

Overdose Problem Associated with Treatment Planning Software for High Energy Photons in Response of Panama's Accident

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ABSTRACT

Background and Purpose: The purpose of this study was to quantify dose distribution errors by comparing actual dose measurements with the calculated values done by the software. To evaluate the outcome of radiation overexposure related to Panama's accident and in response to ensure that the treatment planning systems (T.P.S.) are being operated in accordance with the appropriate quality assurance programme, we studied the central axis and peripheral depth dose data using complex field shaped with blocks to quantify dose distribution errors.

Material and Methods: Multidata T.P.S. software versions 2.35 and 2.40 and Helax T.P.S. software version 5.1 B were assessed. The calculated data of the software treatment planning systems were verified by comparing these data with the actual dose measurements for open and blocked high energy photon fields (Co-60, 6MV & 18MV photons).

Results: Close calculated and measured results were obtained for the 2-D (Multidata) and 3-D treatment planning (TMS Helax). These results were correct within 1 to 2% for open fields and 0.5 to 2.5% for peripheral blocked fields. Discrepancies between calculated and measured data ranged between 13. to 36% along the central axis of complex blocked fields when normalisation point was selected at the Dmax, when the normalisation point was selected near or under the blocks, the variation between the calculated and the measured data was up to 500% difference.

Conclusions: The present results emphasize the importance of the proper selection of the normalization point in the radiation field, as this facilitates detection of aberrant dose distribution (over exposure or under exposure).

Key Words: *Overdose – Treatment planning – Quality assurance – Panama's accident.*

INTRODUCTION

In radiotherapy, a single error or equipment fault can have very severe impact if not discovered before the radiation dose is incorrectly delivered to patients. A system that ensures detection and correction of errors before they result in incorrect dose delivery needs to be in place, i.e. a quality assurance (QA) system. The outcome of radiation overexposure related to Panama's accident and in response to that treatment planning system was operated in accordance with appropriate quality assurance programme [1,2]. Although the T.P.S. accepted entry of the data for multiple shielding blocks as if they were a single block, The result was that patients received a proportionately higher dose than that prescribed. The modified treatment protocol was used for 28 patients, who were treated between August 2000 and March 2001 for prostate cancer and cancer of the cervix [3].

In a recent report, an overview of the importance clinical evidences [4] radiotherapy accuracy was emphasized. It was concluded that a difference in absorbed dose of 10% is detectable for tumours and that a difference of 7% in absorbed dose can sometimes be observed for normal tissue reactions. For the latter figure even 5% has been reported. Another approach has been followed by Ahnesjö. He defined a practical limit where further increase in dose calculation accuracy does not yield an increase in total treatment accuracy, taken into account reported uncertainties in calibration and delivery technique [5]. His conclusion is that at present there is no need for a dose calculation accuracy better than 2%, whereas this ultimately might

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be confined to 1%. Similarly, Mackie et al. reasoned that dose calculation accuracy need not be as accurate as absolute dose calibration while, on the other hand, calculated dose should not deviate too much from prescribed dose, they concluded that dose calculation accuracy should be in the range of 2 to 5% [6].

Isodose curves may be normalized relative to maximum dose, target dose or dose at other selected reference point [7]. ICRU Report No. 50, 1993 pointed out, that the reference point should be selected according to the general criteria:

- 1- The absorbed dose at a reference point should be clinically relevant and representative of the dose throughout the planning target volume.
- 2- The reference point should be easy to define in a clear way.
- 3- The reference point should be selected where the dose can be accurately determined.
- 4- The reference point should be selected in a region where there is no steep dose gradient such as the dose under a block.

The accuracy of dose calculations in treatment planning is very important and the error in dose delivery should not exceed $\pm 5\%$ [8]. Most of the dose calculation algorithms are based on the pencil beam concept [9], which is usually based on Monte Carlo generated energy distributions of photons impinging on a semi-infinite slab. The treatment planning system used in that work is the TMS version 5.1B of Helax AB and is based on a Monte Carlo pencil beam model [5,10]. The other treatment planning system, used in this study is the Multidata treatment planning system versions 2.35 and 2.40. Current dose distribution calculation programs are based on a developed version of the calculation models of the Memorial Sloan Kettering Cancer Center, supporting all standard therapy methods.

MATERIAL AND METHODS

Multidata treatment planning system software versions 2.35 and 2.40 were used to compare calculated results with the experimental values. The machines used were Cobalt 60 unit Theratron 780C, linear accelerator Philips SL 75-5 (6MV) and Varian CL-1800 (18MV) photons. Verification of calculated data using soft-

ware treatment planning system was done by comparison with experimental dose measurements for open and blocked high-energy photon fields.

For each beam quality, the dose in the central axis beam is measured using an ionization chamber 0.6 cc (PTW 30003-0141) and PTW Unidos electrometer. The ion chamber is positioned in a PMMA solid phantom. The measurements were done for a field size 20x20 cm at three different depths 5, 10 and 15 cm. This was done for open and blocked fields for each treatment machine, such that the block was placed in two different positions. In the first position, a 5x5 cm block was centrally placed (Fig. 1-A). In the other position, two 5x5 cm blocks were placed on the periphery of the field (Fig. 1-B).

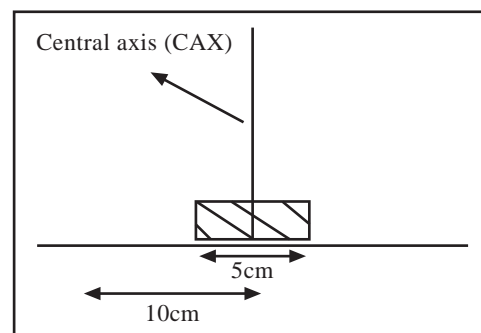


Fig. (1-A): Block position in the transverse view the block is centered at the central axis CAX of the field.

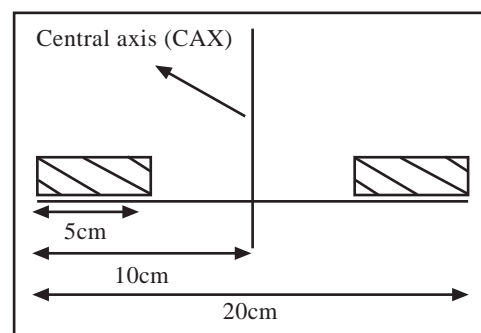


Fig. (1-B): Block position in the transverse view two blocks were placed at the periphery of the field.

Software calculations done by the planning system were compared with actual measurements performed in similar conditions for open and blocked fields of each radiotherapy units. The normalisation point was selected at the point of maximum dose (D_{max}) this was rechecked when

the normalisation point selected near or under the shielding blocks, this can be the case when the isocentre is near the blocks.

The Multidata treatment planning software system accepts for input data blocks entered improperly in a manner other than specified in the user manual [2]. This applies for the Beam's eye view (BEV) when the shielding block outlines cross each other regardless of the direction in which the block is entered or the shape of the block (Fig. 2-A).

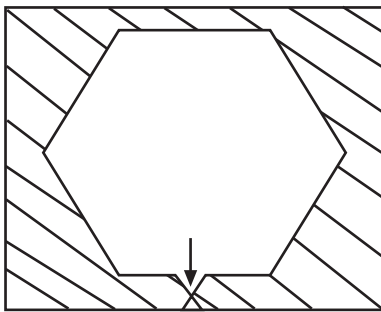


Fig. (2-A): Incorrect crossing block outline (Improper block outline).

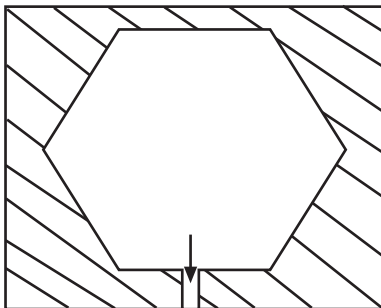


Fig. (2-B): Safe aperture definition with a single continuous line (Proper block outline).

A comparative calculation, for Cobalt-60 unit (Theratron 780C) was done in case of the proper and the improper block. Plans of multiple fields were used in this study to treat certain tumors within the pelvis. The complex field shaped blocks were applied for parallel opposed fields and four fields techniques, to demonstrate the effect for the number of the fields. To evaluate the effect of the energy, the procedures in both cases was repeated using 6MV and 18MV photons.

RESULTS

The calculated doses for the open fields and blocked field edges for the 2D and 3D agreed well with the measured values, they were within 1-2%

and within 0.5-2.5%, respectively. The discrepancies between the calculated and measured doses along blocked central axis ranged from 13 to 36% depending on photon energy and depth (Fig. 3-A). Calculated doses were higher than the measured values along blocked central axis field. For the open field 20 cm x 20 cm at three different depths 5, 10 and 15 cm along the central axes, the estimated dose was given in Table (1), for different energies. It was seen that the discrepancy between the calculated and measured dose ranged from 1 to 2%. The discrepancy in dose varied depending on the beam energy e.g. for Cobalt-60 unit from 1.04 to 1.15%. For the Linear Accelerator SL75-5 (6MV), the dose discrepancy varied between 1.0 to 1.01%, while for CL 1800 (18MV), it varied between 1.3 to 1.8%.

For the blocked central axis field 20 cm x 20 cm at three different depths 5, 10 and 15 cm, the estimated dose was given in Table (2). The dose discrepancy between calculated and measured data ranged from 13% and 36%. The assessment was seen that, the dose varied, for Cobalt-60 unit by about 36.0% at depth 5 cm. At larger depth (15 cm) the discrepancy in dose was about 27.2%. For the Linear Accelerator SL75-5 (6MV), the dose discrepancy varied between 17.3% (at depth 15 cm) to 29.1% (at depth 5 cm), while for CL 1800 (18MV), the dose varied between 13% (at depth 15 cm) to 18.0% (at depth 5 cm). For the blocked field (peripheral blocks) 20 cm x 20 cm at three different depths 5, 10 and 15 cm, the estimated quantity is given in Table (3). The dose discrepancy between the calculated and measured data ranged from 0.5% to 2.5%. The assessment shows that, the dose varied, for Cobalt-60 unit (Theratron 780C) from 0.8 to 1.1% increasing with the depth. For the Linear Accelerator SL75-5 (6MV), the dose varied between 1.01 to 1.08% increasing with depth, While for CL 1800 (18MV), it varied between 0.5 to 2.5% decreasing with depth.

For the blocked field (peripheral blocks) 20 cm x 20 cm at three different depths 5, 10 and 15 cm, the estimated quantity is given in Table (3). The dose discrepancy between the calculated and measured data ranged from 0.5% to 2.5%. The assessment shows that, the dose varied, for Cobalt-60 unit (Theratron 780C) from 0.8 to 1.1% increasing with the depth.

For the Linear Accelerator SL75-5 (6MV), the dose varied between 1.01 to 1.08% increasingly with depth, While for CL 1800 (18MV), it varied between 0.5 to 2.5% decreasingly with depth. Fig. (3-A) summarizes the discrepancy in percentage between calculated and measured data for central axis blocked fields, using Multidata treatment planning system (2-D). On the other hand, a comparative calculation was done between the previous system and Helax planning system software (TMS) version 5.1B and resulted in a variation of about 1% to 2% appeared for open and peripheral blocked fields. While as for the central axis(CAX) blocked fields, discrepancy in dose varied in a range between 3% to 5% as yield in Fig. (3-b).

In case of the proper block outlining (Fig. 2-B), to assure that the data entry defining an aperture shape is correct (properly entered block), one must verify that the block outline does not cross itself. The tumor dose varied between 85% and 98%, (Fig. 4-A) in case of Cobalt-60. While in case of the improper block outlining (Fig. 2-A), this applies for the Beam's eye view (BEV) when the shielding block outlines cross each other regardless of the direction in which the block is entered or the shape of the block. When a block is outlined improperly

into the computer program it will produce substantially higher dose values (50% to 500% for MU or Time) than what one would expect by partially blocking an open field [11]. The tumor dose varied between 55% and 88%, (Fig. 4-B) in case of cobalt-60. This is due to improper block outlining. The maximum dose in case of the Co-60 four-field planning (Fig. 4-B) exceeds the two parallel-opposed field planning by 4%. Regarding the other energies, it was about 26% difference for the 6 MV beam between the two situations, for proper and the improper blocks. While, in case of the 18MV beam, the difference was about 8%.

The same procedures were adopted for the improper block on the Helax planning system software (TMS) version 5.1B. The system did not accept the case according to its limitations and showed that, the point for detector exit dose was not in open beam.

On the other hand, the fulfillment of quality assurance program was done nine years ago, for verification between calculated data on the Multidata software RTP 1.2.3 and that measured using Philips O.S.S (Oncology Support System) software. Differences between calculated and measured data varied within 1%.

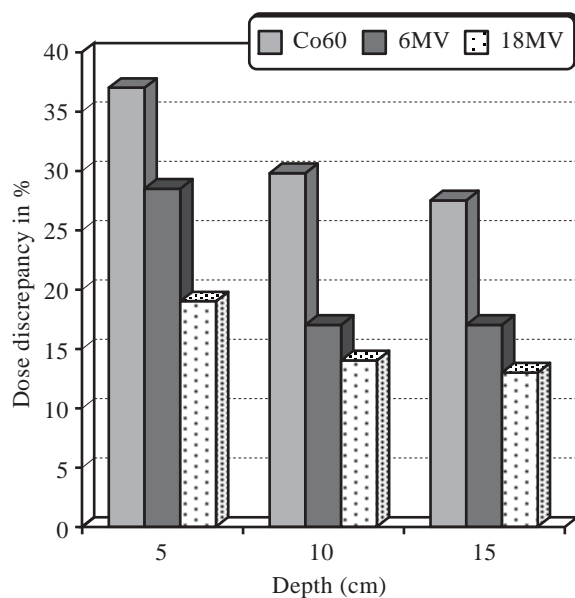


Fig. (3-A): The discrepancy between the calculated and measured data using multidata treatment planning system for central axis (CAX) blocked field in case of Co-60, 6MV and 18MV at different depths.

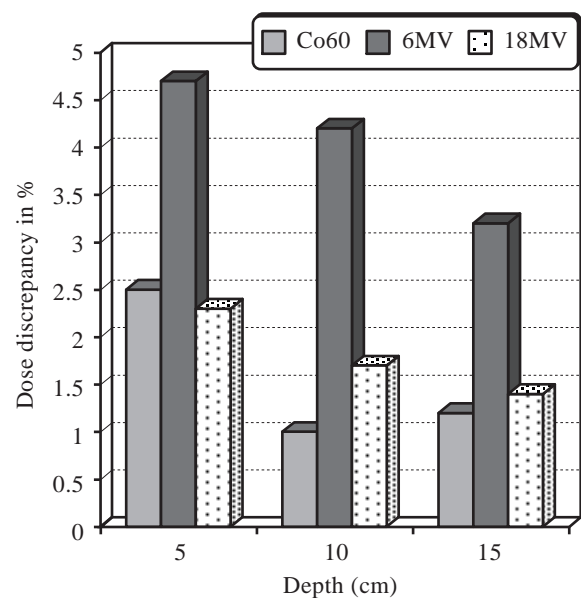


Fig. (3-B): The discrepancy between the calculated and measured data using Helax treatment planning system for central axis (CAX) blocked field in case of Co-60, 6MV and 18MV at different depths.

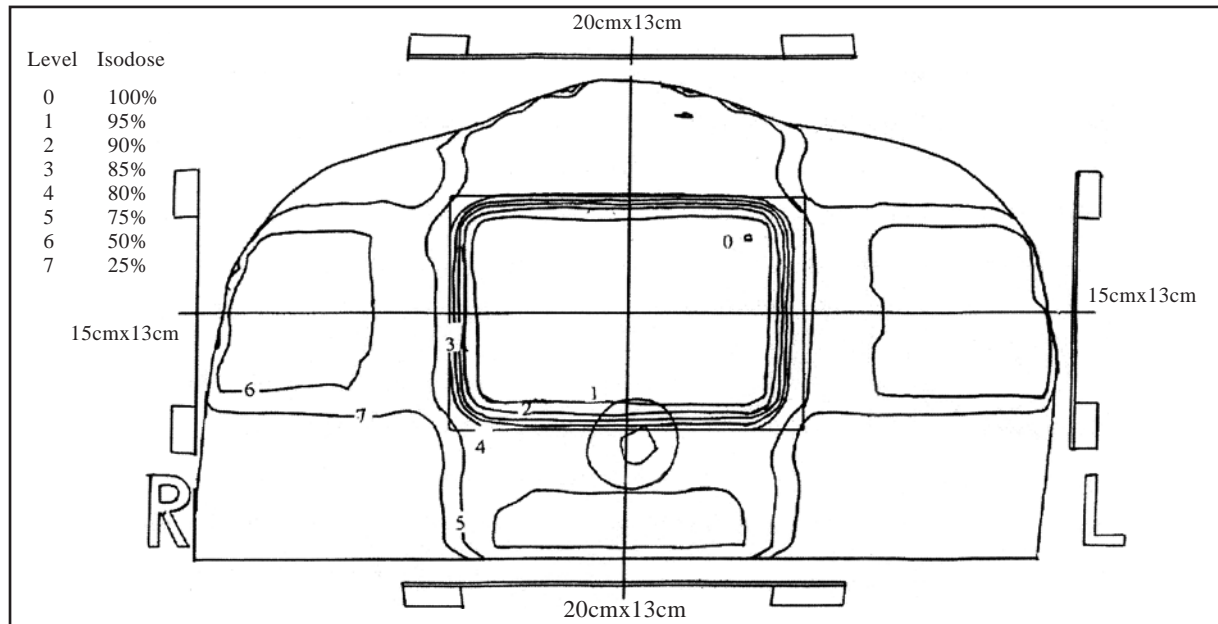


Fig. (4-A): Isodose distribution for bladder patient with four fields using multidata treatment planning system in case of safe aperture definition with a single continuous line (proper block).

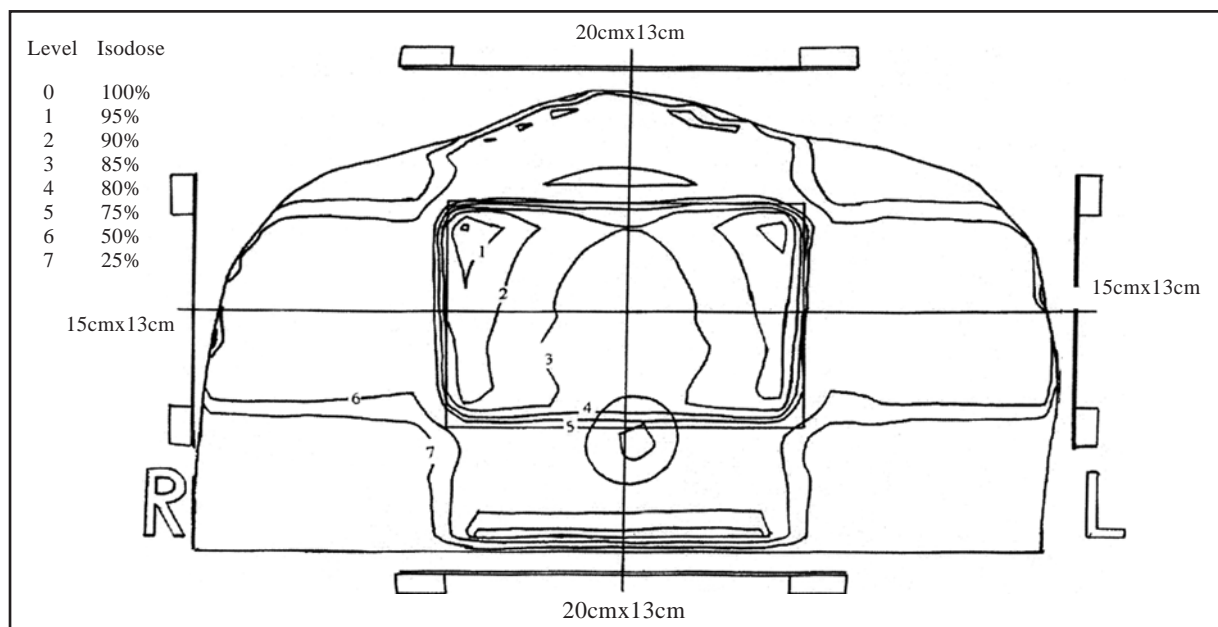


Fig. (4-B): Isodose distribution for bladder patient with four fields using multidata treatment planning system in case of incorrect crossing block outline (Improper block).

Table (1): Comparison between calculated and measured dose (cGy) along central axes open field 20x20cm² at different depths 5, 10 and 15cm for different energies (Co-60, 6MV and 18MV photons).

Depth	Calculated dose			Measured dose		
	Cobalt	6MV	18MV	Cobalt	6MV	18MV
5	81.3	88.4	94.6	80.45±0.1	87.49±0.1	96.2±0.1
10	60.8	70.1	78.3	60.16±0.1	69.97±0.1	79.2±0.1
15	44.5	55.0	63.8	43.98±0.1	54.80±0.1	64.7±0.1

Table (2): Comparison between calculated and measured dose (cGy) along central axis blocked field 20x20 cm² at different depths 5, 10 and 15 cm for different energies (Co-60, 6MV and 18MV photons).

Depth	Calculated dose			Measured dose		
	Cobalt	6MV	18MV	Cobalt	6MV	18MV
5	4.8	3.5	2.5	7.50±0.1	4.94±0.1	3.05±0.1
10	4.3	3.2	2.0	6.10±0.1	3.87±0.1	2.33±0.1
15	3.6	3.1	1.8	4.95±0.1	3.75±0.1	2.07±0.1

N.B.: The measured transmission under block is 4%.

Table (3): Comparison between calculated and measured dose (cGy) along central axis for a peripheral blocked field 20x20cm² at different depths 5, 10 and 15cm for different energies (Co-60, 6MV and 18MV photons).

Depth	Calculated dose			Measured dose		
	Cobalt	6MV	18MV	Cobalt	6MV	18MV
5	80.1	87.5	94.1	79.4	86.6	96.6
10	58.6	70	78.5	57.9	69.28	79.2
15	41.9	55	64.4	41.44	54.4	64.7

N.B.: The measured transmission under block is 4%.

DISCUSSION

In this study, there was a variation between the software data and the actual measured data in case of the central axis blocked fields, which is normally matching most of the expected limitations of the planning systems software algorithms. Calculation inaccuracies remain in the build up tissue interface and penumbra regions, at large depths and under blocks [12]. This explains why always the discrepancy in cobalt-60 unit was higher than the other energies.

We may conclude that, the entering improper blocks outlining to the multidata software will not lead to an overexposure that exceeds 56% in the maximum situation, knowing that in the Panama's accident it was reported in the multidata website [11] that the overexposure reached up to 600%. From several treatment planning cases, the overdose problem (which depends on the selection of the normalization point) was more pronounced in the 2D (Multidata System) than the 3D treatment planning (TMS Helax System). It is important, that such

study aims to obtain the Normalization for 2-D as well as 3-D planning same at the maximum dose point. In the Panama's accident the overexposure may be related to the choice of the reference point near to or under the blocks, which will lead to an overexposure between 100 and 500% for MU or time. Although that selection will be namely matching the ICRU Reports No. 42 and No. 50 [7,13].

In conclusion, wrong selection in the normalization point could contribute to the major probability in the uncertainty for the overexposure in Panama. The use of a plan for verifying the calculation of isodose distributions and machine settings (In vivo Dosimetry), using semiconductor diodes, ensures that the basic procedures associated with treatment techniques are in agreement within a pre-determined range of accuracy. It may be concluded that, comparative studies succeeded to emphasize the close results of the planning system software calculations, either the 2-D Multidata or 3-D treatment planning "TMS Helax", to the real treatment situations, without the use of complex shielding blocks, which was very clear from the discrepancy percentages.

In radiotherapy, a single error or equipment fault can have very severe or even fatal consequences if not discovered before the radiation dose is incorrectly delivered to patients. A system that ensures detection and correction of errors before they result in incorrect dose delivery needs to be in place, i.e. a quality assurance (QA) system. Treatment planning systems represented a critical component in radiotherapy and therefore it was important to include them in the quality control procedures at radiotherapy departments. They should include verification by manual calculation of the treatment time and dose to the selected point.

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