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Quanitative and qualitative analysis of Image Quality and Imaging Dose of KV CBCT from XVI Elekta Linac.

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Abstract

Purpose: *Quantify and evaluate the mechanical stability and image quality emerged by (XVI) system of over time. Measuring the imaging radiation dose delivered to patient during CBCT scan to study the impact of imaging dose on the total effective dose received by patient.*

Materials and Methods*: In this study we monitor the mechanical stability of XVI system over time by imaging a dense sphere phantom positioned at isocenter and the stability of 3Dimage quality properties produced by CBCT using Catphan phantom 503over time. Finally, both CT dose index (CTDI) and dose measurements with TLDs were performed .*

Results: *The run charts for the mechanical tests and image quality tests showed that The XVI exhibits along term stability in flex and stable image quality over time. The values of CBCTDIw for head-and-neck and pelvis protocols were 1.6 and 21 mGy respectively. The total effective doses from the head-and-neck and pelvic protocols were 1.6 and 11 mSv, respectively. The average TLD doses obtained for head and neck and pelvis are 0.8 mGy, 20 mGy respectively.*

Conclusion: *The XVI CBCT provided volumetric information for image guidance with acceptable image quality and low tolerated radiation dose. This imaging tool gave a better standard for patient daily setup verification before and during treatment.*

Keywords: *IGRT, XVI, CBCT, Image Quality, Imaging dose*

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I. Introduction

Cone beam computed tomography (CBCT)systems mounted into a linear accelerator have become available within radiotherapy departments asJaffray*et al*has first published in 1998 and became commercially available in 2005. The CBCT system enables a sequence of images of 2D radiographic projection to be acquired from a kV source and flat panel detector imaging system as it rotates around the patient either during treatment or before treatment. X-ray imaging is an important method for patient positioning and target localization in radiation the rapyso;it has contributed strongly in improving the precision of radiation delivery and sparing normal tissues. KV-CBCT is a widely used Image Guided Radiation Therapy IGRT technique owing to its rich image information and faster in image acquisition process. (Murphy MJ, et al.,2007;Strocchi S , et al .,2012 ;Cho BC , et al., 2013)

The CBCT is a complicated system form the Mechanical point of view as it represents the coincidence MV x-ray source isocenter of linac and the KV x-ray source isocenter from CBCT, so, the mechanical stability and image quality have to be assessed always over time. Accurate dosimetry of imaging radiation from CBCT scans is important because it would provide radiation oncologists with useful information about excessive doses to radiosensitive organs. IGRT adds an imaging dose to the therapeutic radiation dose, which is already high .This could create a complex distribution of the dose and increase the risk of the development of secondary malignancies, which has given rise to the need for ways of evaluating and minimizing the imaging dose. Accurate evaluation of the dose delivered to specific organs is very important to assess the risk of complications due to CBCT scans (Murphy, et al.,2007; Aird , et al., 2004).

The AAPM TG111 report has recommended that integral dose be included in the investigation of imaging dose and imaging protocols should be optimized to avoid unnecessary exposure to tissues further from the target (Dixon , et al., 2010). Point doses do not vary significantly with scan length and so are not sufficient

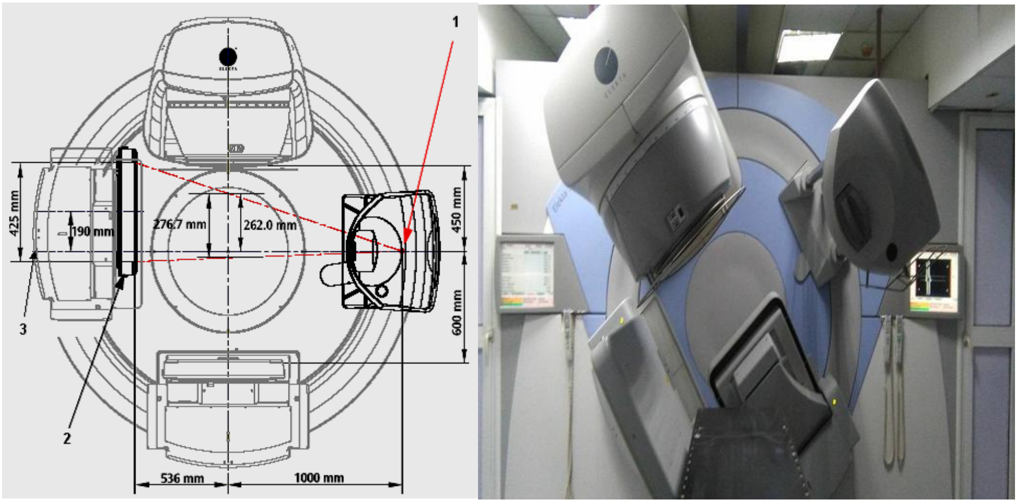
to assess and compare the integral dose of different protocols. In linear accelerator CBCT, integral dose is highly dependent upon the length of collimation along the patient.
The aim of this study is to review the methods employed to date in the measurement of concomitant imaging dose from CBCT versus a comparable of image quality.

II. Materials and Methods:

Equipment

The measurements were performed on an Elekta Synergy linear accelerator (Elekta, Stockholm, Sweden) with a CBCT system that consists of a kV X-ray source, a large area flat panel detector and X-Ray Volumetric Imaging (XVI) software. The kV imaging system is mounted perpendicular to the MV treatment axis, and is calibrated such that the imaging (kV) and treatment (MV) isocenters coincidence.

The CBCT collimators small, medium and large are user selectable, depending upon the desired field of view (FOV). Additionally, the longitudinal extent is selectable to field lengths of 35.2 mm, 135.4 mm, 178.7 mm, and 276.7 mm through a choice of 2, 10, 15, and 20 collimators. A collimator is therefore, known by these two dimensions and will be referred to as S10, M10and M20. Details about the infrastructure of XVI CBCT collimators, FOV and KV panel design and position are described in Elekta training guide of XVI section 3.



(a) (b)

Figure(1): schematic diagram shows the structure of XVI (a)and linac synergy equipped with XVI CBCT (b);1.KV X-Ray beam focal spot, 2.Image receptor (kV imaging panel),3. KV X-Ray beam reference axis, (perpendicular to kV image receptor plane)

Image quality tests were carried out using Catphan phantom 503 (Phantom Laboratory, Catphan® 500 and 600 Manual) , mechanical stability for MV-KV isocenter coincidence were performed using ball bearing phantom (Elekta Training guide Manual for XVI R4 document no 101571302,2013;Elekta Customer Acceptance Tests for XVI R4 document no 4513370228604,2008.)

.The average weighted Cone Beam Computed Tomography Dose Index $CBCTDI_w$ was measured using Farmer 0.6 cm^3 ion camber and CTDI phantom (Kim ,et al., 2010). Body doses for head-and-neck and pelvic region were measured using TLD.

2.1 Image quality stability and mechanical stability of CBCT

2.1.1Image acquisition tests

Image quality tests are performed depending on the parameters and presets of operating XVI CBCT (Bassionnette , et al., 2007) described previously using a specialized phantom (Catphan phantom 503) for assessing quality of images produced by CBCT as shown in figure (2).Detailed procedures for image quality tests uniformity , spatial resolution and low contrast visibility are described in Elekta customer acceptance test manual of XVI section 3.1

Figure (2): Catphan phantom for image quality tests

2.1.2 Mechanical stability of KV-MV coincidence system

A corner stone procedure to be used to evaluate the mechanical stability of XVI CBCT system over time is the Flexmap procedure which is the difference between the MV and kV imaging systems isocenter deviation (Bassionnette , et al .,2008) . It is performed at nine separate occasions with about one week interval. This procedure is carried out using ball bearing phantoms shown in figure (3,a) which is imaged in each occasion using KV-CBCT from XVI at time and traditional MV image with the EPID of the LINAC.

Each time we match the KV image from CBCT with the MV image on the software of the XVI system to find out the deviation in kV-MV isocenter in each direction which is the flex in the isocenter. This deviation is given on the screen as the table correction in the three directions X,Yand Z as shown in figure (3, b).Detailed description of procedures of setting up the phantom and performing matching processes on XVI software is stated in Elekta customer acceptance test manual of XVI section 3.2.

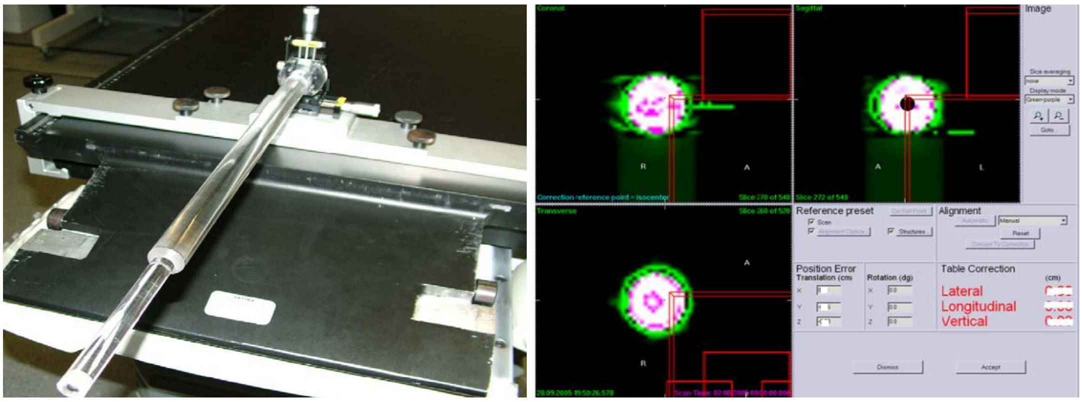


Figure (3): shows the setup of (a) ball bearing phantom and (b) the matching process on XVI system.

2.2.CBCTDI$_w$ Measurements

Although CBCT has broad beam characteristics, computed tomography dose index (CTDI) is an appropriate approach for dose reporting if a small ionization chamber such as 0.6 cm^3 Farmer type ionization chamber was used to measure the central and peripheral doses in the phantom. For the measurement of standard CT dosimetry, a 16 cm diameter head and a 32 cm diameter body standard Perspex CT dosimetry phantom with length 15cm were used to measure the dose for the regions of head and pelvis respectively .The weighted CBCTDI$_w$ is used for approximating the average dose over a single slice using the following equation (Murphy , et al.,2007;Ding ,et al., 2009):

$$CBCTDI_w(mGy) = [1/3]\ CBDI\ (center) + [2/3]\ CBDI\ (peripheral) \qquad (1)$$

Where CBDI (center) is a point dose at central axis and CBDI (peripheral) is an average point dose at peripheries .Volume CBCT dose index (CBCTDI$_{vol}$) is the weighted average of CBDI measurements divided by the pitch .The pitch is the ratio between the length of the treatment couch moves during one 360° gantry rotation and the width of the radiation beam. For the CBCT scanning, $CBCTDI_{vol}$ takes into account the parameters that are related to specific scanning protocols and is defined by the following equation:

$$CBCTDI_{vol} = CBCTDI_{w}/pitch \quad (2)$$

But for the CBCT, pitch is set to 1 as it is only one rotation Then,

$$CBCTDI_{vol}\ (mGy) = CBCTDI_{w} \quad (3)$$

In clinical practice, radiation measuring generally starts with the dose length product (DLP) which is given by the following equation:

$$DLP(mGy.cm) = N \times d \times CBCTDI_{w} \quad (4)$$

Where N is the no. of rotations, d stands for the length of scan. The DLP reflects the total absorbed dose of a complete scan acquisition (the dose for a series of slices).To simulate head and neck CBCT, the head phantom was centered at the isocenter and scanned using the S10 and S20 collimators and 100 kVp beams. Half-rotation (~ 200°) scans are commonly used for head and neck CBCT.
The effective dose for a specific anatomic area can then be calculated according to the formula:

$$E\ (mSv) = E_{DLP}\ .DLP \quad (5)$$

Where E_{DLP} is given in (mSv/mGy.cm) and is specific for each anatomic site.Due to limitations for preparing the suitable and special CTDI head and body phantoms to measure the CTDI from XVI,KV-CBCT then the Rando phantom was used for this purpose.

2.3 TLD Measurements

Thermo luminance dosimeters (TLD)measurements performed using Rando phantom (Rando phantom is a whole body phantom except for arms and legs) consisting of 2.5 cm thick slices as shown in Figure (4.a) It is used for dosimetry purposes which gives an estimation of the received patient dose in XVI scan.

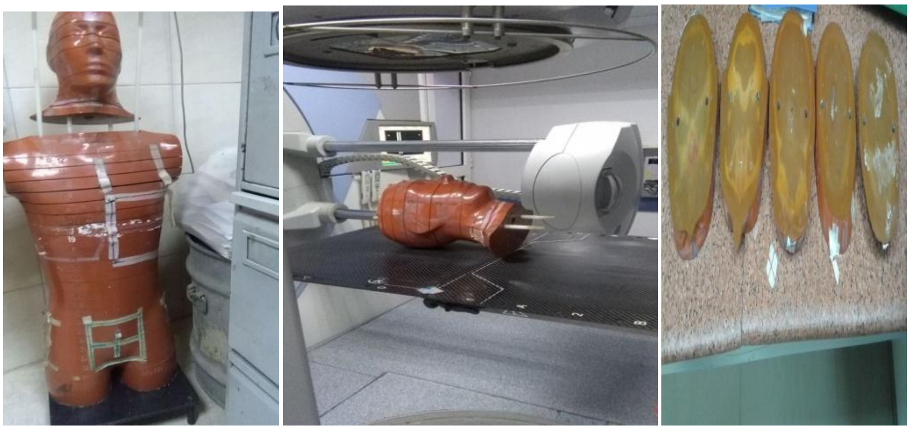
TLD100 LiF with 3mm dimensions (fabricated Harshow system)are placed between the slices of the Rando phantom. Before inserted in the phantom , the TLDs are warmed up to empty shallow traps. The TLDs are then positioned in the phantom at various positions, which should represent both the deep and peripheral positions in each of the Rando phantom slices.

2.3.1Pelvismeasurements

After placing the TLDs, the phantom is then placed on the couch at isocenter. A pelvis preset120 kV and 650 mAs are used for the XVI scan with collimator M20.

2.3.2 Head and neck measurements

The same procedure as described in pelvis Measurements is performed for a head-and-neck measurements. Head-and-neck preset100 kV and 36.1 mAs is chosen in the XVI software, which uses a S20 collimator and a small FOV. Thirty TLDs were placed at locations that best covered the whole head-and-neck site. A head-and-neck scan is made in a 200degreesrotation. Absolute doses were recorded at the center and periphery of head and body phantom. The TLDs were read with a Harshaw 4500 reader (Harshaw Thermo Electron, Solon, USA). Figure (4,b,c) shows a picture of the Rando head phantom and the positions at which doses were measured for CBCT scanning.



Figure(4) whole rando phantom(a) the set up for scanning (b) the positions used for TLD measurements (c) .

III. Results and Discussions

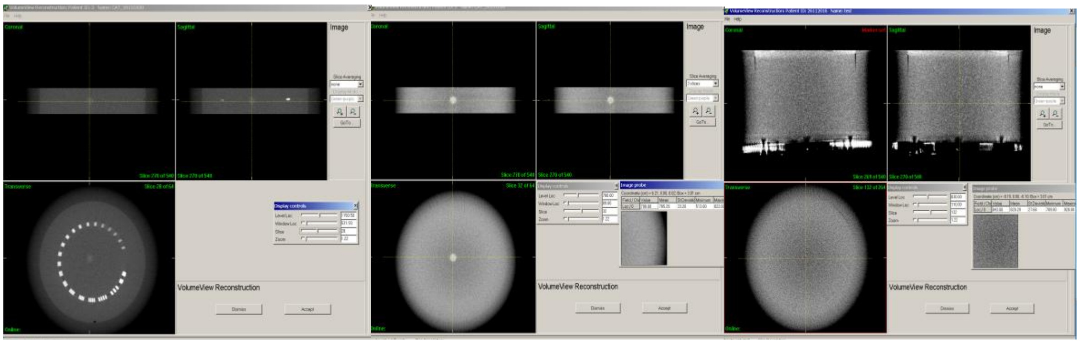
3.1. Image quality and Mechanical stability of CBCT

3.1.1. Image quality stability.

Different image properties of the XVI system produced from the acceptance tests done through nine times. Data are recorded and analyzed according to tolerance levels exhibited by manufacturer as shown in table (1) which displayed and analyzed with XVI software system as shown in figure (5) during a three month period.

Table (1): the results of image quality for head and neck scanned during three month period.

Image property	Measured mean value	Tolerance value set by Elekta
3-D Uniformity	0.9%	≤2%
3-D Spatial resolution	0.8 lp/mm	≥ 0.7 lp/mm
3-D Low contrast visibility	2.6%	≤3%



(a)(b)(c)

Figure (5):Image quality properties exhibited by XVI software analysis; (a) spatial resolution, (b) contrast visibility, (c) Uniformity.

3.1.2. Mechanical stability of KV-MV isocenter.

The results of MV- KV matching and the evaluation of deviations between them are as shown in table (2) which show relatively small variations in the flex from week to week. Only three occasions show a deviation greater than the tolerance limits. Uncertainty factors involved in the flex map procedure are analyzed and the largest errors arise from the matching procedure figure (3,b). Moving the acquired image of the dense ball one pixel relative to the plan, can result in a difference of the kV flex by 0.1 mm.

Table (2): results of MV and KV registration accuracy and the flex in the isocenter

week no.	MV registration accuracy (mm)			Kv registration accuracy(mm)			Difference in KV-MV (mm)			SPECS ≤ 1mm
	x	y	z	x	y	z	X	Y	Z	
1	0.20	0.00	0.15	1.00	0.20	-0.05	1.20	0.20	0.10	out
2	0.15	-0.10	0.00	-0.15	0.60	0.00	0.00	0.50	0.00	
3	0.10	0.00	0.20	0.05	0.00	-0.10	0.15	0.00	0.10	
4	-0.20	0.19	-0.13	0.40	-0.09	0.13	0.20	0.10	0.00	
5	-0.18	0.13	0.00	0.38	-0.13	0.18	0.20	0.00	0.18	
6	0.17	-0.30	0.30	0.07	0.80	-0.20	0.10	1.10	0.10	out
7	0.00	0.20	0.00	-0.10	0.00	0.15	-0.10	0.20	0.15	
8	0.00	-0.25	0.10	0.20	0.05	0.00	0.20	-0.20	0.10	
9	0.14	0.10	0.00	-0.14	-0.30	-0.50	0.00	0.20	0.50	0ut

3.2.CBCTDIw measurement

The CBCTDIw measured using the 0.6 cm^3 Farmer-type ionization chambers in either the 16 cm or 32 cm diameter CTDI phantom according to the scanning protocol. The CBCTDIw is an indicator of the average radiation absorbed dose. The dose reduction at the periphery and the maximum dose at the central in the longitudinal dose profile were found.

3.2.1.$CBCTDI_W$ measurements for pelvis.

The XVI software displays that the dose received in pelvis scan is approximately 16 mGy. A measurement according to Section 2.2.2 gives $CBCTDI_W$ values as shown in Table 3.

Table (3): shows the doses recorded by TLD for the pelvis rando phantom

Treatment	$CBCTDI_c$	$CBCTDI_p$	CBCTDIw	N.d	DLP	E_{DLP}	Effective dose
M10	9.5	20	16.5	13.73	226.5	0.019	4.30
M20	13	25	21	27.67	581.0	0.019	11.05

3.2.2. CBCTDI measurements for head and neck.

Calculated doses for a head and neck scan using a S10 collimator, withpreset,100 kV and 36.1 mAs

Table (4): shows the TLD doses recorded for the head and neck rando phantom

Treatment	$CBCTDI_C$	$CBCTDI_P$	$CBCTDI_w$	N.d	DLP	EDLP	Effective dose
Head	1.2	1.8	1.6	27.67	44.2	0.0023	0.10
Neck	1.2	1.8	1.6	27.67	44.2	0.0054	0.23

The effective doses are relatively low compared to pelvis scan, partly due to that the scan is made in half the rotation of pelvis scan and partly because the preset uses lower kV and mAs.

3.3. TLD doses

The mean absorbed doses and of the Rando Phantom measured by TLD for the head-and-neck and pelvic regions are shown in Table 5 and6.

3.3.1.Pelvis Measurements

Results of TLD measurements for the pelvis region are shown in table 5. It is obvious that the doses are higher near the edges of the phantom and decreasing lower towards the centre of the phantom. This is because of the non-linear depth dose curve across the phantom which is due to the attenuation of photons. In slices 31-32 the mean absorbed dose is 22.05 mGy and in slices 32-33 the mean absorbed dose is 20.68 mGy.

The doses in the upper slices are slightly higher which probably depends on the increasingly amount of material that scatter radiation in the upper region. TLD are placed also between slices 27-28, which is located 13 cm above slices 31-32 which considered being outside the range of beam, the dose received to those TLD was about 4 mGy. Despite, it is outside the scanning beam but scattering has an impact to the dose absorbed to it.

Table (5): shows the mean absorbed dose to TLD positioned at pelvis slices

Slice no.	Mean absorbed dose mGy
31-32	22.05
32-33	20.68
27-28	4.00

3.3.2.Head and Neck Measurements

The distance between Slices5-6and 9-10 is about 10 cm beyond in the G-T direction, a distance that is within half the irradiated length at isocenter which is 27.67 cm. This means that all TLDs are within the beam. The received doses to the TLDs are presented at table 6.

Table (6): the mean doses per slice in head and neck phantom measured by TLD

The Alderson–rando phantom ,head and neck region	
Slices	**Mean dose**
4-5	0.6
5-6	0.7
6-7	1.0
8-9	0.7
9-10	0.5

It is obvious shows that the absorbed doses are much lower compared to the pelvis scan. The major reasons are that preset uses much less mAs and that the scan is made in a half rotation. Also, the preset uses 100 kV instead of 120 kV as with pelvis scan.

IV. Conclusions

This study has demonstrated that XVI- CBCT system exhibits a reliable mechanical stability which expressed as the coincidence of KV-MV isocenter and image guidance with comparable 3D image quality stability over time with a relatively low-dose 3D volumetric. It was shown that received effective doses, based on CTDI-measurements, were about 11.05 mSv for pelvis scans-equal to that from ordinary CT scan- and about 0.18 mSv for head-and-neck scans.

Taking into account, the accumulated dose from KV-CBCT for prostate cancer patient imaged on daily basis, it will contribute to the total dose received by the patient about 120 cGy which is of great impact on the organ at risk, and the cost benefit rational must be considered for imaging dose evaluation.

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