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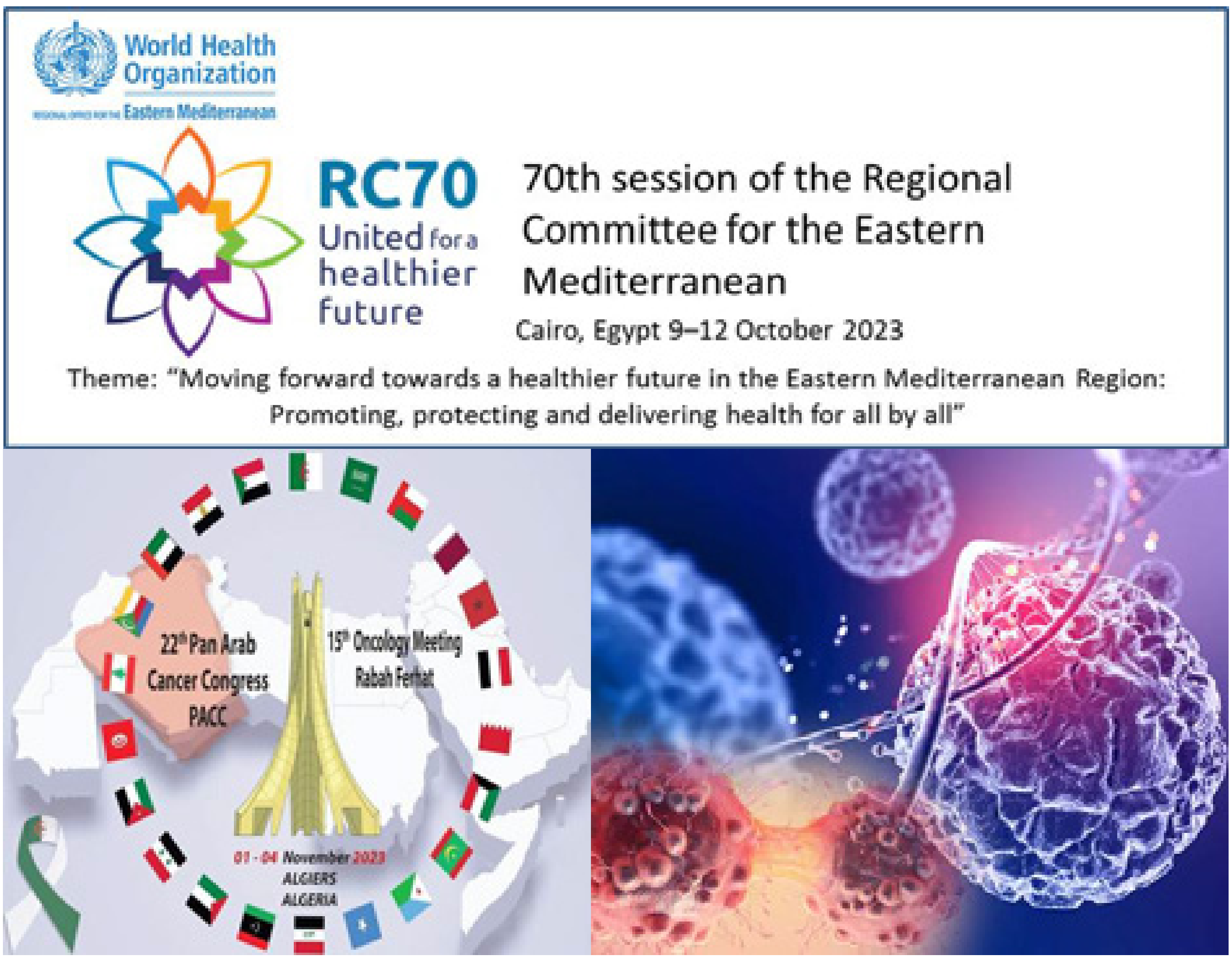

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Beam Focal Spot Offset Determination for Linear Accelerators: A Phantom less Method

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Abstract:

The effectiveness of radiotherapy treatment is influenced by the position of beam focal spot; therefore, it is important to verify the beam focal spot periodically. In this study the beam focal spot offset is measured using an electronic portal imaging (EPID) based technique and co– rotational penumbra modulation technique(CPM).

Materials and Methods: This method utilizes one set of jaws and the multileaf collimator (MLC) to form a symmetric field and then a 180º collimator rotation was utilized to determine the radiation isocenter defined by the jaws and the MLC, respectively. The difference between these two isocentres is then directly correlated with the beam focal spot offset of the linear accelerator. In the current study, the method has been used for Varian ClinaciX and Elekta Versa HD linear accelerators. Since an Elektalinac with the Agility® head does not have two set of jaws, a modified method that making use of one set of diaphragms, the MLC and a full 360º collimator rotation is implemented.

Result: The method is validated against CPM and found to be in agreement within 0.00923± 0.009360 mm (SD) also the method has been found to be reproducible to within 0.0365 mm (SD).

Conclusion: The method could be used for routine quality assurance (QA) to ensure that the beam focal spot offset is in tolerance.

Keywords: QA,focal spot. EPID, ClinaciX, Versa HD

Introduction:

Quality assurance (QA) of the linear accelerator (linac) is an important part of safe radiotherapy. The linac's beam steering circuitry controls the position and distribution of the electrons (beam spot) on the target that influences treatment and imaging properties of the linac[1,2]. It has also reported that the beam focal spot offset can change over intrafraction[3,4] as well for longer periods[5]. Ideally, the beam focal spot offset should be aligned along the collimator axis of rotation as assumed by the treatment planning system (TPS). The beam focal spot offset can affect the dosimetric and geometrical properties of the beam, such as symmetry and flatness of the beam size and position of the isocenter. The beam focal spot offset measurement methodology proposed by Chojnowski et al[6] using an electronic portal imaging device (EPID) based and phantom–less technique was a adopted in this study, since been shown to produce quick and accurate measurements. As EPID is an integral part of modern linear accelerator, enabling the same in

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QA saves time.The method was developed from the fact that if the radiation source is aligned with the collimator axis of rotation (CAOR) then the radiation isocenter position determined by the collimator rotation is independent of the type of field collimation used: jaws (diaphragms) or mutileaf collimator (MLC). Radiation isocentre depends on the type of collimation, if radiation source and collimator axis of rotation are misaligned. The physical position and distance of jaws and MLC are different concerning the radiation source. Accurate positioning of beam focal spot is very important in the success of radiotherapy treatment.

Materials and Methods

Measurements were conducted on ELEKTA VersaHD (Elekta Oncology Systems, Crawley, UK) linear accelerator equipped with the iViewGT amorphous silicon electronic portal imaging device (a–Si EPID) for 6MV and 15MV beams and VARIAN ClinaciX(Varian Medical Systems, Palo Alto, USA) with amorphous silicon 1000(aS1000) electronic portal imaging device (EPID). For each beam100 MUdose is delivered to an EPID at a gantry angle 0°. The iViewGT EPID is positioned at a Source–Imager–Distance (SID) of 160 cm. And validation of this method is done using ion chamber method (co–rotational penumbra modulation method).

Method

For ElektaVersaHD linear accelerator, the field size is set to 10 x 10 cm^2 and acquired the portal images for 100MU for collimator angles 0°, 90°, 180° and 270°. In the two 100MU images acquired at the opposite collimator angles of 0° and 180°, diaphragms determine the beam center in the in–plane direction while the MLC determine the beam center in the cross–plane direction. Utilizing two additional fields, with opposite collimator angles of 90° and 270°, the diaphragms were then used to determine the beam center in the cross–plane direction while the MLC determines the beam center in the in–plane direction. And measurements were done for 6MV and 15MV beam.

For Varian ClinaciX, first jaws were set to 10 x 10 cm^2 and delivered 100 MU at collimator angles 90° and 270° and then the beam is imaged using the EPID. The whole process is then repeated with jaws retracted and 10 x 10 cm^2 MLC defined fields. The position of the acquired images of the beam center is calculated in both in– plane and cross–plane directions. Measurements were done for 6MV beam. Differences between beam centers defined by diaphragms and the MLC can be calculated from this and further correlated with the beam focal spot position. The magnitude of the misalignment can then be calculated using the equation.

$$D_{RFS} = a \times D_{EPI}$$

Where:

D_{RFS} = Radiation focal spot offset

D_{EPI} = Measured distance between field centers using the EPID

a = machine- and procedure-specific proportionality factor

$$a = \frac{1}{\frac{(d_{epi}-d_{dia})}{d_{dia}} - \frac{(d_{dia}-d_{mlc})}{d_{mlc}}}$$

Where:

d_{epi} = distance from the focal spot to the EPID

d_{jaw} = distance from the focal spot to the jaws

d_{mlc} = distance from the focal spot to the MLC.

Images were acquired using EPID. Images in DICOM format are then analysed using MATLAB (The MathWorks, Inc., Natick, USA) software, so that beam centres defined by jaws and MLC were determined. The filtering function of the code helped in fine tuning of the measurement.

Validation of this method with an ionisation chamber (0.6cc Farmer type) based method (co–rotational penumbra modulation method) is done[8]. For this, the sensitivity of a chamber to small changes in jaw position with a half–blocked field is measured, i.e., changes in charge collected per 100MU per 1 mm change in either the half–blocked X or Y jaw position at the isocenter level. For example set the Y_1 jaw to –0.3,–0.2,–0.1, 0, 0.1, 0.2, 0.3, while setting the Y_2 jaw in maximum opened position and take chamber readings for 100MU. And Correlated geometrical shift of the jaw at the level of the physical jaw, i.e., 1 mm shift of X and Y jaw at isocenter level equals 0.406 mm and 0.319 mm shift, respectively for Varian ClinaciX, and Elekta Versa HD 0.4702mm shift, at the physical X and Y jaws position (for Varian ClinaciX jaws X and Y are located 40.6 cm and 31.9 cm respectively from the source, and for ElektaVersaHD X jaw is replaced with MLC and Y jaw is located at 47.02cm from the source). The charge collected from the chamber determines the amount the focal spot is obscured by the jaw. Therefore, from the chamber point of view being half–blocked by the jaw, moving a jaw infinitesimally is equivalent to a shift of the source (a first–order linear approximation). Based on the geometric ratios of lengths of similar triangles, the position of the source is proportional to a shift of either X or Y jaws by:

$$D_{RFS} = \frac{dic}{dic - djaw} \times z$$

Where:

D_{RFS} = Radiation focal spot offset

Z = Jaw shift (either X or Y)

d_{ic} = distance from the X-ray target (focal spot) to the ionization chamber

d_{jaw} = distance from the X-ray target (focal spot) to the X or Y jaws

Statistical Analysis

The difference in foal spot offset measurement with EPID and ion chamber method were compared using "student test".

Result

The Beam focal spot offset was measured using both the EPID method and verified with Ionization chamber method for ElektaVersaHD and Varian ClinaciX linear accelerators. Measurements were performed using both diaphragms and MLC at the four cardinal collimator angles and two opposite collimator angles (90° and 270°) for Elekta VersaHD and Varian ClinaciX linear accelerators respectively. The differences in the position of the centres for each field in cross–plane and in–plane directions are used as a measure of the beam focal spot misalignment. Although the diaphragms and MLC have the common rotation axis they are at different distances from the effective radiation source position. It means that their respective beam centers will project differently onto the EPID if the beam focal spot is misaligned with the collimator axis.

The mean difference obtained for beam focal spot offset measurement of both machines using EPID and ionization chamber is 0.00923±0.009360 mm.

Measurements showed that focal spot offsets is less than 0.1 mm in each direction for 6MV beams of each linac, but 15MV beam of the Elekta linac had a larger misalignment in the cross–plane direction, –0.23535 mm (Table1).

The average standard deviation (1 SD) of the focal spot offset obtained for the 2 linacs is 0.0365 mm. The reproducibility results show that the method is reproducible to the order of hundredths of a millimetre for the two linacs investigated (since 1SD = 0.0365), for a test where tenths of a millimetre would be the clinically required level of accuracy[1].

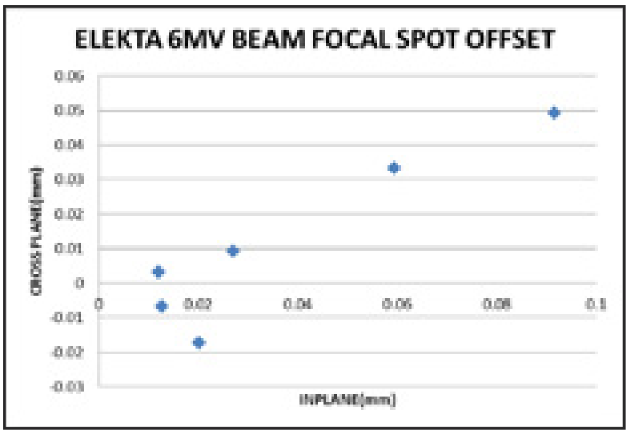

Fig.1 Elekta 6MV beam focal spot offset

Fig 1–3 represents beam focal spot offset obtained for Elekta and Varian machines.

Discussion

Accuracy of dose delivery depends on the accuracy of beam focal spot. In this study, an EPID based method has been implemented for measuring the beam focal spot offset from the CAOR. Earlier introduced methods for the determination of imaging devices[9] and radiotherapy beams were tedious and of complex nature with association of separate measuring tools[10–12]. As EPID is a part of modern linac, the suggested method is easier and faster compared to other methods. Since, jaws and MLC are at different distances from the effective source position, the beam centers projected onto the EPID will be different, if the beam focal spot of particular energy is misaligned with the CAOR[7]. From the measurements the difference in the position of the centers of acquired images can be found and used as a measure of the beam focal spot position with respect to collimator axis of rotation. The test frequency proposed to do is once a month (monthly QA) thereby the linac's positional beam circuitry is checked. Conventional QA programmes rely on large field measurements which overcomes beam angle steering, and are often checked using indirect methods[1]. The method used in this study identifies the miscalibration in positional beam steering

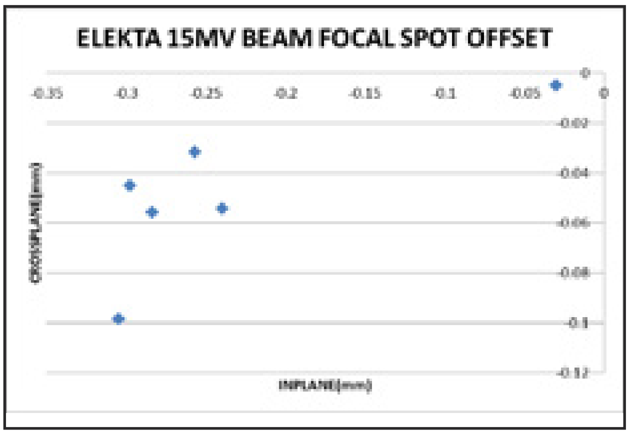

Fig.2 Elekta 15MV beam focal spot offset

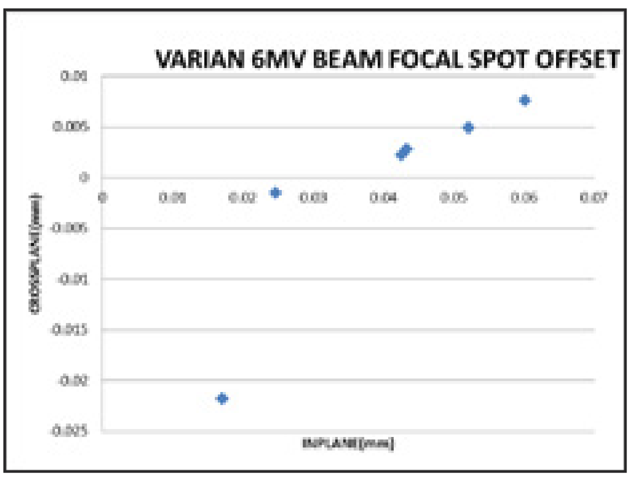

Fig 3: Varian 6MV beam focal spot offset

	ELEKTA VERSA HD				VARIAN Clinac ix	
MEASUREMENT	6MV		15MV		6 MV	
	CROSSPLANE (mm)	INPLANE (mm)	CROSSPLANE (mm)	INPLANE (mm)	CROSSPLANE (mm	INPLANE (mm)
1	0.0593	0.0333	–0.3046	–0.0985	0.0247	–0.0015
2	0.0202	–0.0173	–0.2836	–0.0559	0.0426	0.0022
3	0.0271	0.0091	–0.2975	–0.0452	0.0171	–0.0218
4	0.0127	–0.0068	–0.2570	–0.0317	0.0433	0.0028
5	0.0916	0.0493	–0.2394	–0.0544	0.0602	0.0076
6	0.0121	0.0030	–0.0300	–0.0051	0.0521	0.0049
AVERAGE	0.03716	0.01176	–0.23535	–0.0484	0.04	0.00296
SD	0.03184	0.02504	0.103576	0.03875	0.01613	0.010643

Table1: Reproducibility measurements of the focal spot offset using the EPID on two different linacs

	ELEKTA VERSA HD				VARIAN ClinaciX	
	6 MV		15 MV		6 MV	
	In–plane (mm)	cross–plane (mm)	in plane (mm)	cross–plane (mm)	in plane (mm)	cross–plane (mm)
Ion chamber	0.03820	0.01379	–0.2552	–0.0611	0.0204	0.00108
EPID	0.03716	0.01176	–0.2353	–0.0484	0.04	0.00296
Difference	0.00104	0.00203	0.01985	0.0127	0.0196	0.000188

Table2: Validation of the phantomless method of focal spot offset measurement with the ionization chamber method

directly, and also helps in reducing the same. It will ensure the beam symmetry and geometrical positioning of beam penumbra. The method is reproducible to within 0.0365 mm (SD). From the reproducibility results, the method is reproducible to the order of hundredths of a millimeter for the two linacs investigated for a test where tenths of a millimetre would be the clinically required level of accuracy.

The EPID result is in agreement with the ion chamber–based method to within 0.00923± 0.009360 mm (1 SD). The method could easily be incorporated into a departmental routine linac QA (Quality Assurance) program. The study presents similar results as that of Chojnowski et al[6,7]. Recent study by Ravindra. Shende et al [14] using a graphical method for beam focal spot alignment, implies necessity of a fast test method to increase the accuracy of modern radiotherapy treatment methods. S Herwiningsih and A Fielding conducted study to determine the optimum focal spot size and shape of Elekta Axesse linac equipped with the beam modulator using a BEAMnrc Monte–Carlo linac model for 6MV and concluded that an elliptical shape of the focal spot results in a better match with the measured data with the size of 0.2 cm in X–axis and 0.3 cm in Y–axis direction[15].

Conclusion

An accurate, easier and faster method of radiation beam focal spot alignment is presented successfully in this study.Measurement involving EPID overcomes the complexities pointed in the already established measurement methods. Current method helps every radiotherapy department, to include beam focal spot alignment test in their routine QA programme, which was not done due to complexity involved in performing the QA. The technique is independently validated and is shown to be accurate and robust with reproducibility of 0.0365 mm (SD).

Conflict of Interest:

There is no conflict of Interest.

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