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A Study of the TPS Based Beam-Matching Concept for Medical Linear Accelerators at a Tertiary Hospital

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Abstract

The flexibility in radiotherapy can be improved if patients can be moved between any one of the department's medical linear accelerators (LINACs) without the need to change anything in the patient's treatment plan. For this to be possible, the dosimetric characteristics of the various accelerators must be the same, or nearly the same. The purpose of this work is to describe further and compare measurements and parameters after the initial vendor-recommended beam matching of the five LINACs. Deviations related to dose calculations and to beam matched accelerators may compromise treatment accuracy. The safest and most practical way to ensure that all accelerators are within clinical acceptable accuracy is to include TPS calculations in the LINACs matching evaluation. Treatment planning system (TPS) was used to create three photons plans with different field sizes 3 × 3 cm, 10 × 10 cm and 25 × 25 cm at a depth of 4.5 cm in Perspex. Calculated TPS plans were sent to Mosaiq to be delivered by five LINACs. TPS plans were compared with five LINACs measurements data using Gamma analyses of 2% and 2 mm. The results suggest that for four out of the five LINACs, there was generally good agreement, less than a 2% deviation between the planned dose distribution and the measured dose distribution. However, one specific LINAC named "Asterix" exhibited a deviation of 2.121% from the planned dose. The results show that all of the LINACs' performance were within the acceptable deviation and delivering radiation dose consistently and accurately.

Keywords

Radiotherapy, Beam-Matching, Linear Accelerator, Dosimetry

1. Introduction

Linear accelerators (LINACs) are commonly used in radiotherapy to deliver high-energy x-ray beams to cancerous tissues with precision. The accurate and consistent delivery of radiation is crucial in radiotherapy to ensure that the intended dose is deposited in the tumour while minimizing damage to surrounding healthy tissues. Beam-matching deviations in LINACs refer to variations in the characteristics of the radiation beams produced by different machines or even within the same machine over time. These deviations can have clinical relevance and potential impacts on radiotherapy treatments. For example; treatment planning relies on precise knowledge of the LINAC beam characteristics. Any deviations in beam matching may lead to inaccuracies in treatment planning, compromising the ability to achieve the intended dose distribution.

The possibility of switching of patients among available LINACs from the same vendor within a high-volume radiotherapy centre is critical for successful radiotherapy treatment [1] [2]. Switching of patients may be necessitated by various reasons, including breakdown of LINACs or an unexpected increase in patient numbers. However, in cases where patients are undergoing stereotactic body radiation therapy (SBRT) or stereotactic fractionated radiotherapy, a switch from one LINAC to another requires extremely careful considerations since submillimeter accuracy in dose delivery is desired [1]. A difference in dose delivery with a margin of 5% difference may lead to changes of 10% to 20% in tumour control probability and 20% to 30% in normal tissue complication probability [3] [4]. However, successful radiotherapy despite switching patients from one LINAC to another can only be possible where dosimetric parameters of the LINACs are "beam-matched" [4].

Beam-matching guarantees that the dosimetric characteristics of LINACs from the same vendor are nearly the same, thus making it possible for patients to be treated using any of the LINACs within the facility without changing the patient treatment plans [5]. Several studies have reported the benefits of beam-matching [1]-[7]. Vendors do define a criterion for beam-matching [4]. In the case of Elekta LINACs, the beam-matched LINACs are defined in the TPS using the same beam model. This TPS beam model is availed by the vendor during acceptance testing. Specific beam profiles and percentage depth dose (PDD) measurements are undertaken at acceptance testing to verify the matching for broad square fields such as 10×10 cm^2 and 30×30 cm^2 [6]. For example, Elekta stipulates that for the purpose of matching, a photon beam requires the percentage depth dose at 10 cm (PDD_{10}) to be within ±1% for beam-matched LINACs. Furthermore, Elekta stipulates that for beam profiles of 10×10 cm^2 and 30×30 cm^2 field sizes at a depth of 10 cm, the averaged point dose within the region covering 80% of the full width half maximum (FWHM) ought to be within a 2% difference in comparison to the same points from beam profiles of beam-matched LINACs [1]. A confirmation or agreement between dosimetric data is an assurance that a single beam model can be used for a cohort of LINACs from the

same vendor [6] [7]. However, the beam-matching often defined by the vendor in most cases are not strict enough to guarantee optimal beam-match [4]. Therefore, consistency in dose delivery is essential to achieving the desired treatment outcome. Beam-matching deviations can lead to variations in the dose delivered to target area, potentially resulting under dosing or over dosing. Beam-matching deviation in LINACs can have significant clinical implications, affecting treatment accuracy, normal tissue toxicity, and overall treatment outcome.

2. Materials and Methods

2.1. Overview

A study was conducted to determine the extent of the beam-match between the five Elekta (Elekta, Stockholm, Sweden) LINAC machines installed at a tertiary hospital. The study aimed to create various treatment plans using a phantom and deliver each of these plans with each linear accelerator independently, to assess the level of similarity between the planned and the measured dose distributions for each machine. By assessing the deviations between the measured and the planned dose distributions for each LINACs, the extent of the beam-match of the machines could be analysed.

In order to evaluate the level of the beam-match of the machines in a broad clinical sense, the treatment plans that were set-up included plans for each photon beam energy that is available at each machine, namely 6 MV and 10 MV, as well as for a number of field sizes. Small, medium and large field sizes (3×3 cm^2, 10×10 cm^2 and 25×25 cm^2 respectively) were used, to include as many different clinical possibilities as possible.

2.2. Creating the Treatment Plans

Prior to creating treatment plans, phantom was assembled in the computed tomography (CT) scanner and CT images of the phantom were acquired to be used in the TPS. Abdominal protocol with 3 mm slices was employed during the CT scans. The scanned phantom consisted of 5 cm thick perspex slabs placed on top of the couch, the additional 4.5 cm thick Perspex slabs placed on top with the PTW Detector 1500 (2D array) sandwiched between the 5 cm and 4.5 cm thick perspex slabs.

The 2D array with resolution of 5 mm was used to outline the clear treatment plan validation by comparing dose distribution with machine measured dose distributions to identify any discrepancies, so each row of detectors was visible using 3 mm slices. After the CT images had been acquired, they were exported to the TPS.

In the treatment planning system, the phantom was contoured. This was done in a similar manner as contouring the body of a patient. This allows the TPS to calculate the planned dose received by the entire phantom. After contouring the phantom, the treatment plans were created.

To create the treatment plans, a prescription point was created on the central detector, in the centre of its collecting volume. This is the point at which the radiation dose of 1.5 Gy was prescribed to. This is also the point in the phantom that was placed at the LINAC isocenter when the treatment plans were delivered using each machine. The choice of using a prescription of 1.5 Gy was arbitrary. Common prescriptions used for actual patient treatments usually range from 1.5 Gy - 2.5 Gy per fraction. A single anterior beam was created in order to deliver the treatment dose. No other beams were used.

The treatment plan was duplicated five times, resulting in six plans, each prescribing 1.5 Gy at the prescription point. For the first three plans, the energy of 6 MV was considered. In the first 6 MV plan, the field size was opened to 1.5 cm on each side of the prescription point, both laterally and longitudinally, resulting in a 3×3 cm^2 field. The field size of the second 6 MV plan was opened to 5 cm on each side, both laterally and longitudinally, resulting in a 10×10 cm^2 field. Finally, for the third 6 MV plan, the field size was opened to 12.5 cm on each side, both laterally and longitudinally, resulting in a 25×25 cm^2 field. The same procedure was repeated for the other three treatment plans, except that the considered energy was 10 MV. This resulted in six total treatment plans, three of which were for 6 MV, and three for 10 MV. Each plan aimed to deliver 1.5 Gy at the central detector in the 2D array, using a single anterior beam, and a field sizes of 3×3 cm^2, 10×10 cm^2 and 25×25 cm^2, respectively. By using numerous treatment plans, each with different field sizes, the accuracy of the correlation between the treatments over large and small field sizes, as well as across two different energies, could be investigated. Using only a single field size or single energy would not have given a broad enough picture of the true correlation between the delivered treatments and the original treatment plan.

After the treatment plans had been created, the dose distributions (doseplane) of each plan were exported via the network onto the verisoft software, which were used later to compare with the measured dose distributions. A patient was also created on Mosaiq with the same patient information as was used on the TPS for the six treatment plans. This allowed for the plans to be chosen under the patient's name on the Mosaiq software at each LINAC when the plans were delivered. The Mosaiq system was used because it is the system that is routinely used in our department to carry out patient treatments. The system automatically records when a patient (or phantom in this case) is treated, using any of the LINACs in the department.

2.3. Delivering the Treatment Plans

Before each LINAC was used to deliver the treatment plans, the LINAC was correctly warmed up, and all the relevant quality assurance (QA) procedures and checks as outlined in the South African Standards for Quality Assurance in Radiotherapy (SASQART) were performed and were successful. These checks verify both the mechanical performance of the LINAC, such as if the isocentre for

the gantry, treatment couch and collimator are aligned, as well as the dosimetric performance of the machine.

The same process was used to deliver the treatment plans at each linear accelerator. First, the phantom needed to be assembled on the treatment couch, in the same way that it was assembled at the CT scanner. Once it had been assembled, the LINAC centre field and isocenter lasers were used to position the phantom so that the central detector of the 2D array was at the LINAC isocenter. The 2D array was connected to detector interface, which was connected to a computer within the control room of the LINAC. This allows for the computer to record measurements taken using the 2D array while the beam was on.

After the phantom had been correctly set-up and the set-up was verified, the patient that was created on Mosaiq was opened on the Mosaiq computer in the control room. The first treatment plan was loaded, which was 6 MV with a 3×3 cm^2 field size. At the same time, the Mephysto VeriSoft application was opened on the secondary computer in the LINAC control room. The first treatment plan was delivered, and the dose distribution was measured. After the measurement was taken, the planned dose distribution (dose-plane) was opened in VeriSoft alongside the measured dose distribution. This allowed for easy comparison of the two distributions. The measured dose distribution values were copied from the VeriSoft software into an Excel spreadsheet, along with the planned dose distribution values. Additionally, the gamma analysis values for each point in the plan were also copied into this spreadsheet, to be used later. This procedure was followed for the remaining five treatment plans, until the measured dose distribution data was obtained for all six plans.

Using the measured dose distribution values and the planned dose distribution values, the difference between them at each point in the plan could be assessed. This also allowed for the calculation of the percentage deviation between the planned and measured dose distributions at each point that was measured in the dose distribution. Using these deviations, the average deviation over the whole plan could also be determined, as well as the point of maximum deviation between the planned and measured dose distributions for each plan.

The above process was repeated at each of the five linear accelerators in the department that are being evaluated. This resulted in measured data being obtained for six treatment plans, for each linear accelerator.

2.4. Gamma Index Analysis

The gamma index analysis method which utilizes specialized software functionality of VeriSoft, which is designed for quality assurance, was used to evaluate the agreement between the planned and delivered dose distributions. The gamma index was used to calculate the agreement between the planned and measured dose distributions. The gamma index is a quantitative measure that considers both dose difference and distance-to-agreement (DTA) criteria.

The gamma index analysis is of the form

$$\Gamma = \sqrt{\left(\frac{\Delta D}{D}\right)^2 + \left(\frac{\Delta d}{DTA}\right)^2} \quad (1)$$

where ΔD is the dose difference of a specific point and D is the maximum dose in the reference or planned distribution at that point; Δd is the distance difference in mm between the points in the reference and evaluated measured distributions. DTA is the distance-to-agreement criterion which defines the toleranc the manuscript will proceed to the typesetting stage, which may take some time. 3% Dose to 3 mm agreement criteria was employed for data analyses.

Analysing treatment plans in this way is normal practice in the department to ensure that the radiation therapy treatments for volumetric modulated arc therapy (VMAT) or intensity modulated radiotherapy (IMRT) are delivered accurately and precisely to the intended target while minimizing dose to healthy surrounding tissues.

3. Results

The average deviations between the dose distributions of the treatment plans and the measured dose distributions are shown in Table 1 and Table 2. These deviations indicate the difference between the planned dose and the delivered dose at various points within the treatment plan. This allows us to analyse the performance of each LINAC at each point in the plan. Commonly in radiotherapy, maintaining a deviation of less than 2% is acceptable, however there is no exact threshold for the specific deviation that is anaylsed in this report.

To calculate the deviations, the planned dose distribution for each field size and energy were normalized, so that at each point in the original treatment plan we obtained the percentage of the maximum dose in the original treatment plan

Table 1. The average deviations between the treatment plan dose distributions and the measured dose distributions for the 6 MV photon beam of each LINAC.

6 MV					
Field Size (cm^2)	Deviation (%)				
	Asterix	Calvin	Dexter	Hobbes	Obelix
3 × 3	1.379	0.791	0.728	0.695	0.802
10 × 10	1.634	0.809	0.844	0.780	0.988
25 × 25	2.121	0.741	1.128	1.033	1.294

Table 2. The average deviations between the treatment plan dose distributions and the measured dose distributions for the 10 MV photon beam of each LINAC.

10 MV					
Field Size (cm^2)	Deviation (%)				
	Asterix	Calvin	Dexter	Hobbes	Obelix
3 × 3	1.584	1.018	0.874	0.863	0.895
10 × 10	1.522	0.918	0.777	0.767	0.882
25 × 25	1.432	1.179	0.868	1.066	1.337

at that point. This was repeated for the data that was obtained at each LINAC, *i.e.*, the data was normalized so that at each point in the delivered plan we obtained the percentage of the maximum dose in the same plan, for each field size and energy. Once both sets were normalized, the deviations could easily be determined by taking the absolute value of the difference between the planned dose and the delivered dose at each point in the plan.

As seen in Table 1 and Table 2, each of the five LINACs showed less than a 2% deviation between the planned dose distribution and the measured dose distribution, except for one LINAC (Asterix) at one energy and field size (6 MV, 25 × 25 cm^2) which showed a deviation of 2.121% from the planned dose distribution.

Dose Distribution

Figures 1-5 show the plotted percentage deviation between the planned dose

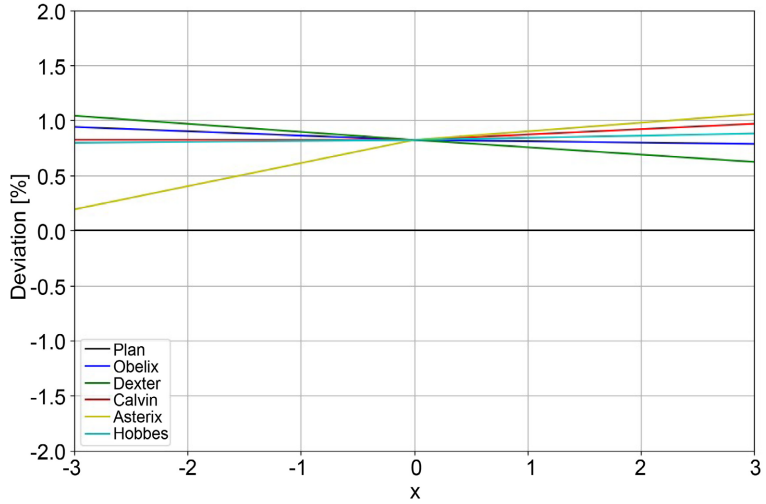

Figure 1. Plotted percentage deviation between the planned dose distribution and the measured dose distribution for 6 MV photon beam and 3 × 3 cm^2 field size.

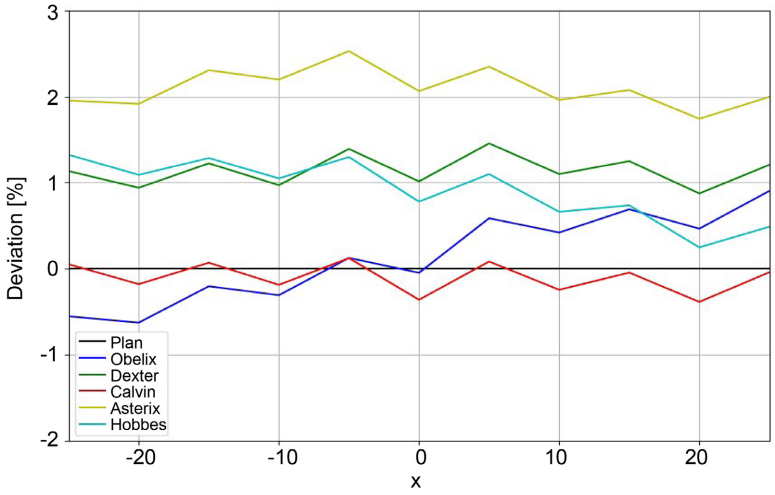

Figure 2. Plotted percentage deviation between the planned dose distribution and the measured dose distribution for 6 MV photon beam and 25 × 25 cm^2 field size.

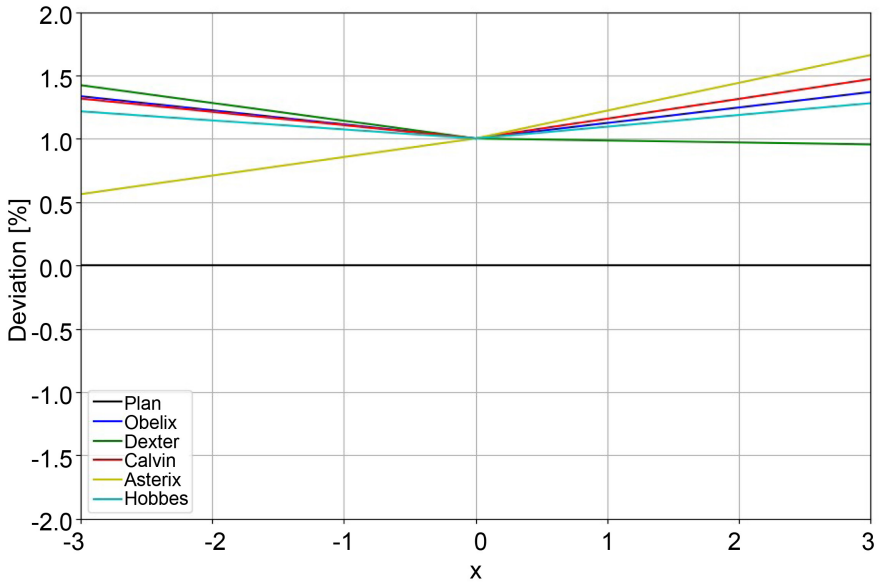

Figure 3. Plotted percentage deviation between the planned dose distribution and the measured dose distribution for 10 MV photon beam and 3 × 3 cm2 field size.

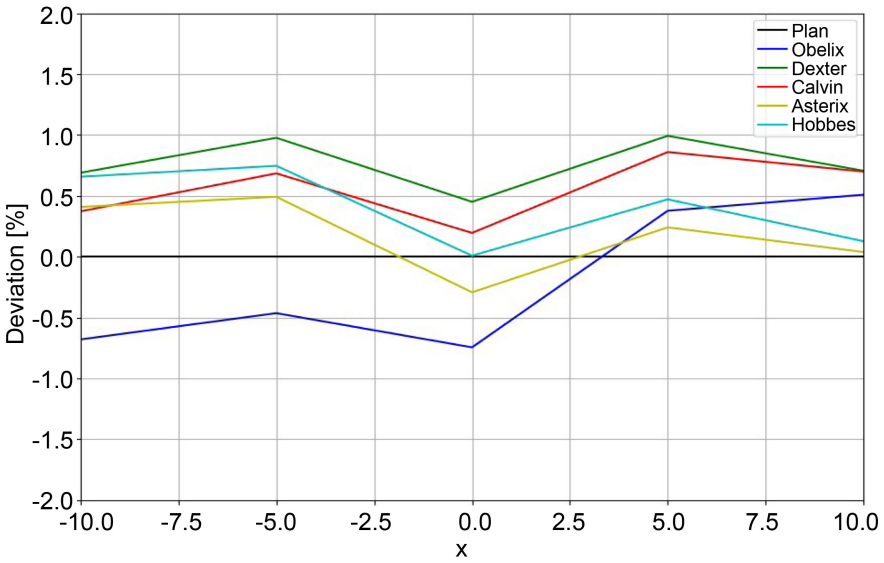

Figure 4. Plotted percentage deviation between the planned dose distribution and the measured dose distribution for 10 MV photon beam and 10 × 10 cm^2 field size.

distribution and the measured dose distribution for the various field sizes and energies used.

4. Discussion

The results suggest that for four out of the five LINACs, there was generally good agreement, less than a 2% deviation between the planned dose distribution and the measured dose distribution. However, one specific LINAC named "Asterix" exhibited a deviation of 2.121% from the planned dose distribution under specific condition of 6 MV and 25 × 25 cm^2. The deviation values, which

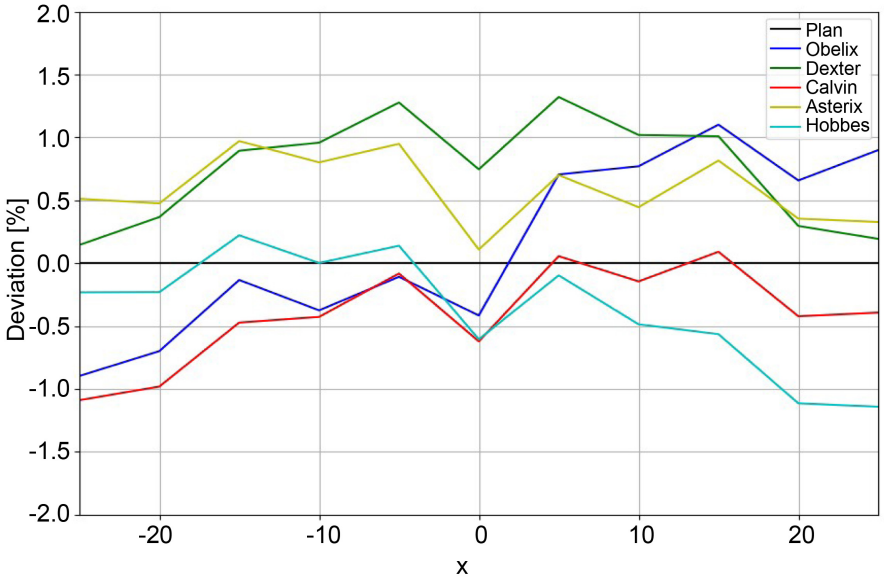

Figure 5. Plotted percentage deviation between the planned dose distribution and the measured dose distribution for 10 MV photon beam and 25 × 25 cm^2 field size.

represent the difference between the planned dose distribution and the measured dose distributions, serve as indicators of how closely the LINACs are adhering to the intended dose delivery.

In the context of radiation therapy, maintaining a low deviation typically less than 2% is crucial to ensure the precision and reliability of the treatment. The LINAC named "Asterix" was slightly higher discrepancy at a specific energy and field size, this particular case may warrant further investigations or considerations.

5. Conclusion

All five machines were within 2% deviation of the planning data, except for one machine, namely Asterix, which only deviated by slightly more than 2% for one energy and one field size (6 MV, 25 × 25 cm^2). The results show that all of the LINACs' performance were within the acceptable deviation and delivering radiation dose consistently and accurately.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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