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Original Article

Accuracy Evaluation of Treatment planning Dose Calculation for 6MV Photon Beam

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Abstract

This study's primary goal is to accomplish the accuracy of the algorithmic calculation of the collapsed cone photon dose in the treatment planning system (TPS) (Monaco). The work was done using doses of the linear accelerator for the Elekta Synergy Platform for 6 photon beams through the Yin chamber in the Water Ghost. Our results were compared with additional distributions from the planning system. Of great help in this study was our use of a 3D water phantom to measure the beam data, which yielded profiles (open square fields and notched fields), as well as percentage depth doses, and absolute doses, for the energy of beam 6 MeV photon beams produced by an Elekta Synergy Platform (linac) linear accelerator. The field sizes were 5X5 cm^2, 10X10 cm^2, 15X15 cm^2, and 20X20 cm^2, with corresponding depths of 5 cm, 10 cm and 20 cm. These measurements were obtained in water using ionization chambers. Lastly, the measured values were compared with the calculated dose and various conditions. that comparison, we discovered that there was great agreement between the measured and calculated output doses. Under all parameters of energy, SSD, and size of field, for both wedged and open fields, doses at depths below the maximum dosage calculated on-axis or off-axis in both the fields or penumbra region were found to be in agreement with the observed dose. The only case where estimated and measured doses accord (with a ≤3% difference) for photon 6 MV in the Central axis of beam data high dose gradient (&1) gradient. The deviations (&) of PPD curves show good agreement with the literature.

***Keywords**:* Treatment planning system, Quality assurance, Photon beam, Local dose deviation, Confidence limit.

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Introduction

Elekta (Elekta Oncology Systems, Crawley, UK) is the manufacturer of the Elekta Synergy accelerator. Hundreds of these accelerators are currently in clinical usage. Electron and photon beams can be delivered via the Elekta Synergy. The accelerator can be employed in 3D conformal and intensity modulation mode to irradiate exceedingly complex objects. International recommendations state that commissioning and acceptability testing must be completed prior to first clinical use. Afterwards, the quality control test needs to be run on a regular basis. The dosimetric and mechanical test findings for the Elekta Synergy accelerator installed in the Aswan Ongology Center in Egypt are presented in this paper. We have provided the systematic steps of the Elekta Synergy linear accelerator for photon beam only energies in our study (Alam et al., 1997).

1.2. Radiotherapy Treatment Planning Process

The one of the crucial phases in the radiation therapy procedure for patients is precisely calculating the dose between prescribing the dose to the clinical volume of target and administering the actual dose. To guarantee optimal treatment outcomes in radiation therapy, the most advanced tools and methods for treatment planning must be accessible. This involves actually purchasing and putting into practice a treatment planning system (TPS) that can compute absorbed dose distributions with a reasonable degree of accuracy, particularly in cases where tissue heterogeneities are present (Bakai and Nusslin 2003).

The actions involved in deciding how the radiation treatments will be administered are generally included in the treatment planning process. In this step, patient data acquisition, picture acquisition, beam information acquisition, image conversion into a suitable patient anatomical model, dose calculation (including dose algorithm selection and heterogeneity correction), and beam information acquisition are all covered. Planning documentation, implementation, verification, review, and send to planning data from TPS to the linac and patient record are all part of the process (Carrasco et al., 2007).

1.3 Quality Assurance (QA)

The International Standards Organization (ISO) defines quality assurance (QA) as any planned or systematic steps required to offer sufficient confidence that a good or service will meet specified quality requirements. In the field of radiation oncology, quality is specifically defined as the entirety of the elements or characteristics of the radiation oncology service that impact its capacity to meet the explicit or implicit objective of providing patients with effective therapy. Functional performance criteria are the main focus of continuous quality assurance (QA) for radiation treatment equipment. Data analysis, prospective research design, and patient care that is both safe and effective depend on quality assurance. (Depuydt et al., 2002).

2. Materials and methods

2.1 Materials

2.1.1 Treatment planning system (TPS)

The TPS used in the present work is the Monaco Planning System, the photon dose-calculation algorithm evaluated in the present study is the Collapse cone Algorithm, of the algorithms used to calculate photons supported in Elekta. The calculate doses for photon beams uses an irregular field algorithm that is based on data measures in phantom, for different field sizes and depths.

2.1.2 Medical linear accelerator (linac)

The Elektra Synergy Platform Linac with used in this work. It products two photons beam energies at 6MV and 10MV (Fraass et al., 1998).

2.1.3 Phantom

The blue water phantom is a measuring device for the analysis and measurement of the radiation field of liner accelerators and is part of the QA Accept system. It consists of a 3-D servo (the phantom tank with mechanics), a control unit with integrated two channel electrometer (CCU) and two ionization chambers (Mia et al., 2019).

2.1.4 The ionization chambers

Two the ionization chamber (CC13) is intended for absolute and relative dosimetry of photon n beams in radiotherapy. The chamber is waterproofed and utilized mostly to characterize the radiation beams of radiotherapy accelerators by relative measurements using an air scanner or water phantom. They are ideal for 3D dosimetry in a water phantom.

2.1.5 DOSE^2 Electrometer

The DOSE^2 used to measure the absolute dose (Harms et al., 1998).

2.2 Methods and tests data

Off axis beam profiles (OAR) and percentage depth dose (PDD), which are estimated in TPS and agree with linac readings, are referred to as relative dose calculation (RDC). Plotting OAR and PDD curves for the measured dose and estimated dosage, we measured two field sizes, 5x5 cm^2 to 20x20 cm^2, for two energies, 6MV and 10MV, at varied depths (dmax, 5, 10, and 20) cm, where dmax for the 6MV=1.6 cm and for the 10MV=2.2 cm. Plot the profile curves in OARs curves, then compute the standard deviation (SD) and mean deviation (MD). This is applicable to all of the regions (&1, &2, &3, &4) that are shown in the section after this one (Low and dempsey, 2003).

The following formula can be used to express differences between computation and measurement findings as a percentage of the locally measured dose:

$$\delta\% = \frac{D_{Calc} - D_{meas}}{D_{meas}} \times 100 \qquad (1)$$

Using the concept of The NCS (2021), it can be divided a photon beam into four regions with different tolerances for δ as follows (Mijnhee et al., 2004):

1- Low dose gradient area (δ1) is the region along the beam's central axis that is beyond the depth of dosage maximum.

2- Points in the buildup and penumbra region that are both on and off the central axis. points close to interfaces are also included in this region: high dose gradient area (δ2).

3- Low dose gradient areas (δ3) are located off the central axis but inside the beam (for example, within 80% of the geometrical beam).

4- Low dose gradient areas (δ4) are locations outside the geometrical beam where the dose is less than, say, 7% of the central axis dose at the same depth.

5- RW50(radiological width), is the difference between a profile's width at the beam axis and half its height.

6- $\delta_{50\text{-}90}$: the space between the penumbra's 50% and 90% points (with relation to the profile's maximum), which is sometimes called (beam fringe).

In low dosage zones, where dose estimations are naturally less precise, the final criterion, &4, is used. As a result, in certain situations, it is not helpful to correlate the value of the locally measured dosage with variations between computations and measurements. In those situations, an alternate method is to substitute equation (1) with:

$$\&_4\% = \frac{D_{Calc} - D_{meas}}{D_{meas,CAX}} \times 100 \qquad (2)$$

Where the dose measured at a location on the central axis of beam (Dmeas, CAX) at Similar depth as the point under investigation is related to the deviation for points out-side the beam. for example, when the dose is extremely low, can use the same strategy. Then, the dose measured at a point on the Open beam's central axis at the same depth may be connected to the deviation. In such an assessment, it is advised to incorporate both criterion δ4 values from equations (1) and (2). Occasionally, two additional values are suggested that are helpful for comparing isodose calculation and profile results, particularly when reproducing the fundamental beam data by the TPS. (NCS2021; Venselaar et al., 2001.)

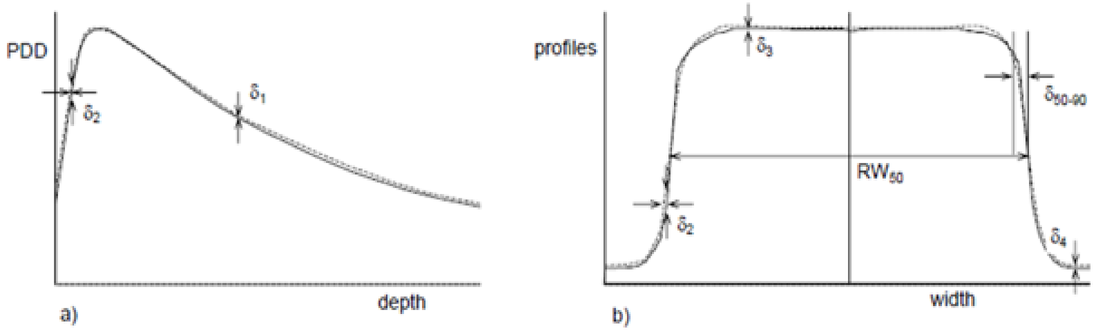

Fig. 1. Regions of validity of the criteria d1±d4, radiological width RW50, and beam fringe d 50±90 to compare calculated and measured depth-dose (PDD) curves (a) and beam profiles (b).

2.2.1 Criteria for acceptability and Suggested tolerances of dose calculations

Rather stringent requirements must be fulfilled when a TPS is to replicate (relative) dosage measurements at certain sites from the fundamental beam data set. Table 1's requirements are meant to be applied to all TPS model calculation that are commonly used in clinical practice. The suggested values for tolerances δ1–δ4 are separated based on how complex the test settings get. The two distinct degrees of geometric complexity are as follows (Sahool et al., 2012):

1. Simple, homogeneous geometry. For the purpose of calculating dosage levels in uniform phantoms for fields devoid of specialized accessories. These test scenarios cover several SSD configurations and rectangular field widths.
2. Intricate geometry (wedge). Greater tolerances are permitted when calculating doses for complex instances. Among these scenarios are beams with wedges (Venselaar et al., 2001; IAEA2004)

2.2.2 Suggested Tolerances for a Set of Numerous Data Points(Confidence Limit) :-

Some of the data points may surpass the accuracy criterion in a study that evaluates a large number of data points from comparable scenarios, but the total outcome may still be highly excellent. If several similar points fall well inside the criterion, then a single point that surpasses the requirement need not result in a poor overall score. There are instances where a substantial amount of data points like complete PDD curves or depth profiles are accessible and must be assessed. Reporting the outcomes of a lengthy test method with lots of data points is also not always an easy chore. To support the final conclusions, it is necessary to compare several test scenarios, which calls for the application of statistical methodologies. As a result, the amount confidence limit was developed as a method of assessment in these circumstances (Van Dyk et al., 1993; Van Bree et al., 1991).

Table1: Proposed values of the tolerances for δ for application in different test configurations

	Region	Homogeneous , simple geometry (open fields)	Complex geometry (wedge fields)
$\&_1$	Central beam axis data high dose, low dose gradient	2%	3%
$\&^*_2$	Build up region of central axis beam, penumbra region of the profiles high dose, high dose gradient	2mm or 10%	3mm or 15%
$\&_3$	Outside central beam axis region high dose, low dose gradient	3%	3%
$\&_4^{**}$	Outside beam edges low dose, low dose gradient	30 %(3%)	4% (40%)
RW_{50}^{***}	Radiological width high dose, high dose gradient	2mm or 1%	2mm or 1%
δ_{50-90}	Beam fringe high dose high dose gradient.	2mm	3mm

Note:
* One of the two tolerance values should be used
** These figures are normalized to the local dose, or at the dose at a point at same depth on the central beam axis
*** The percent figure should be used for field sizes larger than 20 cm
****More complex geometry is defined as a combination of at least two complex geometries

The standard deviation (1SD) of the difference and the mean deviation between measurement and calculation for several data points under similar circumstances are used to calculate the confidence limit. The definition of the confidence-limit Δ is:

$$\Delta = |\text{mean deviation}| + 1.5 \times SD \quad (3)$$

A factor of 1.5 is advised in its place, as it is associated with a Probability of one-sided confidence of P=o.o65. Although it was selected quite randomly, factor 1.5 has worked well for this reason in clinical practice. In equation (3), a factor larger than 1.5 would have highlighted the random mistakes, but a factor smaller than 1.5 would have increased the systematic deviations' relative relevance (Starkschall, 2000; Sandilos et al., 2005).
Selecting a sufficient number of data points is important in order to draw conclusions that are statistically meaningful. Sometimes combining data from various beam qualities and field sizes will be necessary for that reason. For the sake of a particular study, points must be representative; that is, they must only contain points that are fully inside the beam and omit points that are in the build_up area or the penumbra1. (Venselaar et al., 2001).

2.2.3 Data of Depth dose

Open beam depth dosage information along the square field sizes' central axis of: 5x5, 10x10, 15x15 and 20x20 (cmxcm) for depths dmax , 5 ,10, 20 cm were measured.

2.2.4 Open field's data

For each of the aforementioned square fields, four open beam pr0files at depths dmax, d5 cm, d10 cm and d20 cm were acquired (Özgüvena et al., 2014).

2.2.5 Wedge fields data

Data of Depth dose and 4 profiles- beam for square field sizes of 5x5, 10x10, 15x15,and 20x20 (cmxcm) were used for wedge of 60° nominal angle. When comparing the computed wedge beam profiles at depths of 5 cm, 10 cm, and 20 cm with corresponding observed values, the disparities between the calculated and measured beam data were compared and evaluated. were conducted based on Mott and West (2003).

3. Results and Discussion

3.1 Results

3.1.1 Open field's data

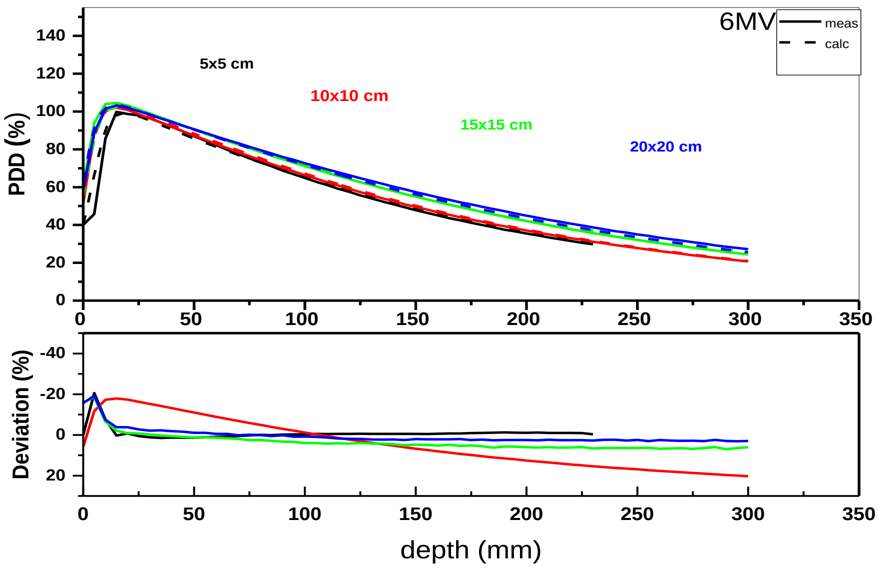

Fig .2 PDD-curves for 6 MV photon beams (open fields).

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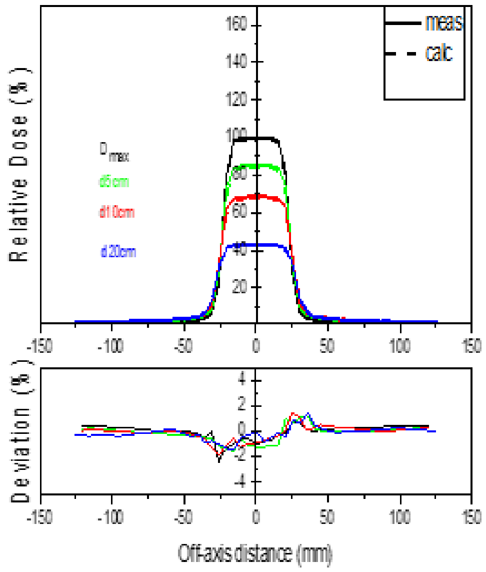
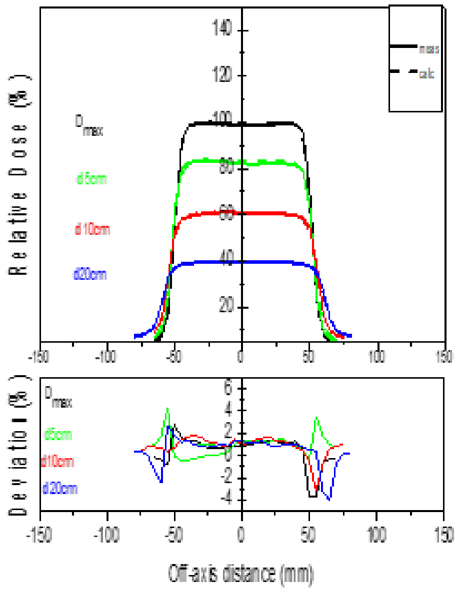
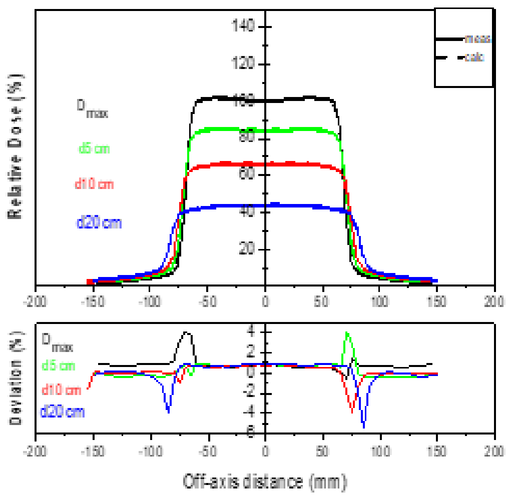
a- 6 MV measured and calculated RELs for field size 5×5 Cm^2 at different depths and the deviation.



b- 6 MV measured and calculated RELs for field size 10x10 Cm^2 at different depths and the deviation.



c- 6 MV measured and calculated RELs for field size 15×15 Cm^2 at different depths and the deviation.



d -6 MV measured and calculated RELs for field size 20x20 Cm^2 at different depths and the deviation

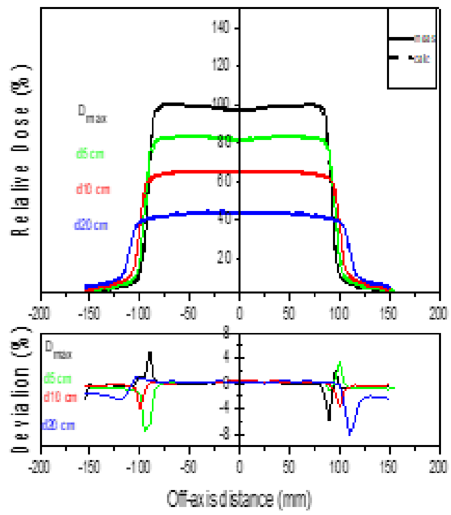


Fig .3 Relative Open fields curves for 6 MV photon beams

Table 2: The analysis of PDDs and RELs for 6 MV open fields

Description of geometry	Deviation (δ)	Mean deviation	Standard deviation	Confidence limit	Tolerance
Open fields	**δ1**	0.314%	2.302%	3.768	2%
Open fields	**δ2**	-0.228mm	0.818mm	1.455mm	2mm
Open fields	**δ3**	0.288%	0.797%	1.484%	3%
Open fields	**δ4**	-0.325%	0.797%	1.527%	3%
Open fields	**RW50**	0.063mm	0.432mm	0.711mm	2mm
Open fields	**δ50-90**	-0.430mm	2.22mm	3.762mm	2mm

In the test of open square fields, the TPS computations show a mean deviation of -0.32% and high agreement with the measured data. The largest deviation, or |d|max, was 0.28%, and all test points fell within the 2% tolerance level that is advised. Furthermore, since the TPS- tends to underestimate dosage in very large fields, data clearly show that variances become persistently negative as field size increases (Venselaara and Welleweerd, 2001; Wu, 2002).

3.1.2 Wedge fields data

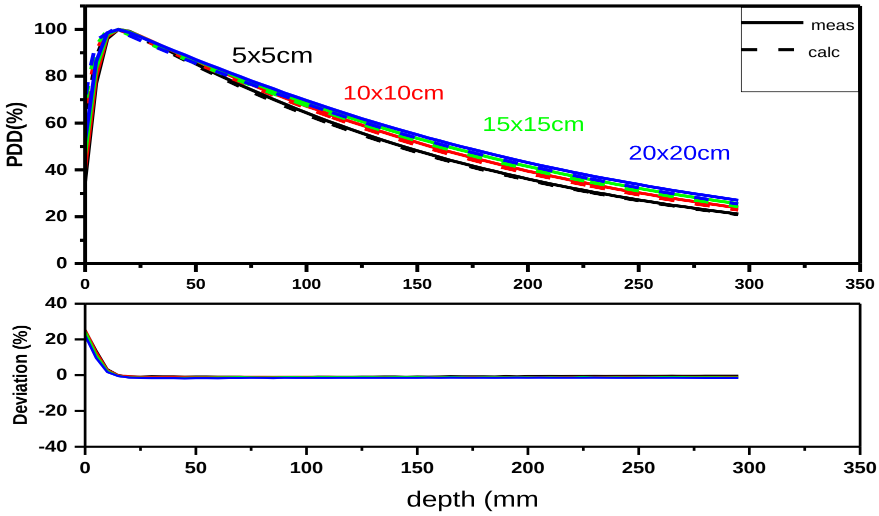


Fig .4 PDD- curves for 6 MV photon beams (wedge fields).

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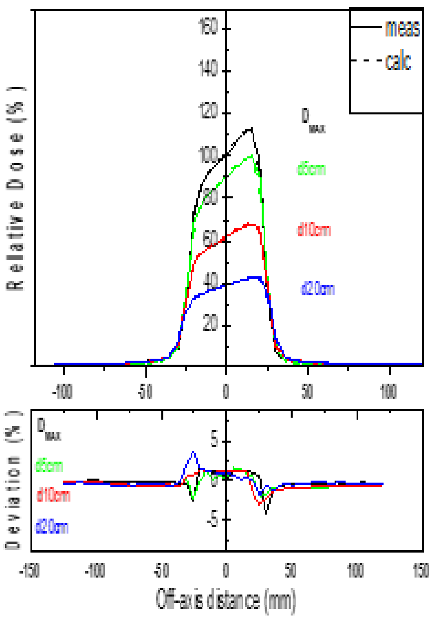
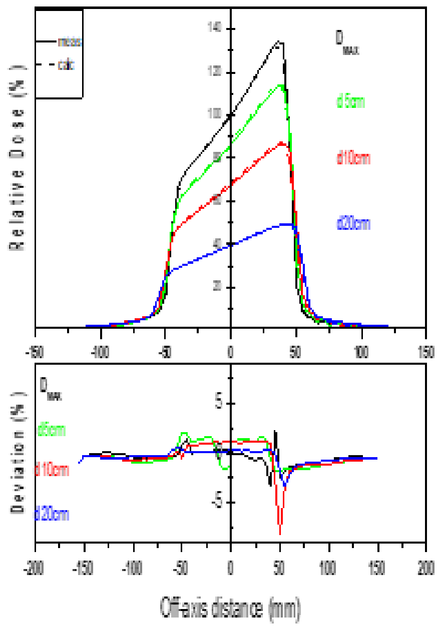
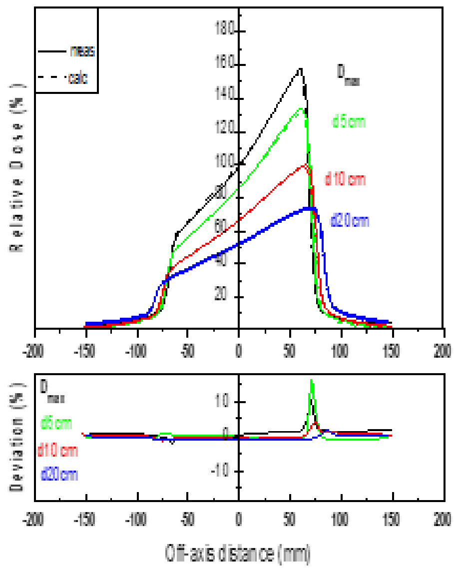
a -6 MV measured and calculated RELs. For wedge field size 5×5 Cm² at different depths and the deviation.



b -6 MV measured and calculated RELs for wedge field size 10x10 Cm² at different depths and the deviation.



c -6 MV measured and calculated RELs for wedge field size 15×15 Cm² at different depths and the deviation.



d-6 MV measured and calculated RELs for wedge field size 20x20 Cm² at different depths and the deviation

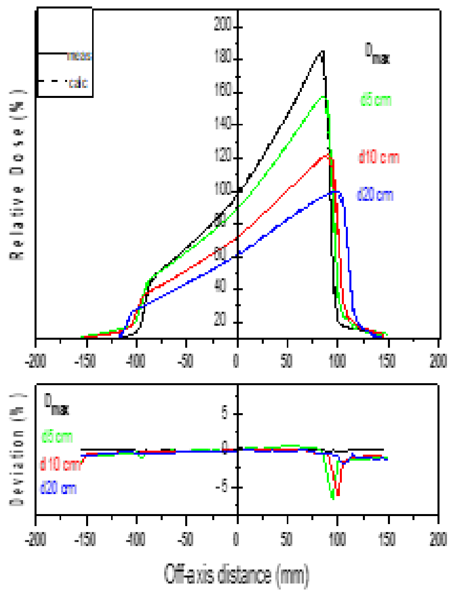


Fig .5 WEDGE fields curves for 6 MV photon beams

Table 3: The analysis of PDDs and RELs for 6 MV wedged fields

Description of geometry	Deviation (δ)	Mean deviation	Standard deviation	Confidence limit	Tolerance
Wedged fields	δ1	-2.278 %	1.091 %	3.915 %	3%
Wedged fields	δ2	0.19mm	0.452mm	0.697mm	3mm
Wedged fields	δ3	0.490 %	0.965 %	1.934 %	3%
Wedged fields	δ4	0.79 %	0.545 %	1.060 %	4%

In wedge square fields test: the accuracy of TPS-calculations was checked for a 60° wedged field. The mean deviation of -2.27% and max deviations of 0.49 %, respectively, while the tolerance level = 3%.

3.2 Discussion

This study set out to evaluate a commercial system of treatment planning diametric performance. The published guidelines for the acceptance of TPS dosage estimates vary greatly. Van Dyk et al. (1993) first published a set of criteria with larger tolerance limits because, at the time, most TPS were using 2-dimensional algorithms.

The used test cases fall into two categories based on according to the test configuration's growing complexity. Within the first set are simple- geometric test cases, which are square fields with different depths. Dosage estimates for fields without specialized accessories are carried out in a homogeneous phantom. The second-group consists of complex geometric test cases called wedge fields. Comparing results for 6 MV open square field sizes using the photon Beam technique. We found that increasing field size frequently led to a decrease in computation accuracy by comparing calculated and observed profiles. The calculations for the regions close to the field-limits indicate an underestimation of the dose as the field size and depth rise. Upon reviewing the confidence limit computation results, it was discovered that in three of the four zones of concern, the results exceeded the suggested limitations for calculation accuracy. The moderate dose gradient zone, designated as δ1, has a confidence limit of 3.76% along the center axis. Nevertheless, the confidence limit would decrease to if the 20x20 cm^2 field study's findings were applied.

Figures 2 to 5 also show data for open fields. Based on the photons mean energy distributions calculated by MONACO for six photon beams in a 5 x 5 to 20 x 20 cm^2 field with 60° physical wedges, we can conclude that the mean energy for PWs increases across the wedge direction compared to open fields. This effect increases with increasing wedge angles. The mean energy of the field increases at all PWs in the wedged beams but at open beams from the heel area to the toe edge. The bigger the wedge angle, the more pronounced this effect is the field at open beam but at wedged beams mean energy increases from the edge of the toe to the heel region across the wedge direction at all PWs. This effect is more significant at larger wedge-angles.

As a result, a general approach was put forth to compute the profile for symmetric open or wedged photon fields at any depth. This algorithm's benefits include depth independence, minimal measurement data requirements, speed, affordability, ease of use, and a reasonable level of accuracy. Additionally, this approach can be used to plot a 2D or 3D isodose for treatment planning in various fields. The computation algorithm has several significant warnings that should be taken into account. (Feye, 2018; Mia et al., 2019).

Conclusion

The set of test settings was used to assess the Monaco Plan's performance. For the majority of the investigated geometries, the Collapse cone estimates coincided with experimental results, indicating that they are feasible for clinical usage. Monaco Plan performs noticeably better for all beam geometries as compared to earlier TPSs that use the Collapse Cone Algorithm.

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Author contribution:

I contributed the practical portion of this work, while Drs. Haroun Al-Sheikh and Hani Ammar reviewed the scientific data and corrected the language.

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