Electron Beam Profile Assessment of Linear Accelerator Using Startrack Quality Assurance Device

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Abstract. Electron beam therapy using linear accelerator done for patients with superficial cancerous tumors. Daily quality assurance is preferable to assess a good treatment for the patients. This study focuses on penumbra, flatness, and symmetry determination for four types of an electron beam using StarTrack 2D array for quality assurance. Electron beam with energies: 6MeV, 9MeV, 12 MeV, and 15MeV for both in-plane (x-axis) and cross-plane (y-axis) using Elekta synergy linac exposed to StarTrack 2D array readings during 16 weeks for testing the performance and stability of StarTrack. The testing protocol used is IEC. The beam profile estimation of variation, when compared with standard values of penumbra, flatness, and symmetry of electron beam energy at the time of commissioning, reveals that all had a variation but these variations are within the limits. It is concluded that StarTrack 2D array detector is favourable in the QA process. Their implementation is not only easy, but gives information about the beam's temporal stability and is particularly suitable for beam steering mounting.

Keywords: StarTrack, Beam Profile, Penumbra, Flatness, Symmetry, IEC.

1. Introduction
Radiation therapy (RT), radiotherapy, is an effective way of treatment for many various forms of cancer using ionizing radiation. The ionizing radiation in this type of cancer treatment is created by machines based on an electron linear accelerator (linac) or by radioactive material. The goal of most radiation treatments is to destroy cancerous tissue [1, 2]. Linear accelerator (linac) is an electromagnetic wave instrument that accelerates charged particles like electrons to high energy via a linear pipe using high-frequency electromagnetic waves. The high energy electron beam itself can be used to treat superficial tumors or to hit a target for x-rays for the treatment of tumors with deep seat [3-5]. The profiles of the electron beams depend on how the flattening system is designed and how it is designed to fit beams together. The flatness of the beams will dramatically change with distance, as dispersed electrons are less energy [6].
Quality assurance is all systematic and planned activities are carried out within the quality program that can be shown to assure that the product or service will meet the quality specifications [7-9].

Quality assurance in radiotherapy’ is all the procedures that guarantee continuity and secure compliance with the medical prescription. Examples of prescription [7, 10].

• Tumor dose (to the target volume).
• The normal tissue requires a minimal dose.
• Adequate patient monitoring to determine the optimum outcome of the treatment.
• Minimal exposure to personnel. It includes both clinical and physics aspects.

The QA checks are categorized into daily, monthly, and annual QA reviews, as well as proposing modern linac technology and modern QA tests to ensure linacs can deliver care in the way expected [11-13]. StarTrack is a device used for routine quality assurance for different energies of electron and photon beam outside of the linear accelerator. It is developed by IBA-dosimetry in collaboration with INFN and the University of Torino, Italy. This device is manufactured by IBA dosimetry Gmph [14, 15]. It is a function of the proprietary system for testing energy and reading independently of the electrometer. StarTrack includes 453 air-vented configuration tailored ionizing chambers for QA devices. The ionizing counters have a gap of about 5 mm. The diameter of ionizing counters 3 mm [14, 15].

The power supply module measurement device can be connected to the main power with the voltage range 100-240V. Startrack is equipped with sensors that measure the ambient of the T (temperature) and P (pressure). It’s weight is 10Kg. Outer Dimensions 56 cm (Length) x 6 cm (High) x 32 cm (Width) (according to AmiPro-Advance (v1.2) System User's Guide). It can make all main tests in one shot such as dose, profiles, diagonals, energy verification, etc. [14, 15].

Advanced, pixel ionization chamber based on linac QA device with special detector configuration to check major QA parameters in one measurement only, for example, daily, weekly, and monthly QA, symmetry, flatness, initial and diagonal axes, field size & penumbra, Wedge check, Linac startup behavior, MLC verification, congruence of light field radiation, photon and electron beam output check. The energy constancy checks for photon & electron beams are possible using an optional buildup plate. You can set up and align the StarTrack easily (treatment couch or gantry mount optional) [14, 15].

B. S. Lazim. et al. [16] aimed to verify the quality assurance of the linear. They used a StarTrack device and Perspex to ensure the photon beam quality of the linear accelerator by measuring the output dose. The findings show an acceptable variability in the output X-ray dose of the linear accelerator type synergy. The achieved variation was ±2% and it was within the permissible range according to the recommendations of the manufacturer of the accelerator (Elekta). Patatoukas GD. et al. [17], illustrate the parameter following (flattening, symmetry, and penumbra) using different systems where the profile of the dose was calculated using phantom and six ion chambers by different filed size and a different depth. They were able to calculate both the penumbra and the symmetry and flattening where all measurements were within the permissible range to check beam quality.

1.1. Beam profile
Dosage distributions along the central beam axis provide only part of the information required to accurately classify the dosage within the patient. Dosage transmitted from 2-D and 3-D is measured together with central axis dose profile data; off-axis data are provided perpendicular to the beam profile of the central beam axis, which is estimated at a certain depth at a certain level, and depth calculation is normally carried out at Dmax [7].

The dose change obtained at a certain depth along the vertical line of the centerline axis is called the beam profile. The beam profiles include penumbral region, flatness, and symmetry [7, 18, 19].

The penumbral region is the edge of the beam and rapid dose changes are seen in this region depending on the scatter from the collimators, the size of the source, and any lateral electronic imbalance. The penumbra region, typically defined as the region among the 80% and the 20% relative dose in the beam profile, is an intrinsic feature of any beam, whether photon or electron [17, 20].
According to IEC, the Electron beam axis penumbra is defined as the maximum distance along the main axis between points of 80% and 20% of the absorbed dose on the radiation beam axis, all measurements being in the plane at standard measurement depth. Its results appear in (mm) or (cm) [7].

The IEC organization defines the standards of flatness beam (F.B) and symmetry beam (S.B) and penumbra region for an electron beam, which is depended on the device used [7]. The flatness (beam flatness) is calculated with the maximum (Dmax) and minimum (Dmin) dose points values within the central 80% of beam width of the beam profile and then with the references [3, 7]:

$$ F.B = \frac{D_{\text{max}} - D_{\text{min}}}{D_{\text{max}} + D_{\text{min}}} \times 100\% $$

where: maximum and minimum doses inside the region are D_max and D_min. According to IEC, the accepted difference flatness along the x and y-axis is 10 mm.

d_max is the most sensible profound for the evaluation of this beam uniformity parameters, usually determines the symmetry (beam symmetry). A typical definition of symmetry is that any two-dose points within the beam profile, which are equal to 3% from the central axis. Areas below the D_max beam profile are alternatively defined on each side (left and right) of the central axis, which extends to 50% (normalized up to 100% at the central axis), and S.B is calculated from [3, 7]:

$$ S.B = \frac{\text{area left} - \text{area right}}{\text{area left} + \text{area right}} \times 100\% $$

According to IEC, beam symmetry is defined as the maximum dosage absorption ratio at points symmetrically moving from the beam axis of radiation and over 1 cm or 3 % inside the standard measuring depth 90 % isodose contour. Its results appear in percentages [7].

This study aimed to Check the StarTrack device validity for using in quality assurance of delivering the electron beam to the target with a chance of variation of in the Elekta linear accelerator radiotherapy device and study the properties of the dose profile toward the x-axis (inline) and y-axis (crossline) for electron using star track for a daily check up for QA than the weekly.

2. Materials and method
This study was conducted from August 2019 to February 2020 in Baghdad center for Radiotherapy and Nuclear Medicine, Baghdad Medical City, Baghdad, Iraq. It is approved by the Institute Review Board (IRB) of the college of medicine, Al-Nahrain University. The study included the uses of important devices: StarTrack device, Perspex sheet, an applicator device. The linear accelerator version used in this study is synergy manufactured by Elekta Company. Readings are acquired within 16 weeks using the StarTrack device. Four energies of the electron beam used in the study. They were 6 MeV, 9 MeV, 12 MeV, and 15 MeV. Fixed field size used of 10 cm x 10 cm at R50. Two planes of the beam profile (BP) were calculated which were inline and crossline. Inline BP represents the measurements of the x-axis plane and crossline BP represents the y-axis plane in StarTrack 2D array detector. The Commissioning method for StarTrack is IEC (International Electrotechnical Commission) standards.

3. Results
The profile of the electron beam is measured by the StarTrack QA device for 16 weeks to indicate the steadiness of readings for four different energies: 6 MeV, 9 MeV, 12 MeV, and 15 MeV.

3.1. Beam profile
3.1.1. Penumbra. The measurement of penumbra obtained from the lateral distance between 80 % and 20% of the isodose curve for relative irradiated dose in cm which detected by StarTrack 2D array detector based on the IEC standards method. The penumbra deviation of results should be adequate or
less than +/-0.20 cm. The mean penumbra value is calculated from the left and right-side for every profile of all energies. The penumbra results are summarized in Table 1. It had been noticed that when the electron beam energy increased, the penumbra width decreased in both planes (inline and crossline). All deviation in penumbra readings is within the boundaries. Figures 1 and 2 are plotted for inline and crossline mean penumbra respectively. It shows that the readings are almost stable along the 16 weeks of QA for both planes and all energies.

Table 1. Mean Penumbra Measurements and Their Inline and Crossline Planes.

| Energy | Inline       | Crossline    |
|--------|--------------|--------------|
|        | Results      | Difference   | Results      | Difference   |
| 6 MeV  | 1.1318±0.0049| 0.0031       | 1.1478±0.0138| 0.0121       |
| 9 MeV  | 0.8878±0.0101| 0.0021       | 0.9034±0.0181| 0.0015       |
| 12 MeV | 0.7015±0.0084| 0.0015       | 0.7109±0.0104| 0.0059       |
| 15 MeV | 0.6006±0.0209| 0.0193       | 0.6059±0.0271| 0.0240       |

Figure 1. Mean penumbra measurements of the Inline plane for 16 weeks with energies (6 MeV, 9 MeV, 12 MeV, and 15 MeV).
Figure 2. Mean penumbra measurements of Crossline plane for 16 weeks with energies (6 MeV, 9 MeV, 12 MeV, and 15 MeV).

3.1.2. Flatness. Table 2 summarize the flatness measurements at 80% isodose line respectively of four electron beam energies obtained from the StarTrack 2D array detector. Based on the IEC method the difference of readings should not exceed 10 mm. It shows that the difference of flatness measurements is within the limits for both inline and crossline. Generally, all the flatness measurement result (at 80%) increases as the beam energy increased. The mean difference of flatness 80% increased as the beam energy increased for both planes except the cross-plane measurements for 12 MeV it is decreased.

Table 2. Flatness at 80% Isodose Line Measurements and Their Differences for Inline and Crossline Planes.

| Energy | Inline | Crossline |
|--------|--------|-----------|
|        | Results | Difference | Results | Difference |
| 6 MeV  | 3.35 ± 0.10 | 0.15 | 3.75 ±0.12 | 0.14 |
| 9 MeV  | 2.31 ±0.17 | 0.18 | 2.63± 0.14 | 0.16 |
| 12 MeV | 1.61± 0.24 | 0.18 | 1.92± 0.25 | 0.07 |
| 15 MeV | 0.9 ± 0.33 | 0.3 | 1.14 ± 0.36 | 0.25 |

Figures 3 and 4 are a representation for flatness 80 % for inline and cross-line planes respectively during the 16 weeks. It appears that the readings are not stable throughout the time especially in weeks 13 and 16 in inline and crossline plane the change in 3rd and 16 weeks (Figure 4) but all changes within the range.
Figure 3. Flatness 80% measurements of Inline plane for 16 weeks with energies (6 MeV, 9 MeV, 12 MeV, and 15 MeV).

Figure 4. Flatness 80% measurements of Crossline plane for 16 weeks with energies (6 MeV, 9 MeV, 12 MeV, and 15 MeV).

3.1.3. Symmetry. Based on the IEC standards method, the difference in symmetry readings or the deviation for electron beams should not exceed +/- 3 %. Table 3 summarizes the results of symmetry for beams measured with the StarTrack 2D array detector. Results reveal that the readings for 6 MeV in crossline are ideal. All differences in measurements are within the limits. Inline symmetry readings decrease when the electron beam energy increased in all energies, while in crossline a reverse process appeared; when the energy increased the symmetry increased also except at 15 MeV it decreased in crossline.
Table 3. Symmetry Measurements and Their Differences for Inline and Crossline Planes.

| Energy | Inline        | Difference | Crossline      | Difference |
|--------|---------------|------------|----------------|------------|
| 6 MeV  | 100.40%±0.14% | 0.14%      | 101.00%±1%     | 0%         |
| 9 MeV  | 100.31%±0.09% | 0.11%      | 101.73%±0.60%  | 0.43%      |
| 12 MeV | 100.36%±0.09% | 0.03%      | 101.80%±0.86%  | 0.33%      |
| 15 MeV | 100.28%±0.06% | 0.01%      | 101.49%±0.55%  | 0.10%      |

Figure 5 and 6 display the symmetry measurements for electron beams for all energies (6 MeV, 9 MeV, 12 MeV, and 15 MeV). They appeared that all the beams have symmetric values with both planes: inline and crossline.

Figure 5. Symmetry measurements of Inline plane for 16 weeks with energies (6 MeV, 9 MeV, 12 MeV, and 15 MeV).
4. Discussion
The electron beam therapy is globally used for the treatment of superficial cancers and it's suitable for treating the disease near the skin surface and not penetrating the deep tissues which are that the important ones in all the unique characteristics of an electron beam. The key requirement of electron beams in clinical use is that the beam flux uniformity. Dose change over the target volume is limited in general in radiation therapy to ensure that the dose is received within the tolerance range in all points of the volume. For commissioning, left-right in-plane profiles and cross-plane profiles are needed. Cross-plane profiles are typically stable and should be the direction to which information is collected. Dose profiles are collected during commissioning with either a manual method or professional computer software for input in a treatment planning unit. The increasing profile should typically be updated to the central axis value and adjusted to the isocentric distance [6], [21].

4.1. Beam profile
Through specifying a setting based on basic flatness and symmetry requirements at a reference depth, the uniformity of the electron beam may be well defined [6]. Any change in the beam profile tells us that there is something wrong with the setting of LINAC and it is not appropriate to apply the same criteria as at commissioning. Thus, at commissioning the profile should not differ by more than 2% from its form. The beam's asymmetry is linked to the beam steering. Flatness and symmetry (IEC 2007) are calculated only inside the 'flattened region' specified by IEC. Symmetry is the dosage amount of symmetrical points on either side of the beamline, and the flatness in each beam is the measure of the average to the minimum dose. Although the standard IEC allows a 3% asymmetry, total beam symmetry with a contemporary accelerator would be easier to achieve [17]. Nonetheless, 3% of the measurement precision is adequate for a fast check.

4.1.1. Penumbra. The requirements of the profile are depended on the treatment planning system (TPS) for modeling the penumbra for open fields (10 cm x 10 cm). It is necessary to have an accurate knowledge of penumbra as a basic step for correct treatment planning and radiation delivery to the patient. For example, the increase in penumbra value above the limits can lead to a large filed which is unnecessary irradiation for healthy tissues [20].
Penumbra results of this study showed that as the electron beam energy increased, the mean penumbra decreased for both in-plane and cross plane. The results disagreed with Patatoukas GD. et. al. 2018 [17] when they declare that as beam energy increased, the penumbra width increased also for different detectors and energies (6, 9, 12, 16, 20) MeV. The difference in readings of this study decreased as beam energy increase except in 15 MeV the mean penumbra difference increased for both planes. But, it is within tolerance. An agreement showed of mean penumbra difference between this study and Patatoukas GD [17], that’s when the beam energy increase the mean percentage difference decreased considerably. The difference in results is may be due to the use of another type of ionizing chamber detectors for QA measurement: a Semiflex (31002, PTW), a Markus (23343, PTW) and Roos (34001, PTW) and one dimensional Linear Array (LA48, PTW), while the detector used in this study is StarTrack 2D array with IEC standard. Also, they use different types of applicators and their study at R100 and R80, while our study is at R50. The penumbra results of this study did not exceed +/-0.20 cm, so the results are stable and accurate with StarTrack 2D array.

4.1.2. Flatness. The flatness of the beam at 80% increased as the beam energy increased also for both planes with an exception for 12 MeV beam energy that shows a decrease with flatness increase. The results in agreement with Zhang S et al 2009 [22] estimated the flatness at 80 % isodose line for electron beams (4,6,7,9,11,12,16 and 20) MeV with 3D blue phantom (Wellhofer, IBA Dosimetry America, Bartlett, TN, U.S.A.) with two CC04 cylindrical ion chambers placed in the radiation field using Varian linear accelerator. Their results agreed with this study for flatness 80 %.

Our results agreed with Pathak P et al 2015 [6] and Patatoukas GD. et. al. 2018 [17]. Pathak P et al 2015 [6] studied the energies (4,6,8,10,12,15, and 18) MeV for different applicators with 2D array from PTW for in-plane using IEC standard methods, cross-plane, and diagonal axis isodose line, multiple field sizes including 10 cm x 10 cm which is the same used in this study using Elekta Synergy linac and Patatoukas GD. et. al. 2018 compares the flatness analysis with different detectors and applicators using Varian linear accelerator. The latter found some variation in flatness with some detectors. StarTrack Readings of this study proved that flatness at 80% is dependable by IEC 2007 [23].

4.1.3. Symmetry. Our results showed that as the electron energies increase the symmetry measurements decreased and the mean difference decreased also for inline and, while the symmetry increases with increasing the energy for the cross-line during 16 weeks. This results in agreement with Pathak P et al 2015 [6] who found out that the electron beams decrease gradually with energies increase for both planes using PTW 2D array detector.

Patatoukas GD. et. al. 2018 [17] also declare that the symmetry decreased as energy increased at different applicators and detectors with some detector present considerable variation. In general, the results for symmetry display a variation but it is safe to conclude that the StarTrack 2D array detector appears the best choice for symmetry measurements.

5. Conclusion
We conclude that there is no variation in measurements of the penumbra, flatness at 80 % isodose line, or in symmetry for electron beam energies 6 MeV, 9 MeV, 12 MeV, and 15 MeV provided from the StarTrack 2D array detector as compared to the standard measurements of IEC standard methods during 16 weeks and gives fast results. So we conclude that StarTrack 2D array detector can be used for the routine measurements of electron beam profiles. Star Track is fast, easy, and efficient to quality assurance of the linear accelerator.

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