A STUDY OF THE ACCURACY OF RECONSTRUCTED BRACHYTHERAPY SOURCE CONFIGURATIONS USING C-ARM X-RAY UNIT, X-RAY SIMULATOR AND CT SCANNER

CHAIYASIT SANITKLANG

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE
(RADIOLOGICAL SCIENCE)
FACULTY OF GRADUATE STUDIES
MAHIDOL UNIVERSITY
2008

Thesis

Entitled

A STUDY OF THE ACCURACY OF RECONSTRUCTED BRACHYTHERAPY SOURCE CONFIGURATIONS USING C-ARM X-RAY UNIT, X-RAY SIMULATOR AND CT SCANNER

……
Mr.Chaiyasit Sanitklang
Candidate

...……..
Assoc.Prof.Yaowalak Chansilpa,
M.D.
Major-Advisor

..……..
Asst.Prof.Chumpot Kakanaporn,
M.Sc.(Medical Physics)
Co-Advisor

...……..
Assoc.Prof.Lalida Tuntipumiamorn,
M.Sc.(Radiological Science)
Co-Advisor

……..……
Asst. Prof. Auemphorn Mutchimwong,
Ph.D.
Acting Dean
Faculty of Graduate Studies

..……..
Assoc.Prof. Nopamon Sritongkul,
M.Sc.(Biochem.)
Chair
Master of Science Programme
in Radiological Science
Faculty of Medicine,
Siriraj Hospital

Thesis

Entitled

A STUDY OF THE ACCURACY OF RECONSTRUCTED BRACHYTHERAPY SOURCE CONFIGURATIONS USING C-ARM X-RAY UNIT, X-RAY SIMULATOR AND CT SCANNER

was submitted to the Faculty of Graduate Studies, Mahidol University

For the degree of Master of Science (Radiological Science)

On

May 16, 2008

..……
Mr.Chaiyasit Sanitklang
Candidate

…….
Assoc.Prof.Sivalee Suriyapee,
M.Eng.(Nuclear Technology)
Chair

……..
Assoc.Prof.Yaowalak Chansilpa,
M.D.
Member

…….
Assoc.Prof.Lalida Tuntipumiamorn,
M.Sc. (Radiological Science)
Member

……..……
Asst.Prof.Chumpot Kakanaporn,
M.Sc. (Medical Physics)
Member

…….
Asst. Prof. Auemphorn Mutchimwong,
Ph.D.
Acting Dean
Faculty of Graduate Studies
Mahidol University

……..……
Clin.Prof.Teerawat Kulthanan,
M.D.,FRCST.
Dean
Faculty of Medicine
Siriraj Hospital,
Mahidol University

ACKNOWLEDGEMENTS

The success of this thesis can be attributed to the extensive support and assistance from my major advisor, Assoc. Prof. Yaowalak Chansilpa, and my co-advisor, Assist. Prof. Chumpot Kakanaporn, Assoc. Prof. Lalida Tantipumiamon, for their valuable advice, encourangement and assistance thoughout the course of this research. In addition, I also wish to express deep appreciation to Assist. Prof. Surat Vinijsorn, Chief Physicist, Division of Radiation Oncology, Department of Radiology, Faculty of Medicine, Siriraj Hospital for his suggestions and comments.

I am also thankful to everybody in Division of Radiation Oncology, Department of Radiology, Faculty of Medicine, Siriraj Hospital for the technical help and good collaboration during the data collections. And especially thank is expressed to Miss Kanitta Kamplong, Miss. Sunan Armaratana, for her advice in the using of C-Arm x-ray unit and Computerized Radiation Treatment planning HDR system, Miss Lukkana Apipunyasopon, for her helpful during the experiments.

I would like to many thanks Assoc. Prof. Malulee Tuntawiroon, Director of School of Radiological Science for valuable opportunity and comment in research proposal.

I would like to thank the technical help during data collection and good cooperation form all therapists, engineers, and staffs in Division of Radiation Oncology, Department of Radiology, Faculty of Medicine, Siriraj Hospital. Special gratitude is expressed to Miss Lukkana Apipunyasopon, Miss Khummook Krongyuth and Miss Piyanan Leamookda for helpfulness and always friendly.

Finally, I am grateful to my family for their financial supports, entirely care, and love. The usefulness of this thesis, I dedicate to my family, friends, all guidance persons and all the teachers whose inspiration has nurtured my life and knowledge.

Chaiyasit Sanitklang

A STUDY OF THE ACCURACY OF RECONSTRUCTED BRACHYTHERAPY SOURCE CONFIGURATIONS USING C-ARM X-RAY UNIT, X-RAY SIMULATOR AND CT SCANNER

CHAIYASIT SANITKLANG 4836288 SIRS/M

M.Sc. (RADIOLOGICAL SCIENCE)

THESIS ADVISORS: YAOWALAK CHANSILPA, M.D., CHUMPOT KAKANAPORN, M.Sc. (MEDICAL PHYSICS), LALIDA TUNTIPUMIAMORN, M.Sc. (RADIOLOGICAL SCIENCE)

ABSTRACT

In brachytherapy exact information of the implant or applicator geometry is necessary for an accurate calculation of dose to tumor and critical organs. Traditionally, the imaging geometry can be obtained from the computed tomography (CT) scanner and conventional x-ray simulator. To avoid moving the patient, the C-arm x-ray unit has become an imaging modality of choice for brachytherapy planning. The aim of this study is to assess the accuracy of brachytherapy source reconstruction using a C-arm x-ray unit and make a comparison with the images reconstructed from x-ray simulator and CT unit for high dose rate treatment planning. The reconstruction procedures were tested by using a C-arm x-ray unit, x-ray simulator and CT scanner to measure the reconstructed accuracy, with an in-house reconstruction accuracy test phantom which containing 135 well defined position markers. With the CT scanner, the study reconstructed 1, 3 and 5 mm slice thickness images. A pair of isocentric orthogonal and variable angle x-ray images were obtained by using x-ray simulator. And a semi-orthogonal technique with the C-arm x-ray unit, with and without reconstruction jig were used to reconstruct the images. The reconstructed distances were compared with the known distances in the reconstruction accuracy test phantom. The average reconstruction accuracies were 0.17 mm and 1.63 mm for the C-arm x-ray unit, with and without reconstruction jig, respectively. For the x-ray simulator the reconstruction error was less than 0.06 mm for both techniques. In the case of CT images, the average deviations for 1, 3 and 5 mm slice thicknesses were 0.05, 0.2 and 0.3 mm, respectively. This study shows that the reconstructed images from the C-arm x-ray unit, x-ray simulator and CT scanner are within acceptable limits except for the reconstruction method from the x-ray C-arm without reconstruction jig.

KEY WORDS: BRACHYTHERAPY / COMPARE ACCURACY / ACCURACY TO RECONSTRUCTED / RECONSTRUCTED BRACHYTHERAPY

91 pp

การศึกษาความถูกต้องในการสร้างภาพแหล่งกำเนิดรังสีระยะใกล้ ด้วยเครื่องเอกซ์เรย์ซี-อาร์ม, เครื่องเอกซ์เรย์ซิมูเลเตอร์และเครื่องคอมพิวเตอร์โทโมกราฟฟี่ (A STUDY OF THE ACCURACY OF RECONSTRUCTED BRACHYTHERAPY SOURCE CONFIGURATIONS USING C-ARM X-RAY UNIT, X-RAY SIMULATOR AND CT SCANNER

ชัยสิทธิ์ สนิทกลาง 4836288 SIRS/M

วท.ม. (วิทยาศาสตร์รังสี)

คณะกรรมการควบคุมวิทยานิพนธ์ : เยาวลักษณ์ ชาญศิลป์, M.D., จุมพฏ คัคนาพร, M.Sc. (MEDICAL PHYSICS), ลลิดา ตันติภูมิอมร, M.Sc. (RADIOLOGICAL SCIENCE)

บทคัดย่อ

ในงานรังสีรักษาระยะใกล้ การทราบตำแหน่งที่แน่นอนของต้นกำเนิดรังสีหรือเครื่องมือ มีความจำเป็นสำหรับความถูกต้องของการคำนวณปริมาณรังสีที่ก้อนเนื้องอกและอวัยวะสำคัญได้รับ โดยปกติภาพรังสีผู้ป่วยที่ได้รับการสอดใส่เครื่องมือจะได้จากเครื่องเอกซ์เรย์คอมพิวเตอร์ (Computed Tomography scanner) และเครื่องเอกซ์เรย์จำลองการรักษา (x-ray simulator unit) เพื่อหลีกเลี่ยงความผิดพลาดที่อาจเกิดจากการเคลื่อนย้ายผู้ป่วย ได้มีการนำเครื่องเอกซ์เรย์ซี-อาร์ม (C-arm x-ray unit) เข้ามาใช้ในการถ่ายภาพรังสี วัตถุประสงค์ของการศึกษาครั้งนี้ เพื่อประเมินความถูกต้องของการสร้างภาพต้นกำเนิดรังสีรักษาระยะใกล้พลังงานสูง โดยการใช้เครื่องเอกซ์เรย์ซี-อาร์ม เปรียบเทียบกับเครื่องเอกซ์เรย์จำลองการรักษา และเครื่องเอกซ์เรย์คอมพิวเตอร์ ขบวนการสร้างภาพจะถูกทดสอบ และวัดความถูกต้องโดยใช้แฟนธอมสำหรับทดสอบที่ประดิษฐ์ขึ้นเอง ภายในแฟนธอมประกอบด้วยตำแหน่งของ markers ที่ทราบตำแหน่งที่แน่นอนทั้งหมด 135 ตำแหน่ง สำหรับภาพที่สร้างด้วยเครื่องเอกซ์เรย์คอมพิวเตอร์จะใช้ภาพตัดขวางที่ความหนา 1, 3 และ 5 มิลลิเมตร ส่วนภาพที่ได้จากเครื่องเอกซ์เรย์จำลองการรักษาจะใช้เทคนิคการสร้างภาพแบบ orthogonal และvariable angle โดยนำข้อมูลจากเครื่องมือและวิธีการข้างต้นมาทำการเปรียบเทียบกับภาพที่สร้างจากเครื่องเอกซ์เรย์ซี-อาร์มด้วยเทคนิค semi-orthogonal ทั้งที่ใช้และไม่ใช้ reconstruction jig ในการสร้างภาพ เมื่อเปรียบเทียบระยะห่างระหว่าง marker 2 ตำแหน่งที่ทราบค่า กับค่าที่วัดได้จากภาพที่สร้างด้วยวิธีการต่างๆ พบว่าค่าความผิดพลาดเฉลี่ยจากการสร้างภาพด้วยเครื่องเอกซ์เรย์ซี-อาร์มเมื่อใช้และไม่ใช้ reconstruction jig เท่ากับ 0.17 และ 1.63 มิลลิเมตร ตามลำดับ สำหรับภาพที่สร้างจากเครื่องเอกซ์เรย์จำลองการรักษาทั้งสองเทคนิคดังกล่าว ให้ค่าความผิดพลาดเฉลี่ยประมาณ 0.06 มิลลิเมตร และการสร้างภาพจากเครื่องเอกซ์เรย์คอมพิวเตอร์ภาพตัดขวางที่ความหนา 1, 3 และ 5 มิลลิเมตร ให้ค่าความผิดพลาดเฉลี่ย 0.05, 0.2 และ 0.3 มิลลิเมตร ตามลำดับ จากการศึกษานี้แสดงว่าการสร้างภาพด้วยเครื่องเอกซ์เรย์ซี-อาร์มร่วมกับการใช้ reconstruction jig, เครื่องเอกซ์เรย์จำลองการรักษา และเครื่องเอกซ์เรย์คอมพิวเตอร์ ให้ค่าอยู่ในช่วงที่สามารถยอมรับได้ ยกเว้นการสร้างภาพด้วยเครื่องเอกซ์เรย์ซี-อาร์มที่ไม่ได้ใช้ reconstruction jig

91 หน้า

CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

Page

LIST OF TABLES (Continued)

Page

LIST OF FIGURES

LIST OF FIGURES (Continued)

Page

LIST OF FIGURES (Continued)

Page

LIST OF ABBREVIATIONS

Abbreviations	Term
ABS	American Brachytherapy Society
ACR-NEMA	American College of Radiology - National Electrical Manufacturers Association
AP	Anterior-Posterior
BPS	Brachytherapy planning system
Ci	Curie
cm	Centimeter
cm^2	Square centimeter
cm^3	Cubic centimeter
CT	Computed tomography
DICOM	Digital Imaging and Communication in Medicine
e.g.	for example
etc.	And other things(Et cetera)
FFD	Focus to Film Distance
FID	Focus to Isocenter Distance
FRD	Focus to Rotation Distance
GE	General Electric
HDR	High Dose Rate
IBU	Integrated Brachytherapy Unit
IFD	Isocentre-film Distance
II	Image intensifier
Ir-192	Iridium-192
LAO	Left Anterior Oblique
LAT	Lateral
LDR	Low Dose Rate

LIST OF ABBREVIATIONS(Continued)

Abbreviations	Term
Lt	Left
m_{AP}	Magnification factor of the AP image
m_{LAT}	Magnification factor of the LAT image
min	minute
mm	millimeter
mm^2	Square millimeter
MRI	Magnetic Resonance Imaging
No	Number
ORC	Orbital rotational center
OS	Observed survival
PA	Posterior-Anterior
QA	Quality Assurance
QC	Quality control
R	Rotate point of c-arm
RAO	Right Anterior Oblique
Rt	Right
S	Second
SAD	Source to axis Distance
SDD	Source to detector Distance
SI	Superior-inferior
Sig	Significant
SSD	Source to Surface Distance
TRS	Technical Reports Series
α	Gantry angle beam1
β	Gantry angle beam2

CHAPTER I
INTRODUCTON

In brachytherapy, data, such as a radiation source position, are needed and the error accompanying these influences the dose prescribed for the patient. The error of the position in the reconstruction whose influence is especially large is made the subject here. There are a two-orthogonal radiography method and a stereo-shift-projection method which has been used for many years most as the simple method of position determination of the small radiation source. The causes of the error of a reconstructed position are the movement of the patient in the radiography, the error in reading of the radiograph and the imperfection of the device such as a simulator. Furthermore, the distance between the focus and the film, the distance of the focus and the origin of the spatial coordinate, a magnification factor, and so on have an influence as an uncertain element. Even if the correct formula obtained geometrically is used, these errors are spread in the calculated position. The formulas which errors are greatly expanded are in the formulas reported until now. In order to improve or maintain the accuracy of position acquisition, quality control and a assurance of quality are important. An influence on the formula of the reading error of the verification radiogram and the various errors is taken into consideration here.

Check items along with the position calculation

1.1. Equipment

Most simple C arm X-ray units are used for position acquisition, and a radiographs are taken from two or more directions. The two orthogonal radiography which can be performed easily is mainly used for the daily treatment. Also a simulator is used to obtained images and its imaging geometry is exactly known. And some situation of brachytherapy treatment planning need computed tomography (CT) scanner for image reconstruction.

1.2. Radiography

The error of the position reconstructed by the two-orthogonal-radiography method is smaller than the error by the shift-projection method. A gap of an angle setup decreases by preparing a lock. In a two orthogonal radiography, a lock is prepared in the place of 0 degree and 90 degrees. In the intracavitary radiotherapy of the carcinoma of the uterine cervix, when taking two X-ray radiographs by the C-arm x-ray unit, the interval of the radiography is usually about 1 minute. If a patient moves between them, it will spread as an error in a radiation source position, and the influence on a treatment planning will pose a problem. The radiography of those other than the right-angled two directions is also possible by C-arm x-ray unit. It is necessary to match each point of space with each X-ray radiograph. There are two methods for the shift-projection method, one is the method of carrying out double exposures to one film, and the other is the method of carrying out the exposure to two films separately. A shift-projection method takes cautions to the. position of the marker of the two-film method. The position of a marker and the two exposure positions of a X-ray tube become about an isosceles triangle, and there are many methods which the triangle must be perpendicular to the film surface.

In order to obtain the dose distribution around an implant or application, the exact position of each source or dwell position in space must be known. For the reconstruction of the source localizations by a treatment planning program, different techniques are available.

1.2.1 Orthogonal reconstruction method

The most widely used radiographic method for source localization is the orthogonal reconstruction method [1]. Two plane radiographs of the implant are taken in a lateral and AP orientation. Either a radiotherapy simulator is used or a localization box with cross-wires on the faces of the box is placed over the patient, figure 1. In the latter case the beams are aligned such that the X-ray images of opposing cross-wires coincide. The advantage of this technique is that AP and lateral radiographs are easily interpreted by the physician. A disadvantage is, however, that sources or X-ray markers in the lateral X-ray film are often difficult to distinguish, particularly in the pelvic region, due to the thickness of tissue and the overlying bony structures.

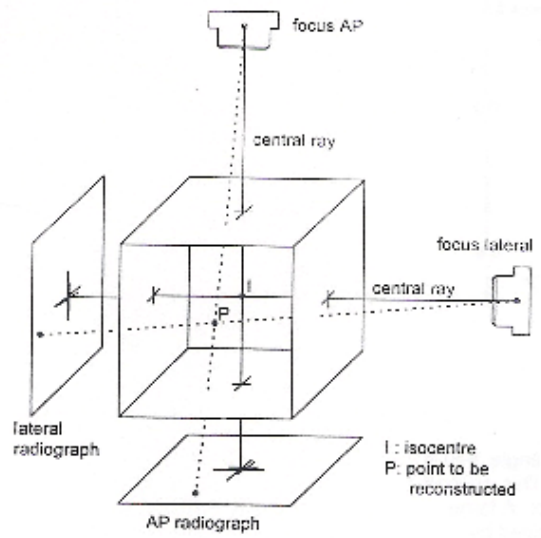


Figure 1. The geometry of orthogonal reconstruction. The beam set-up is obtained by calculation of the localization of the AP and lateral X-ray foci from the cross-wire images on the radiographs.

1.2.2 Semi-orthogonal reconstruction method

Truly orthogonal orientations for the AP and lateral film are not easily obtainable with portable X-ray units. In the semi-orthogonal reconstruction method a reconstruction jig with AP and lateral cross-wires, is placed over the patient and two radiographs (a lateral and AP) are taken, figure 2. It is not necessary for these to be truly orthogonal, since the set-up information will be determined by the computer from the size and the relative distances of the cross-wire lead marker images on each of the two films. This method, therefore, accepts X-ray beams whose central axes do not intersect and are not perpendicular to one another. The only requirement is that the projections of the cross-wires on the two corresponding box faces are visible on the radiographs.

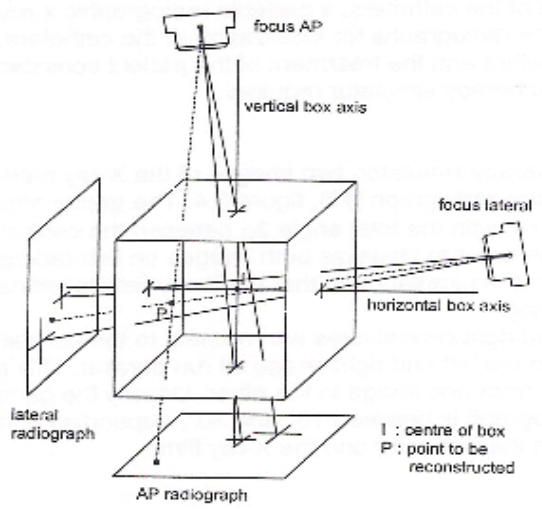


Figure 2. The beam set-up of semi-orthogonal reconstruction

1.2.3 Isocentric reconstruction method

With an isocentric X-ray unit, such as a radiotherapy simulator, two images of the X-ray markers in each catheter can be obtained on a single, large size radiograph [1], figure 3. The gantry angle of the first X-ray beam is -α and of the second beam is +α, with the total angle 2α between the central axes of the projecting

beams taken as large as possible. In order to visualize both images on this radiograph, it is essential that the isocenter is placed in the center of the implant and that the X-ray field is defined such that the two images on the radiograph do not overlap.

Due to the equal angles between the left and right central axes with respect to the normal to the radiograph, lines between corresponding points on the left and right image all run parallel. This aids in the determination of individual seed or dwell positions from one image to the other. Usually the gantry angle of each image with respect to the normal of the radiograph is between 15^0 and 30^0, depending on the extension of the implant and the distance between the isocenter and the X-ray film.

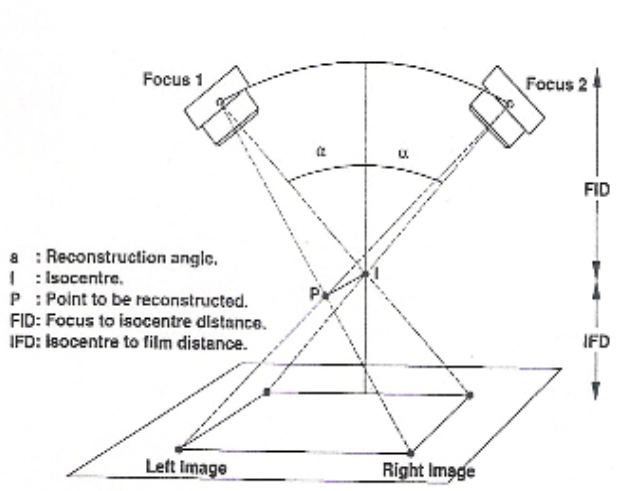


Figure 3. The geometry of radiographs used in the isocentric reconstruction.α = reconstruction angle. FID = focus to isocenter distance. IFD = isocenter to film distance. This method requires an isocentric X-ray unit such as a treatment simulator. The beam set-up is obtained by rotating the gantry over an angle of +α and - α, with α preferable in the range of 15^0 - 30^0.

1.2.4 Variable angle reconstruction method

This method reconstructs the localization of the catheters from two radiographs taken with a therapy treatment simulator [2], figure 4. The only limitation is that the central axes of the projecting beams are not coinciding nor opposing. The reconstruction algorithm requires that the angle, focus-isocenter distance and isocenter-film distance of each radiograph are accurately known. The advantage of this technique is that the implant can be observed fluoroscopically at various gantry angles to define the two gantry angles that display the sources or localization dummies with the highest clarity and least obstruction. It is preferred that the total angle between the two projecting beams lies between 60^0 and 120^0. Of course, the greatest accuracy is obtained when this total angle is 90^0. The orthogonal reconstruction method is a special case, e.g. with gantry angles 0^0 and 90^0.

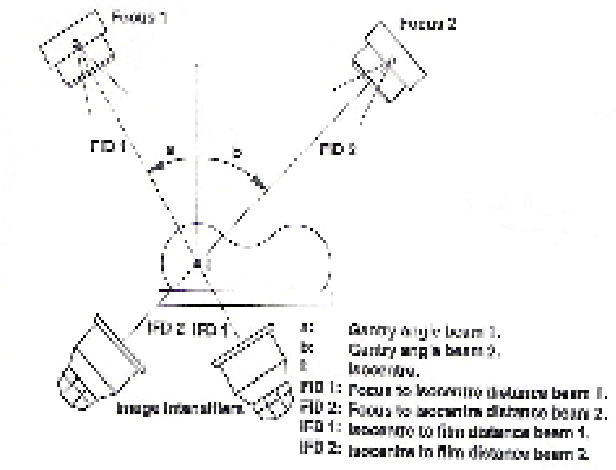


Figure 4. Variable angle reconstruction. α = gantry angle beam 1. β = gantry angle beam 2. FID i = focus to isocenter distance beam i. IFD i = isocenter to film distance beam i. The two gantry angles a, and p are determined such that the catheters are clearly visible on the image intensifier. The total angle $\alpha + \beta$ should preferable lie between 60^0 and 120^0.

1.2.5 Stereo-shift reconstruction method

The set-up is similar to the isocentric method, but, instead of the X-ray tube rotating, it is moved laterally over a given distance [1]. This method is applicable, for instance, with a ceiling mounted X-ray unit where such a lateral movement is available. Usually, the angle between the two projecting beams is very small, typically 7^0, which makes this method very sensitive to even small errors in the measuring of the source images or a small movement of the patient between the taking of the radiographs. If possible, this reconstruction method should be avoided.

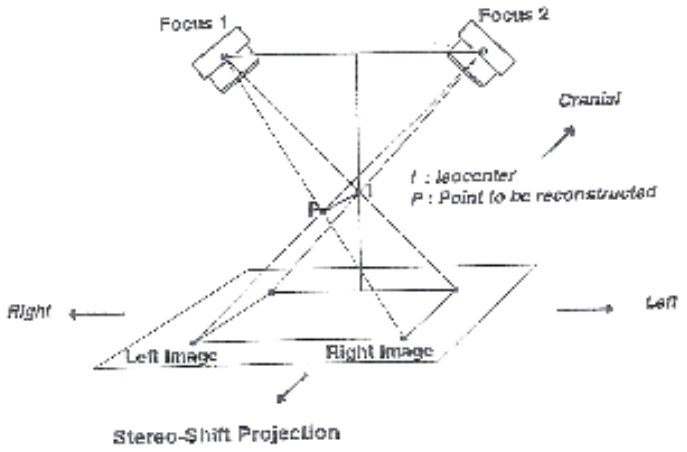


Figure 5. The geometry of radiographs used for source localization in stereo-shift reconstruction method .

CHAPTER II
OBJECTIVE

The objectives of this study are:

1. To compare the localized brachytherapy source reconstruction in the HDR treatment planning by X-ray C-Arm, conventional simulator and CT scanner.
2. To study the reconstruction accuracy of x-ray marker using C-Arm images, with and without a commercial reconstruction jig.

CHAPTER III
LITERATURE REVIEW

The actual source arrangement for brachytherapy is usually decided on the basis radiographic projections obtain in two different directions. However, error or inconsistencies in the image coordinates read from the radiographs can happen for such reasons as patient's movement between the two images, uncertainties in magnification, and the mutual angle between the two radiographic projections. Many workers have outlined various geometrical formulas to infer the position coordinates of seeds in implants for brachytherapy [3], [4], [5], [6], in angiography [7], [8], [9], [10] and other miscellaneous contexts [11]. Metz and Fencil [9] have described several utilizations of the least-squares method to determine 3-D object structure from biplane views of unknown orientation. Moreover, they have suggested that object point can be determined from any three of four consistent linear equations [8].

In 1992, Tabushi K et al [12], interpreted six possible geometrical solutions, and then described a least-squares method for an optimum determination of spatial coordinates. When two radiographic projections were available for reconstruction, it was found that six different combinations of equations could be used to obtain the geometrical solutions for the position of any point. No error in the image coordinates read from radiographs resulted in identical solutions for the six equations. Inaccuracies or errors presented in the image coordinates generated differences among the six solutions. In this case, a least-squares method could be used to determine the optimum position. The utility of such a least-squares optimizing approach was presented in the context of a clinical example.

Then Kolkman-Deurloo et al [13] have examined the reconstruction error using film and on-line images from the integrated brachytherapy unit (IBU). This localizer is isocentric and has an extra degree of freedom in comparison to conventional simulator. They tested the reconstruction accuracy with a 25 markers well defined

position phantom. The study has showed that accurate implant reconstruction was possible using the IBU localizer in combination with the IBU reconstruction algorithm.

Zuofeng Li [14], have developed an algorithm for automatic source localization from postimplant CT images in 2001. The only requirement of this algorithm was knowledge of the number of seeds present in the prostate, thus minimizing the need for human intervention. The algorithm processes volumetric CT data from the patient, and pixels of higher CT numbers were categorized into classes of definite and potential source pixels. A multithresholding technique was used to further determine the number of seeds and their precise locations in the CT volume data. A graphic user interface was developed to facilitate operator review of intervention in the calculation and the results of the algorithm. This algorithm was tested on two phantoms containing non-radioactive seeds, one with 20 seeds in discrete locations and another with 100 seeds with small distances between seeds. The algorithm proved to be quite accurate in localizing seeds in this phantom, at either 1.5 mm or 3.0 mm CT slice thickness. The seed coordinates determined by the software system, using bilinear interpolation of pixel values, agreed with those measured of the phantom to within 1 mm. The tests showed that the algorithm was able to identify the seed locations to within 1 mm of their physical locations for discrete seed locations. It was further able to separate seeds at close proximity to each other while maintaining an average seed localization error of less than 2 mm, with no operator intervention required.

The main problem of a non-isocentric C-arm machine with the variation of the C-arm angle is that the isocenter does not remain in the same position. So in 2001, Cuijpers JP [15] described how a mobile non-isocentric C-arm used to reconstruct brachytherapy applicators using an ‘isocentric’ imaging set-up without using a reconstruction box. He used a non-isocentric C-arm with minor adjustment and a simple method to make use of the relation between the magnification factor and the translational degrees of freedom of the C-arm with a phantom to determine the overall reconstruction accuracy. The images were on-line digitally transferred to the treatment planning system, then reconstructed the brachytherapy applicators isocentricly. His result showed that the accuracy in the reconstruction of the distance of two points was better than 1 mm when using radiograph. When the digital images were used, the maximum error in reconstructed distances equals 3.6 mm for point located in the

corner of the field of view, while the errors in the central part of the field were less than 2 mm.

In 2002, Fung AYC. [16] from Memorial Sloan-Kettering Cancer Center, New York has also studied the brachytherapy source reconstruction accuracy using C-arm images with the phantom embedded with dummy ribbons in a regular pattern. They examined C-arm reconstruction with and without a commercial localization jig. The average error in seed reconstruction was 0.1 cm with a reconstruction jig. And he also examined the reconstruction without the jig, it might provide accurate reconstruction if the images were stretched along one direction to give the same magnification for two orthogonal images.

Palvolgyi J [17] examined the extent to which the potential of a C-arm x-ray unit as a brachytherapy localizer for gynaecological treatments in 2003. He has been published the clinical application of the non-isocentric C-arm using variable angle reconstruction method. The accuracy of the reconstruction has been examined with phantom studies and therapy plans of Fletcher-Suit applications of different variable angles. The error of the measured distances has been less than 1 mm in the central region, while the image intensifier has showed significant distortion (2.5 mm) at the picture edges and corners. So they used the low distortion region for the treatment planning.

2003, Liu et al has also published a new approach for utilizing the C-arm fluoroscopy for brachytherapy treatment planning using the virtual isocenter reconstruction method. Distortion in the fluoroscopic images, with its major component the “pincushion” effect were removed using a software program developed in house that employed a seven parameter polynomial filter. The method provided adequate geometric reconstruction accuracy for both phantom test and clinical application. The filmless process greatly reduced the overall time needed for treatment planning.

CHAPTER IV
MATERIALS AND METHODS

4.1 MATERIALS

4.1.1 The Plato Brachytherapy Treatment Planning System

The PLATO brachytherapy treatment planning system, software V14.2 (Nucletron International B.V., Veenendaal, The Netherlands) was used. It is a tool designed to calculate the treatment times based on a physicians prescription for Nucletron remote afterloading equipment. The physician is responsible for the proper clinical use of the software output and prescribed radiation dose. Prescribing and administering an unsuitable radiation dose may lead to clinical complications. Aid to finding correspondence between two points on two separate images. When place a point in one image, the blue correspondence line in the other image indicates the horizontal on which should place a corresponding point. On the first occasion that place two points, however, the blue correspondence line will not appear until you have placed the corresponding point; this is to let you take into making of the images.

4.1.2 The C-arm x-ray unit

The mobile C-arm x-ray machine figure 6 used in this study is a model OEC 9800 C-arm manufactured by GE OEC Medical Systems, Waukesha, Wisconsin, USA. It has both fluoroscopy and spot x-ray capability. Its image intensifier (II) has a diameter of 9 inches featuring a $1k \times 1k$ digital resolution. The x-ray target to II distance is nominally 100 cm, and the clearance from the bottom of the target housing to the II is 80 cm. The workstation for the C-arm is Ethernet ready, allowing for the direct transfer of digital fluoroscopic images to a treatment planning computer through a local area network The dual monitors of the workstation allow two images to be displayed side-by-side, making image comparison a simple task. If radiographic imaging is desired a film cassette holder can be attached in front of image intensifier of the C-arm x-ray unit.

Figure 6. The GE OEC 9800 mobile C-arm x-ray unit

There are 6 degrees of rotational and linear movements allowing for the proper positioning of the device around the patient. A schematic drawing of the C-arm, illustrating its major components and movements. On the top of the C-arm unit orbit is the x-ray target, and the image intensifier is at the bottom. The C-arm unit is not an isocentric, the central axis of its x-ray beam does not pass through a fixed point in space. The C-arm orbital rotational center (ORC) as shown in figure 7 is offset from the central axis beam by a distance OS in the figure.

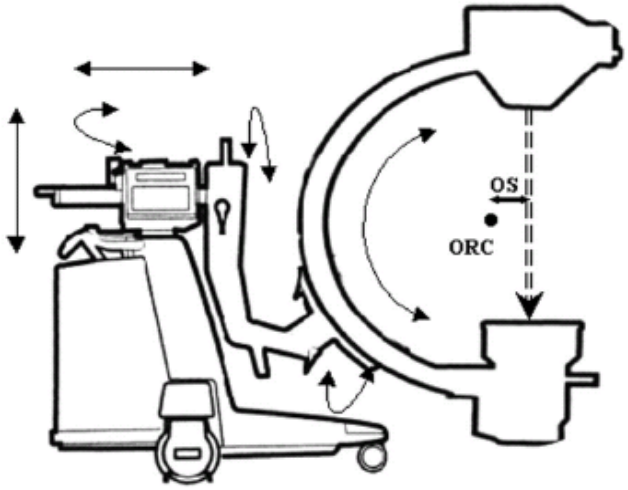


Figure 7. Schematic drawing of the GE OEC 9800 mobile C-arm with its 6 degrees of motion. Sitting on top of the C-arm orbit is the x-ray target, and at the bottom is the image intensifier (II). The C-arm is not isocentric, with the central axis of the x-ray beam offset from the orbital rotation center (ORC) by an amount OS. Such a design provides adequate clearance in the lateral direction without increasing the C-arm orbit size.

4.1.3 X-ray Simulator(Acuity)

The simulator is a useful tool for the determination of extent of disease. The tumor location is generally referenced to surface reference marks, sometime aided by radio-opaque wires or similar markers. The simulator is a isocentric and its image geometry is exactly known. The Acuity system uniquely combines planning, simulation and motion data for verifying patient plans. It is uniquely adapted to brachytherapy positioning and imaging. The Acuity imaging system pairs a high-resolution x-ray tube and a large size amorphous-silicon flat panel image detector to instantly produce and display high-resolution, distortion-free radiographic and fluoroscopic digital images on a computer workstation. Distortion-free digital fluoroscopy images are useful aids in catheter and seed placement as well as verification. Images are accessible through the brachytherapy treatment planning system and can be used immediately for treatment planning. These images also can be exported via DICOM RT to the brachytherapy planning system.

Figure 8. The x-ray simulator(Acuity).

4.1.4 The Computed Tomography Scanner (MARCONI -PQS)

The Marconi Medical Systems PQS CT system (Marconi Medical systems, Highland Heights, OH, USA) is a fourth – generation CT system, which consists of thee major components: Gantry, CT control and patient couch. Typically, the CT slice thickness and spacing are 5 mm. The number of slices varies from 20 to 40 s. One complete set of CT scans includes both anterior–posterior (AP) and lateral scout scans and a series of contiguous transverse images. There are four relevant coordinate systems. One is used to specify the coordinates of a point in the patient (space), one to specify the coordinates of a point on transverse images, one to specify the coordinates of a point on an AP scout image, and the fourth to specify the coordinates on a lateral scout image. For the sake of simplicity, 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.

Figure 9. The Computed Tomography Scanner (MARCONI -PQS).

4.1.5 The Reconstruction Accuracy Test Phantom

The phantom which is designed to the image reconstruction accuracy of the algorithm in localizing x-ray markers and its ability to separate closely located x-ray markers. The dimensions are 15x15x6 cm^3 in length, width and height respectively.

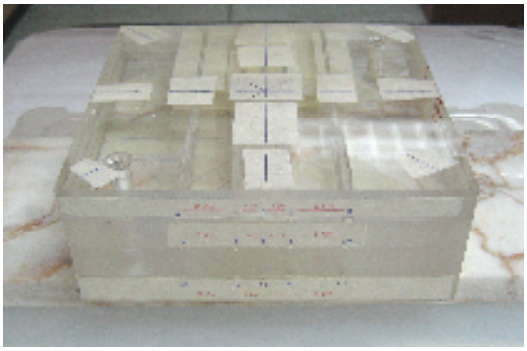


Figure 10. The reconstruction accuracy test phantom with 15 ribbon in plane of inserted x-ray marker.

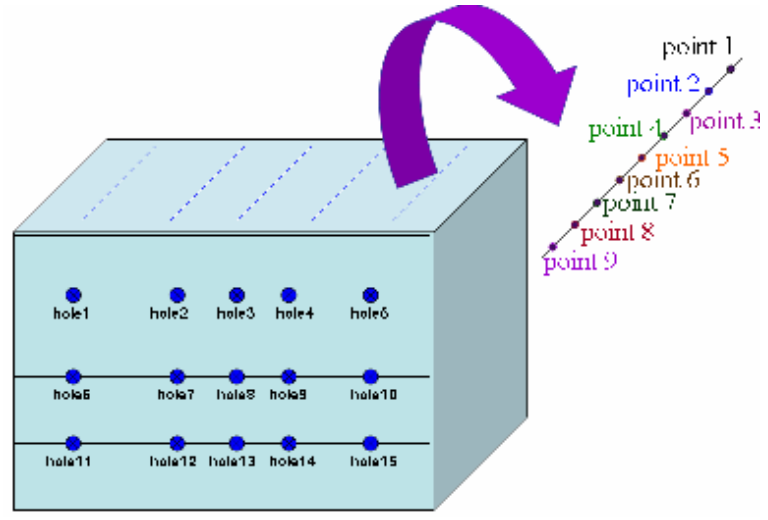


Figure 11. The schematic drawing of reconstruction accuracy test phantom.

4.1.6 Digitizer

The digitizer is a device using for input graphical data such as body control target volume and critical organ of patient to program treatment planning.

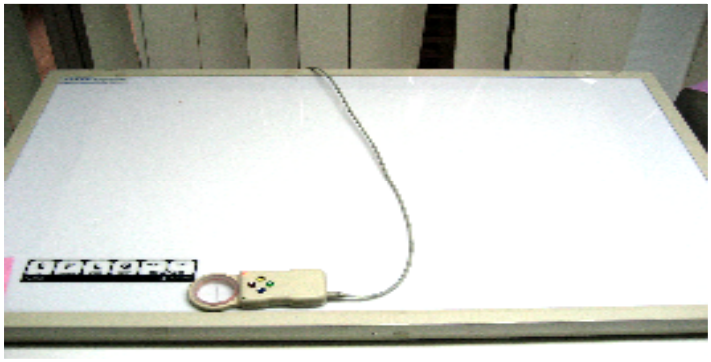


Figure 12. The digitizer with light box.

4.1.7 X-ray marker

The x-ray marker is a device using for simulated position radioactive source. Each ribbon consists of x-ray markers separated 1 cm apart.

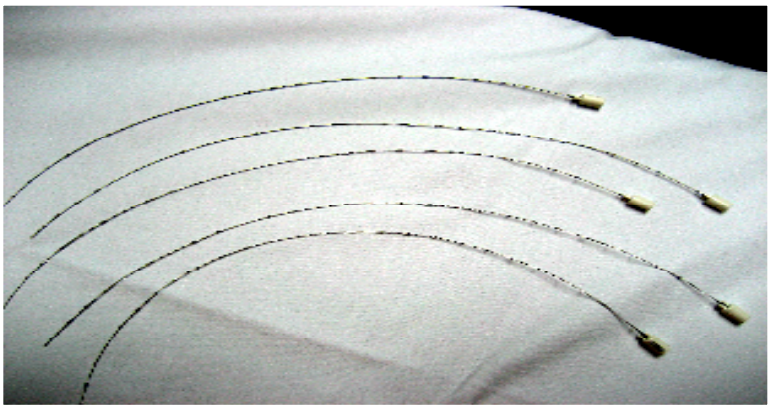


Figure 13. The x-ray marker.

4.1.8 Reconstruction jig

The reconstruction jig (Nucletron, Veenendaal, the Netherlands) consists of five transparent acrylic plates rigidly attached that around the patient. It was constructed with radiopaque initials AP and LAT within the appropriate sides of the jig . These initials will appear on the radiograph as a large AP image which corresponds to the A→P direction, and a large LAT image which corresponds to the L→R direction.

Figure 14. The jig consists of five transparent acrylic plates rigidly attached that surround the patient.

4.1.9 Printer(HP HEWLETT PACKARD)

The HP Color Laser Jet 8550N, included a 100-sheet tray 1, a 500-sheet tray , a 500-sheet tray 3, a printer stand, 32 MB RAM, an HP JetDirect print server (10/100 Base-TX), and an internal hard disk is shown in figure 14.

Figure 15. The printer HP Color Laser Jet 8550N and internal hard disk.

4.1.10 Vernier caliper

The Vernier to make possible readings even smaller than thousandths, an ingenious device is introduced in the form of an additional scale. The Vernier makes possible accurate readings to the ten-thousandth of an inch. The vernier principle may be used to get fine linear readings, angular readings, etc. The principle is always the same. The vernier has one more marking than the number of markings on an equal space of the conventional scale of the measuring instrument.

Figure 16. The vernier caliper

4.1.11 Micrometer

The Micrometer is one of the most accurate mechanical devices in common use. Because of the mechanical advantage due to the “fine pitch” of the screw threads that move the thimble and the right-hand measuring rod, it is easy to use enough force in closing the rods on the object being measured to deform either the rods or the object.

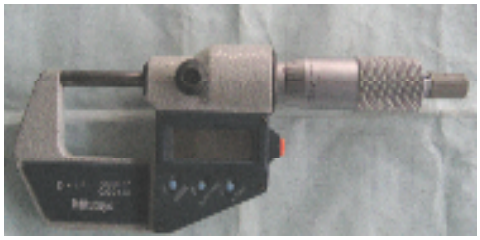


Figure 17. The Micrometer

4.2 METHODS

In order to determine the accuracy of the reconstruction using CT scanner, simulator and x-ray C-arm unit, a reconstruction accuracy test phantom has been used.

This study divides into 3 steps :

4.2.1 Construction of the reconstruction accuracy test phantom

4.2.2 The study of brachytherapy source reconstruction using CT scanner, x-ray simulator and C-arm x-ray unit images.

4.2.3 The determination of reconstruction accuracy using CT scanner, x-ray simulator and C-arm x-ray unit images.

4.2.1 Construction of the reconstruction accuracy test phantom

The phantom (figure 18), was designed to verify the reconstruction accuracy of the brachytherapy planning system algorithm. The dimensions are 15x15x6 cm^3 (length × width × height). The phantom is perspex phantom consisting of four identical slabs of 1.5 cm thickness as indicated in figure 20. The phantom embedded with ribbons of metal x-ray markers in a regular pattern. Fifteen ribbons are arranged along the plane A, B and C that shown in figure 19. Each ribbon consists of 9 x-ray markers separated 1 cm apart. The phantom implanted with 135 x-ray markers. The spacing between ribbons are 1 cm that illustrated in figure 20. Before taking the phantom images we measured accurately the 120 spacing between the x-ray markers with the vernier caliper and micrometer and record all these actual distances to be the referent distance for comparing with the reconstructed distances later.

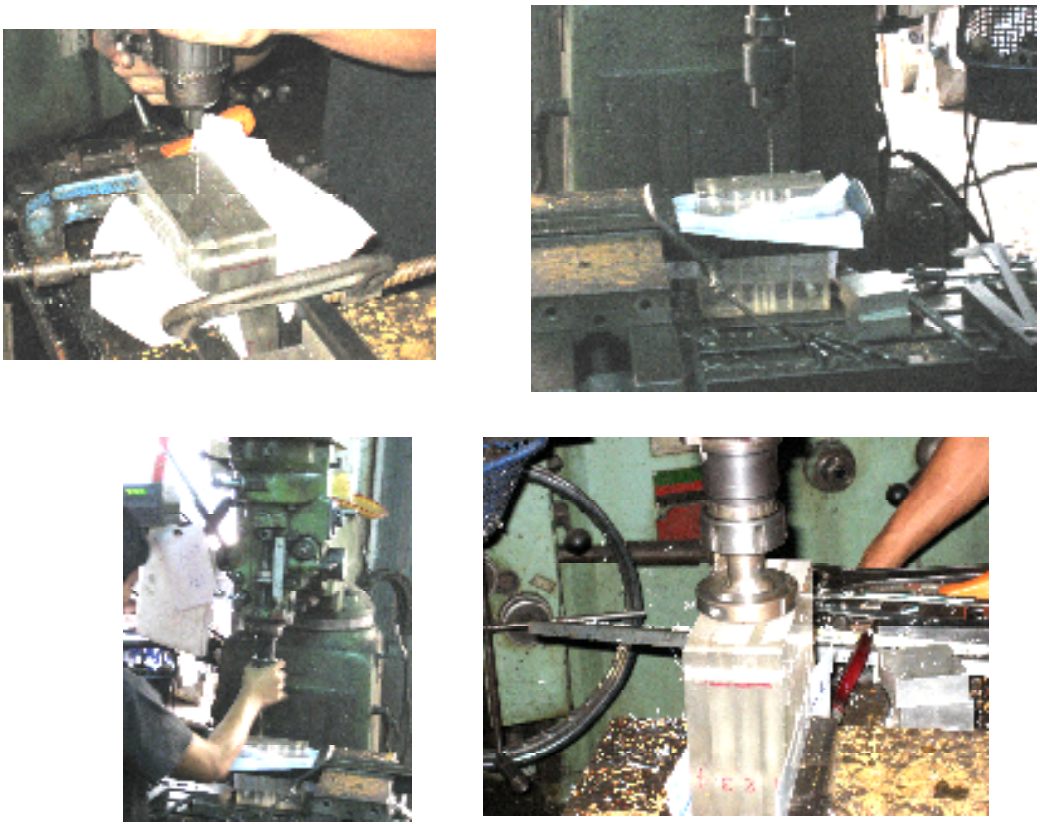


Figure 18. The process of construction of reconstruction accuracy test phantom

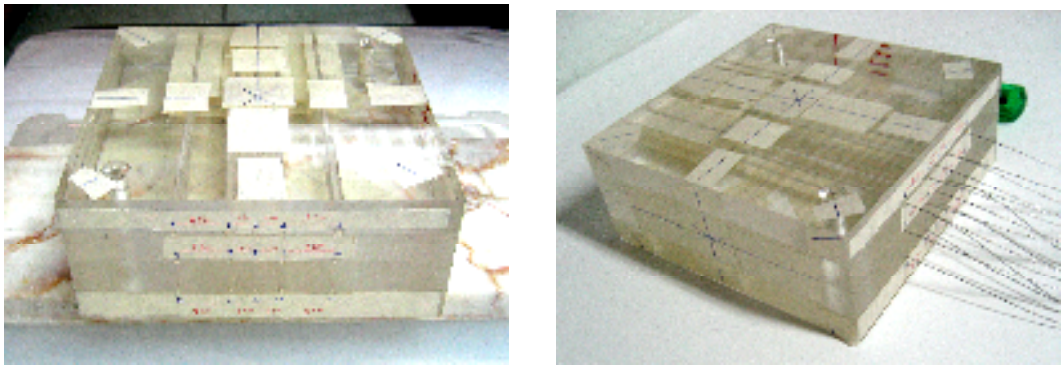


Figure 19. In-house rectangular phantom with regularly spaced x-ray markers embedded. The phantom measures 15x15x6 cm^3 (length × width × height).

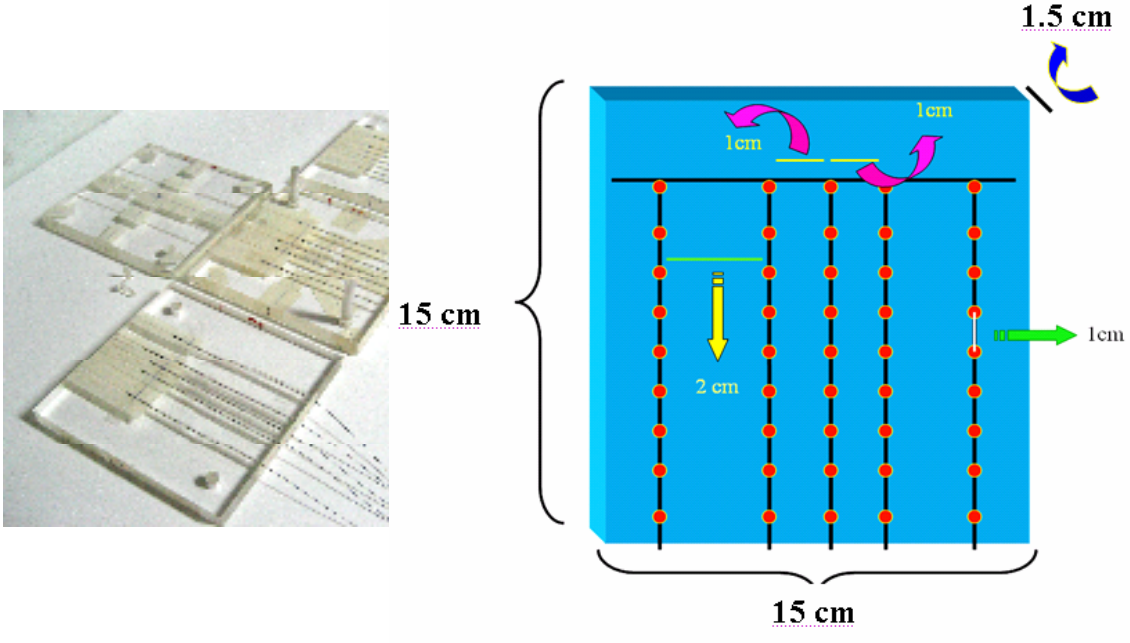


Figure 20. The schematic drawing of reconstruction accuracy test phantom, it consisting of four identical slabs of 1.5 cm thickness. Each ribbon consists of 9 x-ray markers separated 1 cm apart.

.

4.2.2 The study of brachytherapy source reconstruction accuracy using CT scanner, x-ray simulator and C-arm x-ray unit images

Reconstruction techniques

A treatment planning system usually offers several techniques for reconstruction for the localization of the sources in the patient. These may include orthogonal method, semi-orthogonal method, variable angle method, a stereo-shift method, CT based data, or others.

4.2.2.1 Image reconstruction from computed tomography scanner

Before study the brachytherapy source reconstruction accuracy using CT scanner, we assessed the CT image geometrical distortion. The results from the test(shown in Appendix A) showed that the MARCONI-PQS CT scanner's geometrical distortions are less than 1mm according to recommendation of AAPM radiation therapy committee task group No.66 [18].

In order to investigate the quantitative accuracy of x-ray marker reconstruction from CT images, the reconstruction accuracy test phantom images were obtained with varying three different CT slice thickness (1, 3, and 5 mm). Data from the CT shown in figure 22 were read into the Plato brachytherapy treatment planning system via an on-line connection. .

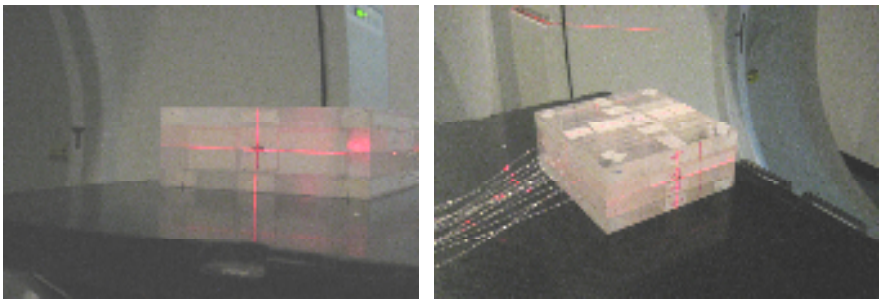
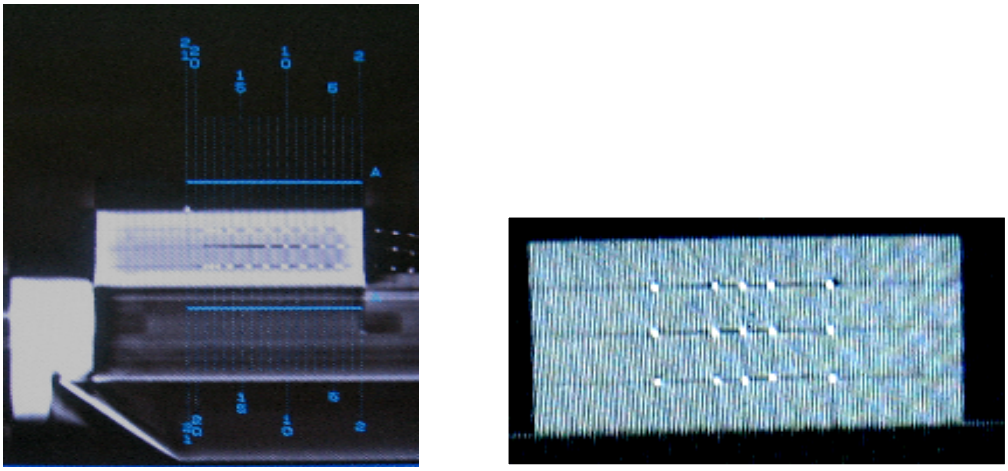


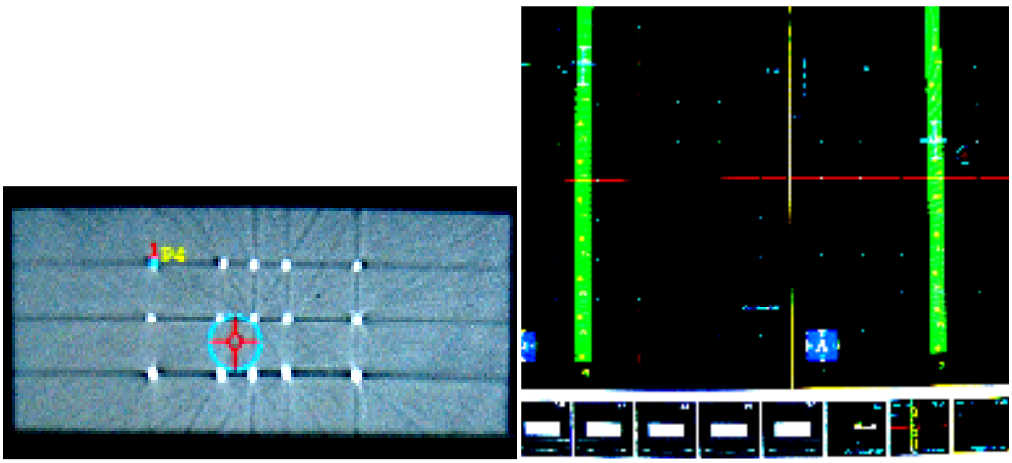
Figure 21. Set laser for the right position of phantom's focus.



(a) **(b)**

Figure 22. The reconstruction accuracy test phantom images from CT scanner at 1,3 and 5 mm CT slices thickness: (a) CT scout view image and (b) transverse view

3D volume images were reconstructed that shown in figure 23. The position of the markers have been reconstructed with the PLATO 'catheter describing points' method, based on the reconstruction of series of radio-opaque markers. Then we measured the spacing between every 2 x-ray makers reconstructed image.



(a) **(b)**

Figure 23. Phantom study with projection view of the localized x-ray markers on the CT transverse view image (a) and reconstructed AP ,LAT view images (b).

4.2.2.2 Image reconstruction from the x-ray simulator unit

The traditional way to obtain reconstruction images of brachytherapy sources for remote controlled afterloading system using an x-ray simulator are a pair of isocentric orthogonal or variable angle x-ray image methods

Before study the brachytherapy source reconstruction accuracy using x-ray simulator unit, we assessed the simulator image geometrical distortions and check the accuracy of the printer and digitizer. The results from the test(shown in Appendix B) showed that the x-ray simulator (Acuity) geometrical distortions are less than 1 mm according to recommendation of SGSMP Report 7. Quality control of treatment planning systems for teletherapy[23].

4.2.2.2.1 Orthogonal reconstruction method

In this method, orthogonal radiographs were taken at right angles with the central axes of the x-ray beams meeting approximately in the middle of the reconstruction accuracy test phantom. Typically AP and lateral radiographs of the phantom taken isocentrically create the needed geometry shown in figure 24 using a x-ray simulator with gantry angles of 0^0 and 90^0.

Data from the x-ray simulator were digitized using digitizer. The imaging geometry of the simulator is exactly known such as imaging magnification and results from the isocentric rotation of the gantry and the position of the focus and imaging plane with respect to the isocenter. 3D images and the position of the markers have been reconstructed with the PLATO BPS V14.2 using variable angle method. And measured the spacing between every 2 x-ray marker positions.

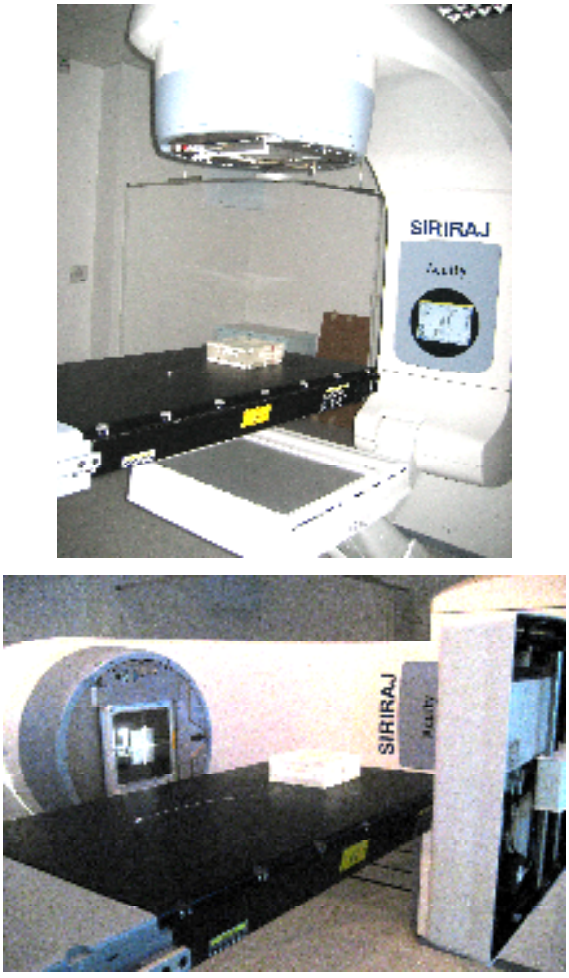
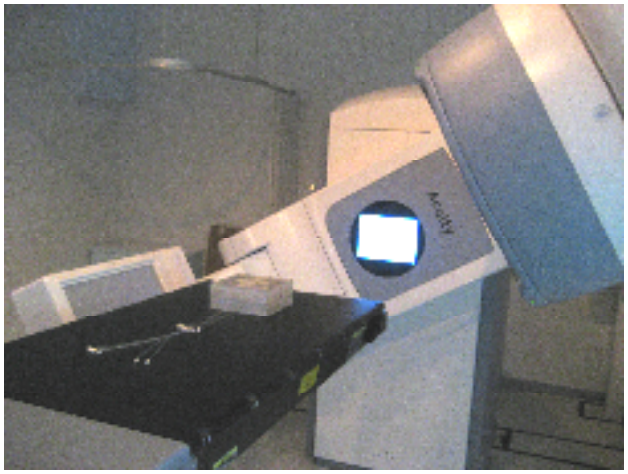


Figure 24. Orthogonal reconstruction method, taken two phantom radiographs of AP and lateral views respectively, a x-ray simulator with gantry angles of 0^0 and 90^0 was used.

4.2.2.2.2 Variable angle reconstruction method

This method reconstructed the localization of the x-ray ribbon from two radiographs taken with an x-ray simulator (figure 25). The reconstruction algorithm required that the angle, focus to isocenter distance and isocenter to film distance of each radiograph are accurately known. The benefit of the technique is the x-ray markers can be observed from fluoroscopically at the various gantry angle and the scope of the two angles of gantry that show source or localization x-ray markers in highest clarity and least overlapping (shown in figure 26). The total angle should preferable lie between 60^0 and 120^0 as shown in the figure 25. In this study, the gantry angles are 300^0 and 60^0 and the total gantry angle was not larger than 120^0. The 3D images and the position of the markers have been reconstructed with the PLATO BPS V14.2 using variable angle method. And measured the spacing between every 2 x-ray marker positions.



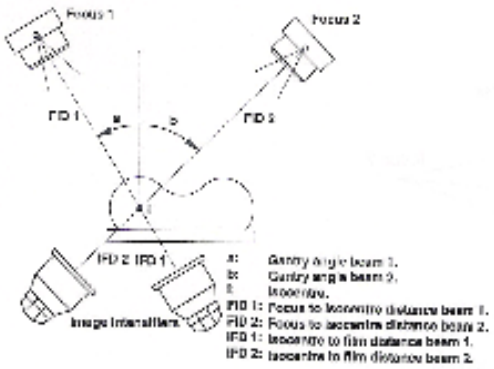
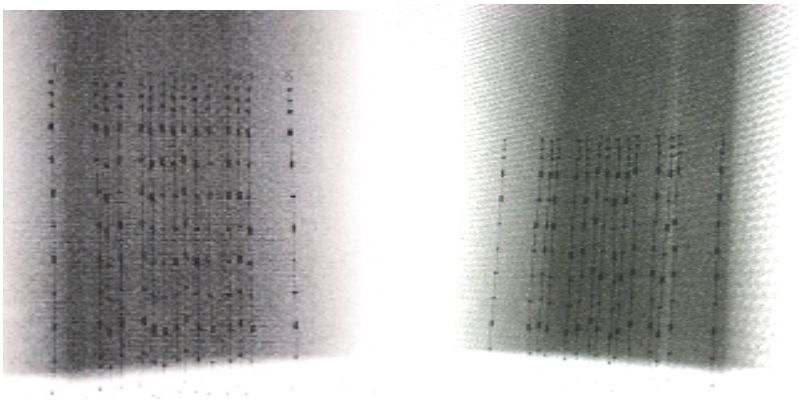


Figure 25. Variable reconstruction, take radiographs of localize x-ray markers in phantom. Need the angle of focus to isocenter and isocenter to film in projecting data in each radiographs that, is known the accuracy.



(a) **(b)**

Figure 26. Images from variable angle reconstruction method using gantry angle, (a) RAO 300^0 and (b) LAO 60^0 respectively.

4.2.2.3 Image reconstruction from the C-arm x-ray unit

Although there are some limitations such as the non-isocentric geometry, geometric distortion and small FOV are found in C-arm x-ray unit. It is designed to meet the needs of brachytherapy treatment planning because of its compact size and give the digital fluoroscopic images.

Before taking digital images from the C-arm x-ray unit, we assessed the accepted image reconstruction accuracy area for clinical use. The results from the verification are shown in Appendix C.

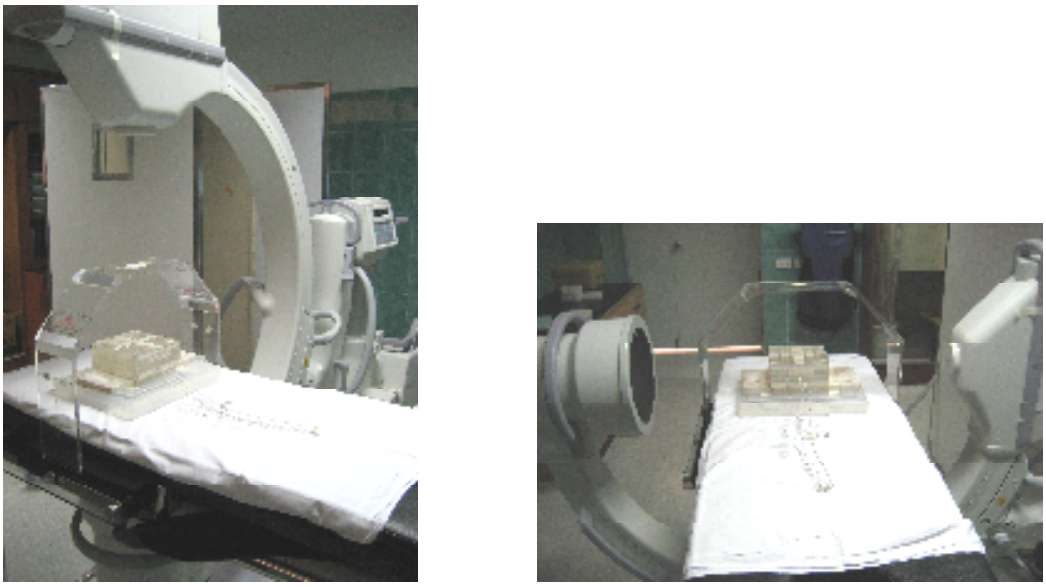
The C-arm x-ray unit used in this study is the conventional non-isocentric unit. It has both fluoroscopy and take radiograph capability. And the workstation for this unit is Ethernet, allowing the direct transfer of digital fluoroscopic images to Plato BPS treatment planning system.

Due to truly orthogonal orientation for the AP and lateral radiographs are not easily performable with C-arm x-ray unit. For this study, we obtained the images using C-arm x-ray unit with semi-orthogonal reconstruction method with and without reconstruction jig with AP and lateral cross-wires, were placed over the patient and

two radiographs were taken. And we measured the spacing between x-ray marker spacing positions for three times to minimize the error from human visualization and also determined the average values.

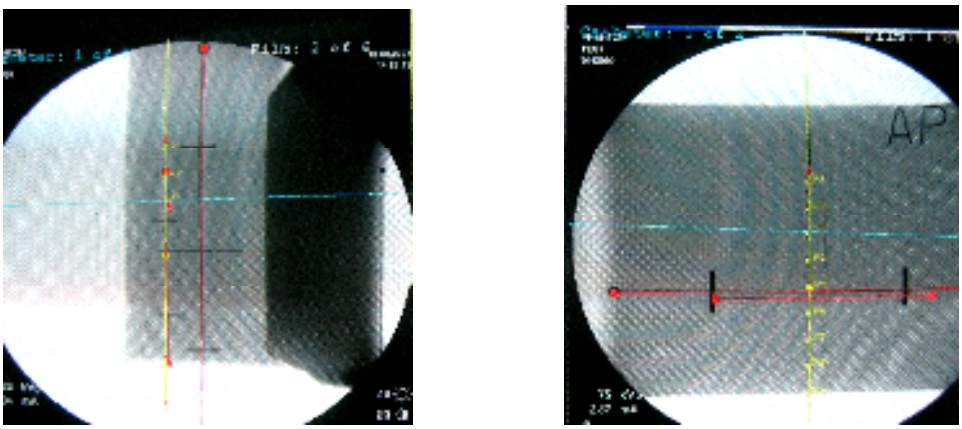
4.2.2.3.1 Semi-orthogonal reconstruction method with the reconstruction jig

In the semi-orthogonal reconstruction method a reconstruction jig with AP and lateral, is placed over the phantom and two radiographs (a lateral and AP) are taken, as shown in figure 27. It is not necessary to be truly orthogonal, because the set-up information will be determined by the computer from the size and the relative distances of the cross-wire lead marker images on each of two radiographs. Semi-orthogonal reconstruction method accepts x-ray beams whose central axis do not intersect and are not perpendicular to one another. The only requirement is that the projections of the cross-wires on were direly transfered to the Plato brachytherapy treatment planning system via an on-line connection. The position of each seed was extracted from a pair of the acquired radiographic images, AP and LAT (figure 28), by manually clicking on corresponding x-ray markers. When there was ambiguity in the exact correspondence, we was able to refer to a fluoroscopic sequence created by continuous screening while the C-arm was rotated between the two views. After the reconstruction images were performed, measure the spacing between every 2 x-ray markers.



(a) (b)

Figure 27. The semi-orthogonal reconstruction method a reconstruction jig in AP(a) and lateral view (b).



(a) (b)

Figure 28. Set of isocentric x-ray images of the phantom used to determine the coordinates of the seeds manually in x-ray space ((a) AP, (b) LAT). The bule-line is the epipolar line corresponding to the marked point in the opposite view. The two yellow crosses are marking the centre of the manually picked seed on the pair of radiographs.

4.2.2.3.2 Orthogonal reconstruction method without the reconstruction jig

Due to the C-arm x-ray unit is not isocentre geometry machine, it's the main problem with a non-isocentric machine with the C-arm angle variation is that the isocentre does not remains the some position. So this reconstruction method is based on the calculation of reconstructed parameters, the FID (Focus-isocenter distance) from the vertical (AP) and lateral position the C-arm and magnification factor.

In Figure 29. the position of the X-ray source and imaging plane are drawn for an orthogonal imaging geometry set-up in which a anterior-posterior (AP) and a lateral images are made. The virtual line connecting the X-ray source with the centre of the image intensifier is denoted as the central ray line. The point in space where the central ray lines for AP and lateral imaging set-up cross is denoted as the intersection point I, and finding the rotate point of C-arm (R), the measurement focus to rotation distance(FRD), focus to film distance(FFD) for anterior and lateral and focus to isocentre distance (FID) for magnification factor.

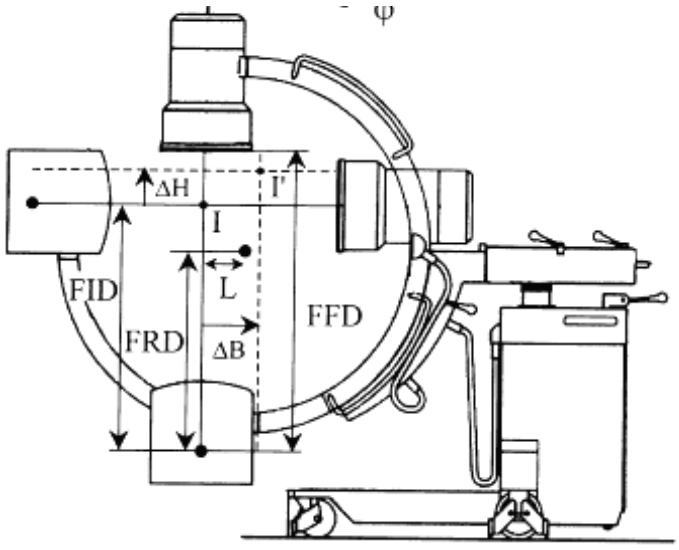


Figure 29. The measurement focus to isocentrer distance (FID), focus to film distance (FFD), focus to rotation distance(FRD) and finding the rotate point of C-arm (R) [15].

The distances FRD and FFD are difficult to be measured simply by ruler because the intersection point is a virtual point in space. Also, the position of the focus and the imaging plane is not easily determined. In order to be able to determine the values of FRD and FFD a straightforward method is presented here. It is based on the relation between the magnification factor of the AP and the lateral image and the height and lateral positions of the C-arm. The relations are given by

L is the distance between the central ray line and the rotation axis.

$$FID_{AP} = FRD + L + \Delta H$$

$$FID_{LAT} = FRD - L + \Delta B$$

The magnification factor (m) of the AP and Lateral images are given by

$$m_{AP} = FFD/(FID_{AP}) = FFD/(FRD + L + \Delta H)$$

and

$$m_{LAT} = FFD/(FID_{LAT}) = FFD/(FRD - L + \Delta B)$$

From our experiment the magnification factor of the AP and Lateral images approximated to 2. After taking the AP and Lateral fluoroscopy images, these data were directly transferred to the PLATO brachytherapy treatment planning system via network. After performing the image reconstruction, we measured all x-ray marker spacings 3 times to minimize the measurement error and also calculated the mean spacing distances.

4.2.3 The determination of reconstruction accuracy using CT scanner, x-ray simulator and x-ray C-arm unit images.

The co-ordinates of the x-ray markers were determined by reconstruction from two radiographs; semi-orthogonal with reconstruction jig method using non-isocentric C-arm x-ray unit , orthogonal method and variable angle method using isocentric x-ray simulator, except a CT-based reconstruction. From these co-ordinates, 120 inter-marker distances were calculated. The reconstruction distances were compared with actual distances measured from the reconstruction accuracy test phantom in the first experiment step (4.2.1). The deviations between the actual and reconstructed distances are calculated and the mean and the standard deviation are determined.

CHAPTER V
RESULTS

5.1 The measured distance in each increment of x-ray markers obtained from reconstruction accuracy test phantom

After making of the reconstruction accuracy test phantom with embedded ribbons of metal x-ray markers. Then we measured accurately the 120 spacing between the x-ray markers with the vernier caliper and micrometer. All the recorded actual distances are shown in the table 1

Table 1. The measured distance of 120 spacing between 10 mm increment x-ray markers.

Distance points (mm)	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
Line								
1	10	10	10	10	10	10	10	10
2	10	10	10	10	10	10	10	10
3	10	10	10	10	10	10	10	10
4	10	10	10	10	10	10	10	10
5	10	10	10	10	10	10	10	10
6	10	10	10	10	10	10	10	10
7	10	10	10	10	10	10	10	10
8	10	10	10	10	10	10	10	10
9	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
11	10	10	10	10	10	10	10	10
12	10	10	10	10	10	10	10	10
13	10	10	10	10	10	10	10	10
14	10	10	10	10	10	10	10	10
15	10	10	10	10	10	10	10	10

5.2 Assessment the accuracy of reconstruction method from various imaging modalities and techniques

5.2.1 Reconstruction accuracy from the Computed Tomography unit

The reconstruction accuracy of the computed tomography unit in the brachytherapy applicator or catheters were performed with the in-house reconstruction accuracy test phantom. The cross-sectional image at three different CT slice thickness of 1, 3 and 5 mm were obtained. Reconstruction of the 15 ribbons in three plane level of the phantom were carried out using the catheter described point method in Plato BPS treatment planning system. Each catheter contains 9 positions of the radio-opaque markers.

5.2.1.1 CT image at 1 mm slice thickness

With the 1 cm increment in 9 positions of the x-ray marker, the measuring distance in each increment obtain from the CT image were compared with these lumen reference length. Then the deviation of the measurement from the reference distance in each marker spacing in 15 ribbons were determined and averaged as presented in table 2. The maximum error of reconstruction points was found to be 0.30 mm in AP and 0.23 mm in Lateral as shown in table 3. The average ± SD of the deviation equal to 0.04 ± 0.07 mm in AP and 0.05 ± 0.07 mm in Lateral view respectively.

Table 2. The deviation in mm of the measuring distance from the reference distance in each marker spacing in 15 ribbons obtained from CT imaging at 1 mm slice thickness.

Line 1	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.9	10.2	9.9	10.2	9.9	10.2	9.90	±	0.00	10.20	±	0.00	0.00	0.00
2-3	10.1	10.2	10.1	10.1	10.1	10.1	10.10	±	0.00	10.13	±	0.06	0.00	0.03
3-4	10.1	10	10	10	10.1	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
4-5	10.1	10	10	10	10.1	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
5-6	9.8	9.8	9.9	9.9	9.8	9.9	9.83	±	0.06	9.87	±	0.06	0.03	0.03
6-7	10.1	9.9	10	9.9	10.1	10	10.07	±	0.06	9.93	±	0.06	0.03	0.03
7-8	10.1	10	10.1	10	10	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
8-9	10.1	10.1	10.1	10	10	10	10.07	±	0.06	10.03	±	0.06	0.03	0.03
Line 2	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.9	10.2	9.9	10.2	9.9	10.2	9.90	±	0.00	10.20	±	0.00	0.00	0.00
2-3	10.1	10.1	10.1	10	10.1	10.1	10.10	±	0.00	10.07	±	0.06	0.00	0.03
3-4	10.1	10.1	10.1	10.2	10.1	10.1	10.10	±	0.00	10.13	±	0.06	0.00	0.03
4-5	10	10	10.1	10	10.1	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
5-6	10	10	10.1	9.9	10	10	10.03	±	0.06	9.97	±	0.06	0.03	0.03
6-7	9.9	9.8	9.8	9.8	9.9	9.8	9.87	±	0.06	9.80	±	0.00	0.03	0.00
7-8	10	10	10.1	10	10.1	10.1	10.07	±	0.06	10.03	±	0.06	0.03	0.03
8-9	10.1	10.1	10.1	10.2	10.1	10.2	10.10	±	0.00	10.17	±	0.06	0.00	0.03
Line 3	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
2-3	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
3-4	10.2	10.1	10.2	10.1	10.2	10.1	10.20	±	0.00	10.10	±	0.00	0.00	0.00
4-5	10	10	10	10	10	10.1	10.00	±	0.00	10.03	±	0.06	0.00	0.03
5-6	9.9	10	9.9	10	9.8	10	9.87	±	0.06	10.00	±	0.00	0.03	0.00
6-7	9.9	9.8	9.9	9.8	9.9	9.7	9.90	±	0.00	9.77	±	0.06	0.00	0.03
7-8	10.2	10.1	10.1	10.1	10.2	10.1	10.17	±	0.06	10.10	±	0.00	0.03	0.00
8-9	10.1	10.1	10.1	10.1	10	10.1	10.07	±	0.06	10.10	±	0.00	0.03	0.00
Line 4	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	10.2	10	10.2	10	10.2	10.03	±	0.06	10.20	±	0.00	0.03	0.00
2-3	9.9	10	9.9	9.9	9.9	9.9	9.90	±	0.00	9.93	±	0.06	0.00	0.03
3-4	10	10.2	10.1	10.2	10	10.2	10.03	±	0.06	10.20	±	0.00	0.03	0.00
4-5	10	10	10.1	10	10	10	10.03	±	0.06	10.00	±	0.00	0.03	0.00
5-6	10.2	10.1	10.2	10.1	10.2	10.1	10.20	±	0.00	10.10	±	0.00	0.00	0.00
6-7	9.7	9.9	9.7	9.9	9.7	9.9	9.70	±	0.00	9.90	±	0.00	0.00	0.00
7-8	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
8-9	10.1	9.9	10.1	9.9	10.1	10	10.10	±	0.00	9.93	±	0.06	0.00	0.03

Line 5	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
2-3	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
3-4	10	10.1	10	10	10	10	10.00	±	0.00	10.03	±	0.06	0.00	0.03
4-5	10	10	10	10	10.1	10.1	10.03	±	0.06	10.03	±	0.06	0.03	0.03
5-6	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10	10	10	10	10.1	10.1	10.03	±	0.06	10.03	±	0.06	0.03	0.03
7-8	10	10	10	10	10	10.1	10.00	±	0.00	10.03	±	0.06	0.00	0.03
8-9	10	10.1	10	10	10	10.1	10.00	±	0.00	10.07	±	0.06	0.00	0.03
Line 6	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
2-3	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
3-4	10	10	9.9	10	10	10	9.97	±	0.06	10.00	±	0.00	0.03	0.00
4-5	10	10	9.9	10	10	10	9.97	±	0.06	10.00	±	0.00	0.03	0.00
5-6	10	10	9.9	10	10	10	9.97	±	0.06	10.00	±	0.00	0.03	0.00
6-7	10	10.1	10	10.2	10	10.1	10.00	±	0.00	10.13	±	0.06	0.00	0.03
7-8	10	10	10	10.1	10	10	10.00	±	0.00	10.03	±	0.06	0.00	0.03
8-9	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
Line 7	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10.2	10	10.1	9.9	10.2	9.97	±	0.06	10.17	±	0.06	0.03	0.03
2-3	10	10	10	10	10	9.9	10.00	±	0.00	9.97	±	0.06	0.00	0.03
3-4	10	10	10	10	9.9	10	9.97	±	0.06	10.00	±	0.00	0.03	0.00
4-5	10	9.9	10	9.8	9.9	9.8	9.97	±	0.06	9.83	±	0.06	0.03	0.03
5-6	10	10	10	10	10	10.1	10.00	±	0.00	10.03	±	0.06	0.00	0.03
6-7	10	10.2	10	10.1	10	10.2	10.00	±	0.00	10.17	±	0.06	0.00	0.03
7-8	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
8-9	10	10	10	10	10	10.1	10.00	±	0.00	10.03	±	0.06	0.00	0.03
Line 8	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
2-3	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
3-4	10.2	10.1	10.1	10	10.1	10	10.13	±	0.06	10.03	±	0.06	0.03	0.03
4-5	10	10.1	10	10	10	10	10.00	±	0.00	10.03	±	0.06	0.00	0.03
5-6	9.8	9.8	9.9	9.9	9.8	9.8	9.83	±	0.06	9.83	±	0.06	0.03	0.03
6-7	10.2	10.1	10.1	10	10.2	10	10.17	±	0.06	10.03	±	0.06	0.03	0.03
7-8	10.2	10.1	10.1	10.1	10.2	10	10.17	±	0.06	10.07	±	0.06	0.03	0.03
8-9	10	10.1	10.1	10	10	10	10.03	±	0.06	10.03	±	0.06	0.03	0.03

Line 9	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
2-3	10	10	10	10.1	10	10.1	10.00	±	0.00	10.07	±	0.06	0.00	0.03
3-4	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
4-5	10	10.1	10	10	10	10	10.00	±	0.00	10.03	±	0.06	0.00	0.03
5-6	10.2	10.1	10.2	10.2	10.2	10.2	10.20	±	0.00	10.17	±	0.06	0.00	0.03
6-7	10	10	9.9	10.1	10	10.1	9.97	±	0.06	10.07	±	0.06	0.03	0.03
7-8	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
8-9	10	10	10.1	10	10	10.1	10.03	±	0.06	10.03	±	0.06	0.03	0.03
Line 10	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
2-3	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
3-4	10.2	10.1	10.2	10.1	10.2	10.1	10.20	±	0.00	10.10	±	0.00	0.00	0.00
4-5	10.2	10.1	10.2	10.1	10.1	10.1	10.17	±	0.06	10.10	±	0.00	0.03	0.00
5-6	9.8	9.8	9.8	9.8	9.8	9.7	9.80	±	0.00	9.77	±	0.06	0.00	0.03
6-7	10.2	10.1	10.2	10.1	10.1	10.1	10.17	±	0.06	10.10	±	0.00	0.03	0.00
7-8	10	10.1	10	10	10	10	10.00	±	0.00	10.03	±	0.06	0.00	0.03
8-9	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
Line 11	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	10.1	10.2	10.1	10.1	10.1	10.13	±	0.06	10.10	±	0.00	0.03	0.00
2-3	10	10.1	10	10	10	10.1	10.00	±	0.00	10.07	±	0.06	0.00	0.03
3-4	10	10	10	10.1	10.1	10	10.03	±	0.06	10.03	±	0.06	0.03	0.03
4-5	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
5-6	10.1	10	10.1	10	10.1	10	10.10	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10.1	10	10.1	10	10.1	10.1	10.10	±	0.00	10.03	±	0.06	0.00	0.03
7-8	10	10	10.1	9.9	10.1	10	10.07	±	0.06	9.97	±	0.06	0.03	0.03
8-9	10.1	10	10.2	10	10.1	10	10.13	±	0.06	10.00	±	0.00	0.03	0.00
Line 12	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10	10	10.1	10	10.1	10.00	±	0.00	10.07	±	0.06	0.00	0.03
2-3	9.9	10	10	10.1	9.9	10.1	9.93	±	0.06	10.07	±	0.06	0.03	0.03
3-4	10	10	10	10.1	10	10	10.00	±	0.00	10.03	±	0.06	0.00	0.03
4-5	9.8	10	9.8	10.1	9.8	10	9.80	±	0.00	10.03	±	0.06	0.00	0.03
5-6	9.9	9.8	10	9.9	10	9.7	9.97	±	0.06	9.80	±	0.10	0.03	0.06
6-7	10.1	10.1	10	10	10	10	10.03	±	0.06	10.03	±	0.06	0.03	0.03
7-8	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
8-9	10	10	10	10.1	10	10	10.00	±	0.00	10.03	±	0.06	0.00	0.03

Line 13	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10.1	10	10.1	10	10	10.00	±	0.00	10.07	±	0.06	0.00	0.03
2-3	10	10.2	10	10.1	10	10.1	10.00	±	0.00	10.13	±	0.06	0.00	0.03
3-4	10	10.2	10	10.1	10	10	10.00	±	0.00	10.10	±	0.10	0.00	0.06
4-5	10	10.1	10	10	10	10	10.00	±	0.00	10.03	±	0.06	0.00	0.03
5-6	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
7-8	10	10	10	10	10	10.1	10.00	±	0.00	10.03	±	0.06	0.00	0.03
8-9	10	10	10	10	10	10.1	10.00	±	0.00	10.03	±	0.06	0.00	0.03
Line 14	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	9.8	10.1	9.8	9.8	9.8	10.00	±	0.17	9.80	±	0.00	0.10	0.00
2-3	10.1	9.7	10.1	9.7	10	9.7	10.07	±	0.06	9.70	±	0.00	0.03	0.00
3-4	10	10	10	10	10.1	10	10.03	±	0.06	10.00	±	0.00	0.03	0.00
4-5	10	10	10.2	10	10.1	10	10.10	±	0.10	10.00	±	0.00	0.06	0.00
5-6	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10	10.1	10	10.1	10	10	10.00	±	0.00	10.07	±	0.06	0.00	0.03
7-8	9.9	9.9	9.9	10	10	10	9.93	±	0.06	9.97	±	0.06	0.03	0.03
8-9	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
Line 15	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	10	10.1	10	10	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
2-3	10.1	10	10.1	10	10	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
3-4	10.1	10	10.1	10	10	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
4-5	10.1	10.1	10.1	10	10	10	10.07	±	0.06	10.03	±	0.06	0.03	0.03
5-6	9.8	9.8	9.8	9.8	9.7	9.7	9.77	±	0.06	9.77	±	0.06	0.03	0.03
6-7	10.1	9.9	10.1	10	10	10	10.07	±	0.06	9.97	±	0.06	0.03	0.03
7-8	10.2	10	10.2	10	10.1	10	10.17	±	0.06	10.00	±	0.00	0.03	0.00
8-9	10.2	10	10.2	10	10.2	10	10.20	±	0.00	10.00	±	0.00	0.00	0.00

Table 3. The deviation in mm of the average differences from the reference distance in each marker spacing in 15 catheters obtained from CT imaging at 1 mm slice thickness.

Marker position	1-2		2-3		3-4		4-5		5-6		6-7		7-8		8-9	
Line	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT
1	0.10	0.20	0.1	0.13	0.07	0.00	0.07	0.00	0.17	0.13	0.07	0.07	0.07	0.00	0.07	0.03
2	0.10	0.20	0.10	0.07	0.10	0.13	0.07	0.00	0.03	0.03	0.13	0.20	0.07	0.03	0.10	0.17
3	0.00	0.10	0.00	0.10	0.20	0.10	0.00	0.03	0.13	0.00	0.10	0.23	0.17	0.10	0.07	0.10
4	0.03	0.20	0.10	0.07	0.03	0.20	0.03	0.00	0.20	0.10	**0.30**	0.10	0.10	0.10	0.10	0.07
5	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.03	0.00	0.00	0.03	0.03	0.00	0.03	0.00	0.07
6	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.00	0.13	0.00	0.13	0.00	0.00
7	0.03	0.17	0.00	0.03	0.03	0.00	0.03	0.17	0.00	0.03	0.00	0.17	0.00	0.00	0.00	0.03
8	0.00	0.10	0.00	0.10	0.13	0.03	0.00	0.03	0.17	0.17	0.17	0.03	0.17	0.07	0.03	0.03
9	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.03	0.20	0.17	0.03	0.07	0.00	0.00	0.03	0.03
10	0.00	0.00	0.00	0.10	0.20	0.10	0.17	0.10	0.20	0.23	0.17	0.10	0.00	0.03	0.00	0.10
11	0.13	0.10	0.00	0.07	0.03	0.03	0.10	0.10	0.10	0.00	0.10	0.03	0.07	0.03	0.13	0.00
12	0.00	0.07	0.07	0.07	0.00	0.03	0.20	0.03	0.03	0.20	0.03	0.03	0.00	0.00	0.00	0.03
13	0.00	0.07	0.00	0.13	0.00	0.10	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03
14	0.00	0.20	0.07	0.30	0.03	0.00	0.10	0.00	0.00	0.00	0.00	0.07	0.07	0.03	0.00	0.00
15	0.07	0.00	0.07	0.00	0.07	0.00	0.07	0.03	0.23	**0.23**	0.07	0.03	0.17	0.00	0.20	0.00
Average ± SD	0.03 ± 0.05	0.09 ± 0.08	0.03 ± 0.04	0.08 ± 0.07	0.06 ± 0.07	0.05 ± 0.06	0.06 ± 0.06	0.04 ± 0.05	0.10 ± 0.09	0.09 ± 0.09	0.08 ± 0.09	0.08 ± 0.07	0.06 ± 0.07	0.04 ± 0.04	0.05 ± 0.06	0.05 ± 0.05

5.2.1.2 CT image at 3 mm and 5 mm slice thickness

Using the same procedure as described in 5.2.1.1, the reconstruction accuracy from CT image at 3 mm and 5 mm slice thickness were determined. Results in table 5 and 7 showed the maximum deviation of the measuring distance from the reference distance in AP view were observed at 0.60 mm both at the CT image at 3 and 5 mm slice thickness with the average ± SD of the error equal to 0.21 ± 0.12 and 0.29 ± 0.16 mm respectively. In Lateral view, the maximum error was 0.60 mm in 3 mm slice thickness and 0.77 mm in 5 mm slice thickness. Average ± SD of error were found to be 0.20 ± 0.13 and 0.28 ± 0.15 mm respectively.

Table 4. The deviation in mm of the measured distance from the reference distance in each marker spacing in 15 ribbons obtained from CT imaging at 3 mm slice thickness.

Line 1	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.7	9.7	9.8	9.7	9.7	9.7	9.73	±	0.06	9.70	±	0.00	0.03	0.00
2-3	9.7	9.8	9.7	9.8	9.7	9.8	9.70	±	0.00	9.80	±	0.00	0.00	0.00
3-4	10.5	10.4	10.5	10.4	10.5	10.5	10.50	±	0.00	10.43	±	0.06	0.00	0.03
4-5	9.8	10	9.8	10	10	10	9.87	±	0.12	10.00	±	0.00	0.07	0.00
5-6	10	10	10.1	10	10	10	10.03	±	0.06	10.00	±	0.00	0.03	0.00
6-7	10.2	10.2	10.1	10.2	10.1	10.2	10.13	±	0.06	10.20	±	0.00	0.03	0.00
7-8	9.7	9.8	9.8	9.8	9.7	9.8	9.73	±	0.06	9.80	±	0.00	0.03	0.00
8-9	9.8	9.8	9.9	9.8	9.8	9.9	9.83	±	0.06	9.83	±	0.06	0.03	0.03
Line 2	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	10.2	10.1	10.2	10.1	10.2	10.10	±	0.00	10.20	±	0.00	0.00	0.00
2-3	9.8	9.8	9.8	9.8	9.8	9.8	9.80	±	0.00	9.80	±	0.00	0.00	0.00
3-4	10.6	10.5	10.6	10.5	10.6	10.5	10.60	±	0.00	10.50	±	0.00	0.00	0.00
4-5	10.2	10.1	10.2	10.1	10.2	10.1	10.20	±	0.00	10.10	±	0.00	0.00	0.00
5-6	10.1	10.2	10.1	10.2	10.2	10.2	10.13	±	0.06	10.20	±	0.00	0.03	0.00
6-7	10.3	10.4	10.3	10.3	10.3	10.4	10.30	±	0.00	10.37	±	0.06	0.00	0.03
7-8	9.7	9.8	9.7	9.8	10	9.8	9.80	±	0.17	9.80	±	0.00	0.10	0.00
8-9	9.9	10.1	9.9	10.1	9.9	10.1	9.90	±	0.00	10.10	±	0.00	0.00	0.00
Line 3	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.3	10.2	10.3	10.2	10.3	10.2	10.30	±	0.00	10.20	±	0.00	0.00	0.00
2-3	9.9	9.7	9.9	9.7	9.9	9.8	9.90	±	0.00	9.73	±	0.06	0.00	0.03
3-4	9.8	9.7	9.8	9.7	9.9	9.8	9.83	±	0.06	9.73	±	0.06	0.03	0.03
4-5	9.8	9.7	9.8	9.7	9.8	9.7	9.80	±	0.00	9.70	±	0.00	0.00	0.00
5-6	10.2	10.2	10.1	10.2	10.1	10.2	10.13	±	0.06	10.20	±	0.00	0.03	0.00
6-7	10.4	10.3	10.3	10.3	10.3	10.3	10.33	±	0.06	10.30	±	0.00	0.03	0.00
7-8	10.3	10.3	10.3	10.3	10.3	10.4	10.30	±	0.00	10.33	±	0.06	0.00	0.03
8-9	9.9	9.8	10	9.9	9.9	9.8	9.93	±	0.06	9.83	±	0.06	0.03	0.03
Line 4	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.2	10.2	10.2	10.2	10.2	10.1	10.20	±	0.00	10.17	±	0.06	0.00	0.03
2-3	10.5	10.4	10.5	10.4	10.5	10.4	10.50	±	0.00	10.40	±	0.00	0.00	0.00
3-4	10.2	10.1	10.2	10.1	10.2	10.1	10.20	±	0.00	10.10	±	0.00	0.00	0.00
4-5	10	10	10	10	10.1	10	10.03	±	0.06	10.00	±	0.00	0.03	0.00
5-6	10.1	10.3	10.1	10.3	10.1	10.3	10.10	±	0.00	10.30	±	0.00	0.00	0.00
6-7	9.7	9.7	9.7	9.7	9.7	9.7	9.70	±	0.00	9.70	±	0.00	0.00	0.00
7-8	9.9	9.9	9.9	9.9	9.9	9.8	9.90	±	0.00	9.87	±	0.06	0.00	0.03
8-9	9.8	9.9	9.9	9.9	9.8	9.9	9.83	±	0.06	9.90	±	0.00	0.03	0.00

Line 5	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.3	10.3	10.3	10.2	10.3	10.3	10.30	±	0.00	10.27	±	0.06	0.00	0.03
2-3	10.2	9.9	10.2	9.9	10.2	9.9	10.20	±	0.00	9.90	±	0.00	0.00	0.00
3-4	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
4-5	9.8	10.1	9.8	10	9.8	10.1	9.80	±	0.00	10.07	±	0.06	0.00	0.03
5-6	10	10	10	9.9	10	10	10.00	±	0.00	9.97	±	0.06	0.00	0.03
6-7	10.2	10.2	10.2	10.2	10.2	10.2	10.20	±	0.00	10.20	±	0.00	0.00	0.00
7-8	9.8	9.8	9.8	9.8	9.9	9.9	9.83	±	0.06	9.83	±	0.06	0.03	0.03
8-9	9.9	9.9	9.9	10	9.9	9.9	9.90	±	0.00	9.93	±	0.06	0.00	0.03
Line 6	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.7	9.8	9.7	9.8	9.7	9.8	9.70	±	0.00	9.80	±	0.00	0.00	0.00
2-3	9.6	9.8	9.6	9.8	9.6	9.8	9.60	±	0.00	9.80	±	0.00	0.00	0.00
3-4	10.4	10.4	10.3	10.4	10.4	10.4	10.37	±	0.06	10.40	±	0.00	0.03	0.00
4-5	10	10	10	10.1	10	9.9	10.00	±	0.00	10.00	±	0.10	0.00	0.06
5-6	10.1	10.2	10.1	10.2	10.1	10.2	10.10	±	0.00	10.20	±	0.00	0.00	0.00
6-7	10.2	10.2	10.2	10.2	10.2	10.2	10.20	±	0.00	10.20	±	0.00	0.00	0.00
7-8	9.7	9.8	9.7	9.8	9.9	9.8	9.77	±	0.12	9.80	±	0.00	0.07	0.00
8-9	9.8	9.9	9.8	9.9	9.8	9.8	9.80	±	0.00	9.87	±	0.06	0.00	0.03
Line 7	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.7	9.7	9.7	9.7	9.6	9.8	9.67	±	0.06	9.73	±	0.06	0.03	0.03
2-3	9.6	9.8	9.6	9.7	9.6	9.8	9.60	±	0.00	9.77	±	0.06	0.00	0.03
3-4	9.8	9.9	9.8	9.9	10	10.2	9.87	±	0.12	10.00	±	0.17	0.07	0.10
4-5	10.2	10.2	10.2	10.1	10.1	10.2	10.17	±	0.06	10.17	±	0.06	0.03	0.03
5-6	10.1	10.2	10.1	10.2	10.1	10.1	10.10	±	0.00	10.17	±	0.06	0.00	0.03
6-7	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
7-8	10.3	10.4	10.3	10.4	10.3	10.3	10.30	±	0.00	10.37	±	0.06	0.00	0.03
8-9	9.8	9.9	9.9	9.9	9.8	9.9	9.83	±	0.06	9.90	±	0.00	0.03	0.00
Line 8	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.6	9.5	9.6	9.5	9.7	9.5	9.63	±	0.06	9.50	±	0.00	0.03	0.00
2-3	9.8	9.9	9.8	9.9	9.8	9.9	9.80	±	0.00	9.90	±	0.00	0.00	0.00
3-4	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
4-5	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
5-6	10.1	10	10.1	10	10.1	10.1	10.10	±	0.00	10.03	±	0.06	0.00	0.03
6-7	10.2	10.2	10.2	10.2	10.1	10.2	10.17	±	0.06	10.20	±	0.00	0.03	0.00
7-8	10.3	10.4	10.3	10.4	10.2	10.5	10.27	±	0.06	10.43	±	0.06	0.03	0.03
8-9	9.7	9.6	9.8	9.6	9.7	9.6	9.73	±	0.06	9.60	±	0.00	0.03	0.00
Line 9	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.7	9.7	9.7	9.7	9.7	9.7	9.70	±	0.00	9.70	±	0.00	0.00	0.00
2-3	9.8	9.8	9.8	9.8	9.8	9.8	9.80	±	0.00	9.80	±	0.00	0.00	0.00
3-4	9.9	9.9	9.9	9.9	9.9	10	9.90	±	0.00	9.93	±	0.06	0.00	0.03
4-5	10	10.2	10.1	10.2	10	10.2	10.03	±	0.06	10.20	±	0.00	0.03	0.00
5-6	10	10	10	10	10	10.1	10.00	±	0.00	10.03	±	0.06	0.00	0.03
6-7	10.3	10.4	10.3	10.4	10.3	10.4	10.30	±	0.00	10.40	±	0.00	0.00	0.00
7-8	10.3	10.3	10.3	10.3	10.3	10.3	10.30	±	0.00	10.30	±	0.00	0.00	0.00
8-9	10.1	10.1	10.1	10.1	10.2	10.1	10.13	±	0.06	10.10	±	0.00	0.03	0.00

Line 10	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.6	9.6	9.6	9.7	9.6	9.6	9.60	±	0.00	9.63	±	0.06	0.00	0.03
2-3	9.6	9.8	9.6	9.7	9.6	9.8	9.60	±	0.00	9.77	±	0.06	0.00	0.03
3-4	9.7	9.7	9.7	9.7	9.7	9.7	9.70	±	0.00	9.70	±	0.00	0.00	0.00
4-5	9.9	9.9	9.9	9.9	9.9	10	9.90	±	0.00	9.93	±	0.06	0.00	0.03
5-6	10.1	10.1	10.1	10.1	10.1	10	10.10	±	0.00	10.07	±	0.06	0.00	0.03
6-7	10.2	10.1	10.1	10.1	10.1	10.1	10.13	±	0.06	10.10	±	0.00	0.03	0.00
7-8	10.2	10.1	10.2	10.1	10.2	10.1	10.20	±	0.00	10.10	±	0.00	0.00	0.00
8-9	9.8	9.6	9.8	9.6	9.8	9.6	9.80	±	0.00	9.60	±	0.00	0.00	0.00
Line 11	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.8	9.6	9.8	9.7	9.8	9.6	9.80	±	0.00	9.63	±	0.06	0.00	0.03
2-3	9.8	9.5	9.8	9.6	9.8	9.5	9.80	±	0.00	9.53	±	0.06	0.00	0.03
3-4	9.9	9.7	9.9	9.7	9.9	9.7	9.90	±	0.00	9.70	±	0.00	0.00	0.00
4-5	10.2	10.1	10.2	10.1	10.2	10.2	10.20	±	0.00	10.13	±	0.06	0.00	0.03
5-6	10.2	10.1	10.2	10.1	10.2	10.1	10.20	±	0.00	10.10	±	0.00	0.00	0.00
6-7	10.2	10.2	10.2	10.1	10.2	10.2	10.20	±	0.00	10.17	±	0.06	0.00	0.03
7-8	10.3	10.3	10.3	10.3	10.3	10.3	10.30	±	0.00	10.30	±	0.00	0.00	0.00
8-9	9.8	9.8	9.8	9.8	9.9	9.8	9.83	±	0.06	9.80	±	0.00	0.03	0.00
Line 12	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.7	9.8	9.7	9.8	9.6	9.9	9.67	±	0.06	9.83	±	0.06	0.03	0.03
2-3	9.6	9.7	9.6	9.7	9.6	9.7	9.60	±	0.00	9.70	±	0.00	0.00	0.03
3-4	9.9	9.8	9.9	9.8	9.9	9.8	9.90	±	0.00	9.80	±	0.00	0.00	0.03
4-5	9.9	10	9.9	10	9.9	10	9.90	±	0.00	10.00	±	0.00	0.00	0.03
5-6	10.3	10.2	10.2	10.2	10.3	10.2	10.27	±	0.06	10.20	±	0.00	0.03	0.03
6-7	10.1	10.1	10.1	10.2	10.1	10.1	10.10	±	0.00	10.13	±	0.06	0.00	0.03
7-8	10.2	10.1	10.2	10.1	10.2	10.1	10.20	±	0.00	10.10	±	0.00	0.00	0.03
8-9	10.1	10.1	10.1	10.2	10.1	10.1	10.10	±	0.00	10.13	±	0.06	0.00	0.03
Line 13	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.3	10.3	10.3	10.2	10.3	10.3	10.30	±	0.00	10.27	±	0.06	0.00	0.03
2-3	10.2	10.2	10.2	10.2	10.2	10.2	10.20	±	0.00	10.20	±	0.00	0.00	0.00
3-4	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
4-5	9.9	9.7	9.9	9.7	9.9	9.8	9.90	±	0.00	9.73	±	0.06	0.00	0.03
5-6	9.6	9.6	9.6	9.6	9.7	9.7	9.63	±	0.06	9.63	±	0.06	0.03	0.03
6-7	9.7	9.9	9.7	9.9	9.7	9.8	9.70	±	0.00	9.87	±	0.06	0.00	0.03
7-8	10.2	9.9	10.2	9.9	10.2	9.9	10.20	±	0.00	9.90	±	0.00	0.00	0.00
8-9	10.3	10.4	10.3	10.4	10.4	10.4	10.33	±	0.06	10.40	±	0.00	0.03	0.00
Line 14	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.3	10.4	10.3	10.4	10.2	10.4	10.27	±	0.06	10.40	±	0.00	0.03	0.00
2-3	10.5	10.6	10.5	10.6	10.5	10.6	10.50	±	0.00	10.60	±	0.00	0.00	0.00
3-4	10.2	10.1	10.2	10.1	10.2	10.1	10.20	±	0.00	10.10	±	0.00	0.00	0.00
4-5	9.9	9.8	9.9	9.8	9.9	9.9	9.90	±	0.00	9.83	±	0.06	0.00	0.03
5-6	10	10	10.1	10.1	10	10.1	10.03	±	0.06	10.07	±	0.06	0.03	0.03
6-7	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
7-8	10.3	10.2	10.3	10.2	10.3	10.2	10.30	±	0.00	10.20	±	0.00	0.00	0.00
8-9	10.1	10.2	10.2	10.2	10.1	10.2	10.13	±	0.06	10.20	±	0.00	0.03	0.00

Line 15	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	9.9	10.1	9.9	10.1	9.9	10.10	±	0.00	9.90	±	0.00	0.00	0.00
2-3	9.7	9.8	9.7	9.8	9.7	9.8	9.70	±	0.00	9.80	±	0.00	0.00	0.00
3-4	10.3	10.4	10.3	10.4	10.3	10.4	10.30	±	0.00	10.40	±	0.00	0.00	0.00
4-5	9.8	9.9	9.8	9.9	9.8	9.9	9.80	±	0.00	9.90	±	0.00	0.00	0.00
5-6	10.2	10.2	10.2	10.1	10.2	10.1	10.20	±	0.00	10.13	±	0.06	0.00	0.03
6-7	10.1	10.1	10.1	10.1	10.1	10	10.10	±	0.00	10.07	±	0.06	0.00	0.03
7-8	10	10.1	10.1	10.1	10	10	10.03	±	0.06	10.07	±	0.06	0.03	0.03
8-9	10.3	10.2	10.3	10.2	10.3	10.3	10.30	±	0.00	10.23	±	0.06	0.00	0.03

Table 5. The deviation in mm of the average differences from the reference distance in each marker spacing in 15 catheters obtained from CT imaging at 3 mm slice thickness.

Marker position	1-2		2-3		3-4		4-5		5-6		6-7		7-8		8-9	
Line	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT
1	0.27	0.30	0.30	0.20	0.50	0.43	0.13	0.00	0.03	0.00	0.13	0.20	0.27	0.20	0.17	0.17
2	0.10	0.20	0.20	0.20	**0.60**	0.50	0.20	0.10	0.13	0.20	0.13	0.37	0.10	0.20	0.10	0.10
3	0.30	0.20	0.10	0.27	0.17	0.27	0.20	0.30	0.13	0.20	0.33	0.30	0.30	0.33	0.07	0.17
4	0.20	0.17	0.50	0.40	0.20	0.10	0.03	0.00	0.10	0.30	0.30	0.30	0.10	0.13	0.17	0.10
5	0.30	0.27	0.20	0.10	0.10	0.10	0.20	0.07	0.00	0.03	0.20	0.20	0.17	0.17	0.10	0.07
6	0.30	0.20	0.40	0.20	0.37	0.40	0.00	0.00	0.10	0.20	0.20	0.20	0.23	0.20	0.20	0.13
7	0.33	0.27	0.40	0.23	0.13	0.00	0.17	0.17	0.10	0.17	0.10	0.10	0.30	0.37	0.17	0.10
8	0.37	0.50	0.20	0.10	0.10	0.10	0.10	0.10	0.10	0.03	0.17	0.20	0.27	0.43	0.27	0.40
9	0.30	0.30	0.20	0.20	0.10	0.07	0.03	0.20	0.00	0.03	0.30	0.40	0.30	0.30	0.13	0.10
10	0.40	0.37	0.40	0.23	0.30	0.30	0.10	0.07	0.10	0.07	0.13	0.10	0.20	0.10	0.20	0.40
11	0.20	0.37	0.20	0.47	0.10	0.30	0.20	0.13	0.20	0.10	0.20	0.17	0.30	0.30	0.17	0.20
12	0.33	0.17	0.40	0.30	0.10	0.20	0.10	0.00	0.27	0.20	0.10	0.13	0.20	0.10	0.10	0.13
13	0.30	0.27	0.20	0.20	0.10	0.10	0.10	0.27	0.37	0.37	0.30	0.13	0.20	0.10	0.33	0.40
14	0.27	0.40	0.50	**0.60**	0.20	0.10	0.10	0.17	0.03	0.07	0.10	0.10	0.30	0.20	0.13	0.20
15	0.10	0.10	0.30	0.20	0.30	0.40	0.20	0.10	0.20	0.13	0.10	0.07	0.03	0.07	0.30	0.23
Average ± SD	0.27 ± 0.09	0.27 ± 0.11	0.30 ± 0.13	0.26 ± 0.14	0.22 ± 0.16	0.22 ± 0.16	0.12 ± 0.07	0.11 ± 0.09	0.12 ± 0.10	0.14 ± 0.11	0.19 ± 0.08	0.20 ± 0.10	0.22 ± 0.09	0.21 ± 0.11	0.17 ± 0.08	0.19 ± 0.12

Table 6. The deviation in mm of the measuring distance from the reference distance in each marker spacing in 15 ribbons obtained from CT imaging at 5 mm slice thickness.

Line 1	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.2	10.3	10.2	10.3	10.2	10.3	10.20	±	0.00	10.30	±	0.00	0.00	0.00
2-3	10	10.3	10.1	10.3	10	10.2	10.03	±	0.06	10.27	±	0.06	0.03	0.03
3-4	10.1	10.1	10.2	10.2	10.1	10.1	10.13	±	0.06	10.13	±	0.06	0.03	0.03
4-5	10	10.1	10.1	10.1	10	10.1	10.03	±	0.06	10.10	±	0.00	0.03	0.00
5-6	10	10.3	10	10	10	10.3	10.00	±	0.00	10.20	±	0.17	0.00	0.10
6-7	9.8	10.1	9.9	10	9.8	10	9.83	±	0.06	10.03	±	0.06	0.03	0.03
7-8	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
8-9	10.2	10.5	10.2	10.4	10.3	10.4	10.23	±	0.06	10.43	±	0.06	0.03	0.03
Line 2	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.4	10	10.4	10	10.4	10.1	10.40	±	0.00	10.03	±	0.06	0.00	0.03
2-3	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
3-4	9.7	10.7	9.7	10.7	9.7	10.7	9.70	±	0.00	10.70	±	0.00	0.00	0.00
4-5	10.4	10.8	10.4	10.8	10.3	10.7	10.37	±	0.06	10.77	±	0.06	0.03	0.03
5-6	10.2	10.3	10.2	10.3	10.2	10.3	10.20	±	0.00	10.30	±	0.00	0.00	0.00
6-7	10.4	10.1	10.4	10.1	10.3	10.2	10.37	±	0.06	10.13	±	0.06	0.03	0.03
7-8	9.9	10.5	9.9	10.5	10	10.5	9.93	±	0.06	10.50	±	0.00	0.03	0.00
8-9	9.7	9.7	9.7	9.7	9.7	9.8	9.70	±	0.00	9.73	±	0.06	0.00	0.03
Line 3	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.3	10.2	10.3	10.3	10.3	10.3	10.30	±	0.00	10.27	±	0.06	0.00	0.03
2-3	10.5	10.2	10.5	10.2	10.5	10.2	10.50	±	0.00	10.20	±	0.00	0.00	0.00
3-4	10.3	10.2	10.3	10.2	10.3	10.2	10.30	±	0.00	10.20	±	0.00	0.00	0.00
4-5	10	10	10	10	10	10.1	10.00	±	0.00	10.03	±	0.06	0.00	0.03
5-6	10.3	10	10.3	10	10.3	10.1	10.30	±	0.00	10.03	±	0.06	0.00	0.03
6-7	10.5	10.3	10.5	10.3	10.5	10.3	10.50	±	0.00	10.30	±	0.00	0.00	0.00
7-8	10.6	10.2	10.6	10.2	10.6	10.2	10.60	±	0.00	10.20	±	0.00	0.00	0.00
8-9	10.5	10.3	10.5	10.3	10.5	10.3	10.50	±	0.00	10.30	±	0.00	0.00	0.00
Line 4	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.6	10.3	10.6	10.3	10.6	10.3	10.60	±	0.00	10.30	±	0.00	0.00	0.00
2-3	10.2	10.5	10.2	10.5	10.2	10.5	10.20	±	0.00	10.50	±	0.00	0.00	0.00
3-4	10.3	10.5	10.3	10.5	10.3	10.5	10.30	±	0.00	10.50	±	0.00	0.00	0.00
4-5	10.1	10.2	10.1	10.2	10.1	10.2	10.10	±	0.00	10.20	±	0.00	0.00	0.00
5-6	10.4	10.3	10.4	10.3	10.4	10.4	10.40	±	0.00	10.33	±	0.06	0.00	0.03
6-7	10.2	10.2	10.2	10.2	10.2	10.2	10.20	±	0.00	10.20	±	0.00	0.00	0.00
7-8	10.2	10.2	10.2	10.2	10.2	10.3	10.20	±	0.00	10.23	±	0.06	0.00	0.03
8-9	10.6	10.5	10.6	10.5	10.6	10.5	10.60	±	0.00	10.50	±	0.00	0.00	0.00

Line 5	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
2-3	10.3	10.3	10.3	10.3	10.3	10.3	10.30	±	0.00	10.30	±	0.00	0.00	0.00
3-4	10.3	10.5	10.3	10.5	10.3	10.4	10.30	±	0.00	10.47	±	0.06	0.00	0.03
4-5	10.2	10.1	10.2	10.1	10.2	10.1	10.20	±	0.00	10.10	±	0.00	0.00	0.00
5-6	10.2	10.1	10.2	10.1	10.2	10.2	10.20	±	0.00	10.13	±	0.06	0.00	0.03
6-7	10.3	10.5	10.3	10.5	10.3	10.4	10.30	±	0.00	10.47	±	0.06	0.00	0.03
7-8	10.4	10.3	10.4	10.3	10.4	10.3	10.40	±	0.00	10.30	±	0.00	0.00	0.00
8-9	10.5	10.1	10.5	10.1	10.5	10.2	10.50	±	0.00	10.13	±	0.06	0.00	0.03
Line 6	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.3	10.1	10.3	10.1	10.3	10.1	10.30	±	0.00	10.10	±	0.00	0.00	0.00
2-3	10.5	10.2	10.5	10.2	10.5	10.2	10.50	±	0.00	10.20	±	0.00	0.00	0.00
3-4	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
4-5	10.4	10.2	10.4	10.2	10.4	10.2	10.40	±	0.00	10.20	±	0.00	0.00	0.00
5-6	10.2	10.1	10.2	10.1	10.2	10.1	10.20	±	0.00	10.10	±	0.00	0.00	0.00
6-7	10.5	10.2	10.5	10.2	10.5	10.2	10.50	±	0.00	10.20	±	0.00	0.00	0.00
7-8	10.3	10.4	10.3	10.4	10.3	10.4	10.30	±	0.00	10.40	±	0.00	0.00	0.00
8-9	10.6	10.5	10.6	10.5	10.6	10.5	10.60	±	0.00	10.50	±	0.00	0.00	0.00
Line 7	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.5	10.2	10.5	10.2	10.5	10.2	10.50	±	0.00	10.20	±	0.00	0.00	0.00
2-3	10.2	10.2	10.2	10.2	10.2	10.2	10.20	±	0.00	10.20	±	0.00	0.00	0.00
3-4	10.4	10.2	10.4	10.2	10.4	10.2	10.40	±	0.00	10.20	±	0.00	0.00	0.00
4-5	10.2	10.3	10.2	10.3	10.2	10.3	10.20	±	0.00	10.30	±	0.00	0.00	0.00
5-6	10.1	10.2	10.1	10.2	10.1	10.2	10.10	±	0.00	10.20	±	0.00	0.00	0.00
6-7	10.3	10.3	10.3	10.3	10.3	10.3	10.30	±	0.00	10.30	±	0.00	0.00	0.00
7-8	10.1	10.3	10.1	10.3	10.1	10.3	10.10	±	0.00	10.30	±	0.00	0.00	0.00
8-9	10.2	10.3	10.1	10.2	10.1	10.2	10.13	±	0.06	10.23	±	0.06	0.03	0.03
Line 8	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.3	10.3	10.2	10.3	10.2	10.3	10.23	±	0.06	10.30	±	0.00	0.03	0.00
2-3	10.5	10.4	10.4	10.4	10.4	10.3	10.43	±	0.06	10.37	±	0.06	0.03	0.03
3-4	10.3	10.4	10.3	10.3	10.3	10.3	10.30	±	0.00	10.33	±	0.06	0.00	0.03
4-5	10.3	10.3	10.3	10.3	10.3	10.3	10.30	±	0.00	10.30	±	0.00	0.00	0.00
5-6	10.3	10.3	10.3	10.2	10.3	10.3	10.30	±	0.00	10.27	±	0.06	0.00	0.03
6-7	10.3	10.1	10.3	10.1	10.3	10.1	10.30	±	0.00	10.10	±	0.00	0.00	0.00
7-8	10.3	10.1	10.3	10.1	10.3	10.2	10.30	±	0.00	10.13	±	0.06	0.00	0.03
8-9	10.3	10.3	10.3	10.3	10.3	10.2	10.30	±	0.00	10.27	±	0.06	0.00	0.03
Line 9	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.2	10.3	10.3	10.2	10.3	10.3	10.27	±	0.06	10.27	±	0.06	0.03	0.03
2-3	10.3	10.2	10.2	10.3	10.2	10.3	10.23	±	0.06	10.27	±	0.06	0.03	0.03
3-4	10.4	10.2	10.3	10.2	10.3	10.2	10.33	±	0.06	10.20	±	0.00	0.03	0.00
4-5	10.6	10.5	10.6	10.5	10.6	10.5	10.60	±	0.00	10.50	±	0.00	0.00	0.00
5-6	10.3	10.5	10.3	10.4	10.3	10.4	10.30	±	0.00	10.43	±	0.06	0.00	0.03
6-7	10.4	10.3	10.3	10.3	10.3	10.3	10.33	±	0.06	10.30	±	0.00	0.03	0.00
7-8	10.4	10.5	10.4	10.5	10.4	10.5	10.40	±	0.00	10.50	±	0.00	0.00	0.00
8-9	10.4	10.3	10.4	10.3	10.4	10.3	10.40	±	0.00	10.30	±	0.00	0.00	0.00

Line 10	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.2	10.6	10.2	10.6	10.2	10.6	10.20	±	0.00	10.60	±	0.00	0.00	0.00
2-3	10.6	10.6	10.6	10.6	10.6	10.6	10.60	±	0.00	10.60	±	0.00	0.00	0.00
3-4	10.4	10.2	10.4	10.2	10.4	10.2	10.40	±	0.00	10.20	±	0.00	0.00	0.00
4-5	10.6	10.6	10.5	10.6	10.5	10.5	10.53	±	0.06	10.57	±	0.06	0.03	0.03
5-6	10.4	10.6	10.4	10.6	10.4	10.6	10.40	±	0.00	10.60	±	0.00	0.00	0.00
6-7	10.4	10.6	10.4	10.6	10.4	10.5	10.40	±	0.00	10.57	±	0.06	0.00	0.03
7-8	10.4	10.6	10.4	10.5	10.5	10.5	10.43	±	0.06	10.53	±	0.06	0.03	0.03
8-9	10.6	10.6	10.5	10.5	10.5	10.6	10.53	±	0.06	10.57	±	0.06	0.03	0.03
Line 11	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	10.1	10.1	10.1	10.1	10.2	10.10	±	0.00	10.13	±	0.06	0.00	0.03
2-3	10.1	10.1	10.1	10.1	10.1	10.2	10.10	±	0.00	10.13	±	0.06	0.00	0.03
3-4	10.1	10.3	10.1	10.2	10.1	10.2	10.10	±	0.00	10.23	±	0.06	0.00	0.03
4-5	10.1	10	10.2	10.2	10.2	10.2	10.17	±	0.06	10.13	±	0.12	0.03	0.07
5-6	10.1	10.4	10.1	10.5	10.1	10.5	10.10	±	0.00	10.47	±	0.06	0.00	0.03
6-7	10.3	10.3	10.3	10.3	10.3	10.4	10.30	±	0.00	10.33	±	0.06	0.00	0.03
7-8	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
8-9	10.3	10.3	10.3	10.2	10.3	10.2	10.30	±	0.00	10.23	±	0.06	0.00	0.03
Line 12	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.3	10.1	10.3	10.1	10.3	10.1	10.30	±	0.00	10.10	±	0.00	0.00	0.00
2-3	10	10.1	10.1	10.1	10.1	10.1	10.07	±	0.06	10.10	±	0.00	0.03	0.00
3-4	10.2	10.1	10.2	10.1	10.2	10.1	10.20	±	0.00	10.10	±	0.00	0.00	0.00
4-5	10.3	10.1	10.3	10.1	10.3	10.1	10.30	±	0.00	10.10	±	0.00	0.00	0.00
5-6	10.4	10.3	10.4	10.3	10.4	10.3	10.40	±	0.00	10.30	±	0.00	0.00	0.00
6-7	10.2	10.4	10.2	10.4	10.3	10.4	10.23	±	0.06	10.40	±	0.00	0.03	0.00
7-8	10.3	10.3	10.3	10.3	10.2	10.3	10.27	±	0.06	10.30	±	0.00	0.03	0.00
8-9	10.4	10.2	10.4	10.2	10.5	10.3	10.43	±	0.06	10.23	±	0.06	0.03	0.03
Line 13	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.3	10.3	10.2	10.3	10.2	10.3	10.23	±	0.06	10.30	±	0.00	0.03	0.00
2-3	10.3	10.3	10.3	10.3	10.3	10.3	10.30	±	0.00	10.30	±	0.00	0.00	0.00
3-4	10.4	10.2	10.4	10.2	10.4	10.2	10.40	±	0.00	10.20	±	0.00	0.00	0.00
4-5	10.5	10.3	10.5	10.3	10.5	10.3	10.50	±	0.00	10.30	±	0.00	0.00	0.00
5-6	10.3	10.5	10.4	10.5	10.4	10.5	10.37	±	0.06	10.50	±	0.00	0.03	0.00
6-7	10.4	10.2	10.4	10.2	10.4	10.2	10.40	±	0.00	10.20	±	0.00	0.00	0.00
7-8	10.5	10.3	10.5	10.3	10.5	10.3	10.50	±	0.00	10.30	±	0.00	0.00	0.00
8-9	10.4	10.2	10.4	10.2	10.4	10.2	10.40	±	0.00	10.20	±	0.00	0.00	0.00
Line 14	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.4	10.2	10.5	10.1	10.5	10.1	10.47	±	0.06	10.13	±	0.06	0.03	0.03
2-3	10.6	10.2	10.6	10.1	10.6	10.1	10.60	±	0.00	10.13	±	0.06	0.00	0.03
3-4	10.2	10.3	10.2	10.3	10.2	10.3	10.20	±	0.00	10.30	±	0.00	0.00	0.00
4-5	10.4	10.2	10.4	10.3	10.3	10.3	10.37	±	0.06	10.27	±	0.06	0.03	0.03
5-6	10.2	10.2	10.2	10.3	10.3	10.3	10.23	±	0.06	10.27	±	0.06	0.03	0.03
6-7	10.2	10.2	10.3	10.3	10.2	10.3	10.23	±	0.06	10.27	±	0.06	0.03	0.03
7-8	10.2	10.6	10.2	10.5	10.3	10.5	10.23	±	0.06	10.53	±	0.06	0.03	0.03
8-9	10.4	10.3	10.4	10.4	10.4	10.4	10.40	±	0.00	10.37	±	0.06	0.00	0.03

Line 15	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.5	10.1	10.5	10.2	10.5	10.2	10.50	±	0.00	10.17	±	0.06	0.00	0.03
2-3	10.2	10.1	10.2	10.2	10.2	10.2	10.20	±	0.00	10.17	±	0.06	0.00	0.03
3-4	10	10.3	10	10.3	10	10.3	10.00	±	0.00	10.30	±	0.00	0.00	0.00
4-5	10	10.2	10	10.2	10	10.2	10.00	±	0.00	10.20	±	0.00	0.00	0.00
5-6	10.2	10.3	10.2	10.3	10.2	10.3	10.20	±	0.00	10.30	±	0.00	0.00	0.00
6-7	10.3	10.3	10.3	10.3	10.3	10.3	10.30	±	0.00	10.30	±	0.00	0.00	0.00
7-8	10.2	10.3	10.2	10.2	10.2	10.3	10.20	±	0.00	10.27	±	0.06	0.00	0.03
8-9	10.4	10.1	10.4	10.1	10.4	10.2	10.40	±	0.00	10.13	±	0.06	0.00	0.03

Table 7. The deviation in mm of the average differences from the reference distance in each marker spacing in 15 catheters obtained from CT imaging at 5 mm slice thickness.

Marker position	1-2		2-3		3-4		4-5		5-6		6-7		7-8		8-9	
Line	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT
1	0.20	0.30	0.03	0.27	0.13	0.13	0.03	0.10	0.00	0.20	0.17	0.03	0.00	0.10	0.23	0.43
2	0.40	0.03	0.00	0.10	0.30	0.70	0.37	**0.77**	0.20	0.30	0.37	0.13	0.07	0.50	0.30	0.27
3	0.30	0.27	0.50	0.20	0.30	0.20	0.00	0.03	0.30	0.03	0.50	0.30	0.60	0.20	0.50	0.30
4	**0.60**	0.30	0.20	0.50	0.30	0.50	0.10	0.20	0.40	0.33	0.20	0.20	0.20	0.23	0.60	0.50
5	0.00	0.10	0.30	0.30	0.30	0.47	0.20	0.10	0.20	0.13	0.30	0.47	0.40	0.30	0.50	0.13
6	0.30	0.10	0.50	0.20	0.10	0.10	0.40	0.20	0.20	0.10	0.50	0.20	0.30	0.40	0.60	0.50
7	0.50	0.20	0.20	0.20	0.40	0.20	0.20	0.30	0.10	0.20	0.30	0.30	0.10	0.30	0.13	0.23
8	0.23	0.30	0.43	0.37	0.30	0.33	0.30	0.30	0.30	0.27	0.30	0.10	0.30	0.13	0.30	0.27
9	0.27	0.27	0.23	0.27	0.33	0.20	0.60	0.50	0.30	0.43	0.33	0.30	0.40	0.50	0.40	0.30
10	0.20	0.60	0.60	0.60	0.40	0.20	0.53	0.57	0.40	0.60	0.40	0.57	0.43	0.53	0.53	0.57
11	0.10	0.13	0.10	0.13	0.10	0.23	0.17	0.13	0.10	0.47	0.30	0.33	0.10	0.10	0.30	0.23
12	0.30	0.10	0.07	0.10	0.20	0.10	0.30	0.10	0.40	0.30	0.23	0.40	0.27	0.30	0.43	0.23
13	0.23	0.30	0.30	0.30	0.40	0.20	0.50	0.30	0.37	0.50	0.40	0.20	0.50	0.30	0.40	0.20
14	0.47	0.13	0.60	0.13	0.20	0.30	0.37	0.27	0.23	0.27	0.23	0.27	0.23	0.53	0.40	0.37
15	0.50	0.17	0.20	0.17	0.00	0.30	0.00	0.20	0.20	0.30	0.30	0.30	0.20	0.27	0.40	0.13
Average ± SD	0.31 ± 0.16	0.22 ± 0.14	0.28 ± 0.20	0.26 ± 0.14	0.25 ± 0.12	0.28 ± 0.17	0.27 ± 0.19	0.27 ± 0.20	0.25 ± 0.12	0.30 ± 0.16	0.32 ± 0.10	0.27 ± 0.14	0.27 ± 0.17	0.31 ± 0.15	0.40 ± 0.13	0.31 ± 0.14

From the report of AAPM radiation therapy committee task group No. 66 [18] the recommendation for the reconstruction accuracy should be within ± 1 mm. Results of the ribbons reconstruction from computed tomography unit at three different slice thickness in this study were shown to be in an acceptable criteria.

5.2.2 Reconstruction accuracy from the x-ray simulator unit

In contrast with the cross sectional image from CT, the planar image obtained from x-ray simulator unit with the two different techniques, the orthogonal and variable angle were verified for their accuracy in image reconstruction. The reconstruction accuracy from Acuity x-ray simulator unit with the amorphous silicon detector were presented as the following.

5.2.2.1 The orthogonal reconstruction method

The reconstruction accuracy test phantom with 15 ribbons at 3 plane levels still be used in the study. Two radiographs at 0^0 and 90^0 degree angle were obtained. Then reconstruction the radio-opaque marker were performed with the Plato BPS treatment planning system. Results in table 9 showed the maximum error in this technique was 0.20 mm in both AP and Lateral view. The error found at the points located near the FOV periphery are larger than the points line close to the central axis of the beam. Average error ± SD in the orthogonal reconstruction technique were 0.05 ± 0.06 mm and 0.06 ± 0.07 mm in AP and Lateral view respectively. IAEA technical report series No. 430[19] has recommended the reconstruction should be within ± 1 mm on 1 cm separation between two point sources.

Table 8. The deviation in mm of the measuring distance from the reference distance in each marker spacing in 15 ribbons obtained from x-ray simulator with the orthogonal reconstruction method.

Line 1	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.9	10.2	9.9	10.2	9.9	10.2	9.90	±	0.00	10.20	±	0.00	0.00	0.00
2-3	9.9	10	9.9	10	9.9	10	9.90	±	0.00	10.00	±	0.00	0.00	0.00
3-4	10.1	10	10	10	10	10	10.03	±	0.06	10.00	±	0.00	0.03	0.00
4-5	9.9	10	10	10	9.8	10	9.90	±	0.10	10.00	±	0.00	0.06	0.00
5-6	10.1	10	10	10	10	10	10.03	±	0.06	10.00	±	0.00	0.03	0.00
6-7	10.1	10	10.1	10	10.1	10	10.10	±	0.00	10.00	±	0.00	0.00	0.00
7-8	10.1	10.2	10.1	10.1	10	10.2	10.07	±	0.06	10.17	±	0.06	0.03	0.03
8-9	9.9	10	9.9	10	10	10	9.93	±	0.06	10.00	±	0.00	0.03	0.00
Line 2	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10.1	10	10.1	10.1	10	10.03	±	0.06	10.07	±	0.06	0.03	0.03
2-3	10	10.1	10	10.1	10	10	10.00	±	0.00	10.07	±	0.06	0.00	0.03
3-4	10	10.1	10	10	10	10.1	10.00	±	0.00	10.07	±	0.06	0.00	0.03
4-5	10	10.1	10	10	10	10	10.00	±	0.00	10.03	±	0.06	0.00	0.03
5-6	10	10.1	10	10	10	10	10.00	±	0.00	10.03	±	0.06	0.00	0.03
6-7	10	10.1	10	10.1	10.1	10.1	10.03	±	0.06	10.10	±	0.00	0.03	0.00
7-8	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
8-9	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
Line 3	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	10.1	10	10.1	10.1	10.1	10.07	±	0.06	10.10	±	0.00	0.03	0.00
2-3	9.9	9.9	9.9	9.9	9.9	9.9	9.90	±	0.00	9.90	±	0.00	0.00	0.00
3-4	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
4-5	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
5-6	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
7-8	10	9.9	10	10	10	10	10.00	±	0.00	9.97	±	0.06	0.00	0.03
8-9	10.1	10.1	10.1	10.1	10	10	10.07	±	0.06	10.07	±	0.06	0.03	0.03
Line 4	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
2-3	10.2	10.1	10.2	10.2	10.2	10.2	10.20	±	0.00	10.17	±	0.06	0.00	0.03
3-4	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
4-5	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
5-6	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10	10.1	10	10	10	10.1	10.00	±	0.00	10.07	±	0.06	0.00	0.03
7-8	10	10.3	10	10.1	10	10.2	10.00	±	0.00	10.20	±	0.10	0.00	0.06
8-9	10	10.1	10.1	10.1	10	10.1	10.03	±	0.06	10.10	±	0.00	0.03	0.00

Line 5	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.9	10	9.9	10	9.9	10	9.90	±	0.00	10.00	±	0.00	0.00	0.00
2-3	9.9	10	9.9	10	9.9	10	9.90	±	0.00	10.00	±	0.00	0.00	0.00
3-4	10.2	10	10.1	10	10.2	10.1	10.17	±	0.06	10.03	±	0.06	0.03	0.03
4-5	9.9	10	9.9	10	10	10	9.93	±	0.06	10.00	±	0.00	0.03	0.00
5-6	10.2	10	10.2	10.1	10.2	10.1	10.20	±	0.00	10.07	±	0.06	0.00	0.03
6-7	10.2	10.3	10.2	10.2	10.2	10.1	10.20	±	0.00	10.20	±	0.10	0.00	0.06
7-8	10.2	10	10.2	10.2	10.2	10.3	10.20	±	0.00	10.17	±	0.15	0.00	0.09
8-9	9.9	10	9.9	10	9.9	10	9.90	±	0.00	10.00	±	0.00	0.00	0.00
Line 6	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	10.2	10.1	10.2	10.1	10.2	10.10	±	0.00	10.20	±	0.00	0.00	0.00
2-3	9.9	10	9.9	10	9.9	10	9.90	±	0.00	10.00	±	0.00	0.00	0.00
3-4	10.1	10	10.1	10	10	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
4-5	9.9	10	9.9	10	10	10	9.93	±	0.06	10.00	±	0.00	0.03	0.00
5-6	10.1	10	10	10	10.1	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
6-7	10.1	10	10.1	10	10.1	10.1	10.10	±	0.00	10.03	±	0.06	0.00	0.03
7-8	10	10.2	10.1	10.2	10	10.1	10.03	±	0.06	10.17	±	0.06	0.03	0.03
8-9	9.9	10	9.9	10	9.9	10	9.90	±	0.00	10.00	±	0.00	0.00	0.00
Line 7	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
2-3	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
3-4	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
4-5	10	10.1	10	10	10	10.1	10.00	±	0.00	10.07	±	0.06	0.00	0.03
5-6	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
6-7	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
7-8	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
8-9	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
Line 8	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10.1	10	10	10	10.1	10.00	±	0.00	10.07	±	0.06	0.00	0.03
2-3	10	9.9	10	10	10	9.9	10.00	±	0.00	9.93	±	0.06	0.00	0.03
3-4	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
4-5	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
5-6	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
7-8	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
8-9	10	10.2	10	10.2	10	10.1	10.00	±	0.00	10.17	±	0.06	0.00	0.03
Line 9	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
2-3	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
3-4	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
4-5	10.1	10	10.1	10	10.1	10	10.10	±	0.00	10.00	±	0.00	0.00	0.00
5-6	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10	10.1	10	10.1	10	10	10.00	±	0.00	10.07	±	0.06	0.00	0.03
7-8	10	10.3	10	10.2	10	10.2	10.00	±	0.00	10.23	±	0.06	0.00	0.03
8-9	10.2	10.1	10.2	10.2	10.2	10.1	10.20	±	0.00	10.13	±	0.06	0.00	0.03

Line 10	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.9	10	10	10	9.9	10	9.93	±	0.06	10.00	±	0.00	0.03	0.00
2-3	9.9	10	10	10	9.9	10	9.93	±	0.06	10.00	±	0.00	0.03	0.00
3-4	10.1	10	10	10	10.1	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
4-5	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
5-6	10.1	10	10.1	10	10	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
6-7	10	10	10	10.2	10	10	10.00	±	0.00	10.07	±	0.12	0.00	0.07
7-8	10.2	10.3	10.2	10.3	10.2	10.3	10.20	±	0.00	10.30	±	0.00	0.00	0.00
8-9	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
Line 11	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	9.9	10.1	9.9	10.1	10	10.10	±	0.00	9.93	±	0.06	0.00	0.03
2-3	9.9	9.9	10	9.9	9.9	10	9.93	±	0.06	9.93	±	0.06	0.03	0.03
3-4	10.1	9.9	10.1	9.9	10	10	10.07	±	0.06	9.93	±	0.06	0.03	0.03
4-5	10.1	9.9	10.1	10	10	10	10.07	±	0.06	9.97	±	0.06	0.03	0.03
5-6	10.1	9.9	10.1	10	10	10	10.07	±	0.06	9.97	±	0.06	0.03	0.03
6-7	10.1	10.2	10.1	10.2	10.1	10.2	10.10	±	0.00	10.20	±	0.00	0.00	0.00
7-8	9.9	9.9	9.9	9.9	9.9	9.9	9.90	±	0.00	9.90	±	0.00	0.00	0.00
8-9	10.1	10.2	10.1	10.2	10.1	10.2	10.10	±	0.00	10.20	±	0.00	0.00	0.00
Line 12	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.9	10.2	9.9	10.1	9.9	10.1	9.90	±	0.00	10.13	±	0.06	0.00	0.03
2-3	9.9	10	9.9	10	9.9	10	9.90	±	0.00	10.00	±	0.00	0.00	0.00
3-4	10.1	10	10.1	10	10.1	10	10.10	±	0.00	10.00	±	0.00	0.00	0.00
4-5	9.9	10	10	10	9.9	10	9.93	±	0.06	10.00	±	0.00	0.03	0.00
5-6	10.1	10	10	10	10	10	10.03	±	0.06	10.00	±	0.00	0.03	0.00
6-7	10.1	10	10	10	10.1	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
7-8	10.1	10.2	10.1	10.2	10.1	10.2	10.10	±	0.00	10.20	±	0.00	0.00	0.00
8-9	9.9	10	9.9	10	9.9	10.1	9.90	±	0.00	10.03	±	0.06	0.00	0.03
Line 13	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
2-3	10.1	10	10	10	10.1	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
3-4	10	9.9	10	9.9	10	9.9	10.00	±	0.00	9.90	±	0.00	0.00	0.00
4-5	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
5-6	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
6-7	9.9	10	10	10	10	10	9.97	±	0.06	10.00	±	0.00	0.03	0.00
7-8	10	10.2	10	10.2	9.9	10.1	9.97	±	0.06	10.17	±	0.06	0.03	0.03
8-9	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
Line 14	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	9.9	10.1	9.9	10.1	9.9	10.10	±	0.00	9.90	±	0.00	0.00	0.00
2-3	10.2	10.1	10.2	10.1	10.2	10.1	10.20	±	0.00	10.10	±	0.00	0.00	0.00
3-4	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
4-5	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
5-6	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
7-8	10	10.2	10	10.2	10	10.2	10.00	±	0.00	10.20	±	0.00	0.00	0.00
8-9	10.1	10	10.1	10.1	10.1	10	10.10	±	0.00	10.03	±	0.06	0.00	0.03

Line 15	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.9	10.2	10	10.2	9.9	10.2	9.93	±	0.06	10.20	±	0.00	0.03	0.00
2-3	9.9	10	9.9	10	10	10	9.93	±	0.06	10.00	±	0.00	0.03	0.00
3-4	10.1	10	10.1	10	10.1	10	10.10	±	0.00	10.00	±	0.00	0.00	0.00
4-5	9.9	10	9.9	10	9.9	10	9.90	±	0.00	10.00	±	0.00	0.00	0.00
5-6	10.1	10	10.1	10	10.1	10	10.10	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10.1	10	10.1	10	10.1	10.1	10.10	±	0.00	10.03	±	0.06	0.00	0.03
7-8	10.1	10.2	10.1	10.3	10	10	10.07	±	0.06	10.17	±	0.15	0.03	0.09
8-9	9.9	10	10.1	10	9.9	10	9.97	±	0.12	10.00	±	0.00	0.07	0.00

Table 9. The deviation in mm of the average differences from the reference distance in each marker spacing in 15 catheters obtained from orthogonal reconstruction method.

Marker position	1-2		2-3		3-4		4-5		5-6		6-7		7-8		8-9	
Line	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT
1	0.10	**0.20**	0.10	0.00	0.03	0.00	0.10	0.00	0.03	0.00	0.10	0.00	0.07	0.17	0.07	0.00
2	0.03	0.07	0.00	0.07	0.00	0.07	0.00	0.03	0.00	0.03	0.03	0.10	0.00	0.10	0.00	0.10
3	0.07	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.07	0.07
4	0.00	0.00	**0.20**	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.20	0.03	0.10
5	0.10	0.00	0.10	0.00	0.17	0.03	0.07	0.00	0.20	0.07	0.20	0.20	0.20	0.17	0.10	0.00
6	0.10	0.20	0.10	0.00	0.07	0.00	0.07	0.00	0.07	0.00	0.10	0.03	0.03	0.17	0.10	0.00
7	0.00	0.10	0.00	0.10	0.00	0.10	0.00	0.07	0.00	0.10	0.00	0.10	0.00	0.10	0.00	0.10
8	0.00	0.07	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17
9	0.00	0.00	0.10	0.10	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.07	0.00	0.23	0.20	0.13
10	0.07	0.00	0.07	0.00	0.07	0.00	0.00	0.00	0.07	0.00	0.00	0.07	0.20	0.03	0.00	0.00
11	0.10	0.07	0.07	0.07	0.07	0.07	0.07	0.03	0.07	0.03	0.10	0.20	0.10	0.10	0.10	0.20
12	0.10	0.13	0.10	0.00	0.10	0.00	0.07	0.00	0.07	0.00	0.07	0.00	0.10	0.20	0.10	0.03
13	0.00	0.10	0.07	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.17	0.00	0.10
14	0.10	0.10	0.20	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.10	0.03
15	0.07	0.20	0.07	0.10	0.10	0.00	0.10	0.00	0.10	0.00	0.10	0.03	0.07	0.17	0.03	0.00
Average ± SD	0.06 ± 0.05	0.09 ± 0.07	0.09 ± 0.06	0.06 ± 0.05	0.04 ± 0.05	0.02 ± 0.04	0.04 ± 0.04	0.01 ± 0.02	0.04 ± 0.06	0.02 ± 0.03	0.05 ± 0.06	0.06 ± 0.07	0.05 ± 0.07	0.13 ± 0.07	0.06 ± 0.06	0.07 ± 0.07

5.2.2.2 The variable angle reconstruction method

The reconstructed catheters with the variable angle technique in the Acuity x-ray simulator unit were performed with the two radiographs from 300^0 and 60^0 beam angle. With this technique, The reconstruction accuracy was found to be in the acceptable criteria according to the technical report series No. 430, Table 10 and 11 presented the deviation of the measuring length from reference length and the maximum deviation was found to be 0.20 mm in both AP and Lateral. For the points located near the central axis of FOV, no deviation was detected. Average error were found 0.06 ± 0.06 mm in both AP and Lateral.

Table 10. The deviation in mm of the measuring distance from the reference distance in each marker spacing in 15 ribbons obtained from x-ray simulator with the variable angle reconstruction method.

Line 1	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	10	10.1	10.1	10.1	10.1	10.10	±	0.00	10.07	±	0.06	0.00	0.03
2-3	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
3-4	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
4-5	10	10.1	10	10	10	10	10.00	±	0.00	10.03	±	0.06	0.00	0.03
5-6	10	10.1	10	10.1	10.1	10.1	10.03	±	0.06	10.10	±	0.00	0.03	0.00
6-7	10	10.1	10	10.1	10	10	10.00	±	0.00	10.07	±	0.06	0.00	0.03
7-8	10.2	10.1	10.1	10.1	10.1	10.1	10.13	±	0.06	10.10	±	0.00	0.03	0.00
8-9	10.2	10.1	10.2	10.2	10.1	10.1	10.17	±	0.06	10.13	±	0.06	0.03	0.03
Line 2	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	9.9	10	9.9	9.9	10	9.97	±	0.06	9.93	±	0.06	0.03	0.03
2-3	10.1	10.2	10.1	10.2	10.2	10.1	10.13	±	0.06	10.17	±	0.06	0.03	0.03
3-4	10	10.2	10.1	10.2	10.2	10.2	10.10	±	0.10	10.20	±	0.00	0.06	0.00
4-5	10	10.1	10.1	10	10.1	10	10.07	±	0.06	10.03	±	0.06	0.03	0.03
5-6	10	10.1	10	10	10.1	10	10.03	±	0.06	10.03	±	0.06	0.03	0.03
6-7	10.1	10.1	10.1	10	10.1	10.1	10.10	±	0.00	10.07	±	0.06	0.00	0.03
7-8	10.1	10.1	10	10	10.1	10	10.07	±	0.06	10.03	±	0.06	0.03	0.03
8-9	10	10.1	10	10.1	10.1	10.1	10.03	±	0.06	10.10	±	0.00	0.03	0.00
Line 3	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
2-3	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
3-4	10	10.1	10	10.1	10.1	10.1	10.03	±	0.06	10.10	±	0.00	0.03	0.00
4-5	10	10.1	10	10	10	10.1	10.00	±	0.00	10.07	±	0.06	0.00	0.03
5-6	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10	10.1	10	10	10	10	10.00	±	0.00	10.03	±	0.06	0.00	0.03
7-8	10	10.1	10	10.1	10.1	10.1	10.03	±	0.06	10.10	±	0.00	0.03	0.00
8-9	10	10	10	10.2	10	10	10.00	±	0.00	10.07	±	0.12	0.00	0.07
Line 4	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	10.2	10.1	10.2	10.1	10.2	10.10	±	0.00	10.20	±	0.00	0.00	0.00
2-3	10.1	9.9	10.1	9.9	10.1	9.9	10.10	±	0.00	9.90	±	0.00	0.00	0.00
3-4	10.1	10.2	10.1	10.2	10.1	9.9	10.10	±	0.00	10.10	±	0.17	0.00	0.10
4-5	10	10.1	10	10.1	10	10	10.00	±	0.00	10.07	±	0.06	0.00	0.03
5-6	10.1	10.1	10	10.1	10.1	10	10.07	±	0.06	10.07	±	0.06	0.03	0.03
6-7	10.1	10.1	10	10.1	10.1	10	10.07	±	0.06	10.07	±	0.06	0.03	0.03
7-8	10	10.2	10.1	10.2	10	10.2	10.03	±	0.06	10.20	±	0.00	0.03	0.00
8-9	10	10.1	10.1	10	10	10.1	10.03	±	0.06	10.07	±	0.06	0.03	0.03

Line 5	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
2-3	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
3-4	10.1	10	10.1	10	10	10.1	10.07	±	0.06	10.03	±	0.06	0.03	0.03
4-5	10.1	10	10.1	10	10	10.1	10.07	±	0.06	10.03	±	0.06	0.03	0.03
5-6	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
6-7	10.1	10.2	10	10.1	10.2	10.1	10.10	±	0.10	10.13	±	0.06	0.06	0.03
7-8	10.2	10.2	10.2	10.2	10.2	10.2	10.20	±	0.00	10.20	±	0.00	0.00	0.00
8-9	10.2	10.1	10.2	10.2	10.1	10.2	10.17	±	0.06	10.17	±	0.06	0.03	0.03
Line 6	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	10.1	10.1	10.1	10.2	10.1	10.13	±	0.06	10.10	±	0.00	0.03	0.00
2-3	10.2	10	10.2	10	10.2	10.2	10.20	±	0.00	10.07	±	0.12	0.00	0.07
3-4	10.1	10	10	10	10.1	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
4-5	10.1	10	10.1	10	10.1	10	10.10	±	0.00	10.00	±	0.00	0.00	0.00
5-6	10.1	10	10.1	10	10	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
6-7	10.1	10	10.1	10	10	9.9	10.07	±	0.06	9.97	±	0.06	0.03	0.03
7-8	10.2	10.1	10.2	10.2	10.2	10.2	10.20	±	0.00	10.17	±	0.06	0.00	0.03
8-9	9.9	9.9	10	10	9.9	9.9	9.93	±	0.06	9.93	±	0.06	0.03	0.03
Line 7	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.9	10	9.9	10	9.9	10.1	9.90	±	0.00	10.03	±	0.06	0.00	0.03
2-3	9.9	10	9.9	9.9	9.9	10	9.90	±	0.00	9.97	±	0.06	0.00	0.03
3-4	10	10	10	10	9.9	10	9.97	±	0.06	10.00	±	0.00	0.03	0.00
4-5	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
5-6	10	10	10	10	9.9	10	9.97	±	0.06	10.00	±	0.00	0.03	0.00
6-7	10.1	10	10.1	10	10	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
7-8	10.2	10.1	10.2	10.2	10.2	10.2	10.20	±	0.00	10.17	±	0.06	0.00	0.03
8-9	10.1	10	10.1	10	10.1	10	10.10	±	0.00	10.00	±	0.00	0.00	0.00
Line 8	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.9	10	9.9	10	10	10	9.93	±	0.06	10.00	±	0.00	0.03	0.00
2-3	10	10	10	10	10.1	10.1	10.03	±	0.06	10.03	±	0.06	0.03	0.03
3-4	10.1	10.1	10	10.1	10	10	10.03	±	0.06	10.07	±	0.06	0.03	0.03
4-5	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
5-6	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10	10	10.1	10.1	10	10	10.03	±	0.06	10.03	±	0.06	0.03	0.03
7-8	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
8-9	9.9	10	9.9	10	10.1	10	9.97	±	0.12	10.00	±	0.00	0.07	0.00
Line 9	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10	10	10	10	10.1	10.00	±	0.00	10.03	±	0.06	0.00	0.03
2-3	10.1	10.1	10.1	10.1	10.1	10	10.10	±	0.00	10.07	±	0.06	0.00	0.03
3-4	10	10	10	10	10	10.1	10.00	±	0.00	10.03	±	0.06	0.00	0.03
4-5	10.1	10	10.1	10.1	10.1	10	10.10	±	0.00	10.03	±	0.06	0.00	0.03
5-6	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10	10.1	10	10	10	10	10.00	±	0.00	10.03	±	0.06	0.00	0.03
7-8	10.1	10.2	10.2	10.2	10.1	10.1	10.13	±	0.06	10.17	±	0.06	0.03	0.03
8-9	10.2	10.1	10.2	10.2	10.1	10.2	10.17	±	0.06	10.17	±	0.06	0.03	0.03

Line 10	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.9	9.9	10	10	10	9.9	9.97	±	0.06	9.93	±	0.06	0.03	0.03
2-3	9.9	9.9	9.9	9.9	9.9	9.9	9.90	±	0.00	9.90	±	0.00	0.00	0.00
3-4	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
4-5	10	10	10.1	10	10	10	10.03	±	0.06	10.00	±	0.00	0.03	0.00
5-6	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10	10	10	10	10.1	10	10.03	±	0.06	10.00	±	0.00	0.03	0.00
7-8	9.9	10	9.9	10	9.9	10	9.90	±	0.00	10.00	±	0.00	0.00	0.00
8-9	10.2	10.3	10.2	10.2	10.2	10.2	10.20	±	0.00	10.23	±	0.06	0.00	0.03
Line 11	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	10.1	10	10.1	10.1	10.1	10.07	±	0.06	10.10	±	0.00	0.03	0.00
2-3	10.1	9.9	10.1	10	10.1	10	10.10	±	0.00	9.97	±	0.06	0.00	0.03
3-4	10.1	9.9	10	10.1	10.1	10	10.07	±	0.06	10.00	±	0.10	0.03	0.06
4-5	10.1	9.9	10	10	10.1	10.1	10.07	±	0.06	10.00	±	0.10	0.03	0.06
5-6	10.1	10.1	10.1	10	10.1	10	10.10	±	0.00	10.03	±	0.06	0.00	0.03
6-7	10.1	10	10.1	10.1	10.1	10	10.10	±	0.00	10.03	±	0.06	0.00	0.03
7-8	10.1	10	10.1	10.1	10.1	10	10.10	±	0.00	10.03	±	0.06	0.00	0.03
8-9	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
Line 12	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.9	10.2	9.9	10.2	9.9	10.1	9.90	±	0.00	10.17	±	0.06	0.00	0.03
2-3	9.9	10	9.9	10	9.9	10	9.90	±	0.00	10.00	±	0.00	0.00	0.00
3-4	10.1	10	10.1	10	10.1	10	10.10	±	0.00	10.00	±	0.00	0.00	0.00
4-5	9.9	10	9.9	9.9	10	10	9.93	±	0.06	9.97	±	0.06	0.03	0.03
5-6	10.1	10	10	10	9.9	10	10.00	±	0.10	10.00	±	0.00	0.06	0.00
6-7	10.1	10	10	10.1	10.1	10.1	10.07	±	0.06	10.07	±	0.06	0.03	0.03
7-8	10.1	10.2	10.1	10.2	10.2	10.2	10.13	±	0.06	10.20	±	0.00	0.03	0.00
8-9	9.9	10	10	10.1	10.1	10.1	10.00	±	0.10	10.07	±	0.06	0.06	0.03
Line 13	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10	10	10.1	10	10	10.00	±	0.00	10.03	±	0.06	0.00	0.03
2-3	10	10	10	10	10	10.1	10.00	±	0.00	10.03	±	0.06	0.00	0.03
3-4	10	9.9	10	10	10	10	10.00	±	0.00	9.97	±	0.06	0.00	0.03
4-5	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
5-6	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
7-8	10	10.1	10	9.9	10	10.1	10.00	±	0.00	10.03	±	0.12	0.00	0.07
8-9	10	10	10	10.1	10	10.1	10.00	±	0.00	10.07	±	0.06	0.00	0.03
Line 14	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	10.1	9.9	10	10.1	10.1	10.03	±	0.12	10.07	±	0.06	0.07	0.03
2-3	10.2	10.2	10.1	10.2	10.2	10.1	10.17	±	0.06	10.17	±	0.06	0.03	0.03
3-4	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
4-5	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
5-6	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10	10	10	10	10.1	10	10.03	±	0.06	10.00	±	0.00	0.03	0.00
7-8	10.2	10.1	10.1	10.1	10.1	10.2	10.13	±	0.06	10.13	±	0.06	0.03	0.03
8-9	10.2	10.1	10.2	10.2	10.2	10.2	10.20	±	0.00	10.17	±	0.06	0.00	0.03

Line 15	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.8	9.8	9.8	9.8	9.8	9.9	9.80	±	0.00	9.83	±	0.06	0.00	0.03
2-3	9.8	9.8	9.8	9.8	9.9	9.9	9.83	±	0.06	9.83	±	0.06	0.03	0.03
3-4	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
4-5	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
5-6	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
6-7	10	10	10	10	10	10.1	10.00	±	0.00	10.03	±	0.06	0.00	0.03
7-8	10	10.1	10	10	10	10	10.00	±	0.00	10.03	±	0.06	0.00	0.03
8-9	10.1	10.2	10.1	10.1	10.1	10.2	10.10	±	0.00	10.17	±	0.06	0.00	0.03

Table 11. The deviation in mm of the average differences from the reference distance in each marker spacing in 15 catheters obtained from variable angle reconstruction method.

Marker position	1-2		2-3		3-4		4-5		5-6		6-7		7-8		8-9	
Line	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT
1	0.10	0.07	0.10	0.10	0.00	0.00	0.00	0.03	0.03	0.10	0.00	0.07	0.13	0.10	0.17	0.13
2	0.03	0.07	0.13	0.17	0.10	0.20	0.07	0.03	0.03	0.03	0.10	0.07	0.07	0.03	0.03	0.10
3	0.00	0.00	0.00	0.10	0.03	0.10	0.00	0.07	0.00	0.00	0.00	0.03	0.03	0.10	0.00	0.07
4	0.10	**0.20**	0.10	0.10	0.10	0.10	0.00	0.07	0.07	0.07	0.07	0.07	0.03	0.20	0.03	0.07
5	0.10	0.10	0.10	0.10	0.07	0.03	0.07	0.03	0.10	0.10	0.10	0.13	0.20	0.20	0.17	0.17
6	0.13	0.10	0.20	0.07	0.07	0.00	0.10	0.00	0.07	0.00	0.07	0.03	0.20	0.17	0.07	0.07
7	0.10	0.03	0.10	0.03	0.03	0.00	0.00	0.00	0.03	0.00	0.07	0.00	0.20	0.17	0.10	0.00
8	0.07	0.00	0.03	0.03	0.03	0.07	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.00	0.03	0.00
9	0.00	0.03	0.10	0.07	0.00	0.03	0.10	0.03	0.00	0.00	0.00	0.03	0.13	0.17	0.17	0.17
10	0.03	0.07	0.10	0.10	0.10	0.10	0.03	0.00	0.00	0.00	0.03	0.00	0.10	0.00	0.20	0.23
11	0.07	0.10	0.10	0.03	0.07	0.00	0.07	0.00	0.10	0.03	0.10	0.03	0.10	0.03	0.10	0.10
12	0.10	0.17	0.10	0.00	0.10	0.00	0.07	0.03	0.00	0.00	0.07	0.07	0.13	0.20	0.00	0.07
13	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.06
14	0.03	0.07	0.17	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.13	0.13	0.20	0.17
15	**0.20**	0.17	0.17	0.17	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.10	0.17
Average ± SD	0.07 ± 0.06	0.08 ± 0.06	0.10 ± 0.06	0.08 ± 0.06	0.05 ± 0.04	0.05 ± 0.06	0.03 ± 0.04	0.02 ± 0.02	0.03 ± 0.04	0.02 ± 0.04	0.04 ± 0.04	0.04 ± 0.04	0.10 ± 0.07	0.10 ± 0.08	0.09 ± 0.08	0.11 ± 0.07

5.2.3 Reconstruction accuracy from the C-arm X-ray unit

The advantage from a compact size and a mobility make the C-arm x-ray unit is a imaging modality of choice for brachytherapy planning. However, there are some limitations such as the spatial resolutions, the non-isocentric geometry and small FOV are found in this unit.

In this study, the accuracy of the catheter reconstruction using the semi-orthogonal technique with and without reconstruction jig were determined.

5.2.3.1 With the reconstruction jig

Using a reconstruction jig, the determination of the magnification factor can be easily performed in the treatment planning system. Results in the table 12 showed the deviation of the reconstructed distance from the reference distance in this technique. The maximum error was found at 0.63 mm in AP and 0.57 mm in Lateral view as presented in table 13. The average deviation equals to 0.17 ± 0.15 mm in both AP and Lateral view respectively. The quality of the reconstructed image using the C-arm x-ray unit with a reconstruction jig is in acceptable criteria of the technical report series No. 430 [19].

Table 12. The deviation in mm of the measuring distance from the reference distance in each marker spacing in 15 ribbons obtained from C-arm x-ray unit using semi-orthogonal method with the reconstruction jig.

Line 1	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.4	9.3	9.5	9.6	9.4	9.5	9.43	±	0.06	9.47	±	0.15	0.03	0.09
2-3	10.6	10.6	10.6	10.6	10.6	10.5	10.60	±	0.00	10.57	±	0.06	0.00	0.03
3-4	9.8	10.8	9.8	10	9.8	10.1	9.80	±	0.00	10.30	±	0.44	0.00	0.25
4-5	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
5-6	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
6-7	9.7	10.3	9.7	10.2	9.8	10.2	9.73	±	0.06	10.23	±	0.06	0.03	0.03
7-8	9.7	9.6	9.8	9.9	9.8	10	9.77	±	0.06	9.83	±	0.21	0.03	0.12
8-9	10.6	10.6	10.5	10.4	10.5	10.5	10.53	±	0.06	10.50	±	0.10	0.03	0.06
Line 2	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.4	9.3	9.4	9.5	9.5	9.5	9.43	±	0.06	9.43	±	0.12	0.03	0.07
2-3	10.6	10.5	10.6	10.5	10.5	10.5	10.57	±	0.06	10.50	±	0.00	0.03	0.00
3-4	9.6	9.7	9.6	9.8	9.6	9.8	9.60	±	0.00	9.77	±	0.06	0.00	0.03
4-5	10.1	10.1	10.1	10.1	10.1	10	10.10	±	0.00	10.07	±	0.06	0.00	0.03
5-6	9.9	10.2	9.9	10	10	10.1	9.93	±	0.06	10.10	±	0.10	0.03	0.06
6-7	10.1	10	10.1	10	10.1	10	10.10	±	0.00	10.00	±	0.00	0.00	0.00
7-8	9.8	9.9	9.8	10	9.8	9.9	9.80	±	0.00	9.93	±	0.06	0.00	0.03
8-9	10.3	10.2	10.3	10.4	10.3	10.3	10.30	±	0.00	10.30	±	0.10	0.00	0.06
Line 3	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	10.1	10	9.9	10.2	9.9	10.07	±	0.12	9.97	±	0.12	0.07	0.07
2-3	9.8	9.9	10.2	10	10.1	10	10.03	±	0.21	9.97	±	0.06	0.12	0.03
3-4	10	10.1	10	9.9	10	9.9	10.00	±	0.00	9.97	±	0.12	0.00	0.07
4-5	10.1	10.1	10	10.2	10	10.1	10.03	±	0.06	10.13	±	0.06	0.03	0.03
5-6	10.1	10	9.9	10	10	10	10.00	±	0.10	10.00	±	0.00	0.06	0.00
6-7	10	10.1	10.1	10	10.1	10	10.07	±	0.06	10.03	±	0.06	0.03	0.03
7-8	9.9	9.9	9.9	9.9	9.9	9.9	9.90	±	0.00	9.90	±	0.00	0.00	0.00
8-9	10.2	10.2	10.2	10.3	10.2	10.2	10.20	±	0.00	10.23	±	0.06	0.00	0.03
Line 4	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.7	9.8	9.7	9.8	9.7	9.8	9.70	±	0.00	9.80	±	0.00	0.00	0.00
2-3	10.3	10.1	10.3	10.1	10.2	10.1	10.27	±	0.06	10.10	±	0.00	0.03	0.00
3-4	10.2	10.3	10.2	10.3	10.2	10.2	10.20	±	0.00	10.27	±	0.06	0.00	0.03
4-5	9.8	10	9.8	10	9.8	10	9.80	±	0.00	10.00	±	0.00	0.00	0.00
5-6	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
6-7	10.1	10.1	10.1	10.1	10.1	10	10.10	±	0.00	10.07	±	0.06	0.00	0.03
7-8	9.9	9.7	9.9	9.9	9.9	10	9.90	±	0.00	9.87	±	0.15	0.00	0.09
8-9	10.1	10.1	10.1	10.3	10.1	10.3	10.10	±	0.00	10.23	±	0.12	0.00	0.07

Line 5	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.8	9.8	9.8	9.8	9.8	9.8	9.80	±	0.00	9.80	±	0.00	0.00	0.00
2-3	10.4	10.6	10.4	10.4	10.4	10.5	10.40	±	0.00	10.50	±	0.10	0.00	0.06
3-4	9.8	9.8	9.8	9.8	9.8	9.8	9.80	±	0.00	9.80	±	0.00	0.00	0.00
4-5	10.2	9.9	10.2	10.1	10.1	10.1	10.17	±	0.06	10.03	±	0.12	0.03	0.07
5-6	9.9	9.9	10.2	10.1	10.1	10.1	10.07	±	0.15	10.03	±	0.12	0.09	0.07
6-7	10.2	10.1	10.2	10.1	10.2	10.1	10.20	±	0.00	10.10	±	0.00	0.00	0.00
7-8	9.9	9.9	10	10.1	10	10.1	9.97	±	0.06	10.03	±	0.12	0.03	0.07
8-9	10.2	10.4	9.9	9.6	9.9	9.7	10.00	±	0.17	9.90	±	0.44	0.10	0.25
Line 6	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.6	9.5	9.8	9.6	9.8	9.7	9.73	±	0.12	9.60	±	0.10	0.07	0.06
2-3	10.2	10	10.2	10	10.2	10	10.20	±	0.00	10.00	±	0.00	0.00	0.00
3-4	10.1	10	10.1	10	10	10	10.07	±	0.06	10.00	±	0.00	0.03	0.00
4-5	9.9	9.7	9.9	9.9	9.9	9.9	9.90	±	0.00	9.83	±	0.12	0.00	0.07
5-6	10.4	10.8	10.2	10.4	10.2	10.4	10.27	±	0.12	10.53	±	0.23	0.07	0.13
6-7	10.2	10.3	10.2	10.3	10.2	10.3	10.20	±	0.00	10.30	±	0.00	0.00	0.00
7-8	10.2	10.3	10.2	10.2	10.2	10.2	10.20	±	0.00	10.23	±	0.06	0.00	0.03
8-9	10.1	10.3	10.1	10.2	10.1	10.2	10.10	±	0.00	10.23	±	0.06	0.00	0.03
Line 7	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.5	9.4	9.5	9.6	9.5	9.5	9.50	±	0.00	9.50	±	0.10	0.00	0.06
2-3	10.2	10.1	10.1	10.2	10.2	10.1	10.17	±	0.06	10.13	±	0.06	0.03	0.03
3-4	9.7	9.9	9.7	9.9	9.7	9.9	9.70	±	0.00	9.90	±	0.00	0.00	0.00
4-5	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
5-6	9.9	10.2	9.9	10.2	9.9	10.1	9.90	±	0.00	10.17	±	0.06	0.00	0.03
6-7	10.1	10.1	10	10	10	10	10.03	±	0.06	10.03	±	0.06	0.03	0.03
7-8	10	9.9	10	10.1	10	10.1	10.00	±	0.00	10.03	±	0.12	0.00	0.07
8-9	10	10.1	10	10.2	10	10.1	10.00	±	0.00	10.13	±	0.06	0.00	0.03
Line 8	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	9.8	10	9.8	10.1	9.9	10.03	±	0.06	9.83	±	0.06	0.03	0.03
2-3	10.1	10.2	10.1	10.2	10.1	10.2	10.10	±	0.00	10.20	±	0.00	0.00	0.00
3-4	10.1	10.1	10.1	10.1	10	10.1	10.07	±	0.06	10.10	±	0.00	0.03	0.00
4-5	10	9.8	10	10	10	10	10.00	±	0.00	9.93	±	0.12	0.00	0.07
5-6	10.1	9.9	10.1	9.9	10.1	10	10.10	±	0.00	9.93	±	0.06	0.00	0.03
6-7	10.1	9.9	10.1	9.9	10	10	10.07	±	0.06	9.93	±	0.06	0.03	0.03
7-8	10.3	10.1	10.1	10.1	10.1	10.2	10.17	±	0.12	10.13	±	0.06	0.07	0.03
8-9	10.3	10.1	10.1	10.1	10.1	10.1	10.17	±	0.12	10.10	±	0.00	0.07	0.00
Line 9	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.8	9.4	9.8	9.6	9.8	9.6	9.80	±	0.00	9.53	±	0.12	0.00	0.07
2-3	10	9.9	10	9.9	10	9.9	10.00	±	0.00	9.90	±	0.00	0.00	0.00
3-4	9.5	9.5	9.8	9.8	9.8	9.8	9.70	±	0.17	9.70	±	0.17	0.10	0.10
4-5	10.2	10.2	10.2	10.2	10.2	10.3	10.20	±	0.00	10.23	±	0.06	0.00	0.03
5-6	9.9	10.2	9.9	10.1	9.9	10.1	9.90	±	0.00	10.13	±	0.06	0.00	0.03
6-7	10	10.1	10	10.1	10	10	10.00	±	0.00	10.07	±	0.06	0.00	0.03
7-8	10	9.9	10	9.9	10	10.1	10.00	±	0.00	9.97	±	0.12	0.00	0.07
8-9	10.3	10.1	10.2	10.1	10.2	10.1	10.23	±	0.06	10.10	±	0.00	0.03	0.00

Line 10	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.9	10.2	9.9	10.2	9.9	10.2	9.90	±	0.00	10.20	±	0.00	0.00	0.00
2-3	10.1	10.2	10.1	10.1	10.1	10.1	10.10	±	0.00	10.13	±	0.06	0.00	0.03
3-4	9.9	9.9	9.9	9.9	9.9	9.9	9.90	±	0.00	9.90	±	0.00	0.00	0.00
4-5	9.8	10	9.8	10	9.8	10	9.80	±	0.00	10.00	±	0.00	0.00	0.00
5-6	10.1	9.9	10.1	9.9	10.1	9.9	10.10	±	0.00	9.90	±	0.00	0.00	0.00
6-7	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
7-8	9.8	9.7	9.8	9.7	9.8	9.8	9.80	±	0.00	9.73	±	0.06	0.00	0.03
8-9	10.5	10.8	10.5	10.6	10.5	10.6	10.50	±	0.00	10.67	±	0.12	0.00	0.07
Line 11	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
2-3	10	9.9	10	9.9	10	9.9	10.00	±	0.00	9.90	±	0.00	0.00	0.00
3-4	10.1	9.9	10	9.9	10.1	9.9	10.07	±	0.06	9.90	±	0.00	0.03	0.00
4-5	10.1	9.9	10.2	9.9	10.1	9.9	10.13	±	0.06	9.90	±	0.00	0.03	0.00
5-6	10	9.8	10	10	10	9.9	10.00	±	0.00	9.90	±	0.10	0.00	0.06
6-7	10.4	10.6	10.3	10.4	10.3	10.4	10.33	±	0.06	10.47	±	0.12	0.03	0.07
7-8	9.8	9.9	9.8	9.9	9.8	9.9	9.80	±	0.00	9.90	±	0.00	0.00	0.00
8-9	10.8	10.6	10.5	10.5	10.6	10.6	10.63	±	0.15	10.57	±	0.06	0.09	0.03
Line 12	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.4	9.5	9.6	9.8	9.6	9.8	9.53	±	0.12	9.70	±	0.17	0.07	0.10
2-3	10.4	10.4	10.2	10.2	10.2	10.2	10.27	±	0.12	10.27	±	0.12	0.07	0.07
3-4	9.5	9.5	9.9	9.8	9.9	9.8	9.77	±	0.23	9.70	±	0.17	0.13	0.10
4-5	10.5	10.6	10	10.2	10	10.2	10.17	±	0.29	10.33	±	0.23	0.17	0.13
5-6	9.7	9.5	10	10.2	10	10.2	9.90	±	0.17	9.97	±	0.40	0.10	0.23
6-7	10.3	10.2	10	10.1	10	10.1	10.10	±	0.17	10.13	±	0.06	0.10	0.03
7-8	9.7	9.9	9.8	9.9	9.8	9.9	9.77	±	0.06	9.90	±	0.00	0.03	0.00
8-9	10.3	10.6	10.3	10.5	10.2	10.4	10.27	±	0.06	10.50	±	0.10	0.03	0.06
Line 13	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10.2	9.9	10.1	9.9	10.1	9.9	10.13	±	0.06	9.90	±	0.00	0.03	0.00
2-3	9.9	9.9	9.9	9.9	9.9	9.9	9.90	±	0.00	9.90	±	0.00	0.00	0.00
3-4	10.1	10.2	10.1	10.1	10.1	10	10.10	±	0.00	10.10	±	0.10	0.00	0.06
4-5	9.9	10.1	9.9	10.1	9.9	10	9.90	±	0.00	10.07	±	0.06	0.00	0.03
5-6	10	9.9	10	9.9	10	10	10.00	±	0.00	9.93	±	0.06	0.00	0.03
6-7	10.1	10.1	10.1	10.1	10	10	10.07	±	0.06	10.07	±	0.06	0.03	0.03
7-8	10.1	9.9	10.1	9.9	10	10	10.07	±	0.06	9.93	±	0.06	0.03	0.03
8-9	10.2	10.2	10.1	10.1	10.1	10.1	10.13	±	0.06	10.13	±	0.06	0.03	0.03
Line 14	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	9.8	9.9	9.8	9.9	9.8	9.9	9.80	±	0.00	9.90	±	0.00	0.00	0.00
2-3	10.1	10	10.1	10	10.1	10	10.10	±	0.00	10.00	±	0.00	0.00	0.00
3-4	10	10	10	10	10	10	10.00	±	0.00	10.00	±	0.00	0.00	0.00
4-5	10	10.1	10	10.1	10	10.1	10.00	±	0.00	10.10	±	0.00	0.00	0.00
5-6	10	10	10	10	10	10.1	10.00	±	0.00	10.03	±	0.06	0.00	0.03
6-7	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
7-8	10.2	10.2	10.2	10.3	10.2	10.2	10.20	±	0.00	10.23	±	0.06	0.00	0.03
8-9	10.2	10.3	10.2	10.2	10.1	10.2	10.17	±	0.06	10.23	±	0.06	0.03	0.03

Line 15	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	10	9.9	10	9.9	10	9.9	10.00	±	0.00	9.90	±	0.00	0.00	0.00
2-3	10.1	10.1	10.1	10.1	10.1	10.1	10.10	±	0.00	10.10	±	0.00	0.00	0.00
3-4	9.7	9.9	9.7	9.9	9.7	9.9	9.70	±	0.00	9.90	±	0.00	0.00	0.00
4-5	9.8	9.7	9.8	9.7	9.8	9.7	9.80	±	0.00	9.70	±	0.00	0.00	0.00
5-6	10.2	10.2	10.2	10.2	10.2	10.2	10.20	±	0.00	10.20	±	0.00	0.00	0.00
6-7	10.3	10.2	10.3	10.2	10.3	10.2	10.30	±	0.00	10.20	±	0.00	0.00	0.00
7-8	9.8	9.8	9.8	9.8	9.8	9.8	9.80	±	0.00	9.80	±	0.00	0.00	0.00
8-9	10.2	10.2	10.2	10.2	10.2	10.2	10.20	±	0.00	10.20	±	0.00	0.00	0.00

Table 13. The deviation in mm of the average differences from the reference distance in each marker spacing in 15 ribbons obtained from C-arm x-ray unit using semi-orthogonal method with the reconstruction jig.

Marker position	1-2		2-3		3-4		4-5		5-6		6-7		7-8		8-9	
Line	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT
1	0.57	0.53	0.60	0.57	0.20	0.30	0.00	0.10	0.00	0.10	0.27	0.23	0.23	0.17	0.53	0.50
2	0.57	**0.57**	0.57	0.50	0.40	0.23	0.10	0.07	0.07	0.10	0.10	0.00	0.20	0.07	0.30	0.30
3	0.07	0.03	0.03	0.03	0.00	0.03	0.03	0.13	0.00	0.00	0.07	0.03	0.10	0.10	0.20	0.23
4	0.30	0.20	0.27	0.10	0.20	0.27	0.20	0.00	0.10	0.10	0.10	0.07	0.10	0.13	0.10	0.23
5	0.20	0.20	0.40	0.50	0.20	0.20	0.17	0.03	0.07	0.03	0.20	0.10	0.33	0.03	0.00	0.10
6	0.27	0.40	0.20	0.00	0.07	0.00	0.10	0.17	0.27	0.53	0.20	0.30	0.20	0.23	0.10	0.23
7	0.50	0.50	0.17	0.13	0.30	0.10	0.00	0.10	0.10	0.17	0.03	0.03	0.00	0.03	0.00	0.13
8	0.03	0.17	0.10	0.20	0.07	0.10	0.00	0.07	0.10	0.07	0.07	0.07	0.17	0.13	0.17	0.10
9	0.20	0.47	0.00	0.10	0.30	0.30	0.20	0.23	0.10	0.13	0.00	0.07	0.00	0.03	0.23	0.10
10	0.10	0.20	0.10	0.13	0.10	0.10	0.20	0.00	0.10	0.10	0.10	0.10	0.20	0.27	0.50	0.57
11	0.10	0.10	0.00	0.10	0.07	0.10	0.13	0.10	0.00	0.10	0.33	0.47	0.20	0.10	**0.63**	0.57
12	0.47	0.30	0.27	0.27	0.23	0.30	0.17	0.33	0.10	0.03	0.10	0.13	0.23	0.10	0.27	0.50
13	0.13	0.10	0.10	0.10	0.10	0.10	0.10	0.07	0.00	0.07	0.07	0.07	0.07	0.07	0.13	0.13
14	0.20	0.10	0.10	0.00	0.00	0.00	0.00	0.10	0.00	0.03	0.10	0.10	0.20	0.23	0.17	0.23
15	0.00	0.10	0.10	0.10	0.30	0.10	0.20	0.30	0.20	0.20	0.30	0.20	0.20	0.20	0.20	0.20
Average ± SD	0.25 ± 0.20	0.26 ± 0.18	0.20 ± 0.19	0.19 ± 0.19	0.17 ± 0.12	0.15 ± 0.11	0.11 ± 0.08	0.12 ± 0.10	0.08 ± 0.08	0.12 ± 0.13	0.14 ± 0.10	0.13 ± 0.12	0.16 ± 0.09	0.13 ± 0.08	0.24 ± 0.19	0.28 ± 0.19

5.1.3.2 Without reconstruction jig

With the purpose to increase the accuracy in determination the magnification factor from two orientation radiographs by using a reconstruction jig. There are some conditions which the reconstruction jig can not be used with the patients. In this case the accuracy of reconstruction should be investigated to assess the level of deviation to assure the quality of the treatment delivered to the patients.

Results of the reconstructed marker from the study that without reconstruction jig in showed a significant reconstruction deviation. By the average error was detected less than 2 mm while the maximum error was found in AP and Lateral view to be 3.63 mm and 3.67 mm respectively as shown in table 15.

Table 14. The deviation in mm of the measuring distance from the reference distance in each marker spacing in 15 ribbons obtained from C-arm x-ray unit using orthogonal method without the reconstruction jig.

Line 1	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	11.8	11.6	11.9	11.7	11.6	11.6	11.77	±	0.15	11.63	±	0.06	0.09	0.03
2-3	11.2	11.2	11.2	11.2	11.2	11	11.20	±	0.00	11.13	±	0.12	0.00	0.07
3-4	10.7	11	10.7	11	10.7	11	10.70	±	0.00	11.00	±	0.00	0.00	0.00
4-5	10.8	11	10.8	11	10.8	11	10.80	±	0.00	11.00	±	0.00	0.00	0.00
5-6	10.6	10.6	10.7	10.6	10.6	10.6	10.63	±	0.06	10.60	±	0.00	0.03	0.00
6-7	12.2	12.1	12.2	12.1	12.2	12.1	12.20	±	0.00	12.10	±	0.00	0.00	0.00
7-8	11.9	12.1	11.9	12.1	11.9	12.1	11.90	±	0.00	12.10	±	0.00	0.00	0.00
8-9	12.2	12.2	12.3	12.2	12.2	11.9	12.23	±	0.06	12.10	±	0.17	0.03	0.10
Line 2	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	13.8	13.7	13.6	13.7	13.5	13.6	13.63	±	0.15	13.67	±	0.06	0.09	0.03
2-3	12.6	12.6	12.6	12.6	12.6	12.6	12.60	±	0.00	12.60	±	0.00	0.00	0.00
3-4	12.9	12.6	12.9	12.6	10.8	10.7	12.20	±	1.21	11.97	±	1.10	0.70	0.63
4-5	11.1	11.3	11.2	11.3	10.6	10.6	10.97	±	0.32	11.07	±	0.40	0.19	0.23
5-6	10.8	11	10.8	11	10.8	10	10.80	±	0.00	10.67	±	0.58	0.00	0.33
6-7	10.7	10.7	10.7	10.7	10.7	10.9	10.70	±	0.00	10.77	±	0.12	0.00	0.07
7-8	13	12.8	12.6	12.8	11.8	11.8	12.47	±	0.61	12.47	±	0.58	0.35	0.33
8-9	12.8	12.8	12.8	12.8	12.7	12.5	12.77	±	0.06	12.70	±	0.17	0.03	0.10
Line 3	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	12.5	12.4	12.3	12.4	12.5	12.4	12.43	±	0.12	12.40	±	0.00	0.07	0.00
2-3	11.3	11.2	11.3	11.2	11.3	11.2	11.30	±	0.00	11.20	±	0.00	0.00	0.00
3-4	10.8	10.7	10.8	10.7	10.8	10.7	10.80	±	0.00	10.70	±	0.00	0.00	0.00
4-5	10.8	10.8	10.8	10.7	10.8	10.8	10.80	±	0.00	10.77	±	0.06	0.00	0.03
5-6	10.6	10.6	10.5	10.6	10.6	10.6	10.57	±	0.06	10.60	±	0.00	0.03	0.00
6-7	11.1	11	11.1	11	11	11	11.07	±	0.06	11.00	±	0.00	0.03	0.00
7-8	10.9	10.7	10.8	10.7	10.9	10.7	10.87	±	0.06	10.70	±	0.00	0.03	0.00
8-9	12.1	12.3	12.1	12.3	12.1	12.3	12.10	±	0.00	12.30	±	0.00	0.00	0.00
Line 4	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	12.2	12.2	12.2	12.2	12.2	12	12.20	±	0.00	12.13	±	0.12	0.00	0.07
2-3	11.3	11.1	11.3	11.1	11.3	11.1	11.30	±	0.00	11.10	±	0.00	0.00	0.00
3-4	10.9	10.9	10.8	10.9	10.9	10.9	10.87	±	0.06	10.90	±	0.00	0.03	0.00
4-5	10.9	10.9	10.9	10.9	10.9	10.9	10.90	±	0.00	10.90	±	0.00	0.00	0.00
5-6	10.8	10.9	10.7	10.9	10.8	10.9	10.77	±	0.06	10.90	±	0.00	0.03	0.00
6-7	11.3	11.3	11.2	11.3	11.3	11.3	11.27	±	0.06	11.30	±	0.00	0.03	0.00
7-8	12.1	12.1	12.1	11.9	12.2	12.1	12.13	±	0.06	12.03	±	0.12	0.03	0.07
8-9	11.9	12	11.9	11.8	11.9	12	11.90	±	0.00	11.93	±	0.12	0.00	0.07

Line 5	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	13.6	13.7	13.6	13.7	13.6	13.4	13.60	±	0.00	13.60	±	0.17	0.00	0.10
2-3	12.6	12.6	12.6	12.6	12.6	12.6	12.60	±	0.00	12.60	±	0.00	0.00	0.00
3-4	12.9	12.6	12.7	12.6	12.6	12.6	12.73	±	0.15	12.60	±	0.00	0.09	0.00
4-5	11.1	11.3	11.1	11.3	11.1	11.3	11.10	±	0.00	11.30	±	0.00	0.00	0.00
5-6	10.8	11	10.8	11	10.8	10.9	10.80	±	0.00	10.97	±	0.06	0.00	0.03
6-7	10.7	10.7	10.9	10.9	10.7	10.7	10.77	±	0.12	10.77	±	0.12	0.07	0.07
7-8	12.5	12.6	12.5	12.6	12.5	12.6	12.50	±	0.00	12.60	±	0.00	0.00	0.00
8-9	12.8	12.8	12.8	12.8	12.6	12.8	12.73	±	0.12	12.80	±	0.00	0.07	0.00
Line 6	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	11.9	11.7	11.6	11.6	11.6	11.6	11.70	±	0.17	11.63	±	0.06	0.10	0.03
2-3	11.2	11.2	11.2	11	11.2	11	11.20	±	0.00	11.07	±	0.12	0.00	0.07
3-4	10.7	11	10.7	11	10.7	11	10.70	±	0.00	11.00	±	0.00	0.00	0.00
4-5	10.8	11	10.8	11	10.8	11	10.80	±	0.00	11.00	±	0.00	0.00	0.00
5-6	10.7	10.6	10.6	10.6	10.6	10.6	10.63	±	0.06	10.60	±	0.00	0.03	0.00
6-7	12.2	12.1	12.2	12.1	12.2	12.1	12.20	±	0.00	12.10	±	0.00	0.00	0.00
7-8	11.9	12.1	11.9	12.1	11.9	12.1	11.90	±	0.00	12.10	±	0.00	0.00	0.00
8-9	12.3	12.2	12.2	11.9	12.2	11.9	12.23	±	0.06	12.00	±	0.17	0.03	0.10
Line 7	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	13.6	13.7	13.5	13.6	13.5	13.6	13.53	±	0.06	13.63	±	0.06	0.03	0.03
2-3	12.6	12.6	12.6	12.6	12.6	12.6	12.60	±	0.00	12.60	±	0.00	0.00	0.00
3-4	12.9	12.6	10.8	10.7	10.8	10.7	11.50	±	1.21	11.33	±	1.10	0.70	0.63
4-5	11.2	11.3	10.6	10.6	10.6	10.6	10.80	±	0.35	10.83	±	0.40	0.20	0.23
5-6	10.8	11	10.8	10	10.8	10	10.80	±	0.00	10.33	±	0.58	0.00	0.33
6-7	10.7	10.7	10.7	10.9	10.7	10.9	10.70	±	0.00	10.83	±	0.12	0.00	0.07
7-8	12.6	12.8	11.8	11.8	11.8	11.8	12.07	±	0.46	12.13	±	0.58	0.27	0.33
8-9	12.8	12.8	12.7	12.5	12.7	12.5	12.73	±	0.06	12.60	±	0.17	0.03	0.10
Line 8	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	12.3	12.4	12.5	12.4	12.5	12.4	12.43	±	0.12	12.40	±	0.00	0.07	0.00
2-3	11.3	11.2	11.3	11.2	11.3	11.2	11.30	±	0.00	11.20	±	0.00	0.00	0.00
3-4	10.8	10.7	10.8	10.7	10.8	10.7	10.80	±	0.00	10.70	±	0.00	0.00	0.00
4-5	10.8	10.7	10.8	10.8	10.8	10.8	10.80	±	0.00	10.77	±	0.06	0.00	0.03
5-6	10.5	10.6	10.6	10.6	10.6	10.6	10.57	±	0.06	10.60	±	0.00	0.03	0.00
6-7	11.1	11	11	11	11	11	11.03	±	0.06	11.00	±	0.00	0.03	0.00
7-8	10.8	10.7	10.9	10.7	10.9	10.7	10.87	±	0.06	10.70	±	0.00	0.03	0.00
8-9	12.1	12.3	12.1	12.3	12.1	12.3	12.10	±	0.00	12.30	±	0.00	0.00	0.00
Line 9	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	12.2	12.2	12.2	12	12.2	12	12.20	±	0.00	12.07	±	0.12	0.00	0.07
2-3	11.3	11.1	11.3	11.1	11.3	11.1	11.30	±	0.00	11.10	±	0.00	0.00	0.00
3-4	10.8	10.9	10.9	10.9	10.9	10.9	10.87	±	0.06	10.90	±	0.00	0.03	0.00
4-5	10.9	10.9	10.9	10.9	10.9	10.9	10.90	±	0.00	10.90	±	0.00	0.00	0.00
5-6	10.7	10.9	10.8	10.9	10.8	10.9	10.77	±	0.06	10.90	±	0.00	0.03	0.00
6-7	11.2	11.3	11.3	11.3	11.3	11.3	11.27	±	0.06	11.30	±	0.00	0.03	0.00
7-8	12.1	11.9	12.2	12.1	12.2	12.1	12.17	±	0.06	12.03	±	0.12	0.03	0.07
8-9	11.9	11.8	11.9	12	11.9	12	11.90	±	0.00	11.93	±	0.12	0.00	0.07

Line 10	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	13.6	13.7	13.6	13.4	13.6	13.4	13.60	±	0.00	13.50	±	0.17	0.00	0.10
2-3	12.6	12.6	12.6	12.6	12.6	12.6	12.60	±	0.00	12.60	±	0.00	0.00	0.00
3-4	12.7	12.6	12.6	12.6	12.6	12.6	12.63	±	0.06	12.60	±	0.00	0.03	0.00
4-5	11.1	11.3	11.1	11.3	11.1	11.3	11.10	±	0.00	11.30	±	0.00	0.00	0.00
5-6	10.8	11	10.8	10.9	10.8	10.9	10.80	±	0.00	10.93	±	0.06	0.00	0.03
6-7	10.9	10.9	10.7	10.7	10.7	10.7	10.77	±	0.12	10.77	±	0.12	0.07	0.07
7-8	12.5	12.6	12.5	12.6	12.5	12.6	12.50	±	0.00	12.60	±	0.00	0.00	0.00
8-9	12.8	12.8	12.6	12.8	12.6	12.8	12.67	±	0.12	12.80	±	0.00	0.07	0.00
Line 11	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	11.6	11.6	11.8	11.6	11.9	11.7	11.77	±	0.15	11.63	±	0.06	0.09	0.03
2-3	11.2	11	11.2	11.2	11.2	11.2	11.20	±	0.00	11.13	±	0.12	0.00	0.07
3-4	10.7	11	10.7	11	10.7	11	10.70	±	0.00	11.00	±	0.00	0.00	0.00
4-5	10.8	11	10.8	11	10.8	11	10.80	±	0.00	11.00	±	0.00	0.00	0.00
5-6	10.6	10.6	10.6	10.6	10.7	10.6	10.63	±	0.06	10.60	±	0.00	0.03	0.00
6-7	12.2	12.1	12.2	12.1	12.2	12.1	12.20	±	0.00	12.10	±	0.00	0.00	0.00
7-8	11.9	12.1	11.9	12.1	11.9	12.1	11.90	±	0.00	12.10	±	0.00	0.00	0.00
8-9	12.2	11.9	12.2	12.2	12.3	12.2	12.23	±	0.06	12.10	±	0.17	0.03	0.10
Line 12	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	13.5	13.6	13.8	13.7	13.6	13.7	13.63	±	0.15	13.67	±	0.06	0.09	0.03
2-3	12.6	12.6	12.6	12.6	12.6	12.6	12.60	±	0.00	12.60	±	0.00	0.00	0.00
3-4	10.8	10.7	12.9	12.6	12.9	12.6	12.20	±	1.21	11.97	±	1.10	0.70	0.63
4-5	10.6	10.6	11.1	11.3	11.2	11.3	10.97	±	0.32	11.07	±	0.40	0.19	0.23
5-6	10.8	10	10.8	11	10.8	11	10.80	±	0.00	10.67	±	0.58	0.00	0.33
6-7	10.7	10.9	10.7	10.7	10.7	10.7	10.70	±	0.00	10.77	±	0.12	0.00	0.07
7-8	11.8	11.8	13	12.8	12.6	12.8	12.47	±	0.61	12.47	±	0.58	0.35	0.33
8-9	12.7	12.5	12.8	12.8	12.8	12.8	12.77	±	0.06	12.70	±	0.17	0.03	0.10
Line 13	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	12.5	12.4	12.5	12.4	12.3	12.4	12.43	±	0.12	12.40	±	0.00	0.07	0.00
2-3	11.3	11.2	11.3	11.2	11.3	11.2	11.30	±	0.00	11.20	±	0.00	0.00	0.00
3-4	10.8	10.7	10.8	10.7	10.8	10.7	10.80	±	0.00	10.70	±	0.00	0.00	0.00
4-5	10.8	10.8	10.8	10.8	10.8	10.7	10.80	±	0.00	10.77	±	0.06	0.00	0.03
5-6	10.6	10.6	10.6	10.6	10.5	10.6	10.57	±	0.06	10.60	±	0.00	0.03	0.00
6-7	11	11	11.1	11	11.1	11	11.07	±	0.06	11.00	±	0.00	0.03	0.00
7-8	10.9	10.7	10.9	10.7	10.8	10.7	10.87	±	0.06	10.70	±	0.00	0.03	0.00
8-9	12.1	12.3	12.1	12.3	12.1	12.3	12.10	±	0.00	12.30	±	0.00	0.00	0.00
Line 14	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	12.2	12	12.2	12.2	12.2	12.2	12.20	±	0.00	12.13	±	0.12	0.00	0.07
2-3	11.3	11.1	11.3	11.1	11.3	11.1	11.30	±	0.00	11.10	±	0.00	0.00	0.00
3-4	10.9	10.9	10.9	10.9	10.8	10.9	10.87	±	0.06	10.90	±	0.00	0.03	0.00
4-5	10.9	10.9	10.9	10.9	10.9	10.9	10.90	±	0.00	10.90	±	0.00	0.00	0.00
5-6	10.8	10.9	10.8	10.9	10.7	10.9	10.77	±	0.06	10.90	±	0.00	0.03	0.00
6-7	11.3	11.3	11.3	11.3	11.2	11.3	11.27	±	0.06	11.30	±	0.00	0.03	0.00
7-8	12.2	12.1	12.1	12.1	12.1	11.9	12.13	±	0.06	12.03	±	0.12	0.03	0.07
8-9	11.9	12	11.9	12	11.9	11.8	11.90	±	0.00	11.93	±	0.12	0.00	0.07

Line 15	Measurement1		Measurement2		Measurement3		Average ± SD						Uncertainty	
Marker position	AP	LAT	AP	LAT	AP	LAT	AP			LAT			AP	LAT
1-2	13.6	13.4	13.6	13.7	13.6	13.7	13.60	±	0.00	13.60	±	0.17	0.00	0.10
2-3	12.6	12.6	12.6	12.6	12.6	12.6	12.60	±	0.00	12.60	±	0.00	0.00	0.00
3-4	12.6	12.6	12.9	12.6	12.7	12.6	12.73	±	0.15	12.60	±	0.00	0.09	0.00
4-5	11.1	11.3	11.1	11.3	11.1	11.3	11.10	±	0.00	11.30	±	0.00	0.00	0.00
5-6	10.8	10.9	10.8	11	10.8	11	10.80	±	0.00	10.97	±	0.06	0.00	0.03
6-7	10.7	10.7	10.7	10.7	10.9	10.9	10.77	±	0.12	10.77	±	0.12	0.07	0.07
7-8	12.5	12.6	12.5	12.6	12.5	12.6	12.50	±	0.00	12.60	±	0.00	0.00	0.00
8-9	12.6	12.8	12.8	12.8	12.8	12.8	12.73	±	0.12	12.80	±	0.00	0.07	0.00

Table 15. The deviation in mm of the average differences from the reference distance in each marker spacing in 15 ribbons obtained from C-arm x-ray unit using orthogonal method without the reconstruction jig.

Marker position	1-2		2-3		3-4		4-5		5-6		6-7		7-8		8-9	
Line	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT	AP	LAT
1	1.77	1.63	1.20	1.13	0.70	1.00	0.80	1.00	0.63	0.60	2.20	2.10	1.90	2.10	2.30	2.10
2	**3.63**	**3.67**	2.60	2.60	2.20	1.97	0.67	1.07	0.80	0.67	0.70	0.77	2.47	2.47	2.77	2.70
3	2.43	2.40	1.30	1.20	0.80	0.70	0.80	0.77	0.57	0.60	1.07	1.00	0.87	0.70	2.10	2.30
4	2.20	2.13	1.30	1.10	0.87	0.90	0.90	0.90	0.77	0.90	1.27	1.30	2.13	1.03	1.90	1.93
5	3.60	3.60	2.60	2.60	2.73	2.60	1.10	1.30	0.80	0.97	0.77	0.77	2.50	2.60	2.73	2.80
6	1.70	1.63	1.20	1.07	0.70	1.00	0.80	1.00	0.63	0.60	2.20	2.10	1.90	2.10	2.23	2.00
7	3.53	3.63	2.60	2.60	1.50	1.33	0.80	0.83	0.80	0.33	0.70	0.83	2.07	2.13	2.73	2.60
8	2.43	2.40	1.30	1.20	0.80	0.70	0.80	0.77	0.57	0.60	1.03	1.00	0.87	0.70	2.10	2.30
9	2.20	2.07	1.30	1.10	0.87	0.90	0.90	0.90	0.77	0.90	1.27	1.30	2.17	2.03	1.90	1.93
10	3.60	3.50	2.60	2.60	2.63	2.60	1.10	1.13	0.80	0.93	0.77	0.77	2.50	2.60	2.67	2.80
11	1.77	1.63	1.20	1.13	0.77	1.00	0.80	1.00	0.63	0.60	2.20	2.10	1.90	2.10	2.23	2.10
12	3.63	3.67	2.60	2.60	2.20	1.97	0.97	1.07	0.80	0.67	0.70	0.77	2.47	2.47	2.77	2.70
13	2.43	2.40	1.30	1.20	0.80	0.70	0.80	0.77	0.57	0.60	1.07	1.00	0.87	0.70	2.10	2.30
14	2.20	2.13	1.30	1.10	0.87	0.90	0.90	0.90	0.77	0.90	1.27	1.30	2.13	2.03	1.90	1.93
15	3.60	3.60	2.60	2.60	2.73	2.60	1.10	1.30	0.80	0.97	0.77	0.77	2.50	2.60	2.73	2.80
Average ± SD	2.71 ± 0.78	2.67 ± 0.83	1.80 ± 0.68	1.72 ± 0.74	1.40 ± 0.83	1.39 ± 0.74	0.88 ± 0.13	0.98 ± 0.17	0.71 ± 0.10	0.72 ± 0.19	1.20 ± 0.56	1.20 ± 0.51	1.95 ± 0.60	1.96 ± 0.69	2.34 ± 0.35	2.35 ± 0.35

5.3 Comparison the accuracy of reconstruction method from various imaging modality and techniques

Based on the reconstruction of the series of radio-opaque markers from the well known location in the in-house reconstruction accuracy test phantom. The deviation in distance of the x-ray marker position from point by point in each catheter were analyzed in three different imaging modality (CT scanner, x-ray simulator unit and C-arm x-ray unit). Also the different techniques in each modality, such as the different slice thickness in CT scanner, orthogonal and variable angle method in x-ray simulator unit, the orthogonal method with and without reconstruction in the C-arm x-ray unit were compared and shown in table 16. The average error in each point from 15 ribbons in different techniques and different modalities were also shown as the histogram in figure 30.

Table 16. Summary of the study for assessment of the accuracy to reconstruction brachytherapy source configurations using CT scanner, x-ray simulator unit, and C-arm x-ray unit.

Equipment	CT			Simulator		C-arm	
Techniques	1mm	3mm	5mm	Orthogonal	Variable angle	With jig	Without jig
	AP/LAT	AP/LAT	AP/LAT	AP/LAT	AP/LAT	AP/LAT	AP/LAT
Maximum (mm)	0.30/0.23	0.60	0.60/0.77	0.2	0.2	0.63/0.57	3.63/3.67
Mean (mm)	0.04/0.05	0.21/0.20	0.29/0.28	0.05/0.06	0.06	0.16	1.63
Mean ± SD	0.04±0.07 /0.05±0.07	0.21±0.12 /0.20±0.13	0.29±0.16 /0.28±0.15	0.05±0.06 /0.06±0.07	0.06±0.06	0.17±0.15	1.63±0.86

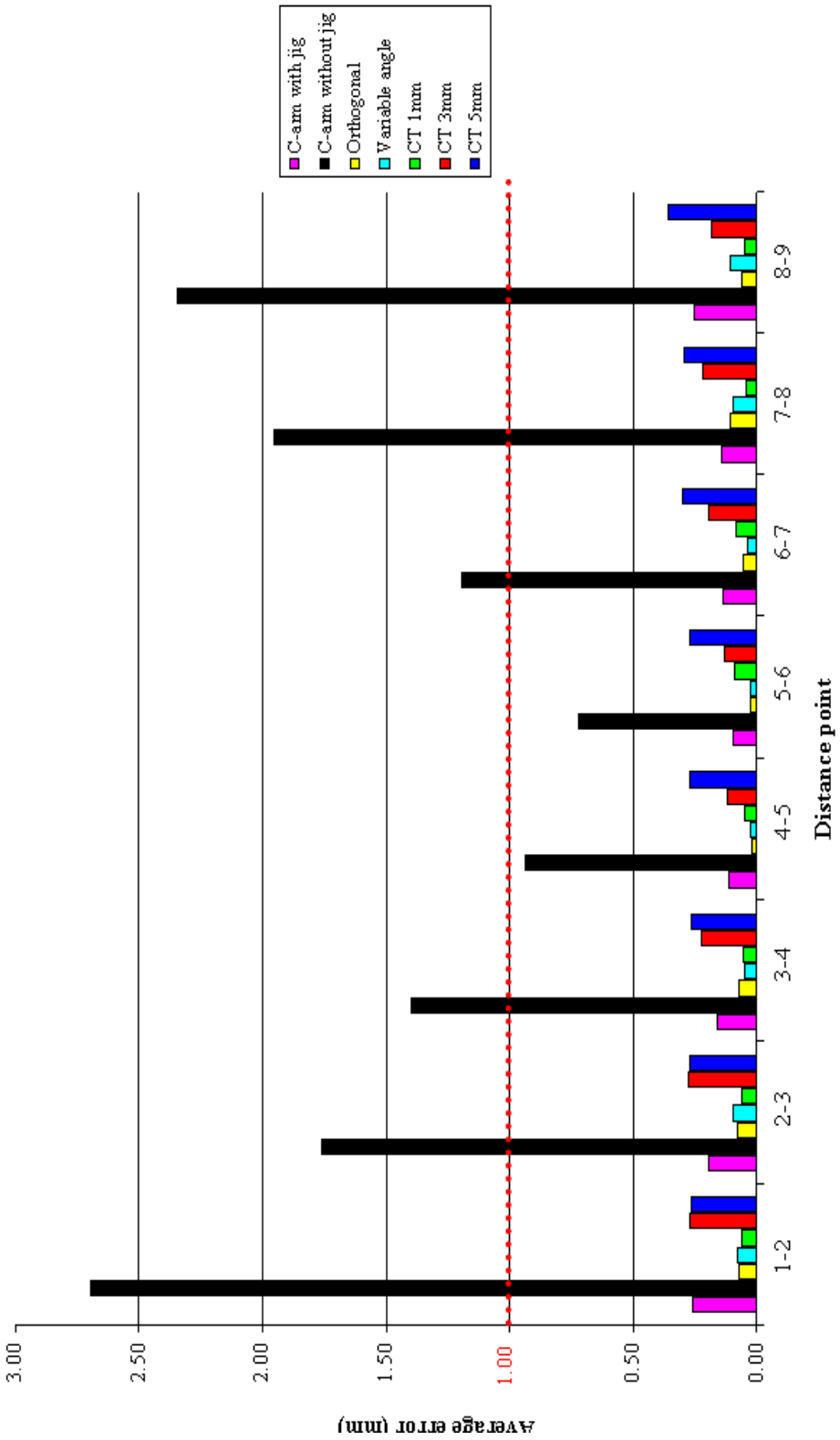


Figure 30. The histogram showed the average reconstruction error for the C-Arm, the conventional simulator, he CT.

CHAPTER VI
DISCUSSION AND CONCLUSIONS

6.1 Discussion

The accuracy of dose calculation in brachytherapy is dependent on the accuracy of source localization. As the HDR brachytherapy unit delivers a large dose in a very short time, the emphasis is on accurate source localization. The brachytherapy plans are based on the frame grabbed images obtained with the C-arm X-ray unit, the conventional simulator, the computed tomography. By the C-arm X-ray unit used semi-orthogonal reconstruction method with reconstruction jig, the conventional simulator used orthogonal and variable angle reconstruction method and the computed tomography used slice thickness 1mm, 3mm,5mm respectively, which the x-ray markers are clearly visible. The error of the reconstructed x-ray markers has been found to be smaller than 1 mm, fulfilling the newest quality assurance requirements proposed by Technical Reports Series No. 430 [19], which described to Compare the reconstructed and actual geometry. The difference should not exceed 1 mm for short distances (<2 cm) and 2 mm for longer distances. The quality of the source reconstruction is important for the accuracy of the dose calculation. For a point source, the dose variation behaves according to the inverse square of the distance to the calculation point; for example, a shift of 1 mm corresponding to a dose variation of 5% is assumed to be a realistic value in the high dose, large dose gradient region and a 1 mm error on a 1 cm separation between two point sources results in a 20% error in the dose at mid-distance.

This study, one human operators for reduces the deviation in the error from inter-observer variation, were localized to visually identify all the x-ray markers in the radiography of CT scanner, x-ray simulator and C-arm images, using the PLATO brachytherapy treatment planning system, software V14.2 (Nucletron International B.V., Veenendaal, The Netherlands) was used. The human operator was localized the

total number of x-ray markers contained in the images. After performing the image reconstruction, we measured all x-ray marker spacings 3 times to minimize the measurement error and also calculated the mean spacing distances.

The accuracy of the reconstruction with a CT scanner, simulator and a C-arm X-ray unit is affected by image parameter such as the distortion of the C-arm image intensifier, the accuracy of the determination of the magnification factor, the accuracy of entering the co-ordinates of points with a mouse from the screen etc. The average, maximum and the standard deviation are given for the obtained deviations between actual and reconstructed distances between the points. The average error of the C-arm X-ray unit reconstruction is only slightly larger than that of the conventional simulator images and 1 and 3 mm CT slice thickness images. Also maximum error and standard deviation are of comparable magnitude. Using simulator, the orthogonal reconstruction method has been found applicable, although the overlapping of the x-ray markers on the lateral images has been the main drawback, as well as the poor visibility of the x-ray markers. While, the variable angle reconstruction method has been found more applicable, that the x-ray markers are clearly separated. In this study, a smaller CT slice thickness (1mm) would improve the accuracy of x-ray markers localization because the weighted centroid positions were computed as the centroid of the x-ray marker . Our study resulted that using 1 mm CT slice thickness leads to higher accuracy than using 3 mm CT. However, it may be prohibitive to use 1 mm CT in routine clinical practice due to cost and time. On the other hand, the agreement between results using 1 mm and 3 mm CT (0.14 mm average differences) demonstrates that using 3 mm CT is an excellent compromise when x-ray marker-orientation information is not desired. And investigation of 5 mm CT slices found that the distances between matched coordinates in 1 mm and 5 mm CT were greater than 0.25 mm. This study suggests that 3 or 5 mm CT is a reasonable choice in routine clinical practice.

This study is to assess by using the reconstruction accuracy test phantom, it had fifteen ribbons are arranged along the plane A, B and C. So the reconstruction error are similar to x-ray simulator and CT scanner images. In the case of patient, some time the x-ray markers are not arranged along the plane. The reconstruction accuracy from CT slice thickness (1, 3 and 5 mm) maybe higher than the x-ray

simulator and C-arm. Because the Computed tomography (CT) produces a volume of data which can be manipulated, through a process known as windowing, in order to demonstrate various structures based on their ability to block the x-ray beam. The scanners allow this volume of data to be reformatted in various planes or even as volumetric (3D) representations of structures.

In the case of reconstruction from fluoroscopy images using the C-arm X-ray unit without reconstruction jig, the average reconstruction error has been found to be smaller than 2 mm and 1.63 mm for AP and LAT, while the maximum errors in distances between points can be as large as 3.63 mm for AP and 3.67 mm for LAT in the corner of the field-of-view, whereas in the central part of the field the errors are less than 2 mm. That is similar to Cuijpers's study [15], the somewhat large errors in the corners are due to geometric distortions caused by the image intensifier. This implies that for keeping dose calculation errors within acceptable limits the applicator should be kept in the centre of the field of view.

6.2 Conclusion

The accuracy in the reconstruction of the distance between two points is better than 1 mm for CT, conventional simulator and C-Arm with reconstruction jig respectively, while C-Arm without reconstruction jig is better than 2 mm. If digital images are used the maximum error in reconstructed distances equals 3.6 mm for points located in the corners of the field of view, whereas in the central part of the field the errors are less than 2 mm.

From this study, it is concluded that this the radiograph of the C-Arm with reconstruction jig can be used for cooperate treatment planning. In view of the patient is not transferred again to the treatment room for the actual treatment and the considerable time gain in performing the reconstruction of the applicator in the planning system when using digital images, this error is considered to be acceptable for clinical use. Our study suggests that C-Arm with reconstruction jig is a reasonable choice in routine clinical practice.

REFERENCES

1. Godden TJ: Physical Aspects of Brachytherapy. Medical Physics, 1988; Handbooks 19: 232-260.
2. Van der Laarse R and De Boer RW. Computerized high dose rate brachytherapy treatment planning, in Brachytherapy HDR and LOR, Proceedings Brachytherapy Meeting Remote Afterloading: State of the Art, Nucletron Corporation, Columbia, 1990: 169-83.
3. Vickery BL and Redpath AT. The reconstruction and dose-rate calculation of radium needle implants, Br J. of Radiol. 1977; 50: 280-285.
4. Gantchew MG and Rosenwald JG. Localization of implanted radioactive wires and computation of the dose distribution. Phys. Med. Biol. 1976; 21: 209-215.
5. Onai Y, Irifune T and Tomaru T. Calculation of dose distribution in radiation therapy by a digital computer. II. Computation of dose distribution in radium therapy. Nippon Acta Radiol. 1969; 28: 1629-1636.
6. Siddon RL and Chin LM. Two-film brachytherapy reconstruction Algorithm. Med. Phys. 1985; 12: 77-83.
7. Guggenheim N, Doriot PA, Dorsaz PA, Descouts P and Rutishauser W. Spatial reconstruction of coronary arteries from angiographic images. Phys. Med Biol. 1991; 36: 99-110.
8. Smith WM and Starmer CF. Error propagation in quantitative biplane cineroentgenography. Phys. Med. Biol. 1978; 23: 677-685.
9. Metz CE and Fencil LE. Determination of three-dimensional structure in biplane radiography without prior knowledge of the relationship between the two views: Theory. Med. Phys. 1989; 16: 45-51.
10. Fencil LE and Metz CE. Propagation and reduction of error in three dimensionnal structure determined from biplane views of unknown orientation. Med. Phys. 1990; 17: 951-961.
11. Godden TJ. Physical Aspects of Brachytherapy. (Hilger, Bristol). Medical Physics. 1988; Handbooks 19: 232-260.

12. Tabushi K, Itoh S and Sakura M. Two-radiograph reconstruction using six geometrical solution sets and least-squares method. Med. Phys. 1992; 19(5): 1307-1310.
13. Kolkman-Deurloo IK, Visser AG, Idzes MH, Levendag PC. Reconstruction accuracy of a dedicated localiser for filmless planning in intra-operative brachytherapy. Radiotherapy and Oncology. 1997; 44(1): 73–81.
14. Zuofeng Li. An algorithm for automatic, computed-tomography-based source localization after prostate implant. Med. Phys. 2001; 28(7): 1410-1415.
15. Cuijpers JP. Clinical use of a non-isocentric C-arm unit for on-line filmless reconstruction of brachytherapy applicators. Radiotherapy and Oncology. 2001; 61: 203-209.
16. Fung AYC. C-Arm imaging for brachytherapy source reconstruction Geometrical accuracy. Medical Physics. 2002; 29(5): 724-726.
17. Pa´lvo¨lgyi J. To what extent can digital images obtained with a non-isocentric C-arm be used for brachytherapy treatment planning in gynaecology. Radiotherapy and Oncology 2002; 67: 107-112.
18. TG No.66, Quality assurance for computed-tomography simulators and the computed tomography-simulation process, Report of the AAPM Radiation Therapy Committee Task Group No. 66
19. TRS no.430, Commissioning and Quality Assurance of Computerized Planning Systems for Radiation Treatment of Cancer, IAEA.
20. Berns, C, Fritz P, Hensley FW and Wannenmacher M. Consequences of optimization in PDR brachytherapy - Is a routine geometrical optimization recommendable. Radiat. Oncol. Biol. 1997; Phys. 37: 1171-1180.
21. Kolotas C, Bim G, Baltas D, Rogge B, Ulrich P and Zamboglou N. CT guided interstitial high dose rate brachytherapy, British J. Radiology.1999; 72: 805-808.
22. Haisong L and Gang C. Automatic localization of implanted seeds from post-implant CT images. Physics in Medicine and Biology. 2003; 48: 1191-1203.
23. SGSMP/SSRPM/SSRFM Report 7. Quality control of treatment planning systems for teletherapy. Swiss Society for Radiobiology and Medical Physics, 1997.

APPENDIX

APPENDIX A

Assessment of the CT images geometrical distortions

To assess the CT images geometrical distortion, using the uncertainty (standard error) for assessment

$$\text{Uncertainty} = \frac{SD}{\sqrt{n}} \quad :$$

Where, SD is standard deviation, n is number of observation.

Scan the reconstruction accuracy test phantom with 3 mm CT slice thickness and verify the position x-ray markers in the phantom. We measured the distance between line 1 and line 3 at the position 1, 8 and 9 at central plane that equal to 3 cm as shown in figure A.1 by using the ruler option on display monitor of MARCONI (PQS) CT scanner and then compared to the actual distance between line 1 and line 3 at the position 1, 8 and 9 on the reconstruction accuracy test phantom. The deviation varies from 0.01-0.04 mm We found that the CT image distortions are within ± 1 mm according to the acceptable criteria of AAPM radiation therapy committee task group No.66 [18].

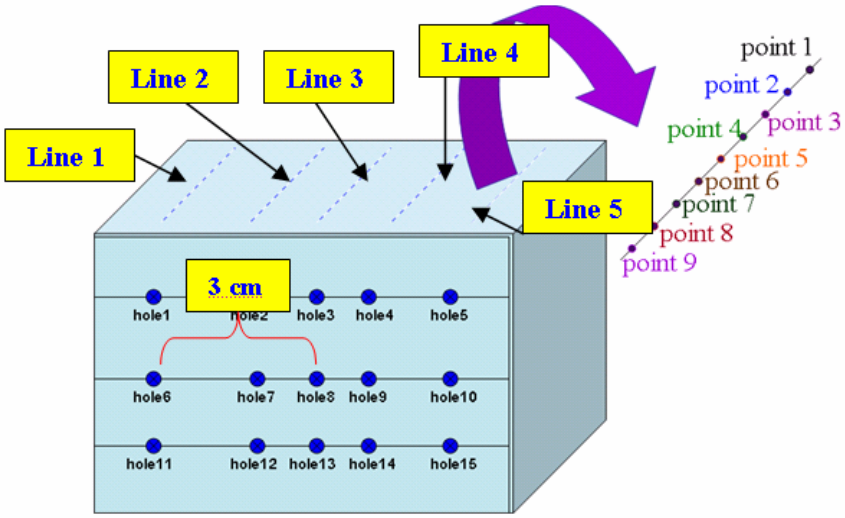


Figure A.1 The schematic measuring distance from the reference distance of reconstruction accuracy test phantom.

Table A.1 The measured distance from line 1 and 3 obtained from CT images taken at 3 mm slice thickness, deviation, uncertainty and compared to actual distance in reconstruction accuracy test phantom

X-ray marker position	Actual Distances between line 1 and 3 (cm)	Measurement 1 (cm)	Measurement 2 (cm)	Measurement. 3 (cm)	Mean (cm) ± SD	Deviation from actual distance	Uncertainty
1	3	3.02	3.01	3.02	3.02 ±.0.00	0.02	0
8	3	2.98	2.99	2.99	2.99 ± 0.01	0.01	0.01
9	3	2.96	2.96	2.96	2.96 ± 0.00	0.04	0

APPENDIX B

Assessment of the x-ray simulator images geometrical distortions

To assess the x-ray simulator images geometrical distortion, taking the radiographs of the reconstruction accuracy test phantom with a line 3 x-ray markers as shown in figure B.1 using orthogonal technique. Then, measured the distance between 2 points on the monitor display by using the ruler option of Acuity. The deviation varied from 0.00-0.02 mm according to the acceptable criteria of SGSMP Report 7. Quality control of treatment planning systems for teletherapy [23]

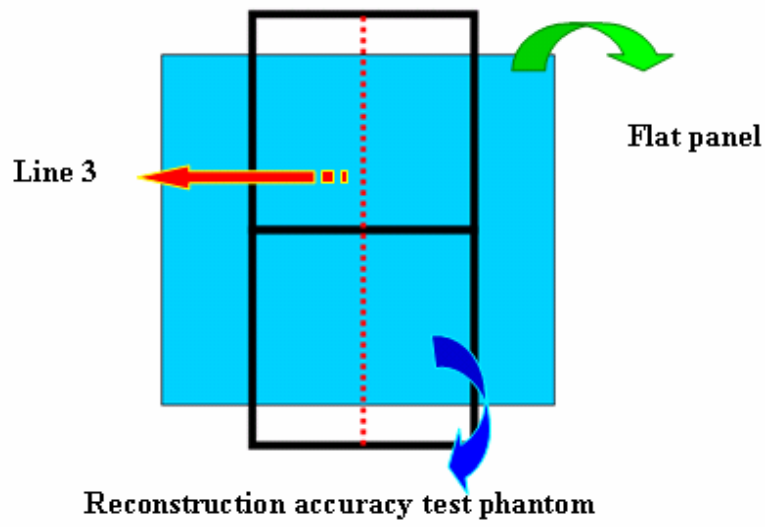


Figure B.1 The schematic diagram shown x-ray markers on the line 3 at central plane of reconstruction accuracy test phantom.

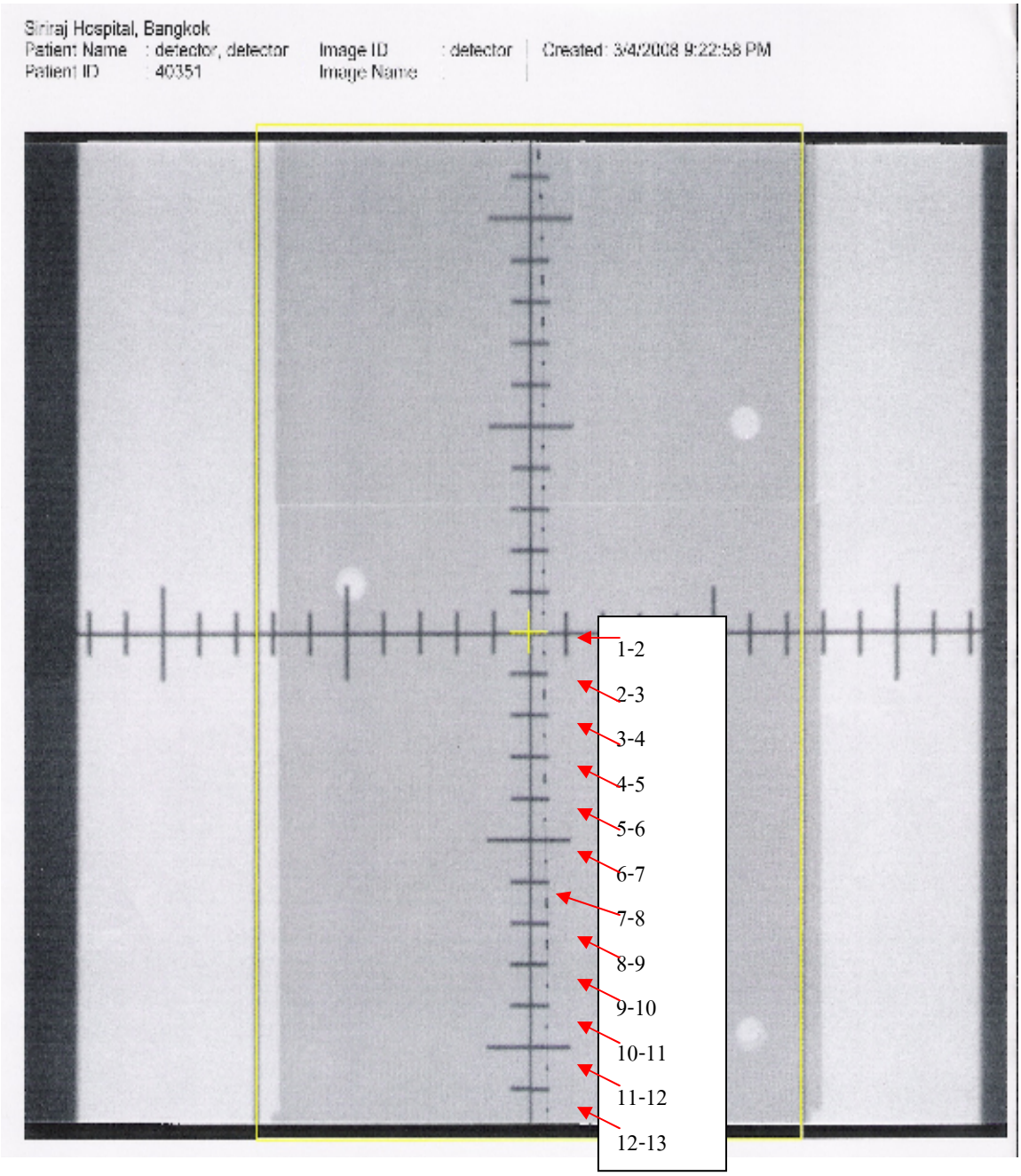


Figure B.2 The x-ray markers line at central plane of reconstruction accuracy test phantom.

Table B.1 The measured distance between each x-ray marker spacing from the AP x-ray simulator image and compared to actual distance in reconstruction accuracy test phantom

.

Marker position	Actual distances(mm)	Measuring No. 1 (mm)	Measuring No. 2 (mm)	Measuring No. 3 (mm)	Mean ± SD	Deviation from actual distance	Uncertainty
1-2	10	10.1	10	10	10.03± 0.06	0.03	0.03
2-3	10	10.1	10	10	10.03± 0.06	0.03	0.03
3-4	10	10	10	10	10± 0.00	0.00	0.00
4-5	10	10	10	10	10± 0.00	0.00	0.00
5-6	10	9.9	9.9	10	9.93± 0.06	0.07	0.03
6-7	10	10	10.1	10	10.03± 0.06	0.03	0.03
7-8	10	10.1	10	10	10.03± 0.06	0.03	0.03
8-9	10	9.6	9.8	9.9	9.77± 0.15	0.23	0.09
9-10	10.1	10.2	10.1	10.1	10.13± 0.06	0.03	0.03
10-11	10	10.1	10.1	10	10.07± 0.06	0.07	0.03
11-12	10	10.1	10	10	10.03± 0.06	0.03	0.03
12-13	10	10.1	10.4	10.3	10.27± 0.15	0.27	0.09

Table B.2 The measured distance between each x-ray marker spacing from the Lat x-ray simulator image and compared to actual distance in reconstruction accuracy test phantom.

Marker position	Actual distances(mm)	Measuring No. 1 (mm)	Measuring No. 2 (mm)	Measuring No. 3 (mm)	Mean ± SD	Deviation from actual distance	Uncertainty
1-2	10	10.2	10	10.1	10.10± 0.1	0.1	0.06
2-3	10	10.1	10.2	10	10.10± 0.1	0.1	0.06
3-4	10	10	10	10.2	10.07± 0.12	0.07	0.07
4-5	10	10	10.2	10	10.07± 0.12	0.07	0.07
5-6	10	9.9	9.9	10	9.93± 0.06	0.07	0.03
6-7	10	10	10.1	10	10.03± 0.06	0.03	0.03
7-8	10	10.1	9.8	10	9.97± 0.15	0.03	0.09
8-9	10	9.6	9.8	9.9	9.77± 0.15	0.23	0.09
9-10	10.1	10.2	10.1	10.1	10.13± 0.06	0.03	0.03
10-11	10	10.2	10.1	10	10.10± 0.1	0.1	0.06
11-12	10	10.1	9.9	10	10± 0.1	0	0.06
12-13	10	10.1	10.4	10.2	10.23± 0.15	0.23	0.09

Check of accuracy of printer

To check the accuracy of printer that prints the graphic data from x-ray simulator (Acquity) for digitizing those data to the PLATO treatment planning, we took the radiographs of the reconstruction accuracy test phantom a line 3 x-ray markers as shown in figure B.1 in AP and LAT view and print out those images to verify the accuracy of the scale in horizontal and vertical directions by measurement with ruler. And we compared the measured values to the actual distance in the reconstruction accuracy test phantom.

Table B.3 shows the accuracy in terms of the deviation in mm of each x-ray marker spacing measurement in printout from the actual distance in reconstruction accuracy test phantom compare in both AP and Lat views. The deviation varies from 0.10-0.43 mm which are agree within the acceptable value of ± 1 mm according to the recommendation of SGSMP report no.7 [23].

.

Table B.3 The deviation in mm of the actual distance in each marker spacing in X-ray marker line 3 radiograph obtained from x-ray simulator with printout data.

X-ray marker position	Deviation (mm)	
	Mean (AP) ± SD	Mean (LAT) ± SD
1-2	0.15 ± 0.00	0.13 ± 0.03
2-3	0.38 ± 0.03	0.25 ± 0.09
3-4	0.12 ± 0.03	0.17 ± 0.03
4-5	0.15 ± 0.00	0.15 ± 0.05
5-6	0.43 ± 0.03	0.43 ± 0.06
6-7	0.40 ± 0.01	0.42 ± 0.07
7-8	0.10 ± 0.01	0.13 ± 0.03
8-9	0.13 ± 0.03	0.17 ± 0.06

Check of accuracy of digitizer

To check the accuracy of the digitizer that used for enterring the position of graphical data from radiograph to PLATO brachytherapy treatment planning, we digitized the known distance of 100 mm for both horizontal and vertical directions using the image utilities program provided within the PLATO utility main menu. Then measured the distance between two points on the monitor display by using the ruler option of PLATO planning and also on the printout by using the standard ruler and compare the distance point in terms of the deviation in mm.

Table B.4 shows the accuracy of digitizer in terms of the deviation in mm of vertical (Y-axis) and horizontal (X-axis) scales measuring from the digitizer and monitor display. The deviation varies from 0.12-0.28 mm which shows an agreement better than 1 mm according to the recommended by SGSMP report no.7 [23].

Table B.4 The deviation in mm in Y-axis and X-axis of 100 mm distance between digitizer and monitor display data.

Measurement	Deviation (mm)	
	Y-axis(AP)	X-axis(LAT)
1	0.28 ± 0.02	0.20 ± 0.05
2	0.17 ± 0.06	0.20 ± 0.00
3	0.13 ± 0.06	0.15 ± 0.05

APPENDIX C

Assessment of accuracy radiography of image intensifier (II) of C-arm x-ray unit

To assess the accepted accuracy area obtained by image intensifier (II) for radiography. The quality of the radiography from the C-arm x-ray unit depended on both the spatial distortion and magnification factor.

We verified the position of the x-ray marker line in the reconstruction accuracy test phantom by taking the radiograph of the phantom with semi-orthogonal technique and the images of AP and Lateral view were on-line digitally transferred to the treatment planning system as shown in figure C. Then, measured the distance on the monitor display by using the ruler option of PLATO treatment planning and compared to the actual distance on the reconstruction accuracy test phantom in terms of the deviation. The deviation varies from 0.07-2.07 mm for AP view and 0.10-2.20 for LAT view respectively. For the spatial distortion of image intensifier, it was seen that the reconstruction error is large for points that lie relatively far away from the center of field of view as the results shown in table C.1 and C.2. The maximum reconstruction error over the entire image intensifier was found to be more than 2 mm (2.07 and 2.2 mm for AP and Lat view respectively) for points that are far from the center 10 cm. Therefore, it is important to consider the errors in reconstructed distance that farther than 9 cm from the center of image intensifier. An error in distance therefore corresponds to a dose calculation error. This implies that for keeping dose calculation error within acceptable limits for clinical use, the applicators should be in center of the field of view

Table C.1 The measured distance of AP view from the reference distance obtained from image intensifier of C-arm x-ray unit.

Distance point	Known Distances (mm)	Measurement 1 (mm)	Measurement 2 (mm)	Measurement 3 (mm)	Mean ± SD	Deviation of the measured distance	Uncertainty
1-2	10	10.2	10.1	10.0	10.10± 0.10	0.10	0.06
2-3	10	10.1	10.0	10.1	10.07 ± 0.06	0.07	0.03
3-4	10	10.1	10.2	10.2	10.17 ± 0.06	0.17	0.03
4-5	10	10.2	10.3	10.2	10.23 ± 0.06	0.23	0.03
5-6	10	10.3	10.3	10.3	10.30 ± 0.00	0.30	0.00
6-7	10	10.4	10.3	10.4	10.37 ± 0.06	0.37	0.03
7-8	10	10.9	10.8	10.9	10.87 ± 0.06	0.87	0.03
8-9	10	10.8	10.8	10.8	10.80 ± 0.00	0.80	0.00
9-10	10	10.8	10.9	10.9	10.87 ± 0.06	0.87	0.03
10-11	10	12.1	12.0	12.1	12.07 ± 0.06	**2.07**	0.03

Table C.2 The measuring distance of LAT view from the reference distance obtained from image intensifier of C-arm x-ray unit.

Distance point	Known Distances (mm)	Measurement 1 (mm)	Measurement 2 (mm)	Measurement 3 (mm)	Mean ± SD	Deviation of the measured distance	Uncertainty
1-2	10	10.2	10.1	10.0	10.10 ± 0.10	0.10	0.06
2-3	10	10.1	10.3	10.1	10.17 ± 0.12	0.17	0.07
3-4	10	10.2	10.2	10.2	10.20 ± 0.00	0.20	0.00
4-5	10	10.2	10.3	10.2	10.23 ± 0.06	0.23	0.03
5-6	10	10.1	10.4	10.3	10.27 ± 0.15	0.27	0.09
6-7	10	10.4	10.6	10.6	10.53 ± 0.12	0.53	0.07
7-8	10	10.9	10.8	10.9	10.87 ± 0.06	0.87	0.03
8-9	10	10.8	12.0	10.8	11.20 ± 0.12	1.20	0.40
9-10	10	10.8	12.1	10.9	11.27 ± 0.15	1.27	0.42
10-11	10	12..3	12.3	12.1	12.20 ± 0.14	**2.20**	0.08

BIOGRAPHY

NAME Mr. Chaiyasit Sanitklang

DATE OF BIRTH 19 June 1978

PLACE OF BIRTH Nakhonratchasima, Thailand

INSTITUTIONS ATTENDED Mahidol University, 2002:
Bachelor of Science
(Radiological Technology)
Mahidol University, 2006:
Master of Science
(Radiological Science)

HOME ADDRESS 34 Saintmerry road, Tambon Naimuang, Muang,
Nakhonratchasima 30000, Thailand.
E-mail: noom_rad19@hotmail.com