 cm. It showed that the current CTV-to-PTV margin used (0.8- 1 cm) is adequate for set up error, although the internal organ margins should also be considered.

KEY WORDS: EPID / SET UP ERRORS / CTV-TO-PTV MARGIN / PELVIC RADIATION THERAPY

97 pp.

การตรวจสอบความถูกต้องของการจัดท่าการฉายรังสีบริเวณอุ้งเชิงกรานด้วยการใช้ ELECTRONIC PORTAL IMAGING DEVICE (EPID)
(SET-UP VERIFICATION DURING PELVIC RADIATION THERAPY USING ELECTRONIC PORTAL IMAGING DEVICE (EPID))

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บทคัดย่อ

ในปัจจุบันเทคนิคการฉายรังสีที่ทันสมัยบริเวณอุ้งเชิงกรานมีการใช้กันอย่างแพร่หลาย ด้วยการกำหนดขอบเขตการฉายรังสี CTV-to-PTV ที่ลดลงกว่าพื้นที่การฉายรังสีแบบปกติ ซึ่งอาจจะทำให้เกิดผลความผิดพลาดในตำแหน่งการฉายรังสี (geometrical misses) ในบางวันของการฉายรังสีหรือตลอดการรักษา ในการศึกษานี้ใช้โปรแกรม Match anatomy เปรียบเทียบตำแหน่งการฉายรังสีจากภาพ Electronic portal image (EPI) กับภาพขณะจำลองการรักษารังสีรักษา (Simulation images) เพื่อวัดความคลาดเคลื่อนในตำแหน่งการฉายรังสีในแนวแกน X, Y และ Z ในการศึกษานี้เราได้ศึกษาหา Bony Anatomy landmarks ที่เหมาะสมในการหาค่า Set-up error ในภาพถ่ายรังสีบริเวณอุ้งเชิงกรานทั้งในภาพ AP และ Lateral Pelvic. จากนั้นเก็บข้อมูลในผู้ป่วยที่มารับการรักษาในโรงพยาบาลศิริราชในช่วงเดือน ม.ค. 2548 – ตุลาคม 2549 จำนวน 34 ราย จากนั้นนำค่าที่ได้จากผู้ป่วยทั้งหมดมาคำนวณหาค่า Individual random/systematic errors, population random/systematic errors หลังจากนั้นนำค่าที่ได้มาหาค่าขอบเขต CTV-to-PTV ที่เหมาะสม และศึกษาปัจจัยที่มีผลต่อค่า Set-up errors ได้แก่กลุ่มผู้ป่วยอายุน้อยกว่า 70 ปีหรือมากกว่าหรือเท่ากับ 70 ปี , กลุ่มเพศชายและเพศหญิง , กลุ่มผู้ป่วยที่มีน้ำหนักน้อยกว่า 65 กิโลกรัม และกลุ่มผู้ป่วยที่มีน้ำหนักมากกว่าหรือเท่ากับ 65 กิโลกรัม และกลุ่มผู้ป่วยที่ใช้ Immobilization (Vacuum-Lock) และกลุ่มผู้ป่วยที่ไม่ใช้ Vacuum-Lock

ผลการวิจัยพบว่าการวาด anatomy landmark 3 ตำแหน่งที่เหมาะสมในภาพ AP และ Lateral ได้ผลไม่แตกต่างจากการวาด anatomy landmarks 5 ตำแหน่ง แต่ควรต้องมีการวาด pubic symphysis ร่วมอยู่ด้วย จากการหาค่า set-up error จากผู้ป่วย 34 คน ผลประกฏว่าค่า set-up error อยู่ในช่วง -0.61 cm ถึง 0.44 cm ในทาง L–R direction (X), -0.84 ถึง 0.77 cm ในทาง A-P direction (Y) และ -0.46 ถึง 0.51 cm ในทาง S-I direction (Z) ค่า Individual random/systematic errors ที่สูงที่สุดอยู่ในแนวแกน Y ค่า population systematic errors (Σ_{pop}) ในแนวแกน X, Y และ Z มีค่าเท่ากับ 0.13 cm, 0.24 cm และ 0.12 cm. และค่า population random errors (σ_{pop}) มีค่าเท่ากับ 0.19 cm ,0.20 cm และ 0.17 cm ในแนวแกน X ,Y และ Z ตามลำดับ ปัจจัยที่มีผลต่อค่า Set-up errors ในการวิจัยนี้ พบว่ามีความแตกต่างทางนัยสำคัญทางสถิติในกลุ่มผู้ป่วยที่ใช้ Immobilization (Vacuum-Lock) และกลุ่มผู้ป่วยที่ไม่ใช้ ในแนวแกน Y (P=0.002) และมีค่าความแตกต่างทางนัยสำคัญทางสถิติในกลุ่มผู้ป่วยที่มีน้ำหนักน้อยกว่า 65 กิโลกรัม และกลุ่มผู้ป่วยที่หนักมากกว่าหรือเท่ากับ 65 กิโลกรัม ในแนวแกน X(P=0.01) เมื่อนำค่า population random/systemic errors มาคำนวณหาขอบเขต CTV-to PTVmargin ในแนวแกน X,Y และ Z มีค่าเท่ากับ 0.46 cm, 0.74 cm และ 0.42 cm ตามลำดับ

จากการวิจัยพบว่า CTV-to-PTV margin สำหรับแก้ค่า set-up error ของการฉายรังสีบริเวณอุ้งเชิงกรานที่คำนวณได้สูงสุดคือ 0.74 cm ซึ่งขอบเขตการฉายรังสีในปัจจุบันในร.พ.ศิริราชที่ใช้อยู่คือ 0.8-1 cm น่าจะเพียงพอและเหมาะสม

CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF ABBREVIATIONS

Abbreviation	Term
3D- CRT	Three dimensional conformal radiation therapy
AMFPI	Active matrix flat-panel imaging
A-P	Antero-Posterior
a-Si, a Si	Amorphous silicon
CI	Conformity Index
cm	Centimeter
CT	Computed Tomography
CT-Sim	Computed Tomography Simulation
CTV	Clinical Target Volume
DCR	Digitally composited radiograph
DRRs	Digitally reconstructed radiographs
EPIDs	Electronic portal imaging devices
FOV	Field of view
GTV	Gross Tumor Volume
ICRU	International Commision on Radiation Units and Measurement
IDU	Image detection unit
IM	Internal Margin
IM-WPRT	Intensity-modulated whole pelvic radiation therapy
ITV	Internal Target Volume
L-R	Left- Right
MLC	Multileaf collimator
mm	Millimeter
MRI	Magnetic Resonance Imaging
OAR	Organ at risk
ODI	Optical distance indicator
PET	Positron emission tomography

LIST OF ABBREVIATIONS (Continued)

Abbreviation	Term
PRV	Planning Organ at Risk Volume
PTV	Planning Target Volume
QA	Quality Assurance
RL	Right lateral
RTP	Radiation therapy treatment planning
RTTs	Radiation therapy technologists
SD	Standard deviation
S-I	Superior –Inferior
SM	Set-up Margin
SPECT	Single Proton Emission Computed Tomography
TFTs	Thin film transistors
$\sum$	Systematic error
$\sum_{ind}$	Individual systematic errors
Σpop	Population systematic errors
σ	Random errors
σ_{ind}	Individual random errors
σ_{pop}	Population random errors

CHAPTER I
INTRODUCTION

1.1 Background

Radiation therapy has been the important modality for treatment of cancer. The aim of radiation therapy is to use ionizing radiation to kill cancer cells in target volume as many as possible, while sparing surrounding normal tissue and organ at risk.

The goal of conformal radiation therapy is to deliver prescribed dose to target volume while minimizing the dose to normal organ. Successful delivery of radiation therapy requires accuracy and setup reproducibility of the patient's position during a day to day of the treatment course. The important for precise radiation therapy requires stringent immobilization and treatment verification (1,2,3).

The introduction of new technology such as intensity modulated radiation therapy (IMRT) and three dimensional conformal radiation therapy (3D-CRT) , poses new challenges for delivering intended target dose and minimizing dose and toxicity to critical normal structures. Too large a margin gives unnecessary dose to surrounding organs at risk, but too small margin between the clinical target volume (CTV) and the field borders will result in geometrical misses at some or even all treatment fractions. To determine these margins between the CTV and field borders, the concept of the planning target volume (PTV) and PTV margin has been introduced. The planning target volume includes margins for uncertainties in organ shape and motion and patient set-up.

Set up errors can be measured using portal imaging by applying either megavoltage film or an electronic portal imaging device (EPID). At present, EPIDs have become available in many institutions to measure set-up errors.

3D-CRT and IMRT pelvic radiation therapy are advance technology used in treatment of pelvic cancer including prostate cancer, gynecological cancer and

genitourinary cancer. However , the pelvic radiation therapy probably has greater set up variations than at any other sites in the body (2) .

Patients being treated to pelvic sites such as prostate and other genitourinary or gynecological sites are difficult to immobilized (3).Many treatment centers make use of rigid immobilization devices in conjunction with standard laser-tattoo alignment to reduce uncertainties such as large cast, customized alpha cradle and Vacuum lock .

The main purpose of this study is to measure the set up errors in pelvic radiation therapy and to determine adequate CTV-to-PTV margin.

The second purpose is to find the factors which influence patient set up errors including age (<70,≥70), sex (male, female), weight (<65 ,≥65) and immobilization device used. (Vacuum lock, No Vacuum lock)

In this study, matching anatomy software in Varian Portal Vision 6 was used to compare electronic portal images with the simulation images and to measure the set up errors in x, y and z directions.

Before we could find the set up errors, we would have to find the reliable way to match anatomy. This study hence included the study to find area of good bony anatomy matching and interobserver variations of medical personnel doing the anatomical matching.

CHAPTER II
OBJECTIVES

The objectives of this study are:

2.1 Primary objective

To find setup errors (systematic and random error) during pelvic radiation therapy using EPIDs in patients treated with 3DCRT and IMRT in Siriraj Hospital and to calculate the CTV- to -PTV margin (concentrate to set-up error margin).

2.2 Secondary objectives

2.2.1 To determine the appropriate methods to match bony anatomical landmarks in AP and Lat pelvic images using matching anatomical software. The study aims to find reliable bony landmarks used for the match and reliability of medical personnel doing the anatomical matching.

2.2.2 To study factors influence patient set up errors: age (<70 vs. ≥70), sex (male vs. female), weight (< 65 vs. ≥ 65 kg) and immobilization devices used (Vacuum lock vs. no vacuum lock).

CHAPTER III
LITERATURE REVIEW

3.1 Radiation Therapy Process (5)

The process of radiation therapy for malignant disease is complex and involve many steps.

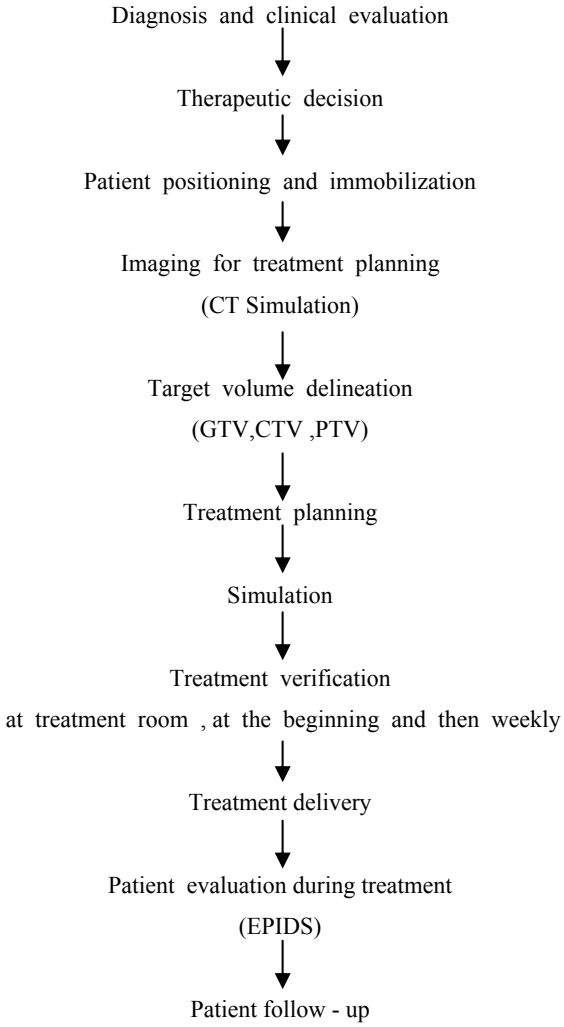

Figure 3.1 The flow chat of 3 dimension conformal radiation therapy process in Siriraj Hospital .

One critical step in this process is the determination of the location and the extent of disease relative to adjacent critical normal structures (target volume delineation).This can be done in many ways from simple clinical examination to complex 3-D imaging modalities. Selection of radiation treatment techniques (conventional ,3D-CRT or IMRT) depends on extension of disease and physician judgment. For 3D-CRT or IMRT, the patient has to take the imaging for treatment planning (CT ,MRI, ultrasound ,SPECT,PET).The images were used to determine the location and extent of disease relative to adjacent critical normal structures (target volume delineation).

Before image acquisition, the other important step for 3D-CRT is to select the immobilization and positioning device for the patient. The aim of the process is to minimize set up error. In the treatment planning step select radiation beams to provide an adequate coverage target volume and minimizing the dose to healthy normal tissue.

Before treatment is initiated, the treatment plan needs to be confirmed by an imaging procedure to ensure that each beam traverses the desired anatomical volume and misses critical structures as planned (treatment verification). Finally, the treatment is delivered.

Intensity-modulated radiotherapy (IMRT) is another approach of conformal radiotherapy that not only conforms high dose to the target volume but also conforms low dose to sensitive structure. IMRT is a special technique of conformal radiotherapy that can adjust radiation dose intensity delivery in each geometric shaping beam so it's dose distribution would conform to the shape of the target not the beam shape.

IMRT is good for target that is not geometrically well separate from the organ at risk or when the target wraps itself around organ at risk. The process of IMRT is similar to that of 3D-CRT , except that after treatment planning , the physicists need to do the QA in the phantom to make sure that dose intensity delivered to the patient will be as accurate as planned.

3.2 Terms and concepts for volumes and margins

3.2.1 The International Commission on Radiation Units and Measurement **(ICRU) Report No 50** (6) has addressed the standardization of terminology and dose specification procedures. Three major concepts that are important to the treatment process are GTV , CTV and PTV.

3.2.1.1 **Gross Tumor Volume (GTV)** is the gross palpable or visible/demonstrable extent and location of malignant growth from imaging studies. The GTV may consist of primary tumor, metastic lymphadenopathy ,or other metastases. The determination of GTV may depend on the diagnostic modality that is use.(e.g., CT, MRI , PET scan , mammography ,palpation).
The adequate dose must be delivered to entire GTV in order to obtain local control.

3.2.1.2 **Clinical Target Volume (CTV)** is a tissue volume that contains a demonstrable GTV and sub clinical microscopic malignant disease, which has to be eliminated. The microscopic disease cannot be visualized but clinical experience has demonstrated that around the GTV, there is generally microscopic sub clinical disease. This could include individual malignant cells (10 micrometers in size),small cell clusters, or micro extensions that cannot be detected by staging or diagnostic procedures. This volume thus has to be treated adequately in order to achieve the aim of therapy, cure or palliation.

3.2.1.3 **Planning Target Volume (PTV)** Ideally**,** the dose distribution should be delivered exactly to a well-defined static CTV however this is impossible due to patient repositioning uncertainties from day to day (set-up error); CTV movement within the patient as a result of breathing, changes in CTV shape as a result of breathing**,** changes in CTV shape as a result of issues such as bladder and rectum volume changes (internal organ movement) , and uncertainties associated with mechanical setup of treatment machine (eg.,field size ,gantry angle, collimator and couch rotation). The PTV is defined as a geometrical concept, and it is defined to select appropriate beam sizes and beam arrangement, taking into consideration the net effect of all the possible

geometrical variations mention above, in order to ensure that the prescribed dose is actually absorbed in the CTV.

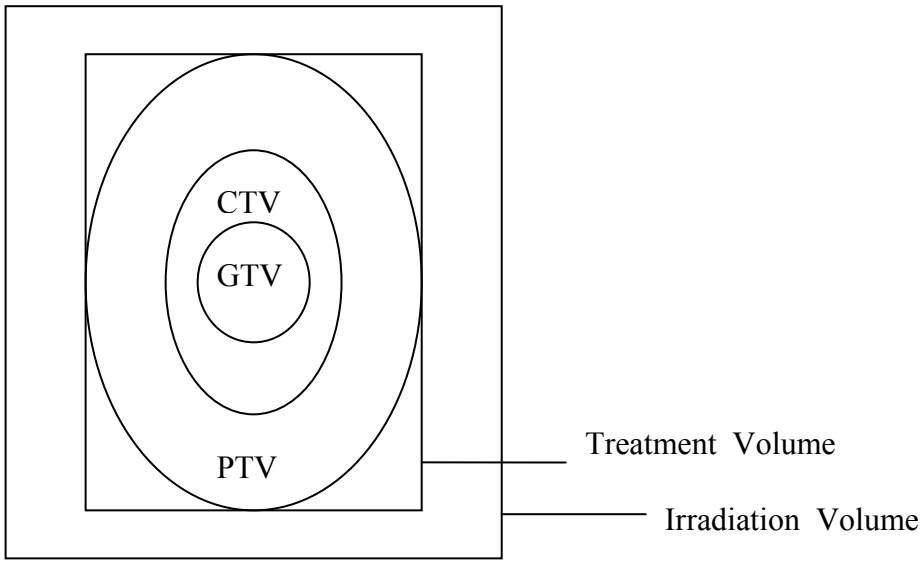

Figure 3.2 ICRU 50 The Volume definitions.(6)

The planning target volume (PTV) during radiotherapy includes margins for uncertainties in organ shape and motion, beam geometry and patient set-up. Both setup errors and organ motion are include in the PTV margins.

3.2.1.4 **Treatment Volume** is the volume of tissue enclosed by the prescribed isodose surface specified by the radiation oncologist , the volume that actually receives a high dose around the planning target volume.

3.2.1.5 **Irradiation Volume** is the volume of tissue that recieves a dose considered significant in relation to tissue tolerance .

3.2.2 ICRU Report 62 (7) is a reviews of the new Supplement to ICRU Report 50**.** Since publication of ICRU Report 50, significant advances in 3-D planning have been made. New conformal irradiation techniques have been introduced and modern imaging procedures provide even more information on the location, shape, and limits of the tumor/target volumes , as well as the normal tissues. Also, there are some limitations and practical issues when using Report 50 methodology that have discussions and debates. For these reasons, the ICRU has decided to publish a

supplement to Report 50 (ICRU Report62) to formulate more accurately some of the definitions of concepts.

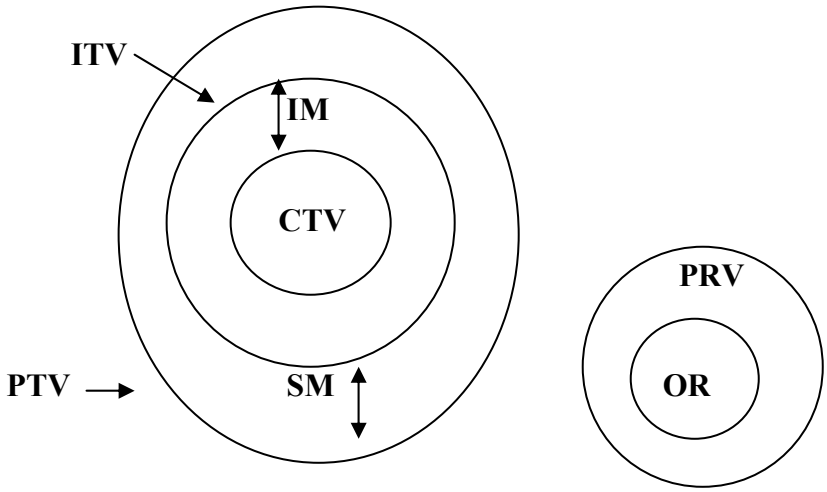

Figure 3.3 ICRU 62 The Volume definitions.

The GTV is the gross extent of the malignant growth as determined by palpation or imaging study. We have to use the term $GTV_{primary}$ and GTV_{nodal} to distinguish between primary disease and other areas of macroscopic tumor involvement such as involved lymph nodes.

On the delineating the GTV: The GTV may appear different in size and shape depending on the examination technique used for evaluation (MRI , CT, surgical exploration) and the Inter-observer variation leading to differences in delineation.

The CTV is the tissues volume that contain a GTV and / or subclinical microscopic malignant disease. The PTV is defined by specifying the margins that must be added around the CTV to compensate for the effects of organ , tumor and patient movements ,and inaccuracies in beam and patient setup.

3.2.2.1 **Internal Margin (IM)** which is defined to account for variations in size, shape, and position of the CTV in relation to anatomical reference points. These variation may result from respiration, different filling of rectum and bladder ,swallowing , heart beat. These variation cannot be easy controlled.

The term of Internal Margin (IM) is added for the variations in position and/or shape and size of the CTV. This defines the **Internal Target Volume**.

3.2.2.2 **Internal Target Volume** (ITV) has been proposed as representing the volume encompassing the CTV and the internal margin .The ITV accounts for the movements of the CTV inside the patient coordinate system. The ITV is a geometrically defined volume fixed in the patient Coordinate System and is specified in relation to internal and external reference points which preferably should be rigidly related to each other through bony structures. The internal target volume (ITV) = CTV + IM

3.2.2.3 **Set-up Margin (SM)** which is defined to accounts for uncertainties , inaccuracies, and lack of reproducibility in patient positioning and alignment of the therapeutic beams during treatment planning and all treatment sessions, it may result from patient positioning variation , mechanical uncertainties of the equipment, dosimetric uncertainties, transfer set-up errors , and human factors.

Size of this margin might be reduced with record and verify systems , patient immobilization devices, and increased skill. Different variations and uncertainties may be either of random error or systematic error.

CTV + IM + SM define the Planning Target Volume (PTV) on which the selection of beam size and arrangement is base. ICRU Report 62 (7) recognizes that simple linear addition of the two margins to account for each of their independent effects may make the PTV inappropriately large and the problem is discussed in some detail. The selection of an overall margin and delineation of the border of the PTV and PRV involve a compromise that requires the experience and the judgment of the radiation oncology team.

3.2.2.4 **Conformity Index**

The concept of a Conformity Index (CI) is introduced and defined as the quotient of the Treated Volume and the volume of the PTV.

$$CI = \frac{TV}{PTV}$$

This definition of the CI implies that the Treated Volume are totally encompasses in the PTV. (ideally one ,CI = 1)

3.2.2.5 **Treated Volume** is the tissue volume that receives at least the dose selected and specified by the radiation oncology team as being appropriate to achieve the purpose of the treatment, tumor eradication or palliation.(e.g. 95%isodose surface)

3.2.2.6 **Irradiation Volume** is the volume that receives a dose considered significant in relation to normal tissue tolerance (e.g. 50 % isodose surface)

3.2.2.7 **The definition of organ at risk.**

Organ at risk (OAR) are defined as those normal tissues whose radiation sensitivity and location in the vicinity of the CTV may significantly influence treatment planning and/or absorbed dose level. The problems resulting from the presence of Organs at Risk is discussed in more detail in the Supplement to Report 50.

The system of classifying Organs at Risk as "serial", "parallel", or "serial-parallel" is discussed, and the use of this system to interpret tolerance of various Organs at Risk is explained (Figure 3.5).

A typical example of a tissue with a high "relative seriality" is the spinal cord, implying that a dose above the tolerance limit, even to a small volume, can totally impair the function of the organ (myelitis).

In contrast, the lung has a low "relative seriality", implying that the main parameter for impairing pulmonary function is the proportion of the organ that receives a dose above the tolerance level. The heart can be considered as having a combined "serial" (coronary arteries) and "parallel" (myocardium) structure.

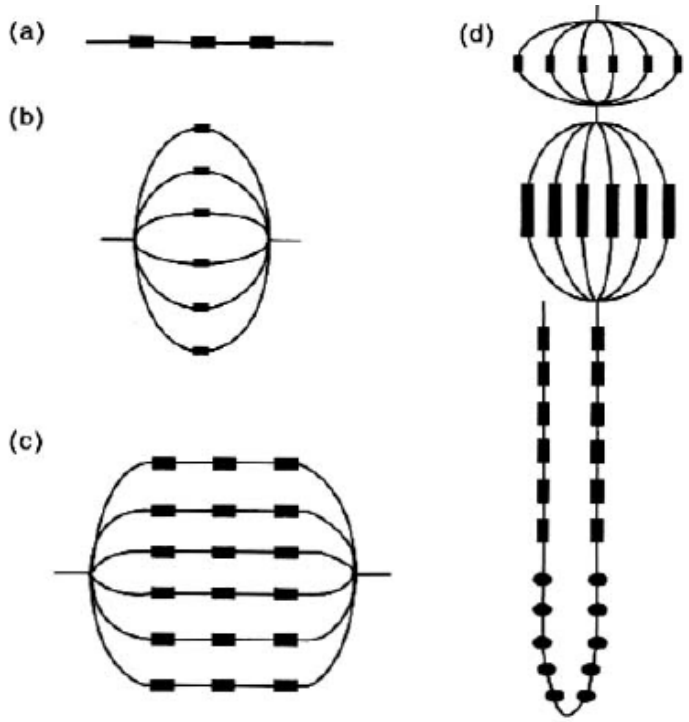

Figure 3.4 Schematic examples of tissue organization structures in the parallel-serial model. (a) a serial string of subunits (e.g., the spinal cord),
(b) a parallel string of subunits (e.g., the lungs),
(c) a serial-parallel string of subunits (e.g., the heart) and
(d) a combination of parallel and serial structures (e.g.,a nephron)(7).

3.2.2.8 **Planning Organ at Risk Volume (PRV)**, in which a margin is added to the OAR to account for movements and changes in shape and/or size of the OAR, as well as set-up uncertainties. Thus, the PRV for the OAR is analogous to the PTV for the CTV. ICRU Report 50 does not address directly how to combine the different positional uncertainties (e.g., setup margin and internal organ motion margin) that make up the PTV or PRV margins. This is a complicated situation since the margins result from random and systematic uncertainties.

3.3 Geometrical uncertainties.

Radiation treatment accuracy can be divided into dosimetric accuracy and geometric accuracy. The geometric accuracy relates to patient positioning and immobilization that has a strong effect on how well we can accurately cover a specified anatomical volume with a desired radiation dose(8).

Numerous publications have presented data on the **accuracy of target volume delineation** , **organ motion** , and **setup accuracy** . The ICRU considers three sources of geometrical uncertainty that may hamper the exact delivery of a plan: patient set-up variation, organ motion and deformation, and machine related errors (9).

A radiation treatment normally consists of one planning session and multiple irradiation sessions .In the planning phase, the patient geometry is visualized using CT or simulator images. The visualized structures are the basis for construction of the treatment plan and the intention is to deliver this plan in all irradiation sessions. Patient set-up errors are due to variations in the daily positioning of the patient on the treatment couch. Some session-to-session variation is unavoidable, even though several measures are taken to ensure a high reproducibility. Day-to-day tumor motion within the patient can occur due to, for example, variations in rectum or bladder filling. Cardiac action and respiration can result in intra-fraction tumor movements. With modern radiotherapy equipment, the machine-related geometrical errors, for example in beam sizes and gantry angles, are generally considered small compared to set-up deviations and organ motion (10).

3.4 Set up error

Set up errors are separate in two main classes

1. The treatment execution variations, often called random error (day –to – day variations or inter-fraction errors).The random error are deviations between difference fractions , during a treatment series

2. The treatment preparation variations often call systematic errors. Systematic errors are deviations between the planned patient position and the average patient position over a course of fractionated therapy(9).

A patient set- up error is the difference between the actual and the intended position of the part of the patient that is irradiated, with respect to the treatment beam during treatment. The intended or reference patient position is recorded on a reference image, being either a simulation image or a digitally reconstructed radiograph (DRR). On the reference image, anatomical structure (e.g. bone , lung ,body contour),radio-opaque markers and the outline of the field are seen. The actual position or the position of the patient during radiation treatment is recorded using port film or EPID. The match anatomy or radio-opaque markers and the outline of the field the patient would be treated will be seen in the port film or EPIDs images (1).

3.5. Systematic and random errors (9),(10),(11)

Systematic or treatment preparation uncertainties errors arise generally during treatment preparation such as errors in the CT aiming lasers or errors in the indicated position in the treatment plan due to organ motion during imaging. For a given patient , the combination of these errors is ‘ frozen ’ into the image ,the treatment plan and treatment itself. For a given patient , therefore , this error is constant throughout treatment , and hence , is a systematic error for the patient. However , the size of systematic errors arising from the same source (for example , organ motion or set-up error at the time of imaging) will be different in different patients.

Deviations from the planned irradiation geometry during a treatment session may be systematic or random. Systematic errors occur if the mean irradiation geometry in the fractionated treatment differs from the geometry in the treatment plan. The mean deviations are then called systematic errors. Fraction-to-fraction variations around the mean deviation are called random errors. It should be noted that the source of systematic and random errors can be the same. For example, the patient set-up during acquisition of the planning CT scan may be considered as one sample from the distribution of day-to-day set-ups which will also cause random errors. However, as the geometry in the planning CT scan defines the reference geometry, the set-up at the couch of the CT-scanner will determine the systematic error.

The combination all of the positional uncertainties , transfer error ,organ motion and set-up error is then generally described adequately by a gaussian distribution. The standard deviation of the combined errors is then called $\sum$.

Random or treatment execution uncertainties introduced by organ motion and patient set-up errors are characterized by standard deviations which may be summed in quadature to yield a combined standard deviation , σ .

The effect of random and systematic errors on the dose is different. Random errors blur the dose distribution, where as systematic errors cause a shift of the cumulative dose distribution relative to the target.

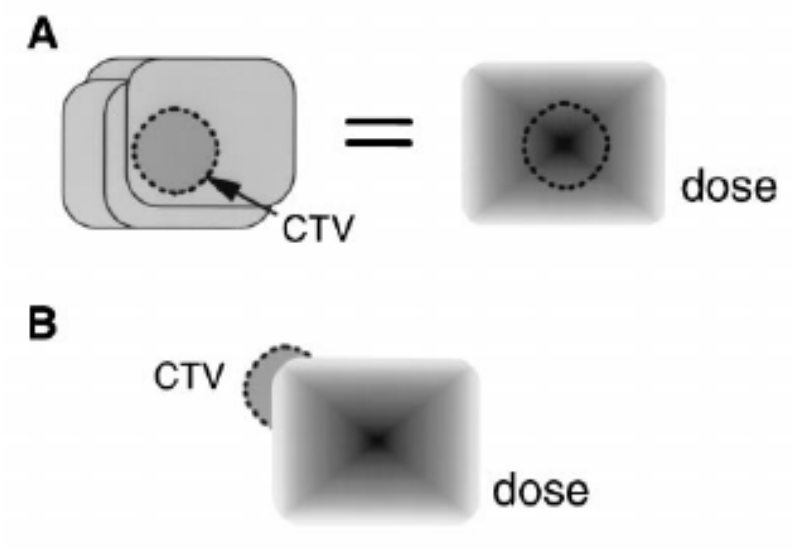

Figure 3.5 Schematic drawing of the impact of geometrical deviations on the dose distribution described in a coordinate system that is fixed relative to the CTV. (A) Treatment execution (random) deviations lead to blurring of the dose distribution. (B) Treatment preparation (systematic) deviations lead to a (unknown) shift of the cumulative dose distribution relative to the CTV (12).

3.6 Analysis of systematic and random set-up error (10)

For an individual patient, both the systematic and the random errors can only be fully assessed after completion of all treatment fractions .Set-up measurements with an

electronic portal imaging device in the first few fractions are sometimes used to estimate the systematic set-up errors, which are then used to drive an off-line correction protocol.

3.6.1 Individual **systematic errors ($\sum_{ind}$)** (4) was calculated as the average deviation of a particular reference structure between simulation and treatment.

$$\text{Individual systematic error} = \sum_{ind} = \frac{\sum_{i}^{N} \Delta i}{N} \qquad (3.1)$$

where N represents the total number of portal images acquired for a particular field

Δi is the calculated deviation for the i th treatment fraction.

3.6.2 Individual random errors (σ_{ind}) (4) was calculated as the standard deviation of the systematic error for a given anatomical feature about the average deviation.

$$\text{Individual random error} = \sigma_{ind} = \sqrt{\frac{\sum_{i}^{N} (\Delta_i - \Sigma)^2}{N-1}} \qquad (3.2)$$

where N represents the total number of portal images acquired for a particular field

Δi is the calculated deviation for the I th treatment fraction.

3.6.3 The population systematic error and the population random errors (4),(11),(12).

The data was calculated for the whole population. Using the individual systematic error and individual random errors to calculate the population systematic error and population random errors for the whole population.

The population systematic errors (Σpop) was calculate as a standard deviation (SD) of all individual systematic errors.

$$\text{The population systematic errors} = \quad \sum_{POP} = \sqrt{\frac{\sum_{i}^{N}\left(\Delta_i - \sum_{ind}\right)^2}{N-1}} \qquad (3.3)$$

where N represents the total number of the patients.

Δi is the calculated deviation for the i th individual systematic errors.

$\sum_{ind}$ is the individual systematic error

The population random errors (σ_{pop}) was calculate as quadratic average of all individual random errors.

$$\text{The population random errors} = \sigma_{POP} = \sqrt{\frac{\sum_{i}^{N}\sigma_{IND}^2}{N}} \qquad (3.4)$$

where N represents the total number of the patients.

σ_{ind} is the individual random error

3.6.4 Calculation of PTV margins

According to ICRU report 50 (6) and 62 (7) , the CTV to PTV margin should account for internal motion and variations in the size, shape, and position of the CTV (internal margin) and setup uncertainties (setup margin) in the patient's position relative to the beam.

Van Herk et al. (9) provided margin recipes for PTVs on the basis of systematic and random errors. In our radiotherapy department, we have chosen a margin such that a minimum of 95% of the prescribed dose covers the CTV for 90% of the patient population.

According to the margin recipe, the corresponding PTV margin could be calculated using the following formula:

$$\text{PTV margin} = 2.5\,\Sigma_{pop} + 0.7\,\sigma_{pop} \qquad (3.3)$$

($2.5\,\Sigma_{pop}$ is the 3D population base margin)

3.7 The Sources of errors and uncertainty. (4), (5),(8), (12)

The treatment accuracy and reproducibility can be thought in terms of selection of the appropriate PTV-to-CTV margin for a particular patient treatment site and set up technique. Local recurrence due to a marginal miss in a treatment plan means that the PTV-CTV margins may not have been adequate or appropriate chosen. To do this , it is necessary for the radiation oncology treatment planning team to study and understand the source of error and uncertainty that are contribute to treatment set up uncertainty include the following

3.7.1 Machine related uncertainties

3.7.1.1. **Mechanical uncertainties for all imaging and patient measurement systems**.

This includes not only the indicators and readouts with which modern radiotherapy simulator , CT scanners , and virtual simulators come equipped but also external contouring devices, patient calipers , and so on. Other characteristics ,such as the difference in how the couch tops flex between the simulator and accelerator, may be considered

3.7.1.2. **Mechanical indicator and readout uncertainties**.

These include alignment of positioning laser and optical crosshairs, light and radiation field congruence, ODI accuracy, digital readouts of gantry angle, collimator angle and field size accuracy , and so on. Also included in this group are such things as the width of the laser lines and quality of the visible field light, which can lead to inconsistent interpretations.

3.7.1.3. Mechanical uncertainties in the medical accelerator.

These include, isocenter tolerance with gantry or collimator rotation ,misalignment of treatment couch movements , and slack in block tray or couch top positioning.

3.7.2. Patient related uncertainties

3.7.2.1. **Patient repositioning uncertainties from treatment to treatment.** This depends on the anatomy site , patient ' s weight and medical condition , stability of fiducial skin marks , patient cooperation and memory of setup , stability of the treatment position for the individual patient (supine, prone and so on) , training and skill of the radiation therapy technologist (RTT) , use of ancillary devices such as foam wedges , head cups, and castes ,and the clarity and completeness of the setup description in the patient ' s radiotherapy chart.

3.7.2.2. **Patient movement during treatment**.

This includes the extent and likelihood of patient motion caused by lack of cooperation , muscle contractions , discomfort in the treatment position, and its likely effect on the position of the CTV and other organs.

3.7.2.3 Intratreatment organ motion uncertainties during a treatment.

This is the extent to which patient respiration , heartbeat ,and peristalsis affect CTV position which respect to the patient coordination system and surrounding organ. The physical and mental state of the patient position also influence the set-up accuracy. In the pelvis organ the movement of the skin marks used for patient positioning relative to the pelvic bones, result in a set-up errors. The skin movement might be due to respiration, weight loss or relaxation of the patient.

3.7.2.4 Intertreatment organ motion uncertainties.

This includes the extent and likelihood that the CTV will change its position with respect to both the patient coordinating system and the surrounding organs because of such things of weight gain or loss, tumor shrinkage or growth , bladder and rectum filling , and so on. These data can typically be acquired only through class studies and can be applied only in statistical manner. Such

studies are usually based upon sequential CT data taken on several day during a course of treatment for a subpopulation of patients.

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3.8 Treatment verification

In radiation therapy treatment verification , the patient treatment position is measured by making a megavoltage film (Port film) or electronic portal imaging of the same field at the treatment unit .

3.8.1 Film imaging (13)

Port film (Therapy verification films) such as cassette film combination eg. The Kodak EC system (Figure 3.7) uses a 1 mm thick copper front screen to produce electrons that then interact with a gadolinium oxysulphide intensifying screen to produce light, which exposes the film. For localization port films there is the EC-L system .

Figure 3.6 Cross-section representation of the Kodak EC-L portal imaging devices (13).

Although the port films are commonly used and widely available , it's quality of the images are usually fair poor and it's time consuming and labor intensive procedure.

3.8.2 Electronic portal imaging devices (EPIDs) (14).

The technology of megavoltage imaging , electronic portal imaging have become widely used procedure in radiotherapy for treatment verification in new radiotherapy facilities.

EPIDs have many advantages over X-ray film (Port film) . The images obtained immediately available for adjust patient or field position during radiotherapy. It 's convenient with the equipment already attach to the treatment machine , the time use for EPIDs are less than conventional port film. The image quality depends on the detectors.

Many different EPIDs have been examined since the early 1980s as alternatives to film for megavoltage imaging. The following discussion on EPIDs will concentrate on features of the matrix ion chamber and the camera-based EPIDs, which are both available commercially. Promising new systems based on active matrix flat panel imaging .(AMFPI.) The new version of EPIDs using amorphous silicon detectors have produced good imaging quality with minimum dose required.

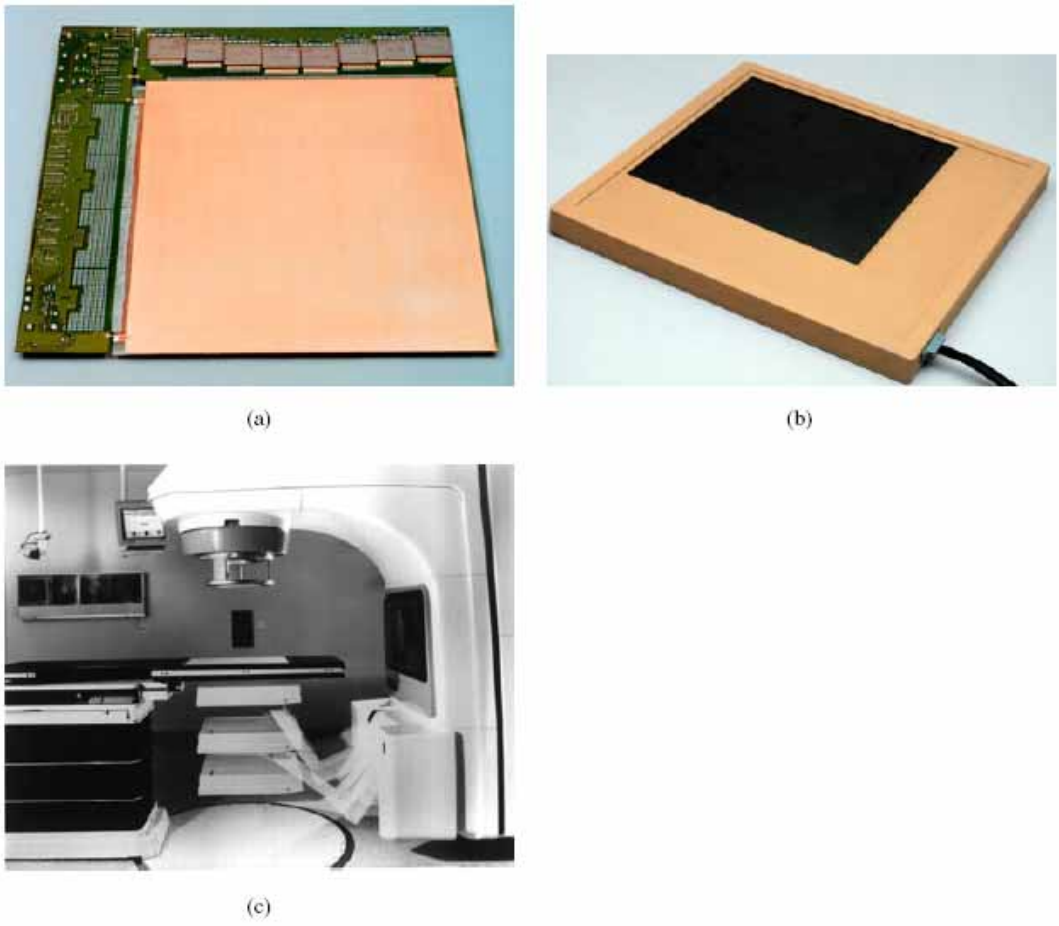


Figure 3.7 Photos of the matrix ionization chamber EPID design. (a)View of inferior components. (b) Early packaging of system in a flm-cassette-like housing.

(c) Varian system mounted on a treatment gantry with the detector housing shown (by means of a multiple – exposure) in three imaging positions (14).

3.8.2.1 **General description of Active matrix , flat-panel imagers (AMFPIs)**

Active matrix , flat-panel imagers (AMFPIs) may be considered to consist of the following subsystems: (a) a large area, pixelated array ; (b) an overlying x-ray converter ; (c) an electronic acquisition system which controls the operation of the array and extracts and processes analog signals from the array pixels and (d) a host computer and information system which sends commands to, and receives digital pixel data from the acquisition system as well as processes , displays, and archives the resulting digital images.

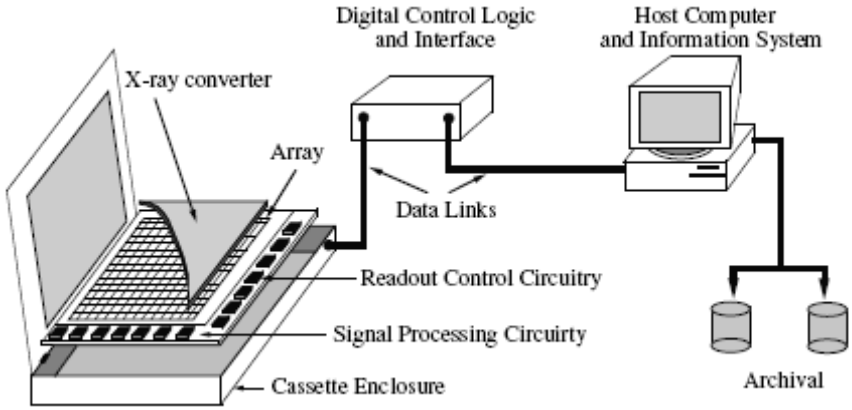


Figure 3.8 Schematic illustration of the elements of an active matrix , flat-panel imager (AMFPI) (14).

3.8.2.1.1 **The Amorphous silicon flat panel imaging devices**

Active matrix flat panel imagers (AMFPIs) based on hydrogenated amorphous silicon (a-Si:H) photodiodes and thin film transistors (TFTs) are a major area of current research . Portal imaging devices based on this technology are starting to become commercially available (Figure 3.10).

	Electa		Siemens	Varian		InfiMed	Eliav	BioScan
	SRI100[a]	iViewGT	BeamView	PortalVision	PortalVision aS500	Theraview	PORTpro	IRIS[b]
Type of detector	Camera	a-Si	Camera	Liquid ion chamber array	a-Si	Camera	Camera	a-Si
Linac mounted	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Detector size (cm^2)	30×38	41×41	35×44	32.5×32.5	40×30	40×40	43×32	10×10 20×20 41×41

Linac, linear accelerator; a-Si, amorphous silicon.
[a]The Electa SRI100 system is soon to be superseded by a camera-based version of iView.
[b]The IRIS system is a prototype.

Figure 3.9 Commercial available electronic portal imaging devices (13).

There are several possible designs but the one with the most development uses a front metal sheet, usually 1 mm copper, with a gadolinium oxysulphide phosphor to convert X-rays to light(Figure 3.10). Other studies of metal plate/phosphor thickness indicate that 1 mm tungsten or 1.5 mm steel bonded to 1 mm thick phosphor seems to produce a good compromise in imaging efficiency . The light is detected using an array of a-Si:H photodiodes controlled by a-Si:H TFT . The photodiodes are electronically read and form the pixels of the image.

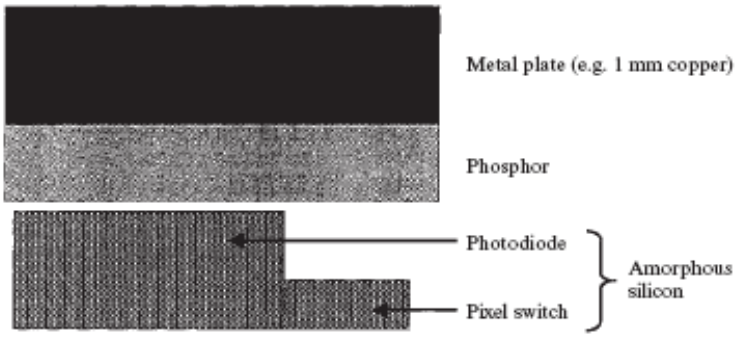


Figure 3.10 Cross-section representation of an amorphous silicon electronic portal imaging device. The illustration shows only one pixel.(13).

3.9 Clinical application of EPIDs (15)

The primary application of EPID includes verification of patient setup and assessment of target and organ motion.Current research includes uses of

EPIDs for compensator design and verification , treatment QA, and patient dosimetry.

3.9.1 Software tools

The complexity of EPID software has evolved over the past decade in response to improved understanding of clinical applications as well as flexibility of acquisition modes for new EPID technology.

3.9.1.1 Image acquisition

A typical portal imaging system will have a user interface that allows selection of different image acquisition modes. Although the range of operating modes may vary, the following are commonly available on commercial EPIDs:

a. Single exposure (localization). In this mode of acquisition, a single image is acquired for a short period of time (typically at the start of the treatment) . The duration of the exposure can either be controlled by a fixed time criterion or by the time that the beam is on.

b. Verification image. Verification images can either be an average of multiple images acquired during a period of treatment, or single images acquired over a longer period of time (higher dose)than the localization images mentioned previously.

c. Double exposure. This mode of operation is similar to that of weekly portal film acquisition. One image is the single exposure image, and the second is an ‘‘open field’’ image. Again, control of each image acquisition may be via fixed time intervals or by the duration of the beam. Typically, the open field and portal images are combined using a weighted sum to produce a single image. A field outline from the portal can also be automatically extracted and overlaid on the open field image.

d. Movie loops. The digital nature of the EPID allows movie loops or on-line fluoroscopy to be acquired during treatment. In some cases, all of the images mentioned previously are generated by summation of one or more images acquired in a loop.

Related literatures

Many authors studied the setup errors in pelvis radiation therapy, patient specific factors and immobilization.

Factor influence the match anatomy software result

To find systematic and random error of the patient , we need to match the planned image (from simulation film or DRR) with port film or EPID. Matching errors would affect the data to calculate for systematic and random errors.

1. Anatomic landmarks for pelvic anatomy matching

Kneebone A et al (2) evaluated the isocenter deviation measuring distance to anatomy landmark used port film. In Superior –Inferior (S-I) direction , **superior pubic sympysis** to inferior field margin was used . In Left- Right (L-R) direction , **Right lat pelvic** wall to right field margin was used **.** In Anterior-Posterior (A-P) direction , **anterior pubic sympysis** to anterior field margin was used.

Haslam JJ et al (16) evaluated the set up errors in IMRT whole pelvic radiation therapy for gynecological malignancies , anatomical landmarks for matching anatomy were **pubic rim ,pubic crest, and obturator foramen** in **AP pelvic** and **sacrum , greater sciatic notch and pubic crest in Lat pelvic**.

Berthelet E et al (17)selected anatomical landmarks for matching anatomy in AP image the structures were **superior and inferior pubic rami , pubic symphysis and obturator foramen**. On the lateral image , the structures were **pubic symphysis , femoral head and acetabulum.**

Bentel GC et al (18) studied the use of hemibody foam casts compared to no fixation in prostate irradiation. To evaluate isocenter shift (>5mm) on each weekly **port film**, the physician **noted the location of the treatment field** and its **isocenter** (**relative to bony landmarks**) and compared this to the simulator film.

Kruse JJ et al (19) rated the clarity of anatomic landmarks in pelvic EPI and portal film. In AP pelvis, the anatomic landmarks were **pubic arch , pelvic brim , symphysis , ischial tuberosities and obturator**. In Lat pelvic, the anatomic landmarks were **sacrum , coccyx , symphysis and femoral head.**

Lewis DG et al (20) studied about the observers variability on anatomy matching in pelvic irradiation. The observers **outlined their own choice of appropriate bony landmarks (e.g.pelvic rim, femoral head)** on the digital simulator image (reference image). And they found a high level of inter-observer and inra-observer consistency .

Nutting CM et al (21) studied the field placement accuracy in the immobilization group and conventional treatment group, simulation time, RTT convenience and patient acceptability. Bony landmarks from the EPI were matched to the simulation image and checked by RTTs. Any displacement of the treatment field center from the isocenter of the simulation image was displayed for each axis. The mean field displacement was calculated for anterior fields in craniocaudal , left – right , and rotation axes and for lateral fields in the antero-posterior , craniocaudal , and rotation axes .The total isocentre displacement for each field was derived geometrically.

2. The Inter-observer variabilities.

Barthelet E et al (17) reported the inter-observer consistency among trained RTTs in anatomy landmark matching for the field placement errors evaluation using EPID in 20 prostate cancer patients.

The inter-observer variation expressed as the standard deviation of the six observers' measurements within each image were 0.7, 1.0, 1.7 and 1.4 mm for AP image (L-R) direction , AP image(S-I) direction , Lat image (A-P) direction and Lat image (S-I) direction , respectively. Variance components analysis showed that the variation attributed to the observers was small compared to variation due to the images.

Lewis DG et al (20) performed a study to evaluate inter-observer variability when assessing patient movement using EPID. Their study has shown that their trained RTTs are able performed the task of portal images assessment with a high degree of consistency with radiation oncologist in matching the anatomy landmark in four pelvis patients using EPID to evaluate field placement errors.

3. Immobilization and patient position

Kneebone A et al (2) assessed the use of rigid immobilization devices for pelvic irradiation in prostate and bladder cancer patients using prone position ,with and without rigid immobilization (**Customized Uvax cast of the pelvis ,ankle-and shoulder-stabilizing device**).They found that the immobilization improves the accuracy of treatment delivery for the prone position.

Haslam JJ. et al (16) evaluated the set up errors in intensity-modulated whole pelvic radiation therapy (IM-WPRT)**. All patient used two customized alpha cradles** in supine position .**The upper alpha cradle was used to immobilize the arms and upper body. The lower alpha cradle was placed under the lower legs and feet.** They found the largest errors was in the AP direction.

Bentel GC. et al (18) studied the use of **hemibody foam casts** from the midchest to below the bottom of the feet (with a knee support) in supine position , compared to no fixation in prostate irradiation. They found the small improved reproducibility in A-P direction.

Nutting CM. et al (21) studied the total isocentre displacement comparing conventional treatment group, supine position with foam head pad and the ankles immobilization , with the immobilization group which patient was placed on a Vac-fix supported the pelvis from the iliac crest to the upper thigh. A foam head pad and ankle stocks were used .The result demonstrated that treatment accuracy was not improve compare to the conventional group. The patient set-up was more difficult in immobilization and also the simulation and treatment time was longer.

4. Set-up errors

Hurkmans CW et al (1) reported that the **population-based systematic and random errors** (the SD of systematic and random errors) in pelvis ranged from **1.1- 4.7** and **1.1-4.9** mm, respectively.

Kneebone A et al (2) evaluated the use of immobilization for pelvic irradiation in prostate and bladder cancer patient in prone position.

They found that the average simulation to treatment isocenter deviation was 8.5

mm in control group and 6.2 mm in immobilization group (p <0.001).

Haslam JJ et al (16) found that the set up errors in **the population systematic and random errors** in 46 patients whole pelvic IMRT ranged from **1.9 to 2.6** and **2.6 to 3.7** mm, respectively .The largest errors was in the AP direction. No correlation between these errors and patient specific factors (age, weight, height).

Bentel GC et al (18) studied the use of **hemibody foam casts** in supine position , **compare to no fixation** in prostate irradiation. They found the small improvement of reproducibility in A-P direction , statistical significant in **isocenter shift (>5mm) was 5.1% vs 12.6 % (p<0.05)**

Nutting CM et al (21) studied the total isocentre displacement compare between conventional treatment group (CTP) and immobilization group (IMS) . Mean isocenter displacement for AP field was 1.7 and 2.0 mm in CTP group and IMS group, respectively (p = 0.07).

The isocenter displacement for Lt lat field were 1.8 and 1.8 mm in CTP group and IMS group (p= 0.98) and for Rt lat field was 2.1 and 1.7 mm (p = 0.06), respectively. The treatment accuracy was not improved.

Mitine C et al (22) determined the distribution of set up errors for patients treated with and without two rigid partial immobilization for pelvic malignancies. They found that an alpha- cradle or orfit - cast immobilization devices improve the reproducibility for pelvic field but there is a small benefit comparative to the cost and the cumbersome place of the device.

CHAPTER IV
MATERIALS AND METHODS

4.1 Materials

4.1.1 CT-Simulation Marconi PQS

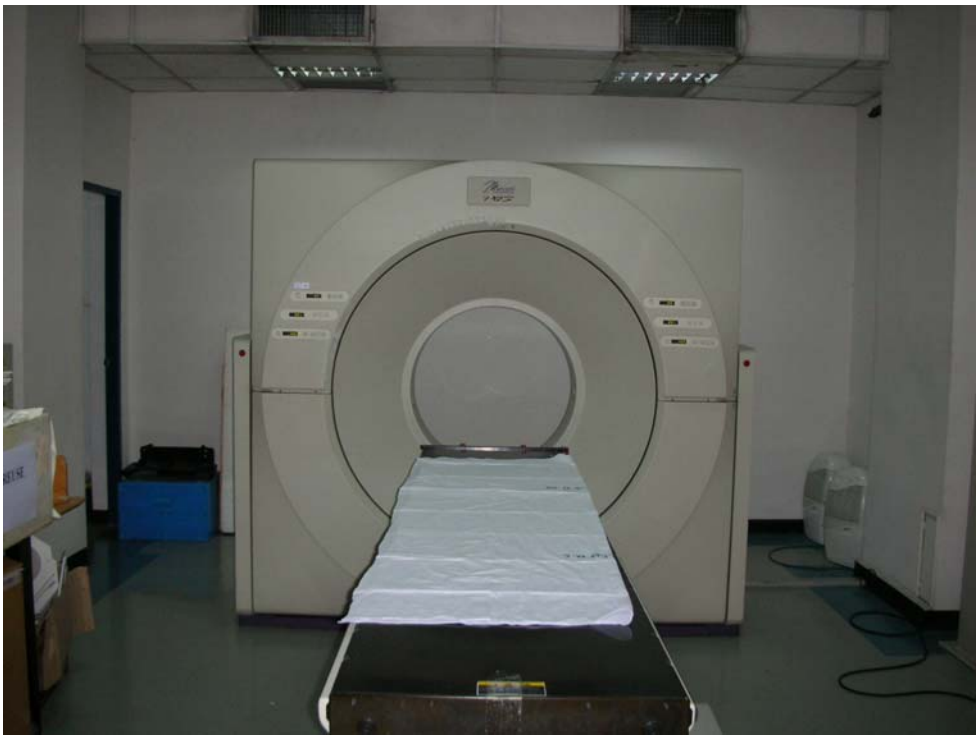


Figure 4.1 CT-Simulation Marconi PQS

The Marconi Medical Systems PQS CT system (Marconi Medical systems, USA) is a fourth – generation CT system, the major components of CT sim are : (1) a CT scanner and couch , (2) a CT computer console (3) one or more net work 3-D image and virtual simulation workstations.(4) a laser marking system , and a (5) laser hardcopy device.

CT simulator is a standard diagnostic CT scanner with an additional laser alignment system and additional software that provides beam edge display, 3-D image reconstructions, and high - quality digitally reconstructions reconstructed radiographs (DRRs).

The physical aperture diameter is 700 mm. The full size FOV is 480 mm. The coordinate systems are selected such that their origins are the isocenter of the CT scanner. The X axis is in the horizontal direction, the Z axis is in the longitudinal direction, and the Y axis is in vertical direction for all four coordinate systems. There are multimodality registration and localization package, digitally composited radiograph (DCR) and RTP network.

4.1.2 The Varian Ximatron C-Series

Figure 4.2 The Varian Ximatron C-Series

The Varian Ximatron C-Series (Varian Oncology Systems, Palo Alto, CA, USA.) (figure 4.2): The Ximatron simulator takes low-dose X-ray images of

patient anatomy for tumor and normal tissue localization . It supports a fully-electronic, film less clinic by producing high-resolution, large, merged images. It integrated with the record and verify system; Varis Vision 6.

4.1.3 Linear accelerator Clinac 23 Ex

Figure 4.3 Linear accelerator Clinac 23 Ex

The Varian Clinac 23 Ex linear accelerator (Varian Oncology Systems, Palo Alto, CA,USA.) (figure 4.3); The linear accelerator can produce dual energy 6 MV and 10 MV x-ray, and six electron energies of 6, 9, 12, 15, 18 and 22 MeV.

The photon field sizes range from 0.3×0.3 cm^2 to 40×40 cm^2 at the isocenter and 4×4 cm^2 to 25×25 cm^2 for electron field sizes. The distance between target to isocenter is 100 cm and the distance from the target to tray is 65.4 cm. There are six stationary therapy dose rates range from 80-400 monitor units per minute.

The MLC leaves are mounted below the conventional collimator, the number of MLC leaves is 120 tungsten leaves.

4.1.4 Amorphouse Silicon EPIDs Portal Vision aS 500

Figure 4.4 Amorphouse Silicon EPIDs Portal Vision aS 500

The Amorphous Silicon EPIDs Portal Vision aS 500 manufacture by Varian Oncology Systems, Palo Alto, CA ,USA (figure 4.4) is a Flat panel photo- diode array. The EPIDs aS 500 is mounted in the Clinac 23 Ex. with dynamic MLC (120 leaves).

The EPIDs system includes

1. an image detection unit (IDU), featuring the detector and accessory electronics
2. an image acquisition unit (IAS2) , containing drive and acquisition electronics and interfacing hardware ,and

3. a dedicated work station (Portal Vision PC) located outside the treatment room.

The IDU is essentially a matrix of 512 x 384 pixels with a resolution of 0.784 x 0.784 mm^2 and a total area of 40 x30 cm^2. Each pixel consists of a light sensitive photodiode and a thin film transistor to enable readout. The electric charge generated by the incident photons is accumulated in the photodiode until the signal is read out and digitized through an analogue to digital (A/D) converter .Overlying the array is a scintillating layer (gadolinium oxysulphide) and a copper metal plate (of ~ 1 mm thickness) , making the portal imager and indirect detection system.

The phosphor scintillator converts incident radiation into optical photon , enhancing the sensitivity of the detector more than tenfold when compared to direct detection system. The total water – equivalent thickness of the construction materials in front of the photodiodes is 8 mm,as specifies by manufacturer .The IAS2 control and reads the IDU .Its local hard disk contains the correction images (i.e. the dark and flood field field acquisition) and the various acquisition parameter set.

4.1.5 Varis Vision 6 Match anatomy software

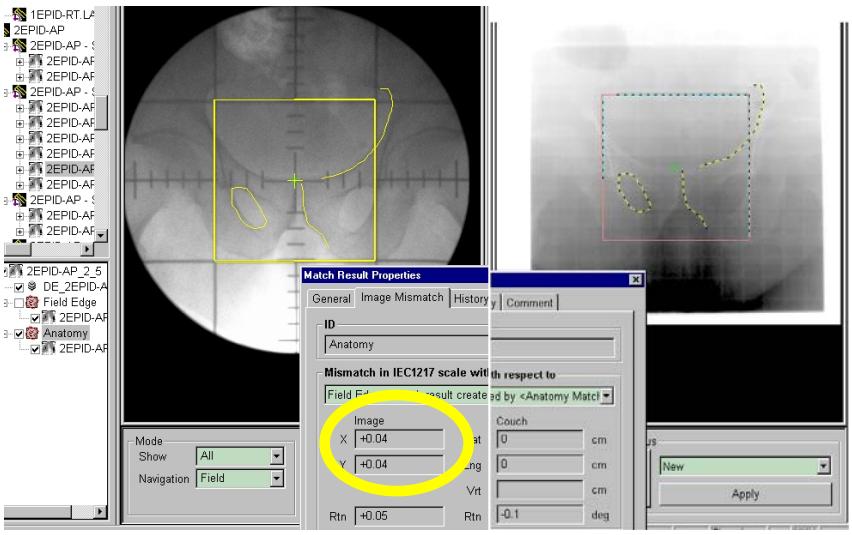


Figure 4.5 Varis Vision 6 Match anatomy software

Varis Vision 6 Match anatomy software (Varian Oncology Systems, Palo Alto, CA, USA.) is the part of portal vision for treatment verification .

The program was used to compare simulation images or digitally reconstructed radiographs (reference image) and electronic portal imaging (treatment images) and measure the field placement errors(set up error) in the treatment fields.

At least three anatomy landmarks were identified and outlined on the reference images. This software uses anatomy matching in reference image and superimpose on the electronic portal images (treatment images). The match anatomy result is shown on the displacement in x and y direction .

4.1.5.1 The reference coordinate system

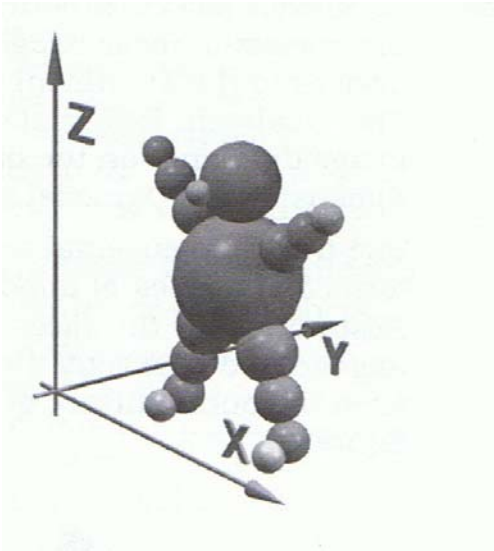


Figure 4.6 The reference coordinate system.

Three dimensional modeling in the treatment prescription task is base on the patient coordinate system.

The X axis is the shoulder – shoulder axis . (Lt –Rt direction)

The Y axis is the front - back axis. (AP- PA direction)

The Z axis is the feet - head axis. (Sup – Inf direction)

4.1.6 Pelvic Laser and Vacuum-lock for Positioning and Immobilization

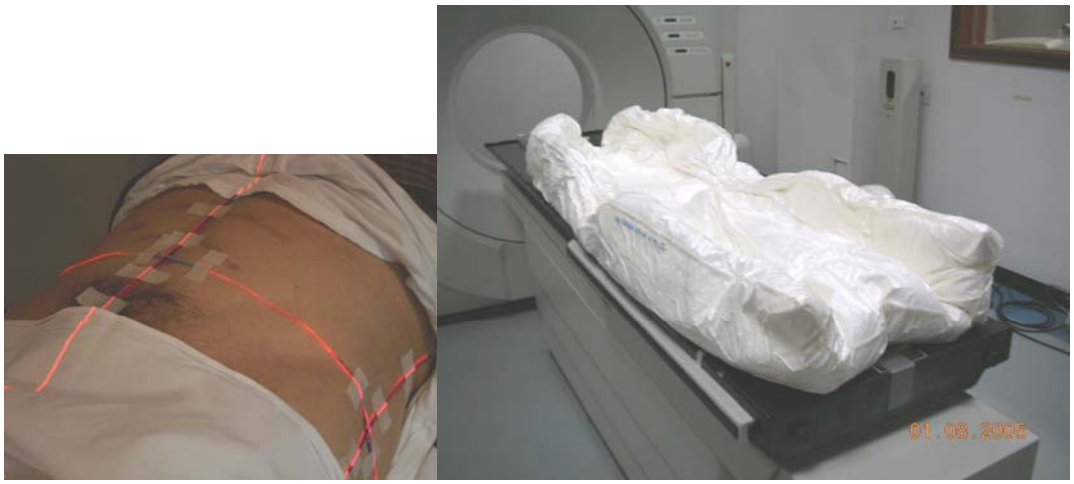


Figure 4.7 (Left) Pelvic laser for setting the position. (Right) Long Vacuum -lock for pelvic immobilization.

Three-point laser set marks were tattooed on the patient 's skin surface at the treatment isocenter, normally base on an anterior and two lateral reference points.

Vacuum -lock (Figure 4.7 right) is a mold immobilization system consists of a urethane bag filled with small polystyrene beads and a vacuum pump. The patient is placed on top of the bag and while semi-deflated, the bag is held close to the patient ‘s body. The air is evacuated by a vacuum compressor connected via a valve in the bag . When the air is fully removed, the mold becomes rigid. The rigid mold will help the radiation technologists to set up the patient position according to the mold. The Vacuum-lock can hold its shape for up to 6 weeks (8).

Vacuum-lock can be re-used for many patients. When air enters the bag, the mold loses its shape and can be re-made. The vacuum-lock has many sizes, for pelvic treatment, there are short (half body) and long (full body) vacuum-lock to be selected for the positioning and immobilization.

4.2 Methods

This study was a retrospective study performed on all of the patients treated with Intensity Modulated Radiotherapy (IMRT) or Three Dimensional Conformal Radiotherapy (3D-CRT) for pelvic area during January, 2005 to October , 2006 at the Division of Radiation Oncology, Department of Radiology, Faculty of medicine Siriraj Hospital.

Research study design : Retrospective study design.

Patient selection:

The inclusion criteria for this study:

1. The patients treated with IMRT or 3D-CRT for pelvic area.
2. The patients treated in supine position.
3. The patients have electronic portal images (EPID) of at least two images.

The exclusion criteria for this study:

1. The patients who have electronic portal images only in AP Pelvic or Lat Pelvic but not both for the same treatment fraction.
2. The electronic portal images do not cover the whole pelvic cavity.

Steps of data collection

As mentioned in the objectives of the studied in chapter 2, there were 3 main objectives for this studied, each objective will required the separate data collection. The method for this study, hence consisted of three main steps.

Step 1 was to determine the appropriate method to match anatomy: to find bony landmarks for matching anatomy in AP and Lat pelvic images, and to determine reliability of personnel doing the match anatomy.

In match anatomy software, three or more anatomy landmarks are required for match anatomy. In routine practice the match anatomy landmarks drawn by

RTTs usually use only 3 landmarks and each RTTs use difference landmarks. This step aims to find which and how many bony anatomy landmarks are required for reliable anatomy matching. Also for the personnel doing the anatomy matching, whether there are variations among different professionals or different individual personal.

Step 2: Aim to find the individual set up errors , individual systematic and random errors , the population systematic and random errors. Then for the whole patient data , the calculation of the adequate CTV- to- PTV margins from the equation : PTV margin = $2.5\ \Sigma pop + 0.7\ \sigma pop$.

Step 3: Study the patient set up error factors : age (<70 ,≥70) , sex (male or female) , weight (<65kg , ≥65kg) and immobilization (Vacuum lock , No Vacuum lock)

Step 1 method:

1.1 Selection of the bony landmarks for anatomical matching:

- **Find the 5 anatomy landmarks for anatomy matching which selected by radiation therapy technologists (RTT).**

  To find the 5 anatomy landmarks which are commonly used by RTT in Siriraj hospital for Varis Vision match anatomy software to find the field placement errors in both AP and Lat pelvic, the Questionnaire were sent to 12 trained radiation therapy technologists (RTTs) who have experience for using match anatomy software. (Appendix A)

  The Questionnaire consisted of pelvic simulation images and electronic portal images. Each RTT selected 3 bony landmarks for used in match anatomy in pelvic.

  The questionnaires were analyzed and collected the 5 bony landmarks most commonly selected by the RTTs.

- **Find 3 anatomy landmarks which have minimum variation for matching anatomy from 5 anatomy landmarks.**

- 3 RTTs and 1 radiation oncologist match anatomy in 5 prostate patients treated with IMRT.

- For finding the set up errors in each patient , the most convenient methods to monitor treatment accuracy and find set up errors are using automatic match anatomy software compare simulation images (reference image) and electronic portal imaging (treatment images). We used Varis Vision match anatomy software compare simulation image and EPI on the first day of treatment.

- The contour were drawn in the simulation images on selected 5 anatomy landmarks in AP and Lat pelvic images. The matching was done and then we recorded the field placement errors.

- Then 5 anatomy landmarks matching results was used as the reference to compare with 10 groups of 3 anatomy landmarks matching in AP and Lat pelvic images (as shown in chapter 5 table 5.1 and 5.2)

- Matched anatomy in the same images, but draw the anatomy landmarks on 3 anatomy landmarks for each group (10 groups).

- Calculated the difference match anatomy result of 5 anatomy landmarks and 3 anatomy landmarks (5 anatomy landmarks - 3 anatomy landmarks) to find the 3 anatomical landmarks that get closest results to the reference with 5 anatomical landmarks.

- Used 95% Wilcoxon signed-rank test to compare the match results.

- Selected the type of 3 anatomy landmarks which closely match anatomy result from 5 anatomy landmarks to be the anatomy drawn in step 2.

1.2 **The Inter-observer variabilities**

The factor which influencing the match anatomy software result are the difference in anatomy landmark for match anatomy and the inter-observer variability on the visual images. This step studied inter-observer consistency between 3 trained RTTs and 1 radiation oncologist in the registration and verification of external beam radiotherapy using match anatomy software.

- Repeat step 1.1 matching by 3 trained RTTs and 1 radiation.
- Studied the intra class correlation of match anatomy result on 5 anatomy landmarks between 3 trained RTTs and 1 radiation oncologist match anatomy in AP and Lat pelvic images.
- Analyzed with Reliability Analysis.

Step 2 method: set-up error analysis and CTV-PTV margin calculation.

In step 2, we aimed to find the individual set up errors calculate individual systematic and random errors, the population systematic and random errors from matching result, then used the population error to calculate CTV-to-PTV margins.

2.1 Finding set-up error in each patient with pelvic radiation therapy

To find the set-up errors from the patients treated with IMRT or 3D-CRT pelvic radiation therapy during Jan, 2005 to October , 2006 at the Division of Radiation Oncology, Department of Radiology, Faculty of medicine Siriraj Hospital.

- Anatomy matching and EPI acquisition

  Using Varis Vision 6 match anatomy 3 bony landmarks compare simulation images (reference image) and electronic portal imaging (treatment images) in AP and Lat pelvic.

  The normal policy of treatment in Siriraj, the patient would get weekly electronic portal images (anterior and lateral) acquired for IMRT treatment and two weekly for 3D-CRT treatment.

  All patients had orthogonal electronic portal images which use double exposure technique. Electronic portal images were taken before treatment sessions began.

  1. Took a planned field images.(treatment field)
  2. Then superimposed double exposure by opened field. (whole pelvic field)

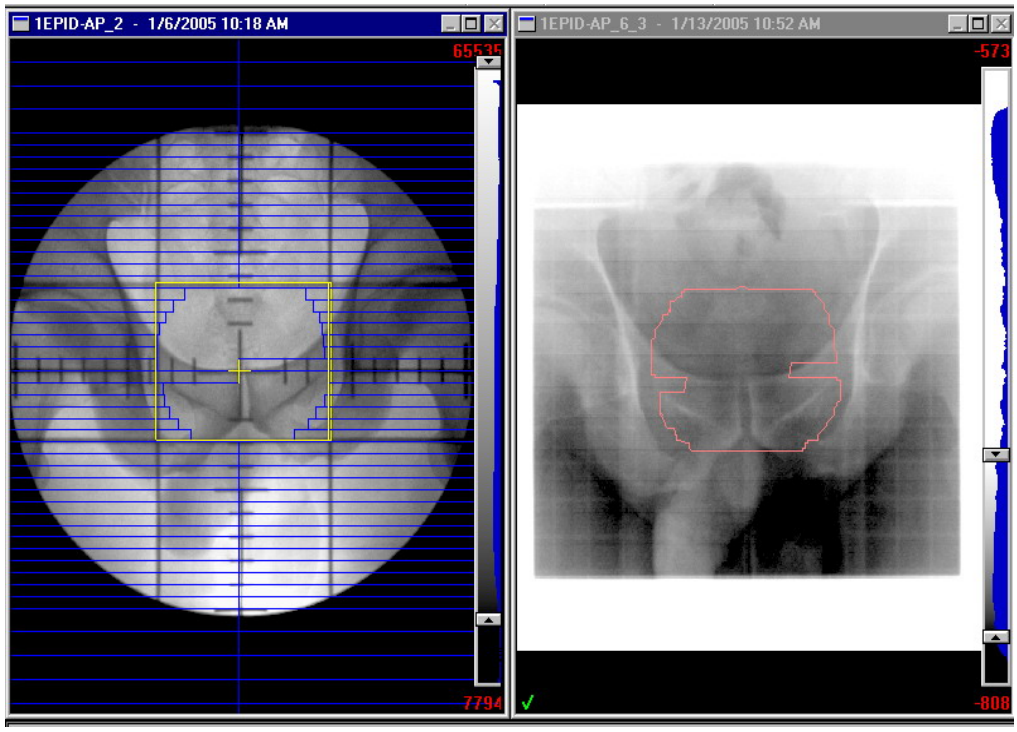


Figure 4.8 Double exposure technique.

-Recorded the set up errors:

The set-up errors in L – R direction (X) and in S – I direction (Z) were measured on AP pelvis images. The set-up errors in A – P direction (Y) was measured on Lat pelvis images (Figure 4.9, 4.10) and the matching results were collected (Appendix B).

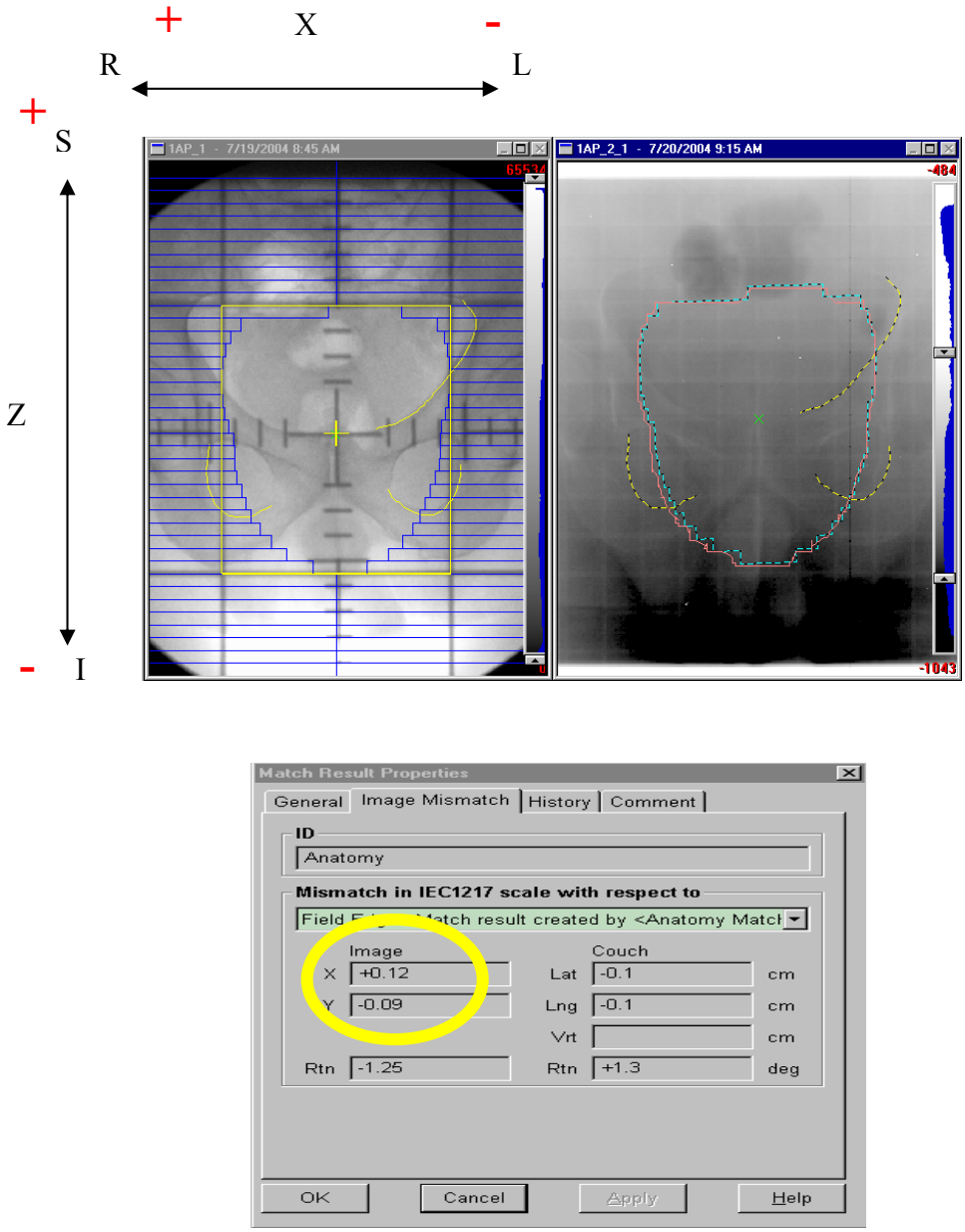
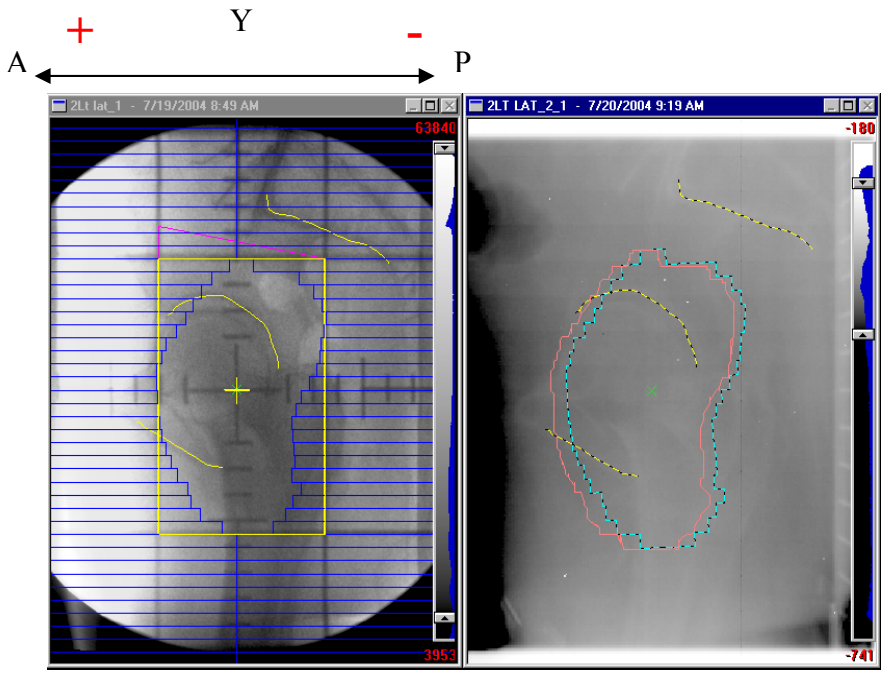


Figure 4.9 The displacement of isocenter in L – R direction (X) and in S – I direction (Z) were measured on the AP Pelvis images.



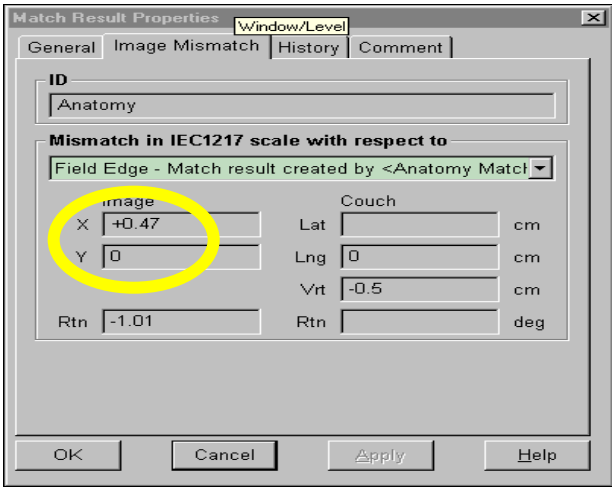


Figure 4.10 The displacement of isocenter in A – P direction (Y) were measured on the Lat pelvis images.

2.2 Calculate the individual systematic errors and individual random errors.

Using the set up error from step 2.1, we calculated individual systematic error and individual random errors in all patients treated with IMRT or 3DCRT pelvic radiation therapy in the study using the equation (4,5) :

Individual systematic errors ($\sum_{ind}$) was calculated as the average deviation of a particular reference structure between simulation and treatment.

$$\text{Individual systematic error} = \sum_{ind} = \frac{\sum_{i}^{N} \Delta i}{N} \qquad (4.1)$$

where N represents the total number of portal images
acquired for a particular field
Δi is the calculated deviation for the i th treatment fraction.

Individual random errors (σ_{ind}) was calculated as the standard deviation of the systematic error for a given anatomical feature about the average deviation.

$$\text{Individual random error} = \sigma_{ind} = \sqrt{\frac{\sum_{i}^{N} (\Delta_i - \Sigma)^2}{N-1}} \qquad (4.2)$$

where N represents the total number of portal images
acquired for a particular field
Δi is the calculated deviation for the I th treatment fraction.

2.3 Calculate the population systematic error and the population random errors:

Using the individual systematic error and individual random errors from step 2.2 to calculate the population systematic error and population random errors for the whole population. (4)

The population systematic errors (Σ_{pop}) was calculated as a standard deviation of all individual systematic errors.

The population random errors (σ_{pop}) was calculated as quadratic average of all individual random errors.

2.4 Calculate population-base margin for pelvis radiation therapy in x, y and z direction

Using the population systematic error (Σ_{pop}) and the population random errors (σ_{pop}) from the whole patients in step 2.3 to calculate the adequate CTV to PTV margins from the equation (8).

$$\text{PTV margin} = 2.5\,\Sigma_{pop} + 0.7\,\sigma_{pop} \qquad (4.3)$$

According to the reference (8), this formula will results to CTV to PTV margin that cover the CTV for 90% of the patients within the 95 % isodose surface**.**

Step 3 method: Study the factors influenced patient set up error

From all of the patients in the study, patients' characteristic were studied to find the factors that might relate to the set up errors. Patients' characteristics that we studied were age(<70, ≥70), sex (male, female), weight (<65 kg , ≥65kg) and immobilization technique (Vacuum-lock, No Vacuum-lock). We analyzed set-up errors for each characteristic by using 95% independent sample T-Test and 95% Factorial ANOVA test.

CHAPTER V

RESULTS

5.1 Step 1 . Selection of the bony landmarks for anatomy matching in AP and Lat pelvis images.

5.1.1 Five anatomy landmarks mostly selected by RTTs.

The five anatomy landmarks mostly selected by twelve RTTs in AP Pelvis were 1. Pubic symphysis

2. Lt pelvic brim
3. Rt pelvic brim
4. Lt obturator foramen
5. Rt obturator foramen.

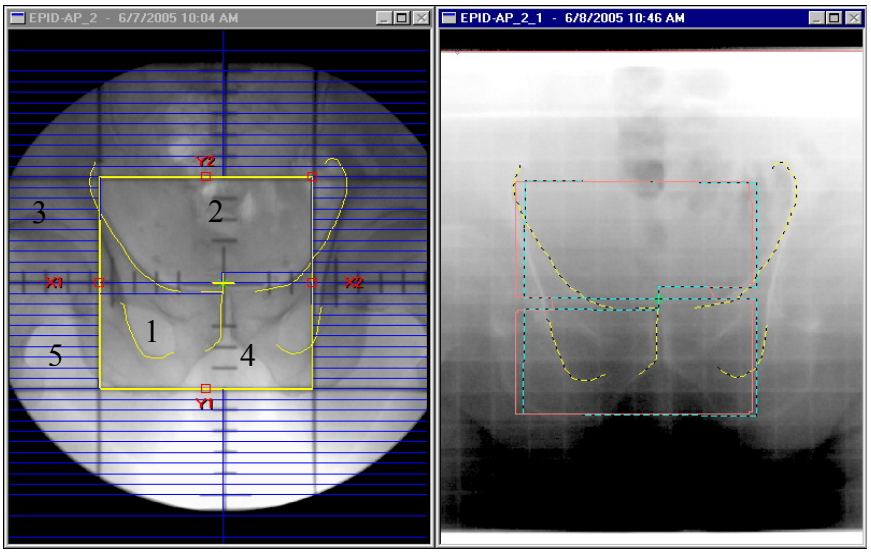


Figure 5.1 The five anatomy landmarks mostly selected by twelve RTTs In AP Pelvis. The contours were drawn on the Pubic symphysis , Lt pubic brim , Rt pelvic brim, Lt obturator foramen and Rt obturator foramen.

The five anatomy landmarks mostly selected by twelve RTTs In Lat Pelvis were 1.Acetabulum

2.Anterior femur

3.Pubic symphysis

4.Posterior femur

5.Sacrum

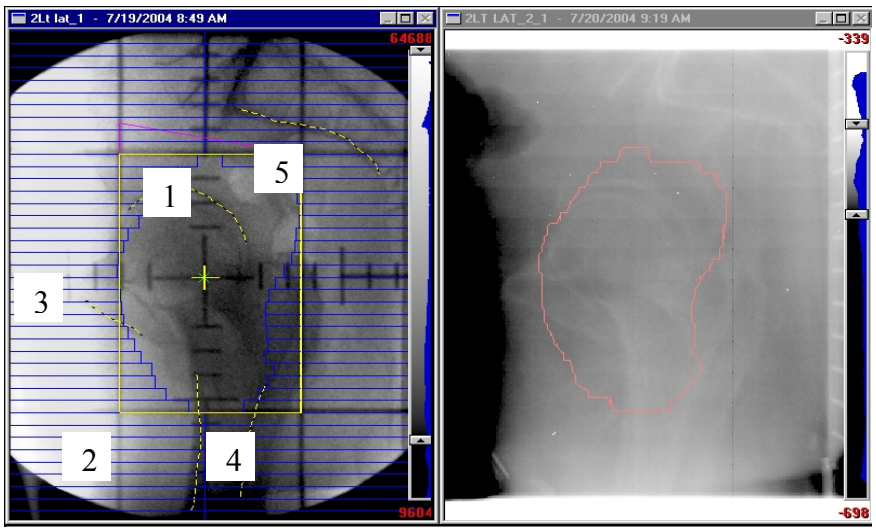


Figure 5.2 The five anatomy landmarks mostly selected by twelve RTTs In Lat Pelvis. The contours were drawn on the acetabulum , anterior femur , pubic symphysis , posterior femur and sacrum.

From 5 anatomy landmarks, we mixed 3 of the 5 anatomical landmarks in each group that resulted in 10 groups of various 3 anatomy landmarks. Then we had total 11 types of anatomical landmarks as shown in table 5.1 for AP images and table 5.2 for lateral images. The matching results in X, Z-AP image, Y, Z-Lat image directions were demonstrated in table 5.3- 5.6 in orderly.

Table 5.1 The 5 anatomy landmarks and 3 anatomy landmarks in AP pelvis.

AP image	Bony landmarks for anatomy matching
Type1	Pubic symphysis, Lt pelvic brim, Rt pelvic brim, Lt obturator foramen, Rt obturator foramen
Type2	Pubic symphysis, Lt pelvic brim, Rt pelvic brim.
Type3	Pubic symphysis, Lt pelvic brim, Lt obturator foramen
Type4	Pubic symphysis, Lt pelvic brim, Rt obturator foramen
Type5	Pubic symphysis, Rt pelvic brim, Lt obturator foramen
Type6	Pubic symphysis, Rt pelvic brim, Rt obturator foramen
Type7	Pubic symphysis, Lt obturator foramen, Rt obturator foramen
Type8	Lt pelvic brim, Rt pelvic brim, Lt obturator foramen
Type9	Lt pelvic brim, Rt pelvic brim, Rt obturator foramen
Type10	Lt pelvic brim, Lt obturator foramen, Rt obturator foramen
Type11	Rt pelvic brim, Lt obturator foramen, Rt obturator foramen

Table 5.2 The 5 anatomy landmarks and 3 anatomy landmarks in Lat pelvis.

Lat image	Bony landmarks for anatomy matching
Type1	Acetabulum, Anterior femur, Pubic symphysis, Post femur, Sacrum
Type2	Acetabulum, Ant femur, Pubic symphysis
Type3	Acetabulum, Ant femur, Post femur
Type4	Acetabulum, Ant femur, Sacrum
Type5	Acetabulum, Pubic symphysis, Post femur
Type6	Acetabulum, Pubic symphysis, Sacrum
Type7	Acetabulum, Post femur, Sacrum
Type8	Ant femur, Pubic symphysis, Post femur
Type9	Ant femur, Pubic symphysis, Sacrum
Type10	Ant femur, Post femur, Sacrum ,
Type11	Pubic symphysis, Post femur, Sacrum

Table 5.3 The match anatomy results from 5 anatomy landmarks and 3 anatomy landmarks on X direction (cm) in AP pelvis on the same image.

AP	Observer	Type1	Type2	Type3	Type4	Type5
Pt1	Dr	-0.91	-0.76	-0.79	-0.77	-0.86
	RTT1	-0.82	-0.8	-0.9	-0.73	-0.82
	RTT2	-0.81	-0.8	-0.9	-0.71	-0.85
	RTT3	-0.7	-0.74	-0.83	-0.76	-0.76
Pt2	Dr	-0.26	-0.17	-0.18	-0.1	-0.24
	RTT1	-0.13	-0.13	-0.05	-0.15	-0.15
	RTT2	-0.04	-0.11	-0.11	-0.13	-0.13
	RTT3	-0.09	-0.08	-0.05	-0.06	-0.14
Pt3	Dr	-0.22	-0.27	-0.12	-0.24	-0.02
	RTT1	-0.27	-0.17	-0.17	-0.1	-0.2
	RTT2	-0.02	-0.11	-0.1	-0.06	-0.16
	RTT3	-0.15	-0.19	-0.19	-0.08	-0.2
Pt4	Dr	0.05	0.03	-0.05	0	0.06
	RTT1	-0.07	0.08	-0.08	-0.11	-0.01
	RTT2	0.03	0.05	0	0.02	0.01
	RTT3	0.06	0.02	-0.06	0.06	0.02
Pt5	Dr	-0.13	-0.09	0.06	-0.13	-0.04
	RTT1	-0.1	-0.03	0.02	-0.03	-0.11
	RTT2	-0.04	-0.04	-0.04	-0.06	-0.12
	RTT3	-0.09	-0.04	0.01	-0.13	-0.06

AP	Observer	Type6	Type7	Type8	Type9	Type10	Type11
Pt1	Dr	-0.79	-0.84	-0.7	-0.69	-0.7	-0.79
	RTT1	-0.81	-0.88	-0.69	-0.62	-0.79	-0.84
	RTT2	-0.78	-0.81	-0.7	-0.76	-0.74	-0.81
	RTT3	-0.87	-0.75	-0.79	-0.68	-0.58	-0.88
Pt2	Dr	-0.16	-0.24	-0.13	-0.11	-0.02	-0.06
	RTT1	-0.18	-0.07	-0.2	-0.25	0.09	0.06
	RTT2	-0.08	-0.06	-0.14	-0.02	-0.05	-0.03
	RTT3	-0.08	-0.09	0.12	-0.02	-0.03	-0.09
Pt3	Dr	-0.03	-0.24	-0.12	-0.06	-0.16	-0.26
	RTT1	-0.13	-0.15	-0.18	-0.19	-0.21	-0.22
	RTT2	-0.07	-0.04	-0.09	-0.06	-0.11	-0.01
	RTT3	-0.06	-0.21	-0.08	-0.19	-0.17	-0.1
Pt4	Dr	0.04	0.02	-0.12	0.08	-0.05	0.06
	RTT1	0.02	-0.02	-0.06	0.06	-0.05	-0.1
	RTT2	0.09	-0.08	0.03	0.01	0.12	0.09
	RTT3	0.1	0.04	0.1	0.18	-0.01	0.06
Pt5	Dr	-0.18	0.03	-0.04	-0.02	0	0
	RTT1	-0.07	-0.03	-0.08	-0.16	-0.04	-0.03
	RTT2	-0.1	-0.01	-0.03	-0.05	-0.02	-0.1
	RTT3	-0.05	-0.15	-0.09	0	-0.08	-0.06

Table 5.4 The match anatomy results from 5 anatomy landmarks and 3 anatomy landmarks on Z direction (cm) in AP pelvis on the same image.

AP	Observer	Type1	Type2	Type3	Type4	Type5
Pt1	Dr	0.08	0.01	-0.01	-0.03	-0.11
	RTT1	-0.05	0.07	0.07	-0.04	-0.04
	RTT2	-0.04	-0.04	-0.06	0	0.01
	RTT3	-0.04	-0.08	-0.16	-0.09	-0.08
Pt2	Dr	0.06	0.06	0.03	-0.03	0.12
	RTT1	0.11	0.08	-0.02	0.14	-0.01
	RTT2	-0.02	0.02	-0.02	0.11	0.07
	RTT3	0.1	0	0.02	0.03	0.06
Pt3	Dr	0.03	0.24	0.04	0.18	-0.1
	RTT1	0	0.15	-0.05	-0.01	-0.03
	RTT2	-0.07	0.01	0.09	-0.01	0.09
	RTT3	0.03	0.12	-0.12	-0.01	0.15
Pt4	Dr	0.02	-0.04	0	-0.05	-0.08
	RTT1	-0.25	-0.21	-0.11	-0.07	-0.05
	RTT2	-0.11	-0.16	-0.11	-0.02	-0.12
	RTT3	-0.21	-0.16	-0.02	-0.11	0.02
Pt5	Dr	0.01	0.15	0.05	0.07	-0.06
	RTT1	-0.03	-0.08	-0.03	-0.09	-0.15
	RTT2	-0.15	-0.01	-0.08	-0.01	-0.01
	RTT3	-0.05	-0.01	-0.14	-0.06	-0.05

AP	Observer	Type6	Type7	Type8	Type9	Type10	Type11
Pt1	Dr	0.05	0.02	0.03	0	-0.02	0.01
	RTT1	-0.01	-0.19	-0.13	0.01	-0.11	-0.15
	RTT2	-0.01	-0.02	0.11	-0.07	-0.12	-0.01
	RTT3	-0.1	0.03	0	0.07	-0.11	0.04
Pt2	Dr	0.11	0.08	0.07	0.1	0.01	0.08
	RTT1	0.02	0.1	0.04	0	0.06	0.07
	RTT2	0	0.15	0.02	0.03	0.07	-0.03
	RTT3	0.12	0.04	-0.03	-0.03	0.22	-0.05
Pt3	Dr	0.14	0.12	0.09	0.17	-0.04	-0.01
	RTT1	-0.08	0.02	0.11	0.1	-0.03	0.08
	RTT2	0.13	0.05	0	0.1	-0.05	0.05
	RTT3	0.11	-0.02	0.29	0.13	-0.02	0.04
Pt4	Dr	-0.11	-0.09	-0.02	-0.11	-0.12	0.05
	RTT1	-0.06	0.07	-0.09	-0.12	0.01	-0.13
	RTT2	-0.02	-0.08	-0.05	0.06	-0.09	-0.18
	RTT3	-0.18	-0.06	0.07	-0.2	0	-0.08
Pt5	Dr	-0.13	0.07	-0.07	0	-0.05	-0.14
	RTT1	-0.16	-0.09	-0.04	-0.11	-0.16	-0.22
	RTT2	-0.1	0	-0.03	-0.07	0.01	-0.11
	RTT3	-0.03	-0.15	-0.08	-0.03	-0.1	0.04

Table 5.5 The match anatomy results from 5 anatomy landmarks and 3 anatomy landmarks on Y direction (cm) in Lat pelvis on the same image.

Lat	Observer	Type1	Type2	Type3	Type4	Type5
Pt1	Dr	0.66	0.71	0.82	0.83	0.72
	RTT1	0.7	0.65	0.63	0.69	0.66
	RTT2	0.76	0.7	0.66	0.8	0.74
	RTT3	0.65	0.45	0.69	0.74	0.74
Pt2	Dr	-0.21	-0.24	-0.03	-0.08	-0.19
	RTT1	-0.18	-0.23	-0.13	-0.08	-0.16
	RTT2	-0.02	-0.13	-0.07	0.01	0.02
	RTT3	-0.2	-0.02	-0.15	0.12	-0.18
Pt3	Dr	0.5	0.4	0.43	0.4	0.53
	RTT1	0.19	0.34	0.15	0.4	0.21
	RTT2	0.33	0.36	0.42	0.42	0.37
	RTT3	0.47	0.16	0.35	0.48	0.48
Pt4	Dr	0.5	0.65	0.54	0.62	0.53
	RTT1	0.22	0.57	0.58	0.44	0.25
	RTT2	0.49	0.62	0.64	0.58	0.49
	RTT3	0.5	0.6	0.45	0.57	0.55
Pt5	Dr	-0.17	-0.34	-0.33	-0.11	-0.26
	RTT1	-0.1	0	-0.14	0.06	-0.16
	RTT2	-0.29	0.05	-0.13	-0.07	-0.19
	RTT3	-0.21	-0.35	0.06	-0.12	-0.13

Lat	Observer	Type6	Type7	Type8	Type9	Type10	Type11
Pt1	Dr	0.97	0.78	0.78	0.71	0.52	0.81
	RTT1	0.96	0.87	0.64	0.12	0.87	0.78
	RTT2	0.72	0.78	0.65	0.56	0.79	0.71
	RTT3	0.56	0.68	0.82	0.51	0.69	0.77
Pt2	Dr	-0.2	0.06	-0.18	-0.16	-0.05	-0.12
	RTT1	-0.16	-0.06	0	-0.07	0.05	-0.09
	RTT2	-0.02	0.06	-0.13	0.09	-0.1	-0.03
	RTT3	-0.09	-0.05	-0.24	-0.03	0.03	0.08
Pt3	Dr	0.31	0.41	0.34	0.44	0.45	0.49
	RTT1	0.3	0.35	0.31	0.25	-0.07	0.21
	RTT2	0.47	0.45	0.37	0.56	0.43	0.51
	RTT3	0.24	0.16	0.54	0.67	0.36	0.54
Pt4	Dr	0.65	0.61	0.41	0.67	0.51	0.49
	RTT1	0.69	0.2	0.52	0.34	0.17	0.05
	RTT2	0.47	0.56	0.58	0.42	0.33	0.37
	RTT3	0.67	0.36	0.58	0.35	0.39	0.33
Pt5	Dr	-0.2	-0.27	-0.06	0.06	-0.29	-0.23
	RTT1	-0.29	-0.07	-0.47	0.02	-0.1	0.08
	RTT2	-0.13	-0.16	-0.11	-0.05	-0.06	-0.15
	RTT3	0.14	-0.11	-0.8	-0.22	-0.35	-0.33

Table 5.6 The match anatomy results from 5 anatomy landmarks and 3 anatomy landmarks on Z direction (cm) in Lat pelvis on the same image.

Lat	Observer	Type1	Type2	Type3	Type4	Type5
Pt1	Dr	-0.05	-1.39	-0.64	-0.18	-0.12
	RTT1	0.9	0.11	-0.09	0.22	0.39
	RTT2	0.12	0.14	0.04	-0.07	0.03
	RTT3	0.06	0.09	0.05	-0.01	0
Pt2	Dr	0.24	0.18	0.33	0.15	0.17
	RTT1	0.1	0.12	0.3	0.16	0.3
	RTT2	0.12	0.14	0.05	0.04	0.24
	RTT3	0.06	0.05	-0.31	0.13	0.09
Pt3	Dr	0.11	0.18	0.06	0.1	0.29
	RTT1	0.04	-0.01	-0.01	0.05	-0.09
	RTT2	0.05	0.04	-0.09	0.01	0.02
	RTT3	0.03	-0.04	-0.09	-0.13	-0.02
Pt4	Dr	-0.06	0.26	-0.04	0.12	0.2
	RTT1	-0.09	0.15	0.11	-0.03	0.1
	RTT2	0	0.09	0.12	-0.01	0.11
	RTT3	0.07	0.16	-0.09	-0.11	0.16
Pt5	Dr	0.03	-0.08	-0.09	-0.02	0
	RTT1	-0.21	-0.07	-0.24	-0.23	-0.06
	RTT2	0.11	-0.01	0.07	-0.1	-0.04
	RTT3	0.1	-0.09	-0.05	-0.11	-0.08

Lat	Observer	Type6	Type7	Type8	Type9	Type10	Type11
Pt1	Dr	-1.79	-0.22	-0.05	-0.16	-1.38	-0.12
	RTT1	-0.05	-0.18	-0.87	-1.55	-0.05	0.52
	RTT2	0.16	0.08	0.22	0.46	0.3	0.38
	RTT3	0.07	0.07	-0.01	0.11	0.27	0.28
Pt2	Dr	0.42	0.43	0.01	-0.02	0.08	0.09
	RTT1	0.3	0.06	0.06	0.03	0.39	0.25
	RTT2	0.34	0.01	0.17	0.34	0.04	0.32
	RTT3	0.08	0.05	0.11	0.28	0.05	0
Pt3	Dr	0.01	0.18	0	0.22	0	0.25
	RTT1	-0.06	-0.08	-0.08	-0.12	-0.42	-0.15
	RTT2	0.1	-0.12	0.11	0.12	-0.05	0.12
	RTT3	0.08	-0.37	0.13	-0.1	-0.06	0.11
Pt4	Dr	-0.03	0.01	0.23	0.15	-0.21	0.1
	RTT1	-0.05	0	0.21	-0.01	-0.04	-0.09
	RTT2	0	-0.01	0.17	0.01	-0.18	0.06
	RTT3	-0.12	-0.34	0.29	-0.18	-0.17	-0.06
Pt5	Dr	-0.01	-0.02	0.22	-0.12	0.01	0.3
	RTT1	-0.03	-0.03	0.21	-0.12	-0.02	0.06
	RTT2	0.09	-0.01	0.33	-0.06	-0.12	-0.02
	RTT3	-0.33	0.02	0.26	-0.15	-0.05	0.08

5.1.2 The 3 bony landmarks which have minimal variation for matching anatomy from 5 bony landmarks using set up criteria:

Calculation the difference match anatomy results of 5 anatomy landmarks and 3 anatomy landmarks (5 anatomy landmarks - 3 anatomy landmarks). Select the type of 3 anatomy landmarks which match anatomy result from 5 anatomy landmarks in AP and Lat images closest to the criteria that we set up. The criteria was set up to find the anatomical landmarks that could commonly drawn with highest reproducibility: the criteria were that the difference match anatomy results in X , Y , Z-AP, Z-Lat direction should be within the range -0.1 , +0.1 cm.

The results of the difference match anatomy are shown in table 5.7-5.10 for AP image X, Z and lat image Y, Z directions in orderly.

Table 5.11 is the summary of the number of images that each type of 3 anatomical landmark drawing cause the difference error > $\pm$ 0.1 cm.

Table 5.7 The difference match anatomy result of 5 anatomy landmarks and 3 anatomy landmarks on X direction (cm) in AP image. (5 anatomy landmarks - 3 anatomy landmarks).

Calculated from Table 5.3

T1 = 5 anatomy landmark (gold standard)

ΔT2 = T1 – T2 ΔT3 = T1 - T3 ΔT4 = T1 –T4

ΔT5 = T1 - T5 ΔT6 = T1 - T6 ΔT7 = T1 - T7

ΔT8 = T1- T8 ΔT9 = T1- T 9 ΔT10 = T1- T10

ΔT11 = T1- T11

AP	Observer	ΔT2	ΔT3	ΔT4	ΔT5	ΔT6	ΔT7	ΔT8	ΔT9	ΔT10	ΔT11
Pt1	Dr	**-0.15**	**-0.12**	**-0.14**	-0.05	**-0.12**	-0.07	**-0.21**	**-0.22**	**-0.21**	**-0.12**
	RTT1	-0.02	0.08	-0.09	0	-0.01	0.06	**-0.13**	**-0.2**	-0.03	0.02
	RTT2	-0.01	0.09	-0.1	0.04	-0.03	0	**-0.11**	-0.05	-0.07	0
	RTT3	0.04	**0.13**	0.06	0.06	**0.17**	0.05	0.09	-0.02	**-0.12**	**0.18**
Pt2	Dr	-0.09	-0.08	**-0.16**	-0.02	-0.1	-0.02	**-0.13**	**-0.15**	**-0.24**	-0.2
	RTT1	0	-0.08	0.02	0.02	0.05	-0.06	0.07	**0.12**	**-0.22**	**-0.19**
	RTT2	0.07	0.07	0.09	0.09	0.04	0.02	0.1	-0.02	0.01	-0.01
	RTT3	-0.01	-0.04	-0.03	0.05	-0.01	0	**-0.21**	-0.07	-0.06	0
Pt3	Dr	0.05	-0.1	0.02	-0.2	**-0.19**	0.02	-0.1	**-0.16**	-0.06	0.04
	RTT1	-0.1	-0.1	**-0.17**	-0.07	**-0.14**	**-0.12**	-0.09	-0.08	-0.06	-0.05
	RTT2	0.09	0.08	0.04	**0.14**	0.05	0.02	0.07	0.04	0.09	-0.01
	RTT3	0.04	0.04	-0.07	0.05	-0.09	0.06	-0.07	0.04	0.02	-0.05
Pt4	Dr	0.02	0.1	0.05	-0.01	0.01	0.03	**0.17**	-0.03	0.1	-0.01
	RTT1	**-0.15**	0.01	0.04	-0.06	-0.09	-0.05	-0.01	**-0.13**	-0.02	0.03
	RTT2	-0.02	0.03	0.01	0.02	-0.06	**0.11**	0	0.02	-0.09	-0.06
	RTT3	0.04	**0.12**	0	0.04	-0.04	0.02	-0.04	**-0.12**	0.07	0
Pt5	Dr	-0.04	**-0.19**	0	-0.09	0.05	**-0.16**	-0.09	**-0.11**	**-0.13**	**-0.13**
	RTT1	-0.07	**-0.12**	-0.07	0.01	-0.03	-0.07	-0.02	0.06	-0.06	-0.07
	RTT2	0	0	0.02	0.08	0.06	-0.03	-0.01	0.01	-0.02	0.06
	RTT3	-0.05	-0.1	0.04	-0.03	-0.04	0.06	0	-0.09	-0.01	-0.03
No. of images cause diff > ± o.1 cm.		**2**	**5**	**3**	**1**	**4**	**3**	**6**	**8**	**5**	**4**

Table 5.8 The difference match anatomy result of 5 anatomy landmarks and 3 anatomy landmarks on Z direction (cm) in AP images. (5 anatomy landmarks - 3 anatomy landmarks).

Calculated from Table 5.4

AP	Observer	ΔT2	ΔT3	ΔT4	ΔT5	ΔT6	ΔT7	ΔT8	ΔT9	ΔT10	ΔT11
Pt1	Dr	0.07	0.09	**0.11**	**0.19**	0.03	0.06	0.05	0.08	0.1	0.07
	RTT1	**-0.12**	**-0.12**	-0.01	-0.01	-0.04	**0.14**	0.08	-0.06	0.06	0.1
	RTT2	0	0.02	-0.04	-0.05	-0.03	-0.02	**-0.15**	0.03	0.08	-0.03
	RTT3	0.04	**0.12**	0.05	0.04	0.06	-0.07	-0.04	**-0.11**	0.07	-0.08
Pt2	Dr	0	0.03	0.09	-0.06	-0.05	-0.02	-0.01	-0.04	0.05	-0.02
	RTT1	0.03	**0.13**	-0.03	**0.12**	0.09	0.01	0.07	**0.11**	0.05	0.04
	RTT2	-0.04	0	**-0.13**	-0.09	-0.02	**-0.17**	-0.04	-0.05	-0.09	0.01
	RTT3	0.1	0.08	0.07	0.04	-0.02	0.06	**0.13**	**0.13**	**-0.12**	**0.15**
Pt3	Dr	**-0.21**	-0.01	**-0.15**	**0.13**	**-0.11**	-0.09	-0.06	**-0.14**	0.07	0.04
	RTT1	**-0.15**	0.05	0.01	0.03	0.08	-0.02	**-0.11**	-0.1	0.03	-0.08
	RTT2	-0.08	**-0.16**	-0.06	**-0.16**	-0.2	**-0.12**	-0.07	**-0.17**	-0.02	**-0.12**
	RTT3	-0.09	**0.15**	0.04	**-0.12**	-0.08	0.05	**-0.26**	-0.1	0.05	-0.01
Pt4	Dr	0.06	0.02	0.07	0.1	**0.13**	**0.11**	0.04	**0.13**	**0.14**	-0.03
	RTT1	-0.04	**-0.14**	**-0.18**	**-0.2**	**-0.19**	**-0.32**	**-0.16**	**-0.13**	**-0.26**	**-0.12**
	RTT2	0.05	0	-0.09	0.01	-0.09	-0.03	-0.06	**-0.17**	-0.02	0.07
	RTT3	-0.05	**-0.19**	-0.1	**-0.23**	-0.03	**-0.15**	**-0.28**	-0.01	**-0.21**	**-0.13**
Pt5	Dr	**-0.14**	-0.04	-0.06	0.07	**0.14**	-0.06	0.08	0.01	0.06	**0.15**
	RTT1	0.05	0	0.06	**0.12**	**0.13**	0.06	0.01	0.08	**0.13**	**0.19**
	RTT2	**-0.14**	-0.07	**-0.14**	**-0.14**	-0.05	**-0.15**	**-0.12**	-0.08	**-0.16**	-0.04
	RTT3	-0.04	0.09	0.01	0	-0.02	0.1	0.03	-0.02	0.05	-0.09
No. of images cause diff > ± o.1 cm.		5	7	5	9	5	7	7	8	6	6

Table 5.9 The difference match anatomy result of 5 anatomy landmarks and 3 anatomy landmarks on Y direction (cm) in Lat images. (5 anatomy landmarks - 3 anatomy landmarks).

Calculated from Table 5.5

Lat	Observer	ΔT2	ΔT3	ΔT4	ΔT5	ΔT6	ΔT7	ΔT8	ΔT9	ΔT10	ΔT11
Pt1	Dr	-0.05	**-0.16**	**-0.17**	-0.06	**-0.31**	**-0.12**	**-0.12**	-0.05	**0.14**	**-0.15**
	RTT1	0.05	0.07	0.01	0.04	**-0.26**	**-0.17**	0.06	**0.58**	**-0.17**	-0.08
	RTT2	0.06	0.1	-0.04	0.02	0.04	-0.02	**0.11**	**0.20**	-0.03	0.05
	RTT3	**0.2**	-0.04	-0.09	-0.09	0.09	-0.03	**-0.17**	**0.14**	-0.04	**-0.12**
Pt2	Dr	0.03	**-0.18**	**-0.13**	-0.02	-0.01	**-0.27**	-0.03	-0.05	**-0.16**	-0.09
	RTT1	0.05	-0.05	-0.1	-0.02	-0.02	**-0.12**	**-0.18**	**-0.11**	**-0.23**	-0.09
	RTT2	**0.11**	0.05	-0.03	-0.04	0	-0.08	**0.11**	**-0.11**	0.08	0.01
	RTT3	**-0.18**	-0.05	**-0.32**	-0.02	**-0.11**	**-0.15**	0.04	**-0.17**	**-0.23**	**-0.28**
Pt3	Dr	0.1	0.07	0.1	-0.03	**0.19**	0.09	**0.16**	0.06	0.05	0.01
	RTT1	**-0.15**	0.04	**-0.21**	-0.02	**-0.11**	**-0.16**	**-0.12**	-0.06	**0.26**	-0.02
	RTT2	-0.03	-0.09	-0.09	-0.04	**-0.14**	**-0.12**	-0.04	**-0.23**	-0.1	**-0.18**
	RTT3	**0.31**	**0.12**	-0.01	-0.01	**0.23**	**0.31**	-0.07	**-0.2**	**0.11**	-0.07
Pt4	Dr	**-0.15**	-0.04	**-0.12**	-0.03	**-0.15**	**-0.11**	0.09	**-0.17**	-0.01	0.01
	RTT1	**-0.35**	**-0.36**	**-0.22**	-0.03	**-0.47**	0.02	**-0.3**	**-0.12**	0.05	**0.17**
	RTT2	**-0.13**	**-0.15**	-0.09	0	0.02	-0.07	-0.09	0.07	**0.16**	**0.12**
	RTT3	-0.1	0.05	-0.07	-0.05	**-0.17**	**0.14**	-0.08	**0.15**	**0.11**	**0.17**
Pt5	Dr	**0.17**	**0.16**	-0.06	0.09	0.03	0.1	**-0.11**	**-0.23**	**0.12**	0.06
	RTT1	-0.1	0.04	**-0.16**	0.06	**0.19**	-0.03	**0.37**	**-0.12**	0	**-0.18**
	RTT2	**-0.34**	**-0.16**	**-0.22**	-0.1	**-0.16**	**-0.13**	**-0.18**	**-0.24**	**-0.23**	**-0.14**
	RTT3	**0.14**	**-0.27**	-0.09	-0.08	**-0.35**	-0.1	**0.59**	0.01	**0.14**	**0.12**
No. of images cause diff > ± o.1 cm.		**11**	**8**	**8**	**0**	**13**	**11**	**12**	**14**	**12**	**10**

Table 5.10 The difference match anatomy result of 5 anatomy landmarks and 3 anatomy landmarks on Z direction (cm) in Lat images. (5 anatomy landmarks - 3 anatomy landmarks).Calculated from Table 5.6

Lat	Observer	ΔT2	ΔT3	ΔT4	ΔT5	ΔT6	ΔT7	ΔT8	ΔT9	ΔT10	ΔT11
Pt1	Dr	**1.34**	**0.59**	**0.13**	0.07	**1.74**	**0.17**	0	**0.11**	**1.33**	0.07
	RTT1	0.79	**0.99**	**0.68**	**0.51**	**0.95**	**1.08**	**1.77**	**2.45**	**0.95**	**0.38**
	RTT2	-0.02	0.08	**0.19**	0.09	-0.04	0.04	-0.1	**-0.34**	**-0.18**	**-0.26**
	RTT3	-0.03	0.01	0.07	0.06	-0.01	-0.01	0.07	-0.05	**-0.21**	**-0.22**
Pt2	Dr	0.06	-0.09	0.09	0.07	**-0.18**	**-0.19**	**0.23**	**0.26**	**0.16**	**0.15**
	RTT1	-0.02	**-0.2**	-0.06	**-0.2**	**-0.2**	0.04	0.04	0.07	**-0.29**	**-0.15**
	RTT2	-0.02	0.07	0.08	**-0.12**	**-0.22**	**0.11**	-0.05	**-0.22**	0.08	**-0.2**
	RTT3	0.01	**0.37**	-0.07	-0.03	-0.02	0.01	-0.05	**-0.22**	0.01	0.06
Pt3	Dr	-0.07	0.05	0.01	**-0.18**	0.1	-0.07	**0.11**	**-0.11**	**0.11**	**-0.14**
	RTT1	0.05	0.05	-0.01	**0.13**	0.1	**0.12**	**0.12**	**0.16**	**0.46**	**0.19**
	RTT2	0.01	**0.14**	0.04	0.03	-0.05	**0.17**	-0.06	-0.07	0.1	-0.07
	RTT3	0.07	**0.12**	**0.16**	0.05	-0.05	**0.4**	-0.1	**0.13**	0.09	-0.08
Pt4	Dr	**-0.32**	-0.02	**-0.18**	**-0.26**	-0.03	-0.07	**-0.29**	**-0.21**	**0.15**	**-0.16**
	RTT1	**-0.24**	**-0.2**	-0.06	**-0.19**	-0.04	-0.09	**-0.3**	-0.08	-0.05	0
	RTT2	-0.09	**-0.12**	0.01	**-0.11**	0	0.01	**-0.17**	-0.01	**0.18**	-0.06
	RTT3	-0.09	**0.16**	**0.18**	-0.09	**0.19**	**0.41**	**-0.22**	**0.25**	**0.24**	**0.13**
Pt5	Dr	**0.11**	**0.12**	0.05	0.03	0.04	0.05	**-0.19**	**0.15**	0.02	**-0.27**
	RTT1	**-0.14**	0.03	0.02	**-0.15**	**-0.18**	**-0.18**	**-0.42**	-0.09	**-0.19**	**-0.27**
	RTT2	**0.12**	0.04	**0.21**	**0.15**	0.02	**0.12**	**-0.22**	**0.17**	**0.23**	**0.13**
	RTT3	**0.19**	**0.15**	**0.21**	**0.18**	**0.43**	0.08	**-0.16**	**0.25**	**0.15**	0.02
No. of images cause diff > ± o.1 cm.		**8**	**11**	**8**	**11**	**8**	**10**	**12**	**14**	**14**	**13**

Table 5.11 The 3 bony landmarks which have variation for matching anatomy from 5 bony landmarks > ±0.1 cm.

Score		**ΔT2**	**ΔT3**	**ΔT4**	**ΔT5**	**ΔT6**	**ΔT7**	**ΔT8**	**ΔT9**	**ΔT10**	**ΔT11**
AP	X	2	5	3	1	4	3	6	8	5	4
	Z	5	7	5	9	5	7	7	8	6	6
	Total No.	**7**	**12**	**8**	**10**	**9**	**10**	**13**	**16**	**11**	**10**
Lat	Y	11	8	8	0	13	11	12	14	12	10
	Z	8	11	8	11	8	10	12	14	14	13
	Total No.	**19**	**19**	**16**	**11**	**21**	**21**	**24**	**28**	**26**	**23**

5.1.3 Statistical analysis for 3 and 5 bony landmarks matching anatomy in AP and Lat pelvic image in five patients ,using 95% Wilcoxon signed – rank test.

We confirmed the results of drawing reproducibility using Wilcoxon signed-rank test. AP image anatomical matching results are shown in table 5.12 and lateral image anatomical matching results are shown in table 5.13.

The results were that there was non statistical difference for AP image anatomical matching for all types of anatomical matching in Z direction. For X direction, there were non statistical difference with type 1-8, 11 anatomical matching but type 9, 10 was statistical difference ($p < 0.05$). The p value of type 8,11 was also low even without statistical significance, this led to our opinion about the importance of having pubic symphysis as one of the anatomy that should be drawn for the AP match anatomy (see table 5.1).

For Lateral image Y direction, the results were that there was non statistical difference anatomical matching with type 1-3, 5-6 and 8-11. Only type 4, 7 was statistical difference ($p < 0.05$). For Z direction of lateral image, there was statistical difference in only type 4 anatomy match. When we looked at table 5.1, the common factors for type 4, 7 anatomy set is that there were not pubic symphysis in the list of the anatomy drawn. Other type of anatomy set that did not have the pubic symphysis in the set were type 3 and 10 which also had quite low p value in our opinion.

This led to similar opinion of the investigator about the importance of having pubic symphysis as one of the anatomy that should be drawn for the match anatomy in Lateral image (see table 5.1).

Table 5.12 Statistical analysis match anatomy result between 3 and 5 bony landmark in AP pelvis on X (Lt-Rt) direction in five patients , using 95% Wilcoxon signed –rank test.

AP image	TYPE2 - TYPE1	TYPE3 - TYPE1	TYPE4 - TYPE1	TYPE5 - TYPE1	TYPE6 - TYPE1
X	-.938(a)	-.484(a)	-.959(a)	-.463(b)	-1.290(a)
Asymp. Sig. (2-tailed)	.348	.628	.337	.643	.197

AP image	TYPE7 - TYPE1	TYPE8 - TYPE1	TYPE9 - TYPE1	TYPE10 - TYPE1	TYPE11 - TYPE1
X	-.350(a)	-1.614(a)	-2.409(a)	-2.225(a)	-1.635(a)
Asymp. Sig. (2-tailed)	.727	.107	.016	.026	.102

Test Statistics(c)
a Based on negative ranks.
b Based on positive ranks.
c Wilcoxon Signed Ranks Test

There were no statistical significant difference between 3 and 5 anatomy landmarks for match anatomy on X (Lt-Rt) direction in AP pelvic ($p > 0.05$) 95% Wilcoxon Signed Ranks Test for type 1-8 and type 11 but the p value was < 0.05 for type 9,10 anatomy match.

Table 5.13 Statistical analysis match anatomy result between 3 and 5 bony landmark in AP pelvis on Z (Sup-Inf) direction in five patients , using 95% Wilcoxon signed –rank test.

AP images	TYPE2 - TYPE1	TYPE3 - TYPE1	TYPE4 - TYPE1	TYPE5 - TYPE1	TYPE6 - TYPE1
Z	-1.527(a)	-.237(b)	-1.009(a)	-.342(a)	-.523(a)
Asymp. Sig. (2-tailed)	.127	.813	.313	.732	.601

AP image	TYPE7 - TYPE1	TYPE8 - TYPE1	TYPE9 - TYPE1	TYPE10 - TYPE1	TYPE11 - TYPE1
Z	-1.103(a)	-1.382(a)	-1.345(a)	-.635(b)	-.019(b)
Asymp. Sig. (2-tailed)	.270	.167	.179	.525	.985

Test Statistics(c)
a Based on negative ranks.
b Based on positive ranks.
c Wilcoxon Signed Ranks Test

There were no statistical significant difference between 3 and 5 anatomy landmarks for match anatomy on Z (Sup-Inf) direction in AP pelvic ($p > 0.05$) 95% Wilcoxon Signed Ranks Test.

Table 5.14 Statistical analysis match anatomy result between 3 and 5 bony landmark in Lat pelvis on Y (AP-PA) direction in five patients , using 95% Wilcoxon signed –rank test.

Lat images	TYPE2 - TYPE1	TYPE3 - TYPE1	TYPE4 - TYPE1	TYPE5 - TYPE1	TYPE6 - TYPE1
Z	-.355(a)	-1.010(a)	-3.439(a)	-1.938(a)	-1.429(a)
Asymp. Sig. (2-tailed)	.723	.312	.001	.053	.153

Lat images	TYPE7 - TYPE1	TYPE8 - TYPE1	TYPE9 - TYPE1	TYPE10 - TYPE1	TYPE11 - TYPE1
Z	-1.980(a)	-.672(a)	-1.307(a)	-.101(b)	-1.158(a)
Asymp. Sig. (2-tailed)	.048	.501	.191	.920	.247

Test Statistics(c)

a Based on negative ranks.

b Based on positive ranks.

c Wilcoxon Signed Ranks Test

There were no statistical significant difference between 3 selected and 5 anatomy landmarks for match anatomy on Y (AP-PA) direction except anatomy land mark type 4 and anatomy landmarks type 7 in Lat pelvic ($p > 0.05$) 95% Wilcoxon Signed Ranks Test.

Table 5.15 Statistical analysis match anatomy result between 3 and 5 bony landmark in Lat pelvis on Z (Sup-Inf) direction in five patients , using 95% Wilcoxon signed –rank test.

	TYPE2 - TYPE1	TYPE3 - TYPE1	TYPE4 - TYPE1	TYPE5 - TYPE1	TYPE6 - TYPE1
Z	-.168(a)	-1.868(a)	-2.354(a)	-.355(b)	-.101(a)
Asymp. Sig. (2-tailed)	.867	.062	.019	.723	.920

	TYPE7 - TYPE1	TYPE8 - TYPE1	TYPE9 - TYPE1	TYPE10 - TYPE1	TYPE11 - TYPE1
Z	-1.681(a)	-1.530(b)	-.710(a)	-1.736(a)	-1.188(b)
Asymp. Sig. (2-tailed)	.093	.126	.478	.083	.235

Test Statistics(c)

a Based on positive ranks.

b Based on negative ranks.

c Wilcoxon Signed Ranks Test

There were no statistical significant difference between 3 selected and 5 anatomy landmarks for match anatomy on Z (Sup-Inf) direction except anatomy land mark type 4 in Lat pelvic ($p > 0.05$) 95% Wilcoxon Signed Ranks Test.

Bony landmarks selected for step 2 study:

From the results of Wilcoxon signed ranks test, the three anatomy landmarks which the investigators picked to do for STEP 2 study must include the pubic symphysis in both AP and Lateral images.

We chose type 4 structures for AP image to be used for step 2 study since it had good reproducibility from table 5.7, 5.8 and 5.11; the structures were:

1. Pubic symphysis 2. Lt pubic brim 3. Rt obturator foramen

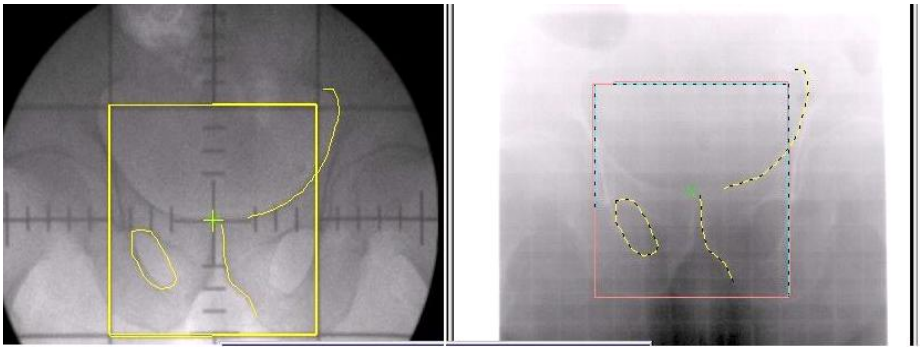


Figure 5.3 The three anatomy landmarks which have good reproducibility for matching anatomy in AP Pelvis.

From table 5.9, 5.10 and table 5.11 the three anatomy landmarks which have minimum variation for matching anatomy in Lat Pelvis were **type5** anatomy set which includes:

1. Acetabulum 2. Pubic symphysis 3. Posterior femur

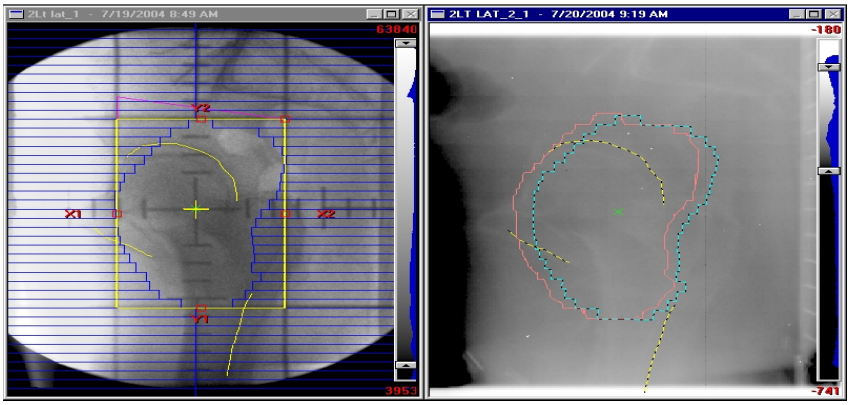


Figure 5.4 The three anatomy landmarks which have minimum variation for matching anatomy in Lat Pelvis.

5.1.4 The Inter-observer variabilities

The match anatomy results from 4 medical personals; one radiation oncologists and 3 RTTs are demonstrated in table 5.16. From the reliability analysis of intraclass correlation between 3 RTTs and 1 radiation oncologist in matching anatomy using 5 anatomy landmarks (table 5.5) in 5 pelvis irradiation patients, the result shown good agreement between 3 RTTs and 1 radiation oncologist in match anatomy ($p = 0.9833$) on x , y and z direction (see table 5.17).

Table 5.16 The match anatomy result between 3 RTTs and 1 radiation oncologist by using 5 bony landmarks in 5 patients on x , y and z direction.

Observer	Patient 1			Patient 2			Patient 3		
	x	z	y	x	z	y	x	z	y
Doctor	-0.91	0.08	0.66	-0.26	0.06	-0.21	-0.22	0.03	0.5
RTT1	-0.82	-0.05	0.7	-0.13	0.11	-0.18	-0.27	0	0.19
RTT2	-0.81	-0.04	0.76	-0.04	-0.02	-0.02	-0.02	-0.07	0.33
RTT3	-0.7	-0.04	0.65	-0.09	0.1	-0.2	-0.15	0.03	0.47

Observer	Patient 4			Patient 5		
	x	z	y	x	z	y
Doctor	0.05	-0.02	0.5	-0.13	0.01	-0.17
RTT1	-0.07	-0.25	0.22	-0.1	-0.03	-0.1
RTT2	0.03	-0.11	0.49	-0.04	-0.15	-0.29
RTT3	0.06	-0.21	0.5	-0.09	-0.05	-0.21

Table 5.17 The reliability analysis of intraclass correlation between 3 RTTs and 1 radiation oncologist in matching anatomy by using 5 anatomy landmarks (table 5.3) in 5 patients pelvis irradiation.

RELIABILITY ANALYSIS - SCALE (ALPHA)

Intraclass Correlation Coefficients One-way random effects model (People Effect Random) ICC 95% Confidence Interval					
Measure	Value	Lower Bound	Upper Bound	F-Value	Sig.
Single Rater	.9365	.8694	.9753	59.9955	.0000
Average of Raters	.9833	.9638	.9937	59.9955	.0000

Step2 Portal image and set-up error analysis

There were 34 patients treated with 3D-CRT or IMRT in Siriraj hospital between January 2005 – October 2006 who got through our inclusion and exclusion criteria. The majority of the patients were treated for prostate cancer (26 patients). The other malignancies that were treated included cervix cancers (7 patients) and bladder cancers (1 patient).

The data was collected and analyzed retrospectively from 34 patients. A total of 169 AP pelvis and 169 Lat pelvis EPIs and 68 reference images (simulation) were analyzed .

5.2.1 Set up errors from 34 patients in x,y and z direction

The patient characteristics and the data of set up errors in X, Y, Z directions of each image set are shown in table 5.18.

The result showed that the set-up errors in L – R direction (X) ranged from (-0.61 cm to 0.93 cm) , (-0.46 cm to 0.51cm) in S - I direction (Z) and (-0.87cm to 0.77 cm) in A – P direction (Y).

Interval of set up errors in each direction was classified in table 5.19 and the magnitude of set up errors in each direction was demonstrated as graph in figure 5.5.

Table 5.18 The patient characteristics and set up errors from 34 patients treated with IMRT and 3DCRT pelvic radiation in x,y and z direction.

Patient No	Immo	Sex	Age	Weight	EPI	L - R (X) cm	S - I (Z) cm	A - P (Y) cm
1	Vac-lok	M	53	75	1	-0.35	0.17	-0.37
					2	0.31	-0.04	0.03
					3	-0.08	0.06	-0.14
					4	-0.23	0.05	-0.36
					5	0.11	0.2	0.03
					6	-0.33	0.19	0.08
					7	-0.27	0.17	0.09
					8	-0.08	0.26	-0.07
2	Vac-lok	M	84	73	1	-0.19	0.08	0.24
					2	-0.07	0.2	0.2
					3	-0.28	-0.17	0.12
					4	-0.2	0.01	0.08
					5	-0.31	-0.02	-0.08
					6	-0.12	-0.16	0.07
3	Vac-lok	M	78	69	1	-0.11	-0.02	0.12
					2	-0.29	0.14	0.14
					3	-0.12	0.03	0.31
					4	0.15	0	0.2
					5	-0.07	0.21	0.33
					6	0.11	0.12	0.61
4	Vac-lok	M	62	75	1	0.01	0.26	0.5
					2	-0.29	0.16	0.42
					3	-0.19	0.17	0.39
					4	0.16	-0.01	0.54
5	Laser	F	76	69	1	-0.23	-0.04	-0.01
					2	0.44	0.49	0.11
6	Laser	M	75	59	1	0.02	-0.09	-0.1
					2	-0.15	-0.08	-0.18

Table 5.18 (continue) The set up errors from 34 patients treated with IMRT and 3DCRT pelvic radiation in x,y and z direction.

Patient No	Immo	Sex	Age	Weight	EPI	L - R (X)cm	S - I (Z)cm	A - P (Y) cm
7	Vac-lok	M	76	66	1	-0.18	-0.05	0.39
					2	-0.46	0.16	0.04
					3	0.36	0.26	0.77
					4	0.3	0.07	0.35
					5	0.43	0.23	0.5
					6	0.16	0.44	0.31
8	Laser	M	74	72	1	-0.37	-0.21	0.43
					2	-0.25	0.08	0.06
					3	-0.13	0.25	0.34
9	Vac-lok	M	72	59	1	0.13	0.2	-0.29
					2	0.17	0.18	0.22
					3	0.15	0.12	0.19
					4	0.12	0.12	0.08
					5	0.27	0.13	-0.09
					6	0.08	0.21	-0.04
					7	-0.03	0.31	-0.11
10	Vac-lok	M	68	76	1	-0.24	0.23	0.4
					2	-0.07	0.45	0.26
					3	-0.09	0.31	0.16
					4	-0.04	0.04	-0.29
					5	-0.14	0.17	0.07
					6	-0.21	0.51	-0.25
					7	0.23	0.44	0.01
					8	-0.07	0.22	-0.05
11	Vac-lok	M	77	68	1	0.44	0.42	0.61
					2	-0.29	0.42	-0.35
					3	-0.13	0.12	0.33
					4	-0.33	0.18	-0.12

Table 5.18 (continue) The set up errors from 34 patients treated with IMRT and 3DCRT pelvic radiation in x,y and z direction.

Patient No	Immo	Sex	Age	Immo.	EPI	L - R (X)cm	S - I (Z)cm	A - P (Y)cm
12	Vac-lok	M	60	60	1	-0.04	-0.01	0.49
					2	0.02	0.03	0.45
					3	-0.03	0.02	0.32
					4	-0.22	0.19	0.27
					5	-0.04	-0.12	0.2
					6	0.06	-0.16	-0.04
13	Laser	F	35	58.5	1	-0.15	0.18	0.2
					2	-0.24	0.33	-0.05
					3	0.05	0.18	0.3
14	Vac-lok	M	76	65	1	0	-0.1	0.31
					2	-0.08	-0.07	0.22
					3	0.31	-0.07	0.21
					4	0.29	0.37	0.14
					5	0.06	0.18	0.41
					6	-0.09	-0.46	0.04
15	Laser	M	59	91	1	0.18	0.03	-0.32
					2	0.08	0.06	-0.6
					3	0.05	0.21	-0.38
					4	-0.05	0.28	-0.41
					5	0.02	0.09	-0.5
					6	0.35	0.31	-0.32
					7	0.25	0.17	-0.67
16	Vac-lok	M	79	63	1	-0.22	0.24	0.13
					2	0.15	-0.23	-0.84
					3	0	0.03	-0.28
					4	-0.04	-0.13	-0.56

Table 5.18 (continue)The set up errors from 34 patients treated with IMRT and 3DCRT pelvic radiation in x,y and z direction.

Patient No	Immo	Sex	Age	Weight	EPI	L - R (X)cm	S - I (Z)cm	A - P (Y)cm
17	Vac-lok	M	73	68	1	-0.23	0.18	-0.07
					2	0.23	-0.13	-0.1
					3	0.15	0.27	-0.39
					4	0.33	0.21	0.19
					5	-0.1	-0.31	-0.23
					6	-0.11	0.31	-0.23
18	Laser	M	72	56	1	0.14	0.09	-0.05
					2	-0.13	0.41	0.32
					3	-0.14	0.1	0.38
					4	0.16	0.13	0.03
					5	-0.32	0.43	0.31
					6	-0.01	0.1	0.31
					7	-0.06	0.29	0.26
19	Laser	M	63	82.5	1	0.34	0.19	-0.17
					2	0.05	0.14	-0.36
					3	0.01	0.03	-0.14
					4	-0.02	-0.13	-0.29
					5	-0.11	-0.17	-0.51
					6	-0.15	-0.11	-0.72
20	Vac-lok	M	58	71	1	-0.17	-0.06	-0.12
					2	0.06	-0.08	0.19
					3	-0.09	-0.01	-0.05
					4	0.02	0.14	0.21
					5	-0.08	0.08	-0.06
					6	0.03	0.19	-0.06

Table 5.18 (continue) The set up errors from 34 patients treated with IMRT and 3DCRT pelvic radiation in x,y and z direction.

Patient No	Immo	Sex	Age	Weight	EPI	L - R (X)cm	S - I (Z)cm	A - P (Y)cm
21	Vac-lok	M	68	61.5	1	0.17	0.25	0.09
					2	0.2	0.26	-0.09
					3	0.15	0.06	-0.05
					4	0.33	0.03	-0.07
					5	0.12	0.27	-0.02
					6	0.16	0.04	0.11
					7	0.33	0.3	-0.03
					8	0.07	0.11	0
22	Laser	M	76	73	1	0.21	0.41	0.12
					2	0.01	-0.17	-0.19
					3	-0.11	-0.05	0.31
					4	-0.1	0.08	-0.32
					5	0.15	-0.32	-0.41
					6	0.16	0.24	-0.06
23	Laser	F	41	69	1	-0.09	0.14	0.26
					2	-0.18	0.14	0.02
					3	-0.1	0.13	-0.34
24	Laser	M	64	75	1	0.32	0.04	0.3
					2	-0.11	0.36	0.19
					3	0.15	0.36	0.2
25	Laser	M	76	58	1	0.17	0.02	-0.22
					2	-0.29	0.13	-0.15
					3	-0.2	0.21	-0.04
26	Laser	M	69	78.5	1	-0.04	-0.07	0.68
					2	-0.31	0.2	0.24

Table 5.18 (continue)The set up errors from 34 patients treated with IMRT and 3DCRT pelvic radiation in x,y and z direction.

Patient No	Immo	Sex	Age	Weight	EPI	L - R (X)cm	S - I (Z)cm	A - P (Y)cm
27	Laser	M	77	55	1	0.09	0.2	-0.38
					2	0.24	0.47	0.08
					3	0.14	0.44	-0.17
28	Laser	M	76	70	1	0.06	0.14	0.3
					2	-0.07	-0.14	0.09
					3	-0.27	-0.17	0.04
					4	-0.07	-0.27	-0.05
					5	-0.22	-0.18	0.06
					6	-0.32	-0.22	-0.05
					7	-0.37	-0.03	-0.22
					8	-0.26	-0.1	-0.11
29	Laser	M	61	59	1	0.12	-0.03	-0.11
					2	0.16	0.4	-0.66
					3	-0.14	-0.22	-0.49
					4	0.2	-0.01	-0.33
					5	-0.15	0.26	-0.5
					6	0.2	-0.03	-0.02
30	Laser	F	44	63	1	-0.08	0.06	0.11
					2	0.01	0.36	-0.38
					3	-0.11	0.3	-0.24
					4	-0.07	0.08	-0.09
31	Laser	F	56	73	1	-0.07	-0.07	-0.06
					2	-0.43	-0.27	-0.36
					3	-0.44	0.19	-0.3

Table 5.18 (continue)The set up errors from 34 patients treated with IMRT and 3DCRT pelvic radiation in x, y and z direction.

Patient No	Immo	Sex	Age	Weight (Kg)	EPI	L - R (X)cm	S - I (Z) cm	A - P (Y)cm
32	Laser	F	60	72	1	-0.02	-0.09	-0.23
					2	0.18	0.2	-0.2
					3	-0.06	0.05	0.08
33	Vac-lok	M	77	88	1	-0.61	0.08	-0.23
					2	0.07	0.16	-0.16
					3	-0.2	0.28	-0.23
					4	0.06	0.3	-0.29
					5	0.1	0.41	-0.49
					6	-0.32	-0.17	-0.2
					7	-0.1	0.14	-0.14
					8	-0.29	-0.21	-0.11
34	Laser	F	68	62	1	0.08	0.14	0.08
					2	0.2	0.03	0.11
Average	-	-	67.15	68.62	-	-0.0175	0.1056	-0.0043
Max	-	-	35	55	-	0.44	0.51	0.77
Min	-	-	84	91	-	-0.61	-0.46	-0.84

Table 5.19 % Set up errors from 34 patients treated with IMRT and 3DCRT pelvic radiation in x,y and z direction.

Setup error (cm)	L - R (X)	S - I (Z)	A - P (Y)
With in ± 0.3	84.62%	84.62%	67.46%
With in ± 0.4	95.27%	91.72%	85.21%
With in ± 0.6	98.82%	100%	95.27%
With in ± 0.8	100%	-	99.41%

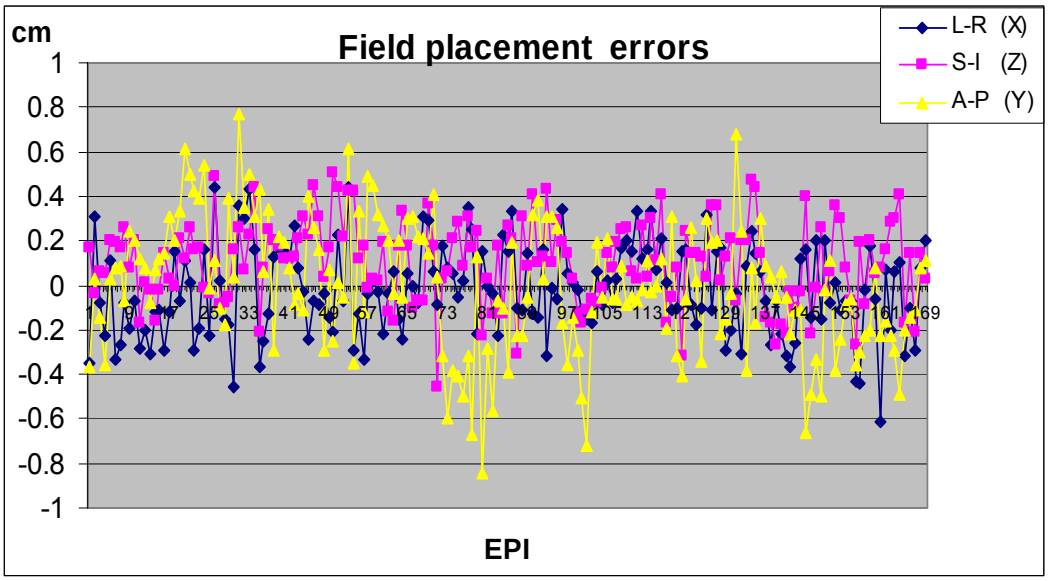


Figure 5.5 The magnitude of set-up errors form 169 AP pelvis and 169 Lat pelvis EPIs and 68 reference images in 34 patients treated with IMRT and 3DCRT in X , Y and Z direction.

5.2.2 The Individual systematic(Σind) and Individual random errors (σind) from 34 patients

Table 5.20 The Individual systematic errors from 34 patients treated with IMRT and 3DCRT pelvic radiation in x ,y and z direction.

Pt No.	Individual systematic errors (cm) Σind			Individual random errors (cm) σind		
	x	Z	y	x	z	y
1	-0.12	0.13	-0.09	0.23	0.10	0.19
2	-0.20	-0.01	0.11	0.09	0.14	0.11
3	-0.06	0.08	0.29	0.16	0.09	0.18
4	-0.08	0.15	0.46	0.20	0.11	0.07
5	0.11	0.23	0.05	0.47	0.37	0.08
6	-0.17	-0.09	-0.14	0.12	0.01	0.06
7	0.10	0.19	0.39	0.35	0.17	0.24
8	-0.25	0.04	0.28	0.12	0.23	0.19
9	0.13	0.18	-0.01	0.09	0.07	0.18
10	-0.08	0.30	0.04	0.14	0.16	0.24
11	-0.08	0.29	0.12	0.36	0.16	0.43
12	-0.04	-0.01	0.28	0.10	0.12	0.19
13	-0.11	0.23	0.15	0.15	0.09	0.18
14	0.08	-0.03	0.22	0.18	0.28	0.13
15	0.13	0.16	0.46	0.14	0.11	0.14
16	-0.03	-0.02	-0.39	0.15	0.21	0.41
17	0.05	0.09	-0.14	0.22	0.25	0.20
18	-0.05	0.22	0.22	0.17	0.15	0.16
19	0.02	-0.01	-0.37	0.17	0.15	0.22
20	-0.04	0.04	0.02	0.09	0.11	0.14
21	0.19	0.17	-0.01	0.09	0.12	0.07
22	0.05	0.03	-0.09	0.14	0.27	0.27
23	-0.12	0.14	-0.02	0.05	0.01	0.30
24	0.12	0.25	0.23	0.22	0.18	0.06
25	-0.11	0.12	-0.14	0.24	0.10	0.09
26	-0.18	0.07	0.46	0.19	0.19	0.31
27	0.16	0.37	-0.16	0.08	0.15	0.23
28	-0.19	-0.12	0.01	0.15	0.13	0.16
29	0.07	0.06	-0.35	0.17	0.23	0.25
30	-0.06	0.20	-0.15	0.05	0.15	0.21
31	-0.31	-0.05	-0.24	0.21	0.23	0.16
32	0.03	0.05	-0.12	0.13	0.15	0.17
33	-0.16	0.12	-0.23	0.24	0.22	0.12
34	0.14	0.09	0.10	0.08	0.08	0.02
MIN	-0.31	-0.12	-0.39	0.05	0.01	0.02
MAX	0.19	0.37	0.46	0.47	0.37	0.43

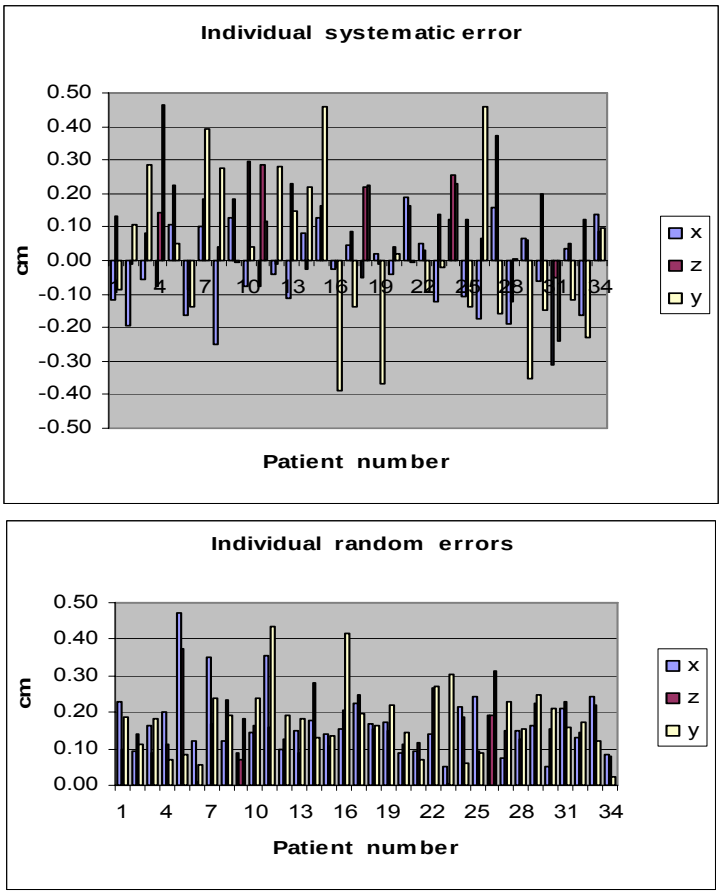


Figure 5.6 The individual systematic errors and the individual random errors reference images in 34 patients treated with IMRT and 3DCRT in x , y and z direction.

Table 5.21 The Range of Individual systematic and random errors from 34 patients treated with IMRT and 3DCRT pelvic radiation in x , y and z direction.

Range	(L - R) X	(A - P) Y	(S – I) Z
The individual systematic error (Σ ind)	-0.31cm to 0.19 cm	-0.39cm to 0.46cm	-0.12cm to 0.37 cm
The individual random error (σind)	0.05 cm to 0.47cm	0.02cm to 0.43 cm	0.01 cm to 0.37cm

5.2.3 Calculate the population systematic errors (Σpop) and population random errors (σpop) from 34 patient treated with 3DCRT and IMRT pelvis radiotherapy .

Σpop = S.D of All. Σind

$$\sigma_{POP} = \sqrt{\frac{\sum_{i}^{N} \sigma_{IND}^{2}}{N}}$$

where N represents the total number of the patients.

σ_{ind} is the individual random error

Table 5.22 The population systematic (Σpop) and population random errors (σpop) from 34 patient treated with 3DCRT

	(L - R) X	(A - P) Y	(S – I) Z
Σpop	0.13 cm	0.24 cm	0.12 cm
σpop	0.19 cm	0.20 cm	0.17 cm

5.2.4 The population base margin for pelvis IMRT and 3DCRT

PTV margin = 2.5 Σpop + 0.7σpop

Table 5.23 The population base margin for pelvis IMRT and 3DCRT using PTV margin calculation.

Population base margin	(L - R) X	(A - P) Y	(S – I) Z
PTV margin	0.46 cm	0.74 cm	0.42 cm

5.3 Study the factors influenced patient set-up errors

The results of Independent T-Test and ANOVA showed similar results that immobilization device was the only significant factor affected Y direction set-up error and weight was the only factor affected X direction set-up error.

5.3.1 Study the factors influenced patient set-up errors with 95% Independent Sample T- Test.

Table 5.24 The factors influenced patient set-up errors using 95% Independent Sample T-Test

Factor		Average Set-up error(cm)			No. image	P-value		
		X	y	z		x	y	z
Immobilization	No Vacuum -Lock	-0.03	-0.08	0.09	76	0.75	0.002	0.44
	Vacuum - lock	-0.02	0.06	0.12	93			
Age	Age < 70	-0.01	-0.05	0.12	82	0.45	0.07	0.27
	Age ≥ 70	-0.03	0.04	0.09	87			
Sex	Male	-0.02	0.00	0.10	149	0.32	0.46	0.60
	Female	-0.07	-0.05	0.13	20			
weight	Weight < 65	0.03	-0.03	0.13	55	0.01	0.44	0.18
	Weight ≥ 65	-0.05	0.01	0.09	144			

-There were no significant difference between patient age (<70, ≥70) and sex (Male or Female) with 95% Independent Sample T- Test.

-There were significant difference in A –P direction(Y) between Vacuum lock group and no immobilization group, and in L-R direction (X) between patient weight (<65 kg ,≥65 kg) with 95% Independent Sample T- Test.

5.3.2 Studied the factors influenced patient set-up errors with 95 % Factorial ANOVA.

Table 5.25 The factors influenced patient set-up errors on X direction with 95% Factorial ANOVA.

Tests of Between-Subjects Effects

Dependent Variable: X

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.365(a)	4	.091	2.298	.061
Intercept	.077	1	.077	1.932	.166
AGE.GR	.043	1	.043	1.090	.298
WT.GR	.274	1	.274	6.907	**.009**
SEX	.070	1	.070	1.770	.185
IMMO	.001	1	.001	.033	.856
Error	6.507	164	.040		
Total	6.964	169			
Corrected Total	6.871	168			

-There were significant difference in L-R direction (X) between patient weight (<65 kg ,≥65 kg) with 95% Factorial ANOVA. (p=0.009)

Table 5.26 The factors influenced patient set-up errors on Y direction with 95% Factorial ANOVA.

.

Tests of Between-Subjects Effects

Dependent Variable: Y

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.085(a)	4	.271	3.324	.012
Intercept	.014	1	.014	.166	.684
AGE.GR	.235	1	.235	2.884	.091
WT.GR	.011	1	.011	.130	.719
SEX	.088	1	.088	1.083	.300
IMMO	.763	1	.763	9.355	**.003**
Error	13.377	164	.082		
Total	14.465	169			
Corrected Total	14.462	168			

There were significant difference in A –P direction(Y) between Vacuum lock group and no immobilization group with 95% Factorial ANOVA.(p=0.003)

Table 5.27 The factors influenced patient set-up errors on Z direction with 95% Factorial ANOVA.

Tests of Between-Subjects Effects

Dependent Variable: Z

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.151(a)	4	.038	1.080	.368
Intercept	.910	1	.910	25.992	.000
AGE.GR	.030	1	.030	.862	.355
WT.GR	.067	1	.067	1.911	.169
SEX	.011	1	.011	.321	.572
IMMO	.052	1	.052	1.499	.223
Error	5.745	164	.035		
Total	7.779	169			
Corrected Total	5.896	168			

There were no significant difference in z direction between patient age($<70, \geq 70$) , sex (Male or Female) and immobilization group with 95% Factorial ANOVA.($p > 0.05$)

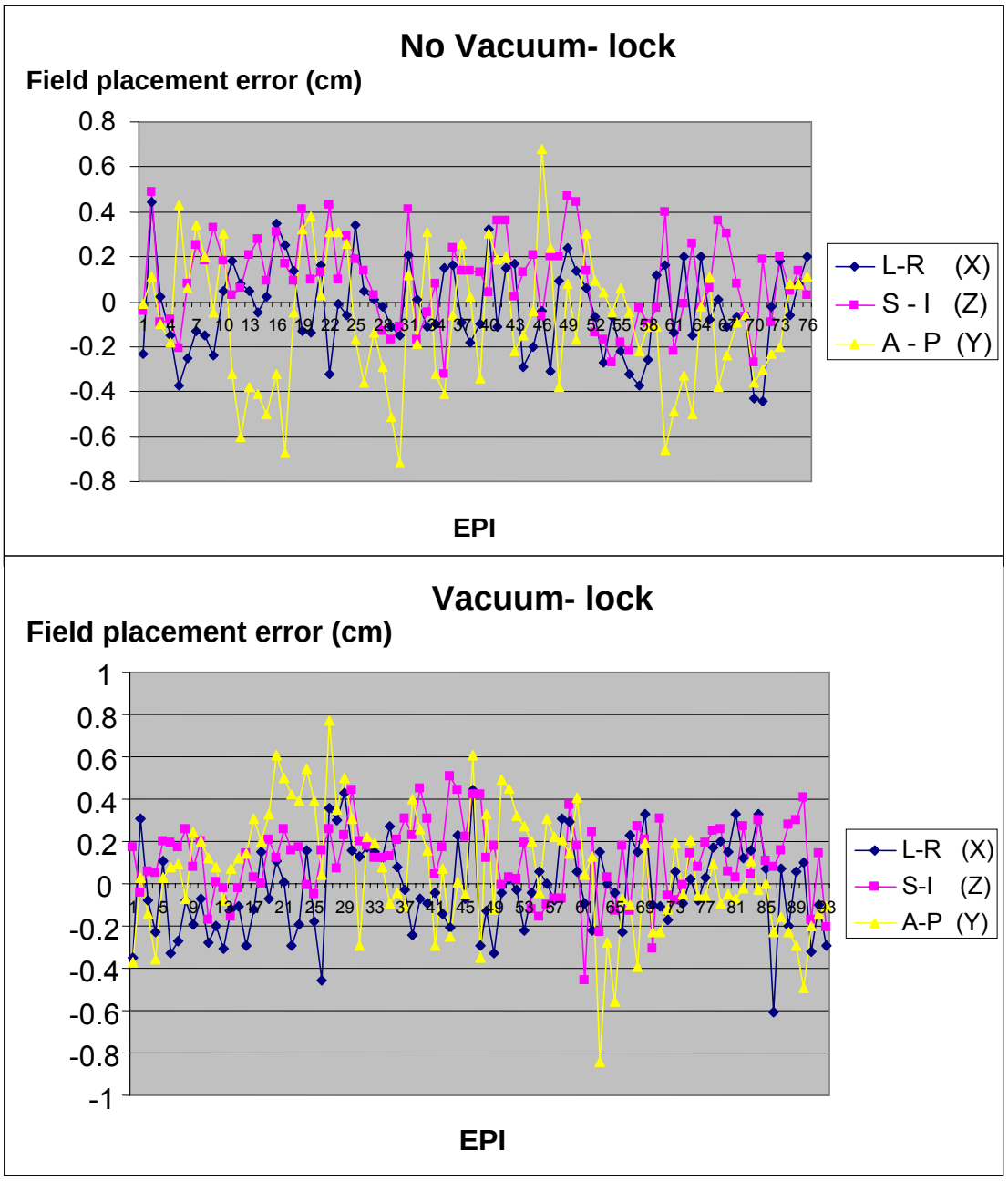
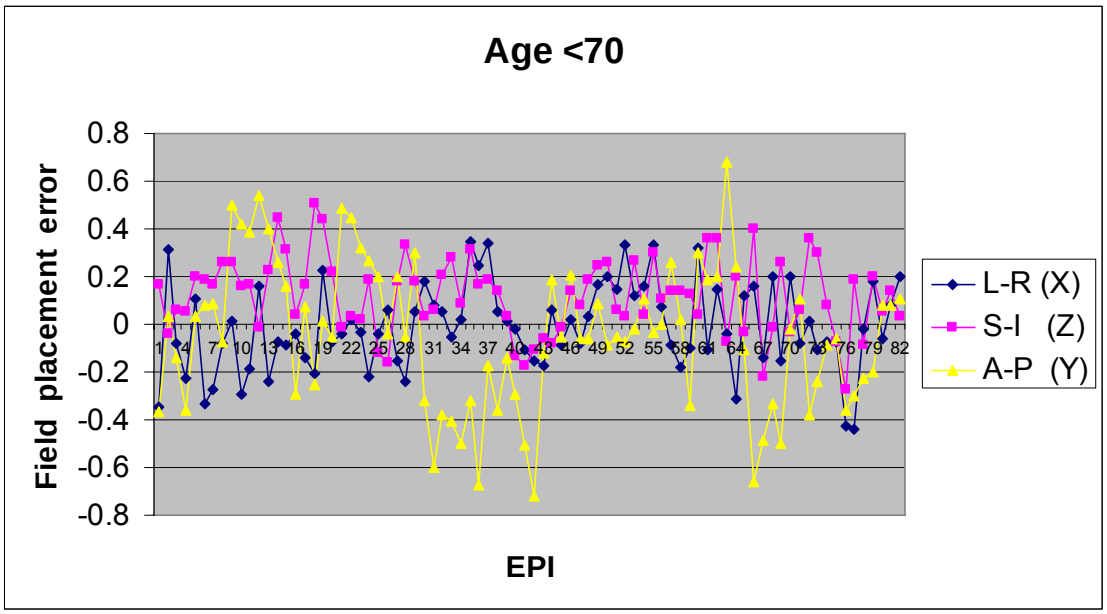


Figure 5.7 Set-up errors in patient no Vacuum-lock group and Vacuum-lock group in 34 patients treated with IMRT and 3DCRT in X , Y and Z direction.



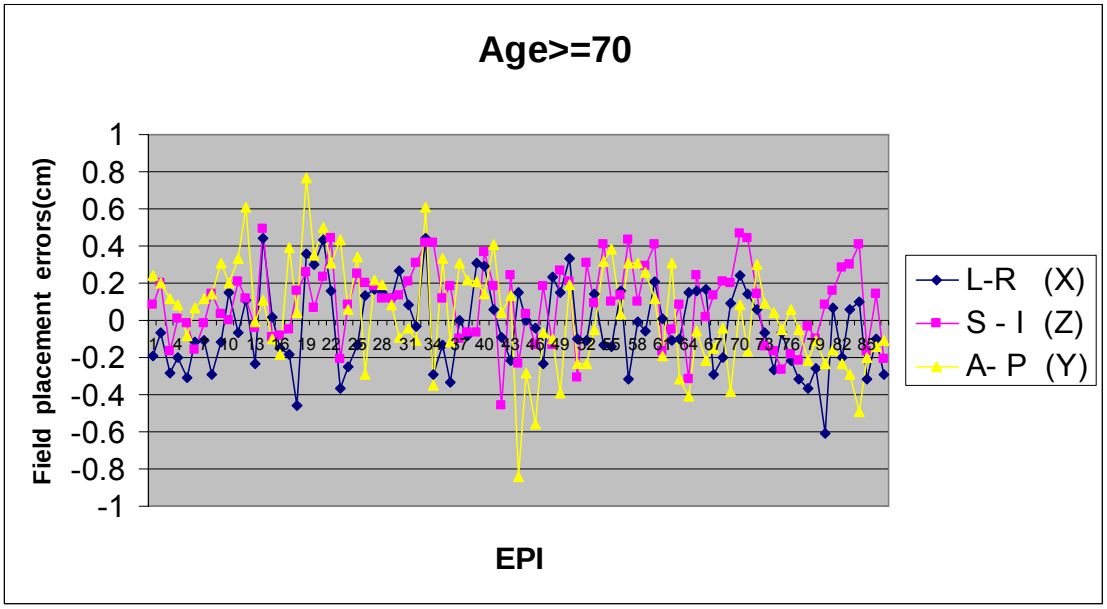


Figure 5.8 Set-up errors in patient Age < 70 and Age ≥ 70 from 34 patients treated with IMRT and 3DCRT in X , Y and Z direction.

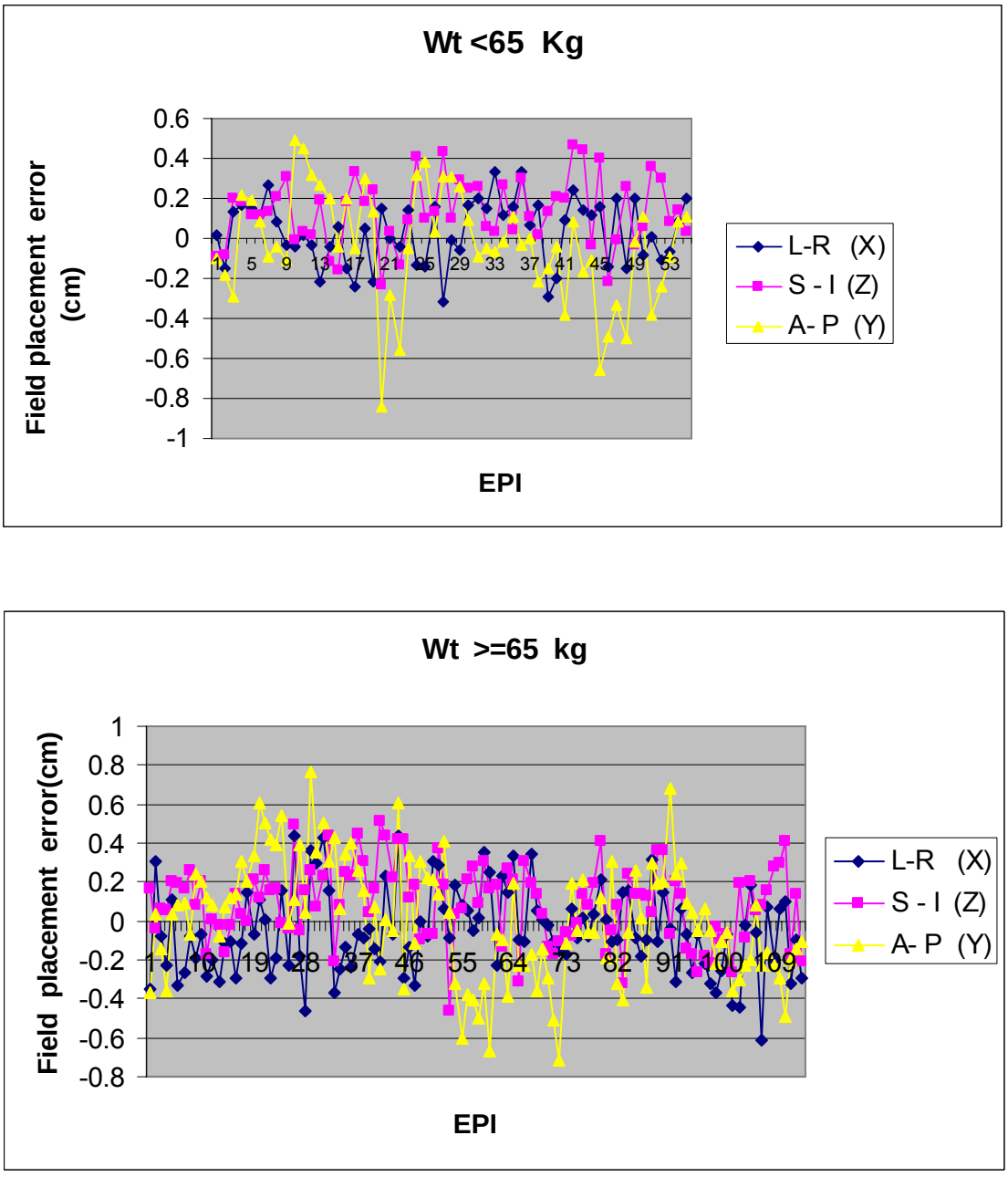
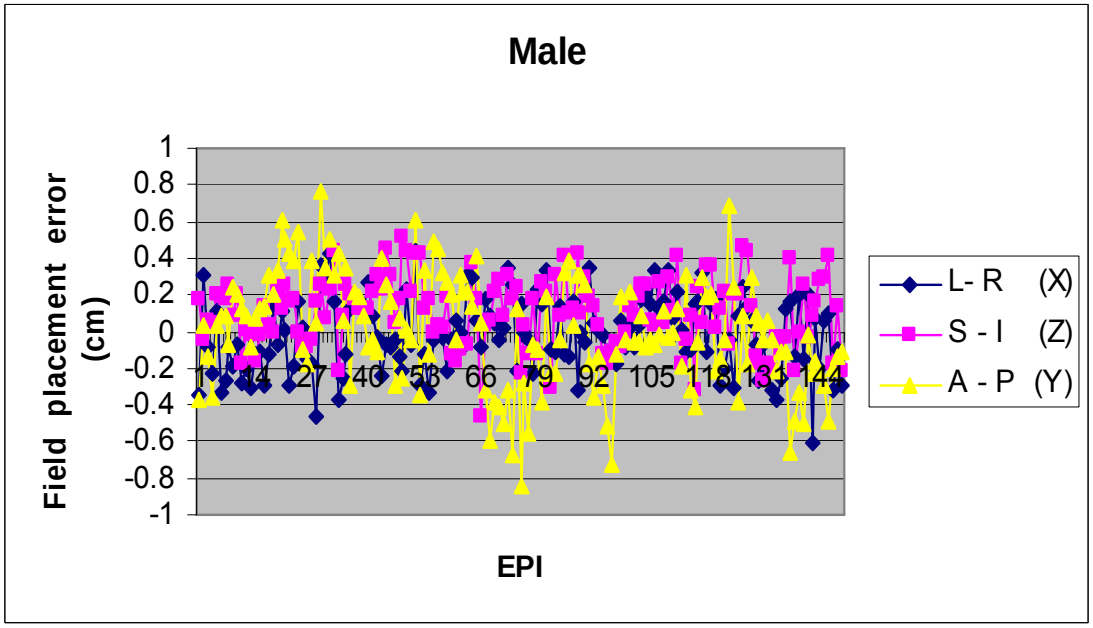


Figure 5.9 Set-up errors in patient weight <65 kg and weight ≥ 65 kg from 34 patients treated with IMRT and 3DCRT in X , Y and Z direction.



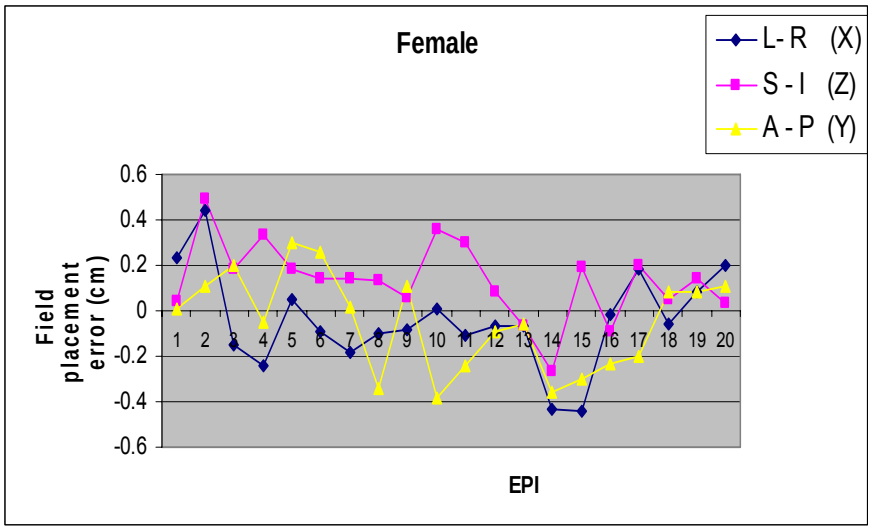


Figure 5.10 Set-up errors in male and female from 34 patients treated with IMRT and 3DCRT in X , Y and Z direction.

CHAPTER VI
DISCUSSION

6.1 DISCUSSION

6.1.1 Anatomy matching in AP and Lat pelvis .

In Radiation Oncology Division , Siriraj hospital ,we use EPIDs and Varis Vision match anatomy software to find field placement errors. There was no standard landmarks used for matching anatomy before this study. In this study we found that selected anatomy landmark for match anatomy affected the match anatomy result.

We tried to find the standardized anatomy matching landmarks. The results of our study only showed that there was no difference between 3 or 5 anatomy matching as long as pubic symphysis was included as one of the 3 structures drawn.

For AP pelvis images, except for pubic symphysis, other bony landmark selected from this study can be pelvic rim or obturator foramen or both. In other studies reviewed, some outlined anatomy matching on their own choice of appropriate bony landmarks e.g. Lewis DG et.al (20) the observers outlined their own choice of appropriate bony landmarks (eg.pelvic rim,femoral heads) on the digital simulator images. Many other studies from several authors (2),(16),(17),(19) , the bony landmark in AP Pelvis image similarly draw on the pubic symphysis and obturator foramen, but different in some bony landmark on pubic brim(19), pubic crest(16), pubic arch**,** ischial tuberosities (19) or pubic rami (17). According to our study, the results should be similar since almost all of the reports have included pubic symphysis as one of the structure drawn for anatomy matching.

In Lat pelvis images, the match anatomy result of our study on three anatomy landmark; Acetabulum , Pubic symphysis and Posterior femur had the

least difference match anatomy result compare to five anatomy landmark (Acetabulum , Anterior femur , Pubic symphysis , Posterior femur and Sacrum). From all of the studies reviewed (2,16,17,19,20), the bony landmark for match anatomy in Lat Pelvis image similarly were drawn on pubic symphysis, femoral head and sacrum. There were some anatomy landmarks that were variably used e.g. greater sciatic notch, pubic crest (16), acetabulum. (17), and coccyx (19).

The more contoured landmarks should result in more accurate anatomy matching, however, the outline 5 anatomy landmarks take time more than 3 anatomy landmark so it is not practically used in the clinic. The result of our study showed that there were no statistical significant difference between 3 and 5 anatomy landmarks for match anatomy in AP pelvic and Lat pelvis ($p > 0.05$) 95% Mann Whitney . From the study and the literature, 3 good anatomy landmarks are good enough for anatomy matching. It also takes less time and more convenient to be used routinely.

The result of bony anatomy drawn are affected by the image quality of electronic portal images. To highlight the bony anatomy, all images should be processed using filter or window and level adjustment. The quality of EPIDs also depends on calibration. In siriraj, we have routine two weekly calibration of a dark-field image (acquired with no radiation passing through the cassette and a flood-field image (acquired with radiation passing through the cassette) for EPIDs.

There were no statistically significant difference in the inter observer variability between 3 RTTs and 1 radiation oncologist in matching anatomy by using 5 anatomy landmarks in 5 pelvis irradiation patients. We concluded from our study that appropriately trained RTT performs for the task of set-up error evaluation had similar degree of consistency compare to radiation oncologist or other individualize trained RTT.

This is similar to literature reports: Lewis DG et al (20) reported good agreement in study of 9 trained RTTs matching the anatomy landmark in four pelvis patients using EPID to evaluated field placement errors in two orthogonal direction of each portal images. Barthelet Eric et al (9) reported the good inter-observer consistency by 6 trained RTTs matching anatomy landmark

evaluated the field placement errors using EPID in 20 patient treated with prostate cancer.

The standard deviation of the six observers' measurements within each image were 0.7, 1.0, 1.7 and 1.4 mm for AP image (L-R)direction, AP image(S-I) direction , Lat image (A-P) direction and Lat image (S-I) direction, respectively. It is noticeable that Lateral images quality is still the problem, there are more errors in the lateral pelvic image matching and also the consistency of anatomy drawn on lateral images showed more inconsistency. Hence for Z direction comparison, we should strict to AP image, and for lateral image we needs to adjust the image qualities to minimize the error from anatomy matching.

6.1.2 Set-up error analysis

Our study found that the set up errors was greatest in A- P direction (-8.4mm to 7.7mm) followed by L- R direction (-6.1mm to 4.4 mm) and S – I direction (-4.6 mm to 5.1 mm)

Population systematic errors ($\sum_{POP}$) and the **population random errors (σ_{POP})** ranged from **1.2-2.4 mm** and **1.7 - 2 mm** respectively. The largest systematic errors was in A- P direction 2.4 mm, followed by L- R direction 1.3 mm, and S – I direction 1.2 mm. For population random errors, A-P direction still had the maximum error of 2 mm, followed by S- I direction 1.9 mm, and L– R direction 1.7 mm.

The result from this study , was comparable to the other studies , **Hurkmans CW etal** (1) studied the report of set-up error accuracy and found that the **population systematic and random errors** (the SD of systematic and random errors) in pelvis range from **1.1- 4.7** and **1.1-4.9** mm , respectively and **Haslam JJ.et.al**.(16)reported that **the population systematic and random errors** in IMRT whole pelvic range from **1.9 to 2.6** and **2.6 to 3.7** mm respectively ,the largest errors was in the AP.

The set up errors in A – P direction measured on Lat pelvis images the larger error may result from the patient weight loss during the course of radiation and the skin mark movement .

Another important factor that can effect set-up error in AP direction is the bladder volume. In our study, we controlled bladder volume in prostate cancer patients by inform the patients to void and drink 500 ml. of water before setting the patients for CT Simulation and treat them at the same period (30 -60 minutes after drinking the water), however, our procedure did not check the actual bladder volume for each treatment. There was no bladder volume control policy in patient with pelvic diseases other than prostate cancer.

6.1.3 Margin calculation

The calculated population base margin CTV – to –PTV margin, to ensure a minimum dose to the CTV of 95% for 90 % of the patients, a margin of $2.5 \sum+0.7\sigma$ is need. In our study , the CTV – to –PTV margins were 4.6 mm in L-R , 4.2 mm in S-I and 7.4 mm in A – P direction. Recently, our routine margin (CTV-to-PTV margin) for pelvic radiation therapy are 0.8-10 mm. which should be adequate except for the target that has internal organ movement, this study was designed to study only for set-up error and not including the internal organ margin. That will be studied in the future.

Our set-up error margin was similar to the study of **Haslam JJ et al** (16) that the margin in A-P direction should be 7.3 mm. Stroom CJ et.al (23) calculated margin using different formula of $2 \sum+0.7\sigma$ for patients with gynecologic tumors , the result was similar with CTV-to-PTV margin of 7 mm.

In our study, the CTV not include the internal organ motion. The registration method only measures the shift of the bony landmark, and it has been well established that the movement of soft tissue does not always correlate with the movement of bone in the pelvis .(16)

6.1.4 Patient -specific factor

- weight (<65 , ≥65)

Our data found that there were significant difference between the patient weight under 65 kg and the patient weight equal or more than 65kg in x (L-R direction) , (P=0.01) .

In addition to soft tissue within the pelvis, for large patients the skin contour can deform greatly especially ones with loose skin, which will affect the set up and result in error of the dose distribution delivered to the patient(16). Millender LE et.al.(24) reported the setup errors in obese man (150 kg) treated with prostate cancer shown the set-up error was greatest in L-R direction (mean 11.4 mm) , S- I direction (mean 7.2 mm) and A-P direction (mean 2.6 mm). That is similar to our result that L-R direction is the set up direction that we have to be very careful in obese patients. Our study did not show the effect of obesity in other direction since Thai people are mostly small and the cut point value that we used for overweight patients was just 65 kg which is less than half of Millender's report.

6.1.5 Immobilization
(Vacuum-lock ,No Vacuum-lock)

There were significant difference in set up errors between the patient treated Vacuum lock group and no immobilization group in A-P direction (y)

Similarly to the studied Kneebone A et al (2) ,Bentel GC. et.al. (18) and Mitine C et al (22) , who reported that the immobilization helps to reduce the set up error in A-P direction. Kneebone A. et.al (2) reported that Uvex cast of the pelvis, along with the used of ankle and shoulder stabilizing devices, the immobilization improve the accuracy of treatment delivery for the prone position patients. The average simulation to treatment isocenter deviation was 8.5 mm in control group and 6.2 mm in immobilization group (p <0.001).

Bentel GC. et.al. (18) studied the used of **hemibody foam casts** in supine position, **compared to no fixation** in prostate irradiation. He found small improvement of the reproducibility in A-P direction.

Mitine C et al (22) studied the distribution of set up errors for patients treat with and without two rigid partial immobilization for pelvic malignancies. They found that an alpha- cradle or orfit - cast immobilization devices improve the reproducibility for pelvic field in x , y and z direction.

CHAPTER VII
CONCLUSION

In conclusion, our study showed that the set-up errors in patient treated with 3DCRT and IMRT in Siriraj Hospital is greater in y (A – P direction) with maximum -8.4 mm follow by x (L-R direction) -6.1 mm and the z (S- I direction) 5.1 mm respectively. The population systematic errors ($\sum_{POP}$) and the population random errors (σ_{POP}) also were highest in y (A – P direction) 2.4 mm and 2 mm respectively similarly to the literature reported. The calculated CTV-to PTV margin was 7.4 mm. It shows that our current margin routinely used in Siriraj Hospital (8-10 mm) provide adequate coverage.

Sex (male and female) and age ($< 70, \geq 70$) were not effect to the set-up error for this study. The immobilization (Vacuum-lock) had the effect in set up error on A-P direction. The weight (<65 kg, ≥ 65 kg) had the effect in set up error on L-R direction.

Trained RTTs performed the task of set-up error evaluate using EPIDs got good consistency with radiation oncologist. Three anatomy landmark drawn for anatomy matching is enough for anatomy matches as long as pubic symphysis is included in both AP and lateral images.

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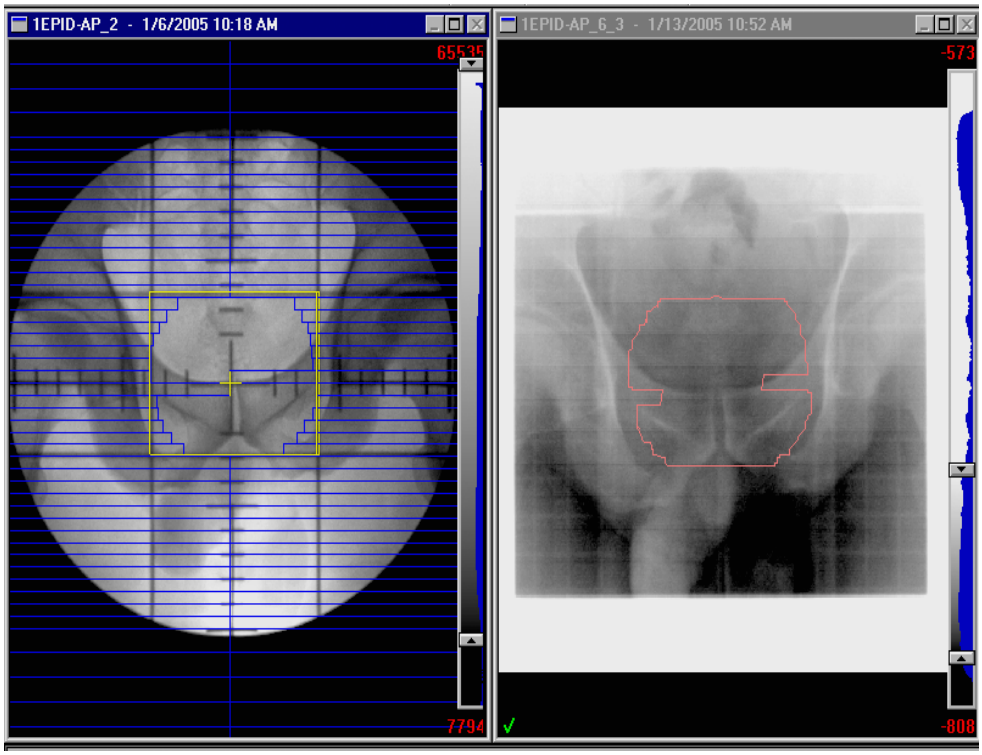
APPENDIX

APPENDIX A

แบบสอบถามการเลือกตำแหน่งการวาด Match Anatomy

ภาพ AP Field

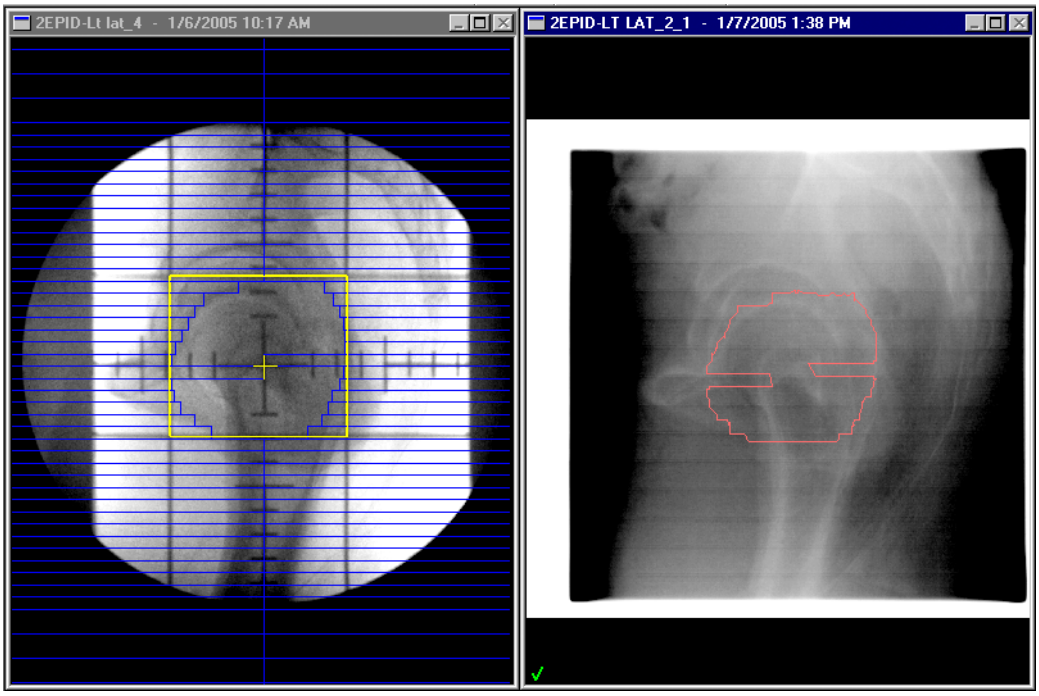


ตำแหน่งที่ท่านเลือกวาด Match Anatomy ระบุตำแหน่งและวาดลงบนภาพ

1.
2.
3.

แบบสอบถามการเลือกตำแหน่งการวาด Match Anatomy

ภาพ Lat Field



ตำแหน่งที่ท่านเลือกวาด Match Anatomy ระบุตำแหน่งและวาดลงบนภาพ

1.
2.
3.

APPENDIX B

TABLE A1

Match anatomy result.

1. Patient name:
2. ID:
3. Age:
4. Weight:

Date	Fraction	Bony Structure	Field placement error		
			L - R (X)	S - I (Z)	A - P (Y)

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