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Insights to Achieve More Accuracy for the Conventional Treatment Planning Systems.

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Abstract

Many documents and protocols had been published in the field of treatment planning systems (TPS) quality assurance, verifying dose calculation to the relevant measurements. International Atomic Energy Agency (IAEA) had published Technical Documents (TEC-DOCs) concerned with the TPS quality assurance intended to the developing countries to suits the conventional facilities in their centers. This work aimed to evaluate the dosimetric performance of the TPS that available in our department, following the guidelines of IAEA. Twelve test cases were chosen to verify the TPS dosimetric performance in homogenous water that can be applied by our available dosimetric tools. Two of these test cases related to the absolute dose measurements on the central axis of the open square field sizes (relative output factor ($S_{c,p}$)) and wedge output factor (WOF) for wedged square field sizes. The other test cases involved relative measurements as percentage depth dose (PDD) curves, beam profiles, off-axis ratio (OAR) dose values, penumbra region, and radiological width $(RW)_{50}$. The results analyzed by the confidence limit concept and the tolerance criteria of acceptability stated by IAEA TEC-DOCs. Results show that TPS calculations are in good agreement with the measurements and within limits except for the parameters $(RW)_{50}$ and (WOF) of the tested field sizes that exceeding the tolerance limits. The deviation (δ) in the TPS calculations of $(RW)_{50}$ = 2.5 mm, the penumbra regions are 2.6 mm and 2.8 mm for photon beam energies 6 and 10 MV, respectively. The proposed analysis display, determining clearly the orientations of calculation errors. This method elaborates errors and their directions in a good way.

Keywords: Quality assurance; Treatment planning systems; Photon beams; Dose calculation; Linear accelerator.

1. Introduction

The radiobiological hazards affecting tumors as well as normal tissues are well interpreted by the dose versus tissue response relationship. In clinical practice, the curves of dose-response are defined to be very steep. If the dose changed by 5% causes a change of 10-30% in the tissue response concerning the steepest portion of such curves [1]. The needed precision in radiation therapy is based on the steepness of these dose-response relationships and on what accuracy is feasible as one accounts for the various steps involved in the radiation treatment process [2].

More studies have been performed on the uncertainties associated with the radiotherapy process. These studies revealed that ±3% error in the dose calculations will yield to ±5% error in the patient radiotherapeutic dose [3–5]. Practically, the medical physicist is responsible for ensuring that the TPS generates the exactness of the dose measurement below this 3% recommendation [6,7].

The core of the Treatment Planning System (TPS) quality assurance (QA) is, therefore, the development of a process that ensures confidence for every patient treated as scheduled optimally and there will be no errors in the TPS calculation in the clinical implementation of the treatment plan. TPS simulates the interaction between the radiation beams of certain angles, field sizes, energies and exposure time or the Monitor Unit (MU) and the tumor target volume implemented by the computed tomography device (CT) [8,9]. The implementation of a top-quality assurance program for the TPS must, therefore, demonstrate practical and direct rules for efficient system user training [10].

Many authors studied the performance evaluation of the accuracy of the treatment planning system for external photon beams [11–29]. Also, many organizations had published quality assurance protocols and reports handling the radiation treatment planning dosimetry verification [30–39]. They developed test packages for verification of TPS accuracy for clinical photon external beam therapy. These test packages permit comparisons of computed doses from TPS with measured values for a series of test conditions.

Although a lot of data is provided in most TPS QA reports, it is difficult for a user to decide which tests a private user needs to administer and which tests should be performed by the seller or group of users of a selected system [10,40,41]**.** Besides, the number of tests conducted in some of these reports is so great that a large investment in manpower would be necessary to carry out them. National and international publications have agreed between themselves on the need to propose a smaller number of quality tests for TPS. A smaller set of tests isn't only suitable for small hospitals with limited resources but is additionally needed by large centres that have a high patient load or limited staff [13]**.** IAEA had published two documents, IAEA TEC-DOC 1540, (2007), and IAEA TEC-DOC 1583, (2008) [42-43], supported guidelines described in IAEA TRS 430 (2004) [36]. These documents implement acceptance and commissioning procedures for TPSs, emphasizing the requirements of the developing world. Nowadays, the radiation therapy field has become more progressed, as it has been introduced many advanced techniques to treat cancer patients more accurately. However, the price of these devices is very expensive for many economically poor countries. Therefore, these countries still use two-dimensional radiotherapy treatment planning devices [44,45]**.** Some researchers intended to use IAEA TEC-DOC 1583 test package in the evaluation of TPS algorithm accuracy and its authenticity for the treatment [46]**.**

The main aim of this investigation is to choose a variety of test cases proposed by the IAEA TEC-DOCs 1540 and 1583 for evaluating our 2D TPS as compared with the measurements. These test cases must suit the dosimetry facilities of our department to realize accurate dose delivery to the patients consistent with the international standards. Establishment a technique that guarantees the quality of the radiotherapeutic dose delivery. Also, in this study another point of view had been proposed can be easily determine the spread direction of the errors and give clear and help to assess the errors inherent in the radiotherapy process.

2. Research Methodology

2.1. Treatment planning system (TPS)

Radiation Oncology Computerized System (ROCS) TPS version 5.1.6 consists of microcomputer-based calculations using data entered alphanumerically and graphically by the operator. External beam calculations use the same TMR (Tissue Maximum Ratio) versus field size and depth data as are used by Monitor Units (MU) program. The calculation to each point is similar to the dose calculation at the same point in the MU program. The distance from the source to the point is calculated, and the appropriate inverse square factor is multiplied by the TMR value for the tissue depth. The TMR is also modified by an off-axis ratio and an edge factor, ROCS physics Manual (1994).[47] The radial dimensions for a given field size are calculated by linear interpolation. In all external beam plans, corrections for both surface obliquity and inhomogeneity of internal structures (if any) are calculated using inverse square correction for the dose intensity at the point and the effective depth for the appropriate TMR factor. The TPS is using Clarkson`s sector integration method as an algorithm for radiation field calculations.

2.2. Measurement instrumentation and techniques

Beam data and test point doses were measured for a photon beam energies 6 and 10 MV produced by Philips SLi15 Linear accelerator. Percentage depth dose (PDD) curves and beam profiles were measured with a fully computerized water phantom (Blue Phantom; Scanditronix/Wellhöfer relative dosimetry system) equipped with two pinpoint waterproof ionization chamber detectors of measurement volume 0.01 cm^3 for relative measurements. Absolute dose measurements were performed with a thimble waterproof ionization chamber (Scanditronix/Wellhöfer FC65-P) of measuring volume 0.65 cm^3 connected to an electrometer (Scanditronix/Wellhöfer Dose1). The FC65-P chamber was calibrated in $N_{D,w}$ (absorbed dose to water calibration factor) according to the IAEA TRS 398 (2000) dosimetry protocol. [35] Test point doses were calculated from the integrated signal in irradiation delivering 100 monitor units (MU).

2.3. TPS water phantom coordinates system

The following coordinate system is defined relative to the water phantom for clarification of beam data and test case geometry and created by using our treatment planning system ROCS:

- The origin is at the isocenter of the treatment unit as shown in Figure (1). The phantom surface is positioned at the isocenter for all the tests except the isocentric test.
- The Z-axis is perpendicular to the water phantom's upper surface and guided from the phantom upward. Only for the oblique test case of entry, the Z-axis coincides with the central axis of the beam and is pointed toward the source.

- The direction of the X-axis defined at angle = 90^o concerning the Z-axis. The plan that contains the perpendicular axes X and Z defined to be at the right angle to the rotation axis of the radiotherapy machine.
- The Y-axis concurs with the rotation axis of the treatment unit gantry and is directed toward the gantry. All calculations are performed at points in the X-Z plane (Y = 0).

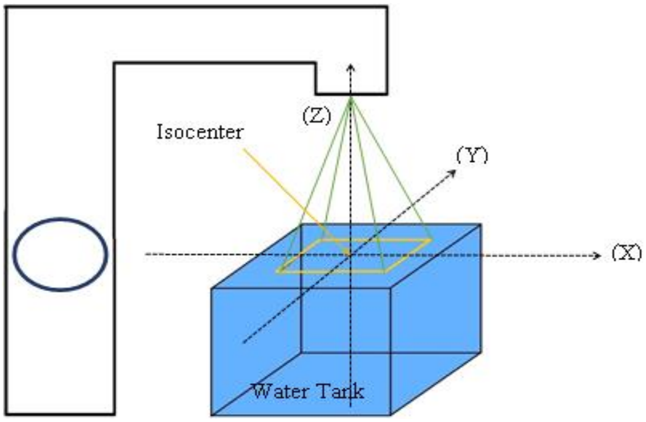

Fig. 1. Co-ordinate system for clarification of beam data and test case geometry.

2.4. Test cases

All the measured cases are compared to the similar (OAD) dose points calculated by the TPS.

2.4.1. Test case (1). Percentage depth dose (PDD)

Percentage depth dose was measured along the central axis of the tested open square field sizes (4x4, 5x5 cm^2 small field coded 1-6, 10x10 cm^2 medium field coded 7-12 and 25x25 cm^2 large field coded 13-18) for depths from 0 to 40 cm.

2.4.2. Test case (2). Relative output factor ($S_{c,p}$)

In this test, the relative output factor ($S_{c,p}$), as defined by Khan, and Gibbons (2014)[48], were measured for wide range of open square field sizes with dimensions of (4, 5, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30 and 32 cm^2) at reference depth = 10 cm.

2.4.3. Test case (3). Small open square field sizes

The profiles of the field sizes (4x4 and 5x5 cm^2) at depths 1, z_{max}, 3, 5, 10, 15, 20, 25 and 30 cm were measured, where z_{max} is the depth of the maximum dose determined by the PDD curves of certain photon energy for field size 10x10 cm^2 at focus source surface distance (FSD) = 100 cm. The dose was determined at the off-axis distance (OAD) = 0, ±1 and ±5 cm on the measured scanned profiles. Also, the acquired measurements were coded from 1 to 8 where every single code will represent three values of the OAD positions.

2.4.4. Test case (4). Medium open square field size

By repeating the test case (3) for field size 10x10 cm^2 at the same depths with assigning the dose at OAD = 0, ±3 and ±9 cm on the measured scanned profiles. These measurements were coded from 9 to 16. Taking into account the calculated dose per MU at z_{max} should be 1 cGy/MU.

2.4.5. Test case (5). Large open square field size

Repeating the test case (3), for the field size 25x25 cm^2 at the same depths with assigning the dose at OAD = 0, ±9 and ±19 cm on the measured scanned profiles. These measurements were coded from 17 to 24.

2.4.6. Test case (6). Rectangular open square field size

This test is designed to evaluate the performance of the TPS when calculating the dose of the elongated field sizes. Repeating the steps of the test case (3) with changing the field size to:

a. 5x25 cm^2, the smaller field dimension is aligned with the patient's transverse axis (X-axis) while the longer field dimension is aligned with the patient's longitudinal axis (Y-axis) and the dose points assigned at OAD = 0, ±1 and ±5 cm. These measurements were coded from 1 to 8 where every single code will represent three measurements of OAD positions.

b. 25x5 cm^2, the longer dimension of the field is aligned with the patient's transverse axis (X-axis) while the smaller field dimension is aligned with the patient's longitudinal axis (Y-axis) and the dose points assigned at OAD = 0, ±9 and ±19 cm. The code numbers of the measurements will be assigned from 9 to 16.

2.4.7. Test case (7). Isocentric open square field size

This test simulates an isocentric treatment using a field size 10x10 cm^2 with the isocenter placed at 15 cm depth. The dose is measured at the same depths as mentioned previously with determining the dose points at OAD = 0, ±2.5 and ±7 cm on the measured scanned profiles. Similarly, the results coded from 1 to 8.

2.4.8. Test case (8). Oblique incidence of open square field size

This test aimed to check the ability of the TPS to account for oblique incidence beam and skin contour variation. The photon beam of field size 10x10 cm^2 at FSD = 100 cm is adjusted with gantry angle = 45^o. The beam profiles were scanned at depths 1, 3, 5, 10, 15 and 20 cm, the dose was determined at OAD = 0, ±3 cm on each profile. The measurements at three OAD positions were coded from 1 to 6 for each depth.

2.4.9. Test case (9). Wedge output factors (WOF)

In this test, the wedge output factor (*WOF*) were measured and compared with the TPS calculations for square field sizes 5x5, 7x7,10x10, 12x12 and 15x15 cm^2 defined at FSD =100 cm and the ionization chamber located at the reference depth = 10 cm. The *WOF* is determined as:

$$WOF = D_{in} / D_{out} \qquad (1)$$

Where, D_{in} and D_{out} are the measured or calculated dose when the wedge is in and out of the beam path, respectively.

2.4.10. Test case (10). Small wedged square field sizes

The profiles of the wedged field sizes 4x4 and 5x5 cm^2 at depths 1, z_{max}, 3, 5, 10, 15, 20, 25 and 30 cm were measured, The dose was determined at the off-axis distance (OAD) = 0, ±1 and ±5 cm on the measured scanned profiles.

2.4.11. Test case (11). Medium wedged square field sizes

Repeating the test case (10), for field size 10x10 cm^2 at the same depths with assigning the dose at OAD = 0, ±3 and ±9 cm on the measured scanned profiles.

2.4.12. Test case (12). Large wedged square field size:

Repeating the test case (10), for field size changed to 25x25 cm^2 at the same depths with assigning the dose at OAD = 0, ±9 and ±19 cm on the measured scanned profiles. Comparisons were made between calculated (D_{calc})and measured (D_{meas}) dose values, for each of the twelve test cases for the 2D treatment planning system (ROCS). Calculations were performed at depths from 1 to 30 cm on the beam central axis, off-axis distances, outside the field sizes and for the penumbra regions. The criteria for acceptability proposed by Venselaar, et al. (2001)[49], provides the difference between calculated and measured dose values as a percentage of the dose measured locally as follows:

$$\delta_1 = 100 \text{ X} \left(\frac{D_{calc} - D_{meas}}{D_{meas}} \right) \% \qquad (2)$$

Where, δ_1 is the percentage standard deviation; D_{calc} and D_{meas} are the calculated and measured dose at a particular point in the phantom respectively.

In the cases where dose points corresponded to low dose region, the results of the comparison were expressed relative to the central axis of the open beam ($D_{meas,cax}$) where:

$$\delta_2 = 100 \text{ X} \left(\frac{D_{calc} - D_{meas}}{D_{meas,\,cax}} \right) \% \qquad (3)$$

The recommended equations for comparison of **TPS** calculation and measured data and sample criteria are given in Table (I). It is noted in the previous steps of measurements, that there is a repetition of mentioning the location of the measurement points and comparing them to the TPS calculations at concerning positions, and this to confirm the accuracy of the measurements for each case and consider these steps as an accurate protocol to determine the uncertainty factor.

IAEA TEC-DOCs 1540 and 1583 [42,43], representing the relative error of each test within the range $-3.25 \leq \delta \leq 3.25$ divided to intervals of value 0.5%. According to the mentioned evaluation method, some tests showed no variation. This study suggested a simple way to demonstrate the number of the relative error (δ) incident, called Data Code no., versus their values.

Table (1). Sample criteria of acceptability for external beam **TPS** calculations.

Description	**Equation for evaluation**	**Tolerance [%]**
Output factors at the reference point	Eq. (2)	2 %
Homogeneous, simple geometry, Central axis data of square and rectangular fields	Eq. (2)	2 %
Off-axis data	Eq. (3)	3%
Complex geometry (Wedged fields, inhomogeneities, irregular fields, asymmetric collimator setting) Central and off-axis data	Eq. (2)	3%
Outside beam edges		
In simple geometry	Eq. (3)	3%
In complex geometry	Eq. (3)	4%
Radiological field width 50%- 50% distance		2mm
Beam fringe/penumbra (50% - 90%) distance		2mm

For comparison of large numbers of data points, it is useful to apply a quantity that combines the influence of systematic and random deviations. Venselaar, et al. (2001)[49], recommended to calculate the quantity confidence limit Δ for this purpose, rather than to use the criterion δ for each point separately. Δ is defined as the sum of the average deviation between calculation and measurement and 1.5 x the standard deviation (SD) in this difference as following:

$$\boldsymbol{\Delta} = |\text{ average deviation }| + 1.5 \times \textbf{SD} \tag{4}$$

Venselaar, and Welleweerd, (2001)[50], suppose that for many test situations with open beams the confidence limit Δ should not exceed a tolerance of 3%, but in more complex cases, a larger value of tolerance was justifiable taken in account the other dosimetric uncertainty.[51]

3. Method Methodology

As mentioned in ESTRO booklet no.7 (2004)[31] and IAEA TRS 430 (2004)[36], where the evaluation of TPS performance is the responsibility of the medical physicist and he should choose the suitable methods to evaluate the TPS on the bases of appropriate uncertainties. So, in our work, another point of view had been suggested to check the accuracy of the proposed evaluation presentations of the IAEA TEC-DOCs [42,43] by focusing more on the relative errors with values approximately zero. This is represented by taking a relation between Data Entry Code Number (the tested field sizes) as X-axis and Relative Error as the Y-axis.

3.1. Percentage Depth Dose:

Figures 2 (a, b) show the histogram of the PDD of the deviation (δ_1) frequency for the tested open square field sizes at photon energies, 6 and 10 MV, respectively. From the histogram it is clear that $-0.5\% \leq \delta_1 \leq 0.5\%$ for 6MV and $\delta_1 \approx 0\%$ for 10 MV. The δ_1 values at both photon energies are within the tolerance criteria ($\delta_1 \leq \pm 2\%$). Using the suggested method as in Figures 2 (c, d), which show the relative errors as a function of the data entry code number. The deviation (δ_1) of the PDD values is $-0.34\% \leq \delta_1 \leq 0.31\%$ and $-0.07\% \leq \delta_1 \leq 0.1\%$ for photon beam energies 6 MV and 10 MV respectively.

This range is less than the presented range described by the figure (2a,b), that based on IAEA TEC-DOCs [42,43]. Linear fitting of δ_1 values versus data code numbers (13-18) and (16-18) calculated for 6 MV and 10 MV, respectively. Figure (2c) demonstrate that the relative error δ_1 values decrease with slope = -0.075 %, where $0 \geq \delta_1 \geq -0.35\%$ for 6 MV. Also, the relative error δ_1 values decrease with slope = -0.05%, where $0.03 \geq \delta_1 \geq -0.07\%$ as shown in Figure (2d). So, the treatment planning system will underestimate the PDD for large field sizes of both photon energies. This negative value means that the calculated value is less than the measured one which leads to under estimated dose. From this notice there is over dose is delivered to the patient at large fields and exceeds as depths increases.

3.2. Relative Output Factor ($\boldsymbol{S_{c,p}}$):

The deviations of the output factors between the TPS calculation and measurement of the open square field sizes are represented by Figures 3 (a, b) for 6 MV and 10 MV respectively. Wherefrom the figure, it is noticed that the deviation (δ_1) is varying as $-1.04\% \leq \delta_1 \leq 1.31\%$ for 6 MV and $-1.26\% \leq \delta_1 \leq 0.89\%$ for 10MV.

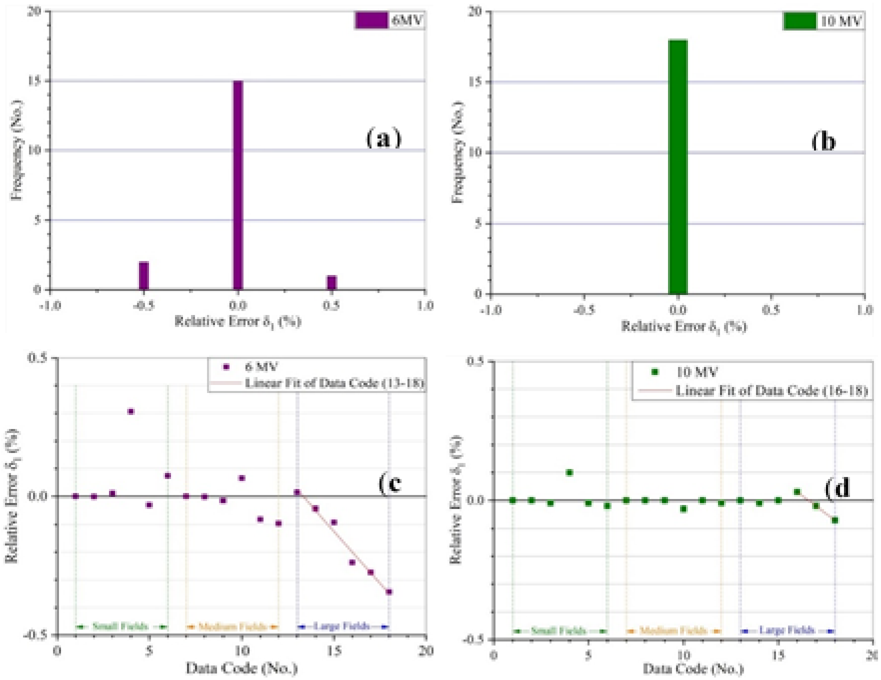

Fig. 2. The relative error [%] of the percentage depth dose for the tested square field sizes 5 X 5 cm^2, 10 X 10 cm^2 and 25 X 25 cm^2, for photon energy 6 and 10 MV respectively, represented against: (**a** and **b**) the frequency incident number, **TEC-DOC 1583** (**2008**), and (**c** and **d**) the data entry code number.

The data are displayed using suggested method and linearly fitted as illustrated in Figures 3 (c and d) for 6 and 10 MV where $1.31\% \geq \delta_1 \geq -0.985\%$, with slope = -0.24% and $0.89\% \geq \delta_1 \geq -1.062\%$ with slope -0.22% for 6 and 10 MV, respectively. δ_1 values of output factor return to increase from medium to large field sizes as $-1.044\% \leq \delta_1 \leq -0.19\%$, with slope = 0.159%, and $-1.062\% \leq \delta_1 \leq -0.53\%$, with slope = 0.181% for 6 and 10 MV, respectively. The interpretation of the output factor data indicates that TPS dose calculations will be underestimated for medium field sizes and the patient will receives higher doses than prescribed one.

3.3. Open Square Field Sizes:

The Excel worksheets that provided with IAEA TEC DOCs 1540 (2007) [42] and 1583 (2008) [43], facilitate the evaluation of the relative error between TPS calculated and measured (small, medium and large) field sizes by representing the deviation data of the tests (3), (4) and (5) as one statistical population group according to equation (3). Figures 4 (a and b) show the number of frequency incidences of the relative error (δ_1) between the TPS calculations and measurements of the whole tested open square field sizes profiles for both photon beam energies 6 and 10 MV, respectively. These figures show excellent values of (δ_1) ≈ 0%, which reflects the coincidence between the TPS calculated and measured profiles in the regions of the low gradient dose (flat portion of the profiles). By focusing more on the previous data from figures (4- c and d), it can be seen that the relative errors (δ_1) are not zero but varying as $-0.1\% \leq \boldsymbol{\delta_1} \leq +0.1\%$ which insure the coincidence between the TPS calculated data and the measurements and are within tolerance criteria.

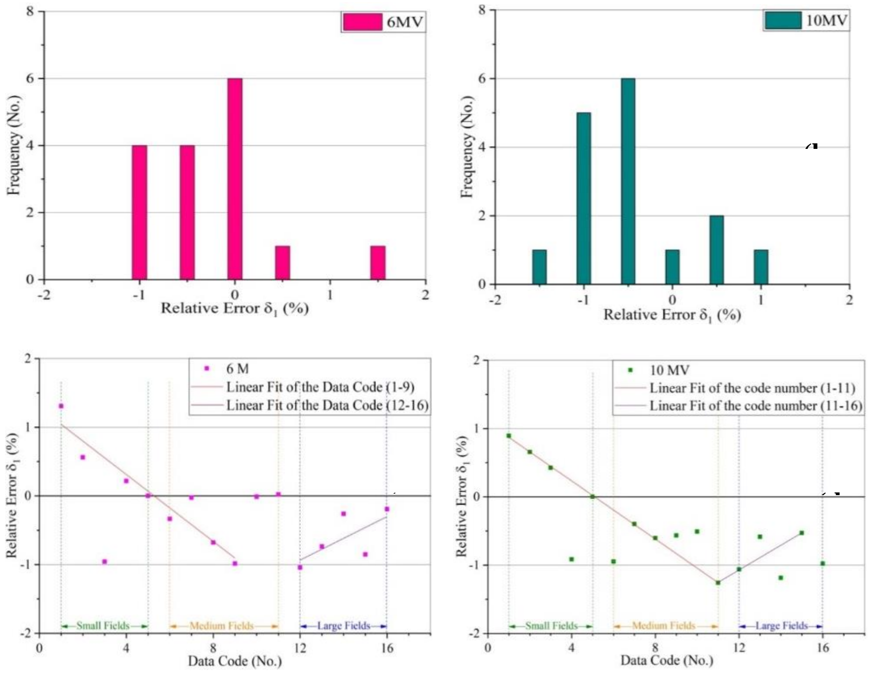

Fig. 3. The frequency of the relative error [%] between the calculated and measured output factors of the tested square field sizes for photon energies 6 amd 10 MV , represented against: (**a** and **b**) the frequency incident number, **TEC-DOC 1583** (**2008**), and (**c** and **d**) the data entry code number.

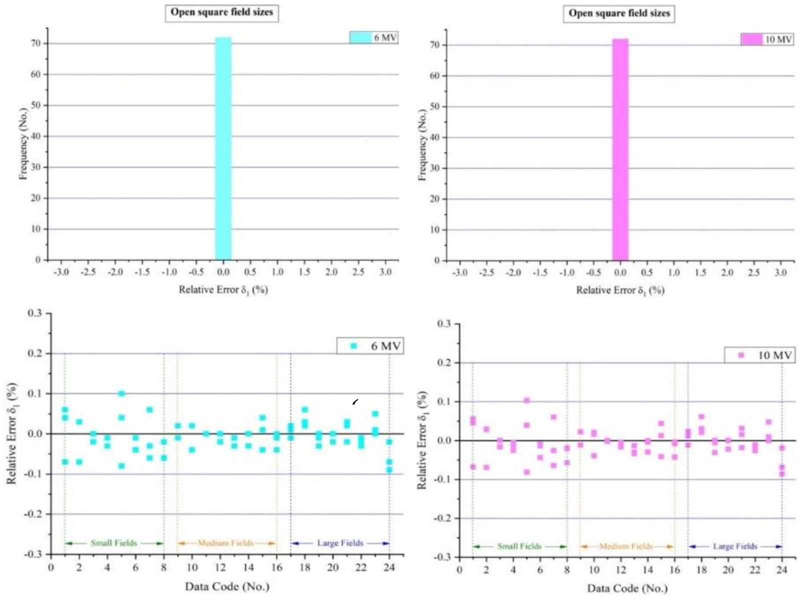

Fig. 4. The relative error [%] between the calculated and measured profiles of the tested square field sizes for photon energies 6 and 10 MV, represnted against:(**a** and **b**) the frequency incident number, **TEC-DOC 1540** (**2007**), and (**c** and **d**) the data entry code number.

Figures 5 (a, b) shows the number of frequency incidences of relative error (δ_2) between TPS calculated and measured off-axis ratio (OAR) values for whole open square field sizes for both photon beam energies respectively where $-0.5\% \leq \delta_2 \leq 0.5\%$ for 6MV, while for 10 MV (δ_2) $\approx 0\%$. Using the suggested method with the same manner as discussed previously, the relative errors are ranging as -0.66% $\leq \delta_2$ $\leq$0.28% for the small field size (data entry code numbers from 1-6) as in figure (5c). Also relative error (δ_2) was -0.23% $\leq \delta_2 \leq$0.14% (data entry code numbers from 7-12) for the medium field size and for the large field size for 6MV as -0.29% $\leq \delta_2 \leq$-0.06% concerning data entry code numbers from 12 to 18.

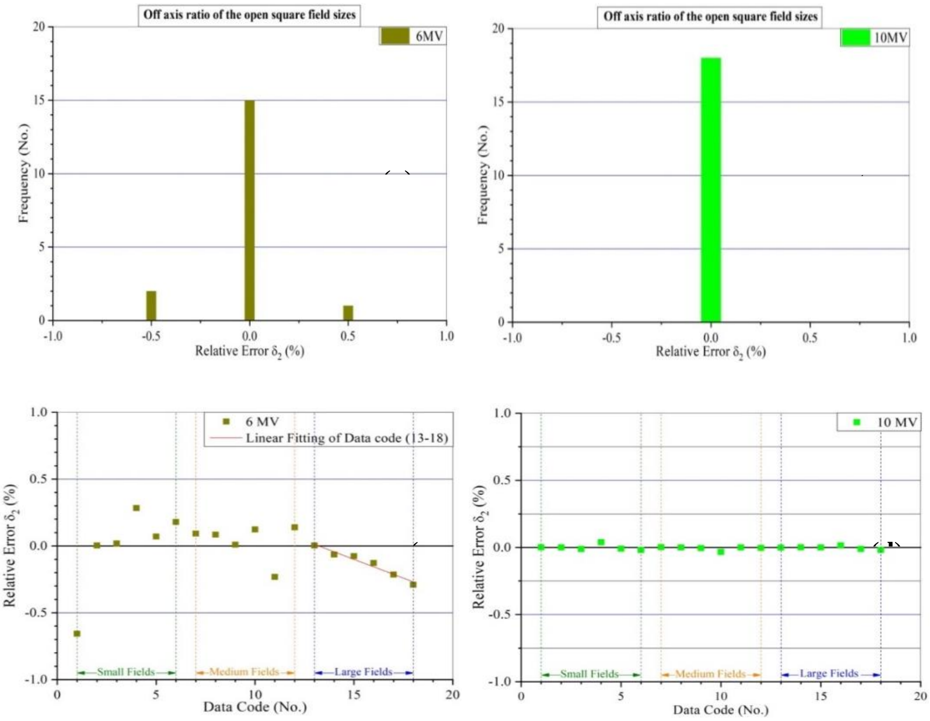

Fig. 5 . The relative error [%] between the calculated and measured off axis ratio values (**OAR**) of the tested square field sizes for photon energies 6 and 10 MV, represnted against: (**a** and **b**)mthe frequency incident number, **TEC-DOC 1583** (**2008**), and (**c** and **d**) the data entry code number.

It is easy to note that the tested TPS calculations are overestimating the dose than the measurements except for the large field size, where the dose calculations are underestimated, and for the small field size at the maximum depth (z_{max}) for photon energy 6 MV. For photon energy 10 MV, Figure 5 (d) shows that δ_2 values are varying as -0.03% $\leq \delta_2 \leq$ 0.04%, note that not all the data equal to zero and very small compared with the tolerance criteria (±3%). Figures (6-a and b), show that the deviation (δ_2) between the TPS calculations and measurements at outside the whole open square field sizes dose values are varying as -0.5% $\leq \delta_2 \leq$ 0% for 6 MV and δ_2 = 0% for 10 MV and their values are accepted according to tolerance criteria that equal to ±3%. Again, Figures 6 (c and d) give another impression when (δ_2) values are drawn versus data entry code numbers for photon energy 6 MV and 10MV. Figure 6 (c) shows that the relative errors are varying as -0.41% $\leq \delta_2 \leq$ -0.03% except for data entry code numbers 4 and 6 that related to the small field size at depths 15 and 30 cm with (δ_2) values equal to 0.15% and 0.21%, respectively, and data entry code number 10 that related to the medium field size at depths 15 with (δ_2) = 0.05%. Figure 6 (d) shows that (δ_2) values for photon energy 10MV are not exactly zero, where (δ_2) values are varying as -0.09% $\leq \delta_2 \leq$ 0%.

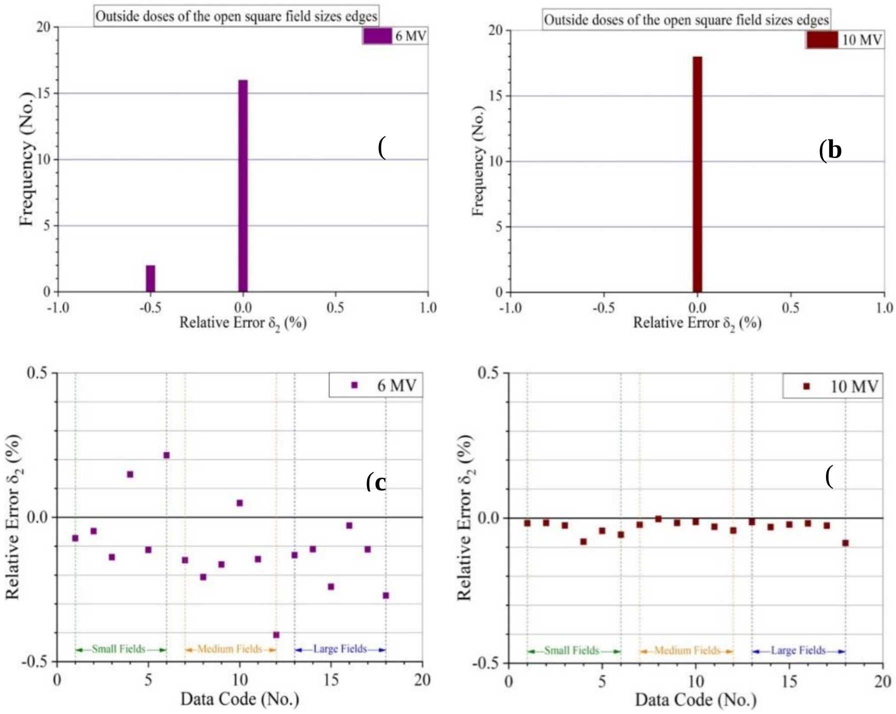

Fig. 6. The relative error [%] between the calculated and measured outside doses values of the tested square field sizes for photon energies 6 and 10 MV, represnted against: (**a** and **b**) the frequency incident number, **TEC-DOC 1583** (**2008**), and (**c** and **d**) the data entry code number.

Figures 7 (a and b), show the number of frequency incidences of the TPS calculated and measured radiological width $(RW)_{50}$ error values of the whole open square field sizes for both photon energies 6 and 10 MV respectively, where the radiological width $(RW)_{50}$ is the distance between the points 50% at the right and left edges of the profile, IAEA TRS 430 (2004) [36]. The $(RW)_{50}$ error values are ranging between -2.5 mm and 2.5 mm. These values are out of tolerance criteria which is equal to ± 2 mm. This is because the used treatment planning system is provided with two dimensions algorithm only and most of the scattering radiations in the third dimension are not well estimated in the dose profiles TPS calculations. Figures 8 (a and b) showed the number of the frequent incidences of the TPS calculated and measured penumbra error values of the whole tested open square field sizes, where the figures illustrate that the penumbra errors are ranging from -2 mm to +2 mm for both photon beam energies 6 and 10 MV. These values of the penumbra errors are accepted by the tolerance criteria, which are ± 2 mm.

3.4. Open rectangular field sizes

In test case (6) the deviation (δ_1) are varying as $-1\% \leq \delta_1 \leq 1\%$ for 6MV and (δ_1) ≈ 0% for 10 MV as shown in Figures 9 (a and b). All of the test points satisfy the tolerance level of ±3%. By using our suggested method, we can focus more on the (δ_1) data by representing the relative error (δ_1) against the data entry code numbers. For photon beam energy 6 MV, Figure 9 (c) shows that the relative error (δ_1) values tending toward the negative direction with the increasing of the data entry code numbers from 1 to 8, where $-0.71\% \leq \delta_1 \leq 0\%$, which indicate that the TPS calculations underestimate the dose at all depths for field size 5 X 25 cm^2.

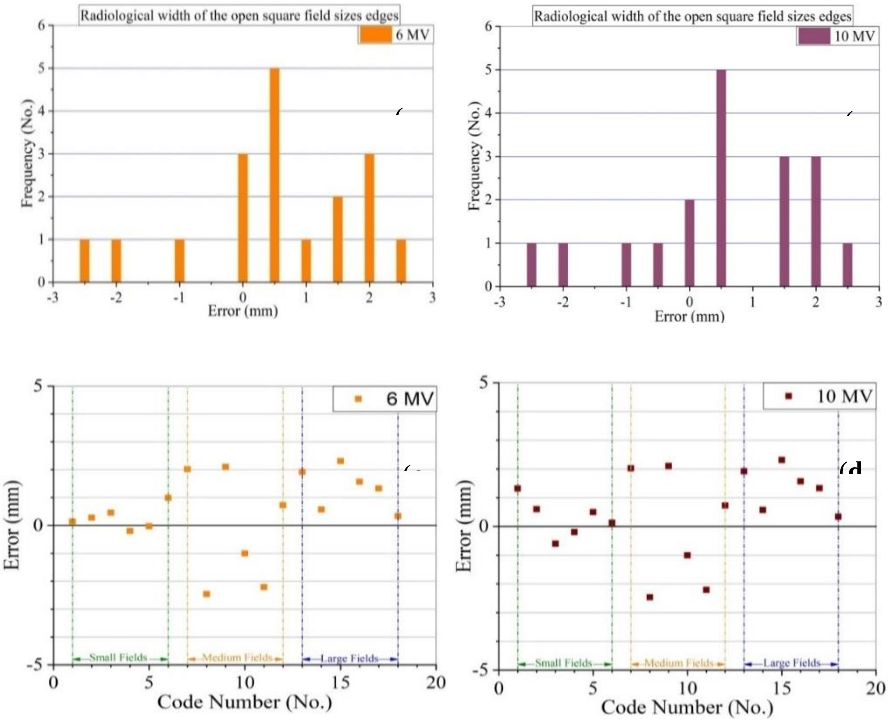

Fig. 7. The frequency of the errors between TPS calculated and measured radiological width values of the tested square field sizes for photon energy 6and 10 MV. represnted against: (a and b) the frequency incident number, TEC-DOC 1583 (2008), and (c and d) the data entry code number.

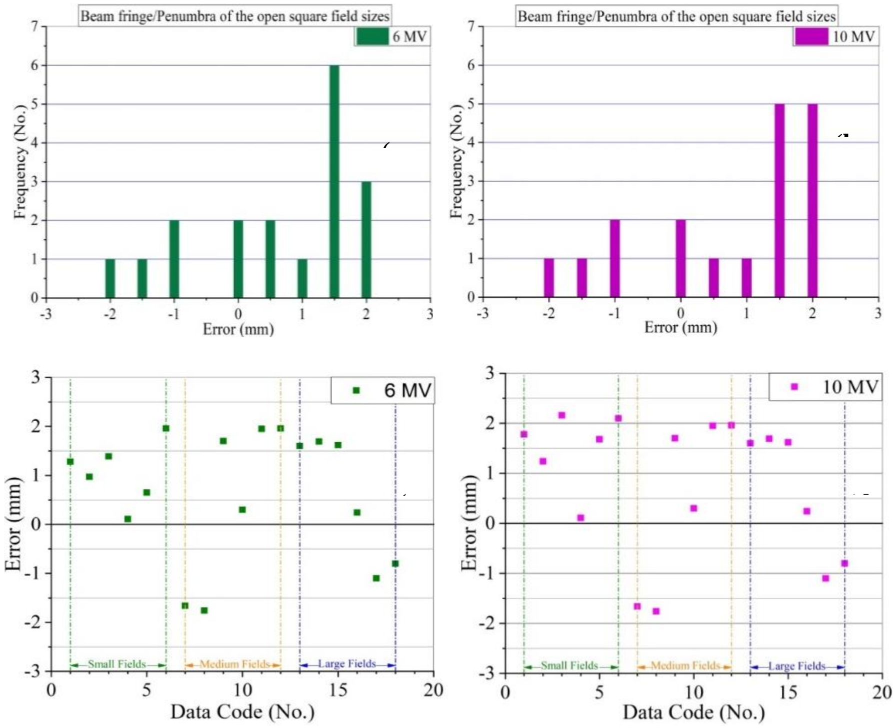

Fig. 8. The frequency of the errors between **TPS** calculated and measured beam fringe or penumbra values of the tested square field sizes for photon energies 6 and 10 MV, represnted against: (**a** and **b**) the frequency incident number, **TEC-DOC 1583** (**2008**), and (**c** and **d**) the data entry code number.

Also, the relative error (δ_1) values tending toward the positive direction with the data entry code numbers increase from 9 to 16, where $-0.75\% \leq \delta_1 \leq 0.64\%$, which indicates that the TPS calculations overestimate the dose at most of the depths for field size 25 X 5 cm^2. For photon beam energy 10 MV, the deviation of the relative error (δ_1) values away from the zero value is decreased. Figure 9 (d) shows that $0.11\% \leq \delta_1 \leq 0.01\%$ at the data code number region from 1 to 8 and $-0.05\% \leq \delta_1 \leq 0.06\%$ at the data code number region from 9 to 16. The decrease in the deviation of (δ_1) values away from the zero value of the photon energy 10 MV is more than those for 6 MV which is due to the more decrease of the lateral scatter component for 10MV than for 6 MV.

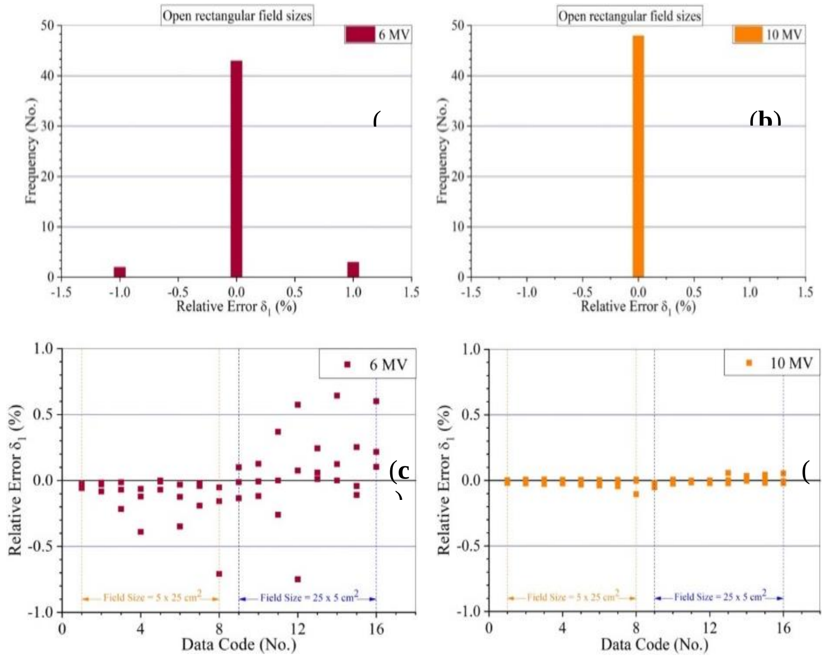

Fig. 9. The relative error [%] between the calculated and measured profiles of the tested rectangular field sizes for photon energies 6 and 10 MV, represnted against: (**a** and **b**) the frequency incident number, TEC-DOC 1540 (2007), and (**c** and **d**) the data entry code number.

3.5. Isocentric open square field size

The deviation of (**δ_1**) of the **TPS** calculations from the measurements in isocentric conditions was investigated and all the obtained data, Figures 10 (a and b) shows that the TPS calculations are in coincidence with the measurements (δ_1) $\approx 0\%$. By changing the presentation of the collected data of (δ_1) for the isocentric field size versus the data entry code number as shown in Figures 10 (c and d) for photon energies 6MV and 10 MV respectively. It is clear that the values are not exactly zero but ranging as $-0.1\% \leq \delta_1 \leq 0.15\%$ for 6MV and $-0.04\% \leq \delta_1 \leq 0.02\%$ for 10 MV.

3.6. Oblique incidence of open square field size:

Also, the oblique beam incidence was investigated; for photon beam energy 6MV, Figure (11a) illustrates that -1% ≤ δ_1 ≤ 1%, but most of (δ_1) values are equal to zero. By using our proposed method, Figure 11 (c) shows that the relative error (δ_1) values are scattered around the zero value. Where 50% of the data are lying in the range -0.4% ≤ δ_1 ≤ 0.4%, 22.2% of the data are ranging as 0.4% ≤ δ_1 ≤ 1% and 27.8% of the data are in the range -1% ≤ δ_1 ≤ -0.4%. For photon beam energy 10MV, Figure 11 (b) shows that (δ_1) = 0%, which reflecting the coincidence between the TPS calculated data and measured open oblique field size dose profiles in the regions of the low gradient dose and the TPS data gives a good prediction of the oblique incident beams. For photon beam energy 10MV, Figure 11 (b) shows that (δ_1) = 0%, which reflecting the coincidence between the TPS calculated data and measured open oblique field size dose profiles in the regions of the low gradient dose and the TPS data gives a good prediction of the oblique incident beams. But Figure 11(d) illustrates that the relative error (δ_1) of the oblique field size is not exactly zero for photon beam energy 10MV and varying as -0.1% ≤ δ_1 ≤ 0.08%.

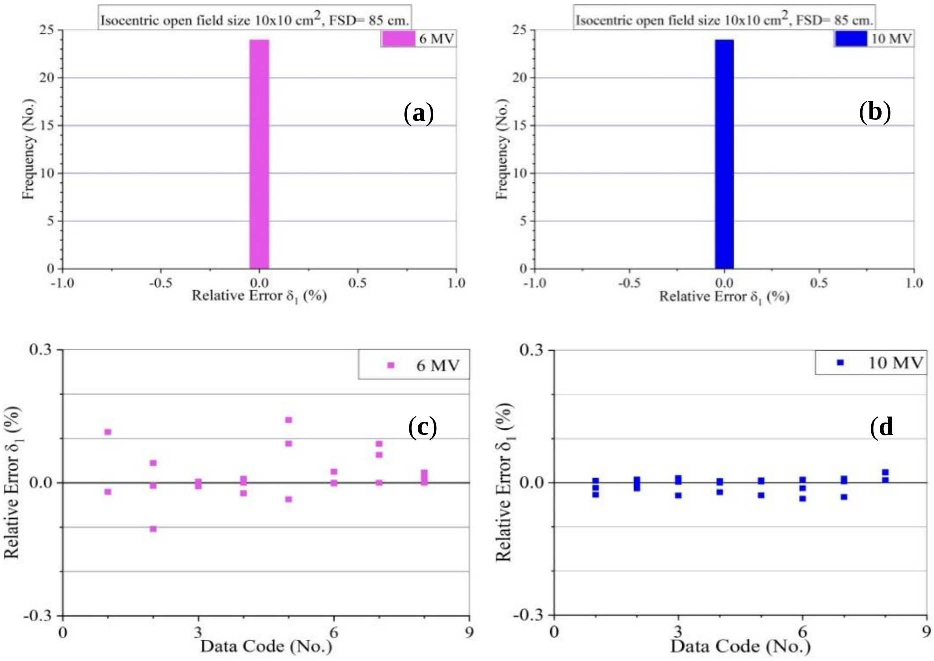

Fig. 10. The relative error [%] between the calculated and measured profiles of the tested isocentric field size for photon energies 6 and 10 MV, represnted against: (a and b) the frequency incident number, TEC-DOC 1540 (2007), and (c and d) the data entry code number.

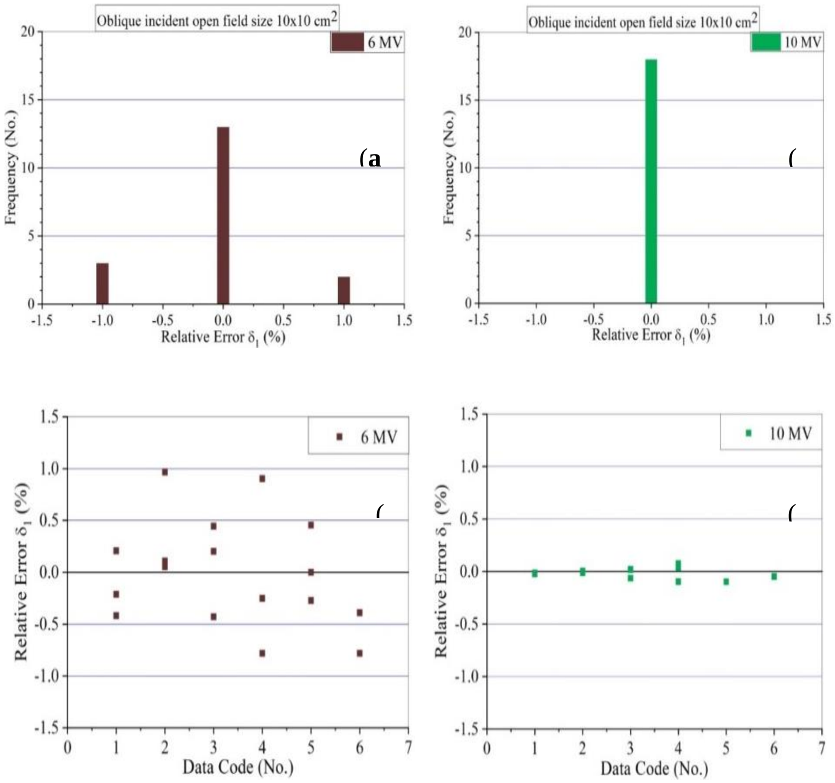

Fig. 11. The relative error [%] between the calculated and measured profiles of the tested oblique incident field size for photon energies 6 and 10 MV, represnted against: (**a** and **b**) the frequency incident number, **TEC-DOC 1540 (2007)**, and (**c** and **d**) the data entry code number.

3.7. Wedge output factors (WOF):

The error of wedge output factors (δ_{WOF}) between the TPS calculations $(WOF)^{calculated}$ and measurements $(WOF)^{measured}$ was investigated. (δ_{WOF}) was varying as $-1 \leq (\delta_{WOF}) \leq 0.5$ for 6MV and $-0.5 \leq (\delta_{WOF}) \leq 0.5$ for 10 MV, as illustrated in Figure 12 (a and b). The deviation factors (δ_{WOF}) for both photon beam energies 6 and 10 MV are within the tolerance range $(\delta_{WOF}) \leq \pm 3\%$ proposed by IAEA TEC-DOC 1583 (2008) [43].

3.8. Wedged square field sizes (small, medium and large):

The (PDD), (OAR) and the outside doses values of the wedged square field sizes were investigated. All the obtained results of the TPS calculations at the specified points are coincidence with relevant measurements.

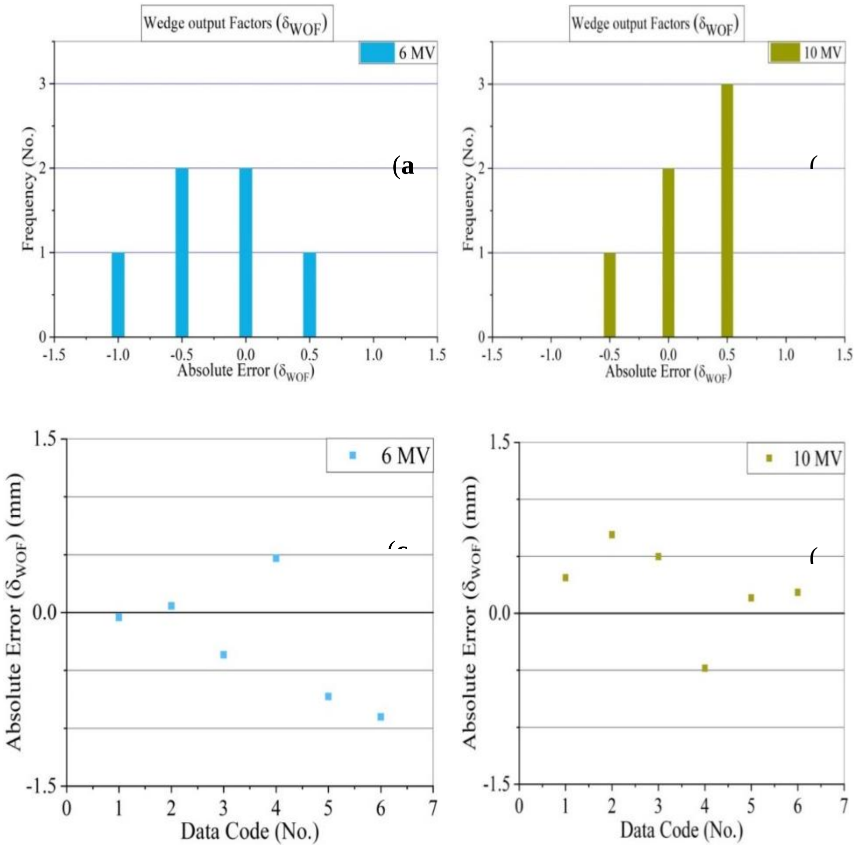

Fig. 12. The frequency of the absolute error (δ_{WOF}) between the calculated and measured output factors of the tested wedged field sizes (**WOF**), for photon energies 6 and 10 MV, represnted against: (**a** and **b**) the frequency incident number, **TEC-DOC 1540 (2007)**, and (**c** and **d**) the data entry code number.

4. Conclusion

The use of the test cases proposed by **IAEA TECDOC**s **1540** and **1583**[42-43] were useful and sufficient for the quality assurance and accuracy verification of the treatment planning systems in the centers of limited resources and patients busy that may exist in the developing countries. In summary, observed deviations between **TPS** calculated and measured dose are well within the set tolerance levels mentioned by **IAEA TECDOC**s **1540** and **1583**. For penumbra regions and radiological widths for the test field sizes of both photon energies, 6 and 10 MV are exceeding the tolerance limits. This is because that the used treatment planning system is provided with two dimensions algorithm only and most of the scattering radiations in the third dimension are not well estimated in the dose profiles **TPS** calculations, so, care should be taken into account when using two adjacent beams in the treatment; they must be displaced away from each other by a distance equal to 2 mm. The suggested method by this study can more useful in the detection of errors that do not appear by using **IAEA TECDOC**s **1540** and **1583**. So, with the proposed display method together with the data generated from dose verification steps that recommended by the IAEA`s protocols, the medical physicist can provide safe radiotherapy service to the patient with acceptable and well evaluated accuracy by using primitive and conventional equipment.

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