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Verification of Photon Beam Data Calculated by a Treatment Planning System Based on Pencil Beam Model

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ABSTRACT

A new three-dimensional treatment system was installed in the Oncology Center, Jeddah. This system is based on the pencil beam model. The aim of this study is to verify the validity of photon beam data as calculated by this treatment planning system by comparing it with measured photon beam data. To do this verification, a quality assurance program, consisting of six tests, was performed. In this program, both the calculated output factors and dose at different conditions were compared with the measured data. As a result of that comparison, we found that the calculated output factor was in excellent agreement with the measured factors. Doses at depths beyond the depth of maximum dose calculated on-axis or off-axis in both the fields or penumbra region were found in good agreement with the measured dose under all conditions of energy, SSD and field size, for open and wedged fields. In the build up region, calculated and measured doses only agree (with a difference ≤ 5%) for field sizes > 7 x 7 cm^2. For smaller fields, the difference was higher than 5% because of the difficulty in dosimetry in that region. In conclusion, dose calculation using treatment planning system based on the pencil beam model is accurate enough for clinical use except when calculating dose at depths above maximum dose for small field size. Accurate dosimetry should be done to overcome this problem.

Key Words: *Radiotherapy - Treatment planning - Computer treatment planning - Pencil beam model - Dosimetry.*

INTRODUCTION

Advances in computer technology have led to the availability of sophisticated three-dimensional (3D) treatment planning systems (TPS) for use in many radiotherapy centers. One aim of introducing such sophisticated 3D-TPSs is to improve the accuracy of dose calculations in radiotherapy planning. The accuracy in radiation therapy has been discussed in several reports which showed that errors in dose delivery should not exceed 5% **[5,8,9,10,13]**. Values as low as 3% have, however, been also mentioned **[6]**. To investigate the accuracy of the TPSs, several quality assurance (QA) programs have been introduced and discussed in the literature **[6,7,11,12,14,15]**. These QA programs mainly check the agreement of the output data from the system with the measured data.

A new 3D-TPS (Treatment Management System-TMS version 3.0B, MELAX, AB, Uppsala, Sweden) was installed in the Oncology Center, Jeddah. This TPS is based on the pencil beam model **[3]** where physical quantities, estimated using conventional measured quantities, are used. The photon dose calculation model in this treatment planning system is based on a convolution algorithm **[3]**. Briefly, the model is used to compute weight for depth dose curves from monoenergetic photons. These monoenergetic depth doses, calculated with the convolution method from Mont Carlo generated point spread functions (PSF), are added to yield the pure photon depth dose distribution **[1]**. The hereby obtained poly-energetic pencil-beam is then used to calculate the dose distribution for a given case by convolution with the machine-specific energy-fluence matrix modulated by the actual field shape. Inversely, the energy-fluence matrix is obtained as a deconvolution of the pencil-beam form the measured dose distribution in a reference situation **[4]**. One of the features of the system is that it calculates the monitor settings for the planned fields **[2]**.

The aim of this study is to verify the validity of the calculated photon beam data in comparison with the measured photon data at different treatment situations.

PATIENTS AND METHODS

To characterize a particular beam in TMS the measurements needed are:

1- Central-axis depth doses at field sizes 5x5, 10x10, 15x15 and 20x20 cm^2 at 90 cm source-surface-distance (SSD). These depth dose data are used in determination of energy spectrum and modelling of contaminating electrons.

2- Inplane and crossplane dose profiles in water at depths of 0.5, 1.5, 5, 10, 15 and 20 cm and 90 cm SSD for the same field sizes as above. These beam profiles data are used for penumbra modelling (i.e. source size and distribution modelling) and modelling of contaminating photons outside the geometric field.

3- Star-shaped dose profiles at the reference SSD and depths (90 and 10 cm, respectively) using a maximum collimator setting. These star profiles are used to calculate energy fluence distribution and for fluence modulation vector for wedges.

4- Head scatter factors and output factors in water for open and wedged fields at the reference SSD and depth using different field sizes. These factors are used to monitor unit calculations.

5- Absolute dose in air at calibration geometry for different field sizes. These data are also used to monitor unit calculation.

All of these measurements were performed for both open and wedge fields. All measured depth dose curves and beam profiles (including star profiles) were scanned using Welhofer WP600 radiation field analyzer using 0.1 cc, IC10 Welhofer ionization camber. Absolute and relative output factors were measured using Farmer dosimeter with 0.6 cc graphite guarded stem ionization chamber type 2571 from Nuclear Enterprise. For measurements in air, the ion chamber was covered by a brass cap to reduce electron contamination and to achieve a proper build up of secondary particles.

Two linear accelerators were used in this study. One accelerator is Siemens Mevatron KDS that has 6 MeV and 18 MeV photon beams. The other accelerator is Siemens Mevatron M6700 that has only 6 MeV photon beam. The two accelerators are provided with fixed wedges of 15˚, 30˚, 45˚ and 60˚. Information regarding the treatment machines is supplied to the planning system. The information is:

1- Treatment head geometry: the distances from the target to each of the flattening filter, monitor chamber, upper and lower collimators, wedge, block tray and isocenter. It includes also the thickness of both lower and upper collimators.

2- Scale information: maximum and minimum settings and direction of increasing setting of gantry rotation, collimator rotation and table rotation.

3- Table positions: maximum and minimum settings and direction of increasing setting of both vertical, lateral and longitudinal movement of the table.

4- Collimator configuration; maximum and minimum settings and direction of increasing setting of the collimators and their labelling.

5- Block information: shadow tray distance, tray transmission, block thickness, block material density and standard block geometries.

These five sets of data are stored in data files.

To verify the photon beam data calculated by TMS, a QA program consisting of the following tests was performed:

1- Investigating the data files of the two linear accelerators which include the data mentioned in the previous paragraph to check for possible bugs in the implementation. This was done by performing some demo treatment plans using different techniques. In these techniques all data files have been used. Then the values in the data files were compared with the output in a calculation performed by the TPS.

2- Evaluating the performance of the system in calculating the absolute dose. The absolute doses at 10 x 10 cm^2 for both open and wedged fields at the reference positions, as described above, were measured. These measured doses were compared to the output calculated by TMS for the corresponding situations.

3- In this test the output factors at reference SSD and depth were calculated for different field sizes from 5 x 5 cm^2 up to the maximum field size (40 x 40 cm^2). The output factor for a certain field size was considered as the dose per monitor unit at the reference SSD and depth on the central axis divided by the corresponding value for the 10 x 10 cm^2 field.

4- This test investigates the ability of the system to reproduce the input data used during implementation of the machines. In this test the depth doses and doe profiles mentioned above were calculated and compared with measured data.

5- To check the energy-fluence modulation matrix, the star profiles measured at reference SSD and depth for maximum field sizes in both open and wedged fields were compared with the corresponding calculated star profiles.

6- In the last test depth dose lines calculated at different SSDs from 80 to 125 cm using 10 x 10 cm^2 field size for both open and wedged fields were compared with the corresponding measured depth dose lines.

RESULTS

1- The information in the data files of the two accelerators was found to agree in all aspects with the output data obtained from the TPS.

2- The absolute doses calculated at the reference point for the three photon beams were in agreement with measurements for both open and wedged fields. The errors were within the limit of truncation errors.

3- The calculated output factors are showing good agreement with the measured values. For open fields using both energies from the two linear accelerators the error in calculated normalized out put factor did not exceed ±0.004 (±0.4%) compared to measured values. Fig. (1) shows an example of this result for open fields of 6 Mev photon from Mevatron M6700. For wedged fields, the error was slightly higher than that of open fields. The maximum difference between measured and calculated normalized output factor in case of wedged field was about 0.001 (1%). This maximum error occur in the maximum field size of 18 MeV photon from KDS Mevatron for 60° wedge. Fig. (2) shows an example of the comparison between calculated and measured normalized output factors for wedged 18 MeV photon fields.

4- The comparison between calculated and measured depth doses and dose profiles for both open and wedged fields showed a negligible difference at depths greater than the depth of maximum dose for all energies. This difference was always less than 1% in both directions. In the build-up region this error was higher than that and depends on the field size. For field sizes ≥ 10 x 10 cm^2, the difference ranged between 2-3%; the larger the size the smaller the error. For field sizes ≤ 10 x 10 cm^2, the error also decreased with increasing the field size and ranged between 3-9%. Examples of the comparison between the calculated and measured depth dose and beam profiles were shown in Figs. (3&4), respectively. The comparison at depths larger than the depth of the maximum dose showed also an excellent agreement between calculated and measured beam profiles for both open and wedged fields with different field sizes in both regions of useful beam and penumbra.

5- Comparison of calculated star profiles with measured data for wedged fields showed excellent agreement for all energies. In both the useful beam and penumbra regions, the difference was < 1% in both directions. This agreement means that, for wedged fields, the input data for the energy fluence modulation matrix is accurately reproducible for the two linear accelerators and for all energies. Fig. (5) shows an example of calculated star profiles when compared to measured star profiles for wedged field.

6- This test compared calculated depth dose lines measured depth dose lines at different SSDs for 10 x 10 cm^2 field sizes. It showed a general agreement between them for different SSDs at depths larger than depth of the maximum dose with difference less than 1%. As found for SSD = 90 cm, the difference in the build-up region varies between 2-3%. Fig. (6) is an example of that comparison.

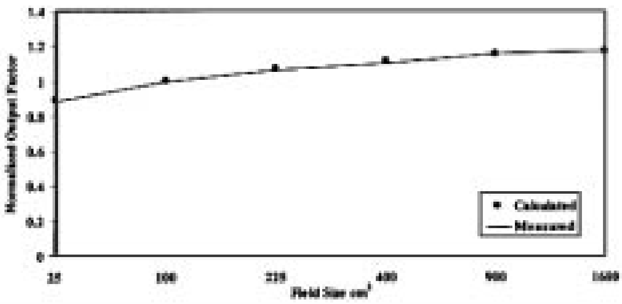

Fig. (1): Normalized ouput factor (output factor divided by output factor of 10 x 10 cm^2 field) for open fields of 6 MeV photon generated by Mevatron M6700 plotted against field size. The line represents the measured output factors and point represents the calculated factors.

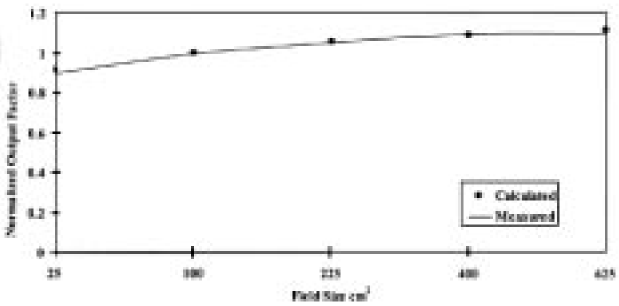

Fig. (2): Normalized output factor (output factor divided by output factor of 10 x 10 cm^2 field) for 45˚ wedged fields of 18 MeV photon generated by Mevarn KDS plotted against filed size. The line represents the measured output factors and point represents the calculated factors.

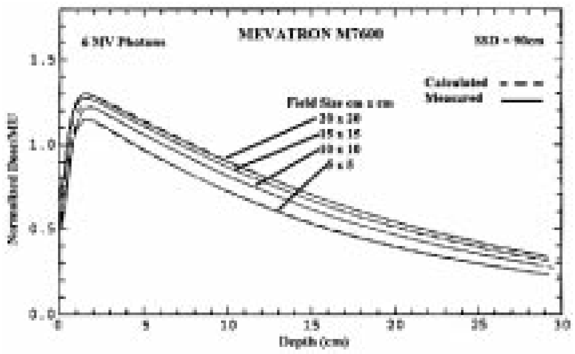

Fig. (3): An example of comparison between measured and calculated depth dose data of 6 MV photons generated by Mevatron M6700 linear accelerator at 90 cm SSD whith 4 different field sizes (5x5, 10x10, 15x15 and 20x20 cm^2). The depth doses divided by monitor unit is normalized at 10x10 cm^2 field. The dotted lines represent calculated data and solid lines represent measred data.

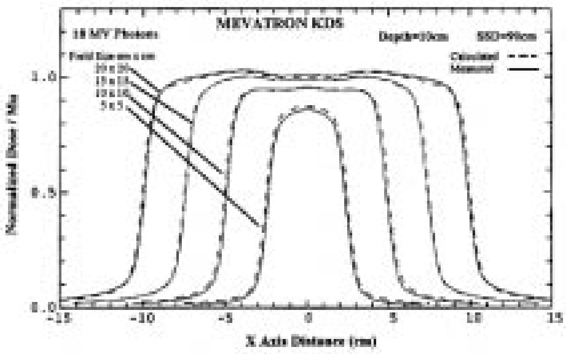

Fig. (4): An example of comaprison between measured and calculated beam profiles of 18MV photons generated by Mevatron KDS linear accelerator at 90 cm SSD with 4 different field sizes (5x5, 10x10, 15x15 and 20x20 cm^2). The doses divided by monitor unit are normalized at 10x10 cm^2 field. The dotted lines represent calculated data and solid lines represent measured data.

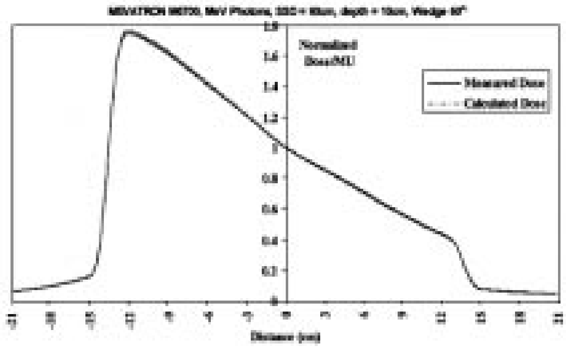

Fig. (5): An example of comparison between measured and calculated beam star profiles of 6MV photons generated by Mevatron M6700 linear accelerator at 90 cm SSD with field size 20x20 cm^2 using 60˚ wedge. These lines represent 45˚ star angle. The doses divided by monitor unit are normalized central axis dose of the same field. The dotted line represents calculated data and solid line represents measured data.

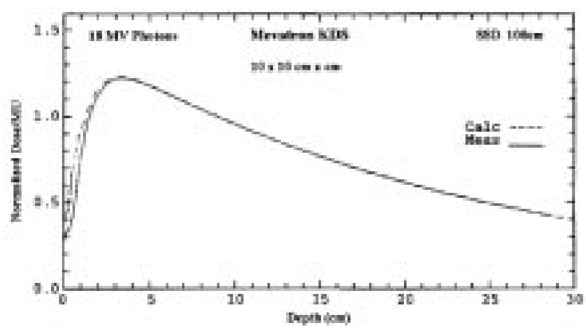

Fig. (6): An example of comparison between measured and calculated depth dose data of 18MC photons generated by Mevatron KDS linear accelerator at 100 cm SSD with 10x10 cm^2. The depth doses divided by monitor unit are normalized at 10 cm depth. The dotted line represents calculated data and solid line represents measured data.

DISCUSSION

As we mentioned above, the overall inaccuracy in dose delivery should not exceed 5%. Before we started to use TMS in routine work, this point was checked and the error in the output factor or dose calculation was estimated to be less than that level.

In the first test we checked the reproducibility of both patient and machine data and we got a near 100% accuracy result. This test is quite essential because any error in the patient or equipment data may lead to a mistake in the treatment setup.

In tests 2 and 3, we found that the calculated output factors were in excellent agreement with measurements made in most cases where the error was always less than 1%. The maximum error (1%) occurred in the 60˚ wedged fields with maximum field size (20 x 20 cm^2) in 18 MeV beam. This field has a rare clinical application.

Tests 4 and 6 showed that at depths larger than the depth of maximum dose, there was good agreement between calculated and measured depth doses and dose profiles. On the other hand, the difference between calculated and measured doses above the depth of maximum dose was higher. For field sizes ≥ 10 x 10 cm^2, the error was in the acceptable range while it was not acceptable for smaller fields. There are two reasons for that high error, one of them is due to inaccuracy in dose measurements in the build up region because of the ionization chamber size (0.1 cc). Further measurements in that region with a smaller chamber may give more accurate results. The other reason of the large error is the difficulties in the modelling of the electron contamination **[11]**. It is known that error due to modelling of electron contamination is higher for larger fields and higher energies. In our work, it was found that the error in the build up region is acceptable (2-3%) in large fields (> 10 x 10 cm^2). Nevertheless, for smaller fields, the error was sometimes not acceptable (3-9%). This means that for these fields, high error is mainly due to dosimetry inaccuracy. Further dosimetry for fields smaller that 10 x 10 cm^2 was done at depths above depth of maximum dose. We found that the difference between measured and calculated dose was higher than 5% in only fields smaller than 7 x 7 cm^2. In clinical application, doses in the build up region for fields < 7 x 7 cm^2 should not be estimated from dose distribution calculated with our TMS unit more accurate measurement in build up region is done.

In test 5, the calculated and measured star profiles of wedged fields were compared for all energies with the maximum field size. They were in excellent agreement (< 1%) because of the modification of the calculating model in that versions. Previous versions showed less agreement especially for the 60˚ wedge **[11]**.

Conclusions:

Dose calculation using TPS based on pencil beam model is generally in excellent agreement with measurements. The only deviation which was not within the limits that have been set up for dose planning systems is the dose calculation above the depth of maximum dose in fields smaller than 7 x 7 cm^2. The reason of that deviation is the uncertainty in dose measurement in the build-up region using 0.1 cc ionization chamber. Additional dosimetry should be done in the region above the depth of maximum dose using a proper dosimeter.

It is concluded that implementation of a pencil beam based TPS is very suitable for accurate radiation therapy treatment planning and its practical use would decrease the uncertainty in radiotherapy.

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