Original Article

# Dosimetric evaluation of a three-dimensional treatment planning system

**Appasamy Murugan[1,2], Xavier Sidonia Valas[1], Kuppusamy Thayalan[1], Velayudham Ramasubramanian[2]**

[1]Medical Physics Division, Dr. Kamakshi Memorial Hospital, No:1, Radial Road, Pallikaranai, Chennai - 600 100. Tamil Nadu, India. [2]Nuclear and Medical Physics Division, School of Advanced Sciences, VIT University, Vellore – 632 014, Tamil Nadu, India.

**Received on:** 29.04.10 **Review completed on:** 21.06.10 **Accepted on:** 11.08.10

## ABSTRACT

The computerized treatment planning system plays a major role in radiation therapy in delivering correct radiation dose to the patients within ±5% as recommended by the ICRU. To evaluate the dosimetric performance of the Treatment Planning system (TPS) with three-dimensional dose calculation algorithm using the basic beam data measured for 6 MV X-rays. Eleven numbers of test cases were created according to the Technical Report Series-430 (TRS 430) and are used to evaluate the TPS in a homogeneous water phantom. These cases involve simple field arrangements as well as the presence of a low-density material in the beam to resemble an air in-homogeneity. Absolute dose measurements were performed for the each case with the MU calculation given by the TPS, and the measured dose is compared with the corresponding TPS calculated dose values. The result yields a percentage difference maximum of 2.38% for all simple test cases. For complex test cases in the presence of in-homogeneity, beam modifiers or beam modifiers with asymmetric fields a maximum percentage difference of 5.94% was observed. This study ensures that the dosimetric calculations performed by the TPS are within the accuracy of ±5% which is very much warranted in patient dose delivery. The test procedures are simple, not only during the installation of TPS, but also repeated at periodic intervals.

**Key words:** Dosimetric evaluation, treatment planning system, Technical Report Series-430

## Introduction

Radiotherapy aims to cure, or locally control the disease, while concurrently minimizing complications in normal tissues. The radiation dose must be delivered within ±5% of the prescribed dose.[1-3] The treatment planning and dosimetry are the main steps in radiotherapy, which includes calibration of the equipments, determination of absorbed dose under reference conditions, phantom measurements under non-reference conditions, calculation of dose distribution in the patient and, finally, treatment delivery via monitor units or treatment time calculation. Consideration of the uncertainties associated with each of the above steps and their propagation increases the demand for accuracy in the dose calculation algorithm employed in the treatment planning. Therefore, quality assurance (QA) is necessary in the commissioning stage of the treatment planning system (TPS) prior to their use in clinical practice.

In the present work, the dosimetric performance of a commercial TPS with a three-dimensional calculation algorithm (Plato V 2.7.2, Nucletron B.V) is studied using a basic beam data set measured for a 6 MV X-ray beam and a set of test case configurations which are based on the TRS-430. The aim is to determine the accuracy of our TPS in dose calculation in a homogenous phantom as well as in the presence of in-homogeneity, and potential limitations of the dose calculation algorithm.

**Address for correspondence:**
Mr. A. Murugan,
Medical Physics Division, Dr. Kamakshi Memorial Hospital, No:1, Radial Road, Pallikaranai, Chennai – 600 100. Tamil Nadu, India.
E-mail: vrs_murugan@rediffmail.com

**Access this article online**
Quick Response Code:
**Website:** www.jmp.org.in
**DOI:** 10.4103/0971-6203.75467

## Materials and Methods

### Treatment planning system

The TPS agreement with the treatment machine is based on IEC 1217 conventions[4] for specifying gantry angle, collimator angle, table angle, wedge orientation and patient orientation, and TPS software operates in a UNIX environment. The photon beam dose calculation algorithm employed by TPS comprises a convolution based approach where the energy fluence distribution is convolved with a dose pencil beam.[5] The dose pencil beam consists of depth-independent width and depth-dependent relative weight. Thus the dose calculation at any arbitrary depth in a homogeneous water phantom involves only one single convolution step for each of the three components. For other depths, the pencil beam components are added using the depth-dependent relative weights. Convolution of the energy fluence distribution with a Gaussian source distribution kernel allows for optimization of the fit between the measured and the calculated edge of the field. In-homogeneities are taken into account by applying the equivalent tissue-air ratio (ETAR) method introduced by Sontag and Cunningham,[6] as described by Yu and Wong.[7]

### Instrumentation and technique

Beam data and test point doses were measured for a 6 MV X-ray beam (Quality Index-0.665) of a Linear Accelerator (Primus, Siemens, Germany). Percentage depth dose curves and beam profiles were measured with a fully computerized radiation field analyzer (Blue phantom, Scanditronix-Wellhofer, Germany) equipped with a thimble- type ionization chamber and semiconductor detectors for relative dose measurements. Absolute dose measurements were performed with ionization chambers (0.13 cc, 0.6 cc farmer type and 40 cc parallel plate type, Scanditronix-Wellhofer) connected to an electrometer (Dose 1, Scanditronix-Wellhofer, Germany). The chamber was calibrated for $N_{D, W}$ according to the IAEA TRS-398 dosimetry protocol.[8]

### Basic beam data

The basic beam data were measured under reference conditions of source to surface distance ($SSD_{ref}$) = 100 cm, reference field ($FS_{ref}$) =10 x 10 cm$^2$, reference depth ($r_{ref}$) =10 cm. The machine was calibrated to deliver 1 cGy/ MU at the depth of maximum dose ($D_{max}$) at 1.7 cm. The beam data used for beam modeling include the following parameters.

### Depth dose data

Open beam depth dose data along the central axis of square field sizes of: 3, 5, 8, 10, 12, 15, 18, 20, 25, 30, 40 (cm x cm) for depths from 0 up to 30 cm were measured.

### Off-axis beam profiles

For each of the above-mentioned square fields, five open beam profiles at various depths of $D_{max}$, 5 cm, 10 cm, 15 cm, and 20 cm were acquired.

### Wedge field data

Depth dose data and five beam profiles for square field sizes of 3, 5, 10, 15, and 20 (cm x cm) were used for each wedge of 15°, 30°, 45°, and 60° nominal angles. Differences between calculated and measured profiles were minimized by adjustment of weight factors according to the comparison of the calculated wedged beam profiles at depths of 3, 5, 10, 15, and 20 cm with corresponding measured values. The comparison and evaluation of differences between calculated and measured beam data were performed in a trial and error fashion using the Beam Data Analysis Software (BDAS).

The output factors, wedge factors, tray transmission factors, and block transmission factors also acquired for the minimum to maximum field size as an input data for the TPS.

### Test data

The selected test cases representing different aspects of the dose computation process as proposed by TRS 430[9] and other authors[10-13] were created. Point dose measurements were performed, and the measured doses were compared with that of TPS calculated values. Test point measurements correspond to different depths ranging from 0.2 to and 15 cm along the central axis for the reference $SSD_{ref}$=100 cm, unless otherwise stated.

#### Test case 1

Square fields ranging from 3 x 3 cm$^2$ (the smallest used in our department) up to 28 x 28 cm$^2$ at the depth of 10 and 15 cm along the central beam axis.

#### Test case 2

Rectangular fields were produced by exchanging the $x$ and $y$ jaws ($x \times y$ and $y \times x$) without collimator rotation. Rectangular fields and equivalent square fields were also examined along the beam axis.

#### Test case 3

SSD variation: 13 test points of isocentric setup were investigated in the beam axis, it includes the Anterior and posterior, box and tangential arrangements of clinical situations with symmetric as well as asymmetric fields.

#### Test case 4

Wedge filter: square fields of 10 x 10 cm$^2$ and 20 x 20 cm$^2$ modified with 15°, 30° and 45° wedge filter were investigated at the depth of 10 cm. Two measurements were performed along the beam axis for each of the possible wedge orientations. The average measured dose value was then compared with the corresponding calculated value.

### *Test case 5*

Central block: a diverging cerrobend block of 4 x 16 $cm^2$ dimension at the isocenter and 7.5 cm thickness resulting in 95% effective attenuation was investigated. Point dose measurements were performed for square fields of 10 x 10 $cm^2$, 15 x 15 $cm^2$ at the depth 10 cm for a SSD of 100 and 90 cm and at a distance of 0.5 and 1 cm away from the shielding block (2.5 and 3 cm from the central beam axis). The dose values were compared with the corresponding calculated values.

### *Test case 6*

Off-center planes: point dose measurements were performed for a variety of square fields and off-centred planes, *i.e*. [5 cm x 5 cm, 2 cm], [7 cm x 7 cm, 3 cm], [10 cm x 10 cm, 4 cm], [13 cm x 13 cm, 5 cm], [15 cm x 15 cm, 6 cm]. The average of the four off-center dose points in the cross-plane and in-plane directions was used as the mean off center dose value in both measurements and calculations.

### *Test case 7*

Oblique incidence: the aim of this test was to check the ability of the TPS to account for oblique incidence and skin contour variation. Using an isocentric setup and gantry angles of ±20°, ±30°, the dose was determined at two depths of 5 cm and 10 cm along the central beam axis for $FSD_{(Gantry\ angle=0°)}$=95 cm and $FSD_{(Gantry\ angle=0°)}$ = 90 cm. Field sizes perpendicular to the beam direction were 10 cm x 10 cm, 15 cm x 15 cm and 20 cm x 20 cm respectively.

### *Test case 8*

Inhomogeneous medium: An air gap of 3 cm height was created in the solid water phantom to check the ability of the TPS to account for the presence of in-homogeneities. The in-homogeneity was perpendicular to the beam axis and shape with a 20 x 20 $cm^2$ side area and 3 cm thickness. Point dose was measured at 10 cm depth, SSD = 100 cm along the central axis for square field sizes of 5 x 5 $cm^2$, 8 x 8 $cm^2$, 10 x 10 $cm^2$, 15 x 15 $cm^2$ .

### *Test case 9*

Asymmetric wedged fields: 16 number of test points were created at the depth of 10 and 15 cm along the beam axis with asymmetric field sizes {10 cm x 15($Y_1$:5,$Y_2$:10) cm}, {3($X_1$:2,$X_2$:3) cm x 10 cm}, {2 cm x 12($Y_1$:8,$Y_2$:4) cm}, {13($X_1$:9,$X_2$:4) cm x 7 cm} with universal wedges of 15° and 45° with both way of insertion.

### *Test case 10*

Build-up region behavior: 75 number of test points were created in the build-up region form 0.2 cm to 1.0 in steps of 1 mm and 1 cm to 2.2 cm in steps of 2mm for the field sizes of 5, 10, and 20 $cm^2$ with open, shielding tray, and wedge. The doses were measured using a parallel plate chamber.

### *Test case 11*

Shaped fields: Three irregular shapes were created using cerrobend blocks as to simulate 3D conformal treatment and 11 number of test points were created at the depths of 3, 5, 10, and 15 cm for simple and complex geometries.

## Results

Calculated ($D_{calc}$) and measured ($D_{meas}$) dose values were compared for each of the eleven test cases. The TPS dosimetric performance was evaluated by calculating the deviation (δ) at the specific depth,[14-16] using

$$\text{Percentage of deviation } \delta = \left\{\frac{D_{calc} - D_{meas}}{D_{meas}}\right\} \times 100\ (\%)$$

In total, 201 test point measurements and calculations were compared for the 6 MV photon beam of the linear accelerator. The final outcome of the comparison is summarized in Table 1, in the form of mean, maximum, and minimum deviations.

In test case 1, the TPS calculations for open square fields are in good agreement with measured values presenting a minimum deviation of –0.28 % and a maximum deviation

**Table 1: Results of test cases**

| *Test case* | *Description of test geometry* | *No. of test points* | *Percentage of deviation between calculated and measured dose δ (%)* | | | *Tolerance ± (%)* |
|---|---|---|---|---|---|---|
| | | | *Min* | *Max* | *Mean* | |
| 1 | Square fields | 18 | - 0.28 | 1.57 | - 0.12 | 2 |
| 2 | Rectangular fields | 14 | -0.08 | 2.38 | 0.75 | 2 |
| 3 | SSD variation (Isometric) | 13 | -1.44 | 0.15 | -0.56 | 3 |
| 4 | Wedged field | 12 | 0.24 | 4.09 | 2.18 | 5 |
| 5 | Central block | 4 | -1.92 | 0.13 | -1.03 | 3 |
| 6 | Off centre | 10 | -2.64 | 0.40 | -0.68 | 3 |
| 7 | Oblique incidence | 18 | -0.92 | 0.81 | 0.02 | 3 |
| 8 | In-homogeneity medium | 10 | 0.93 | 2.67 | 1.92 | 4 |
| 9 | Asymmetric wedged field | 16 | 3.40 | 5.47 | 4.54 | 4 |
| 10 | Build-up region behavior (30-80%) | 75 | -3.51 | 15.63 | 7.95 | 20 |
| 11 | Shaped fields | 11 | -0.44 | 5.94 | 1.86 | 2 |

of 1.57 % [Figure 1] and none of the test points exceed the recommended tolerance level of 2%. The results also reveal that as field size increases, deviations become negative, since the TPS tends to underestimate dose in relatively large fields. It may be the limitation of the algorithm that is used, and our results are agreeing with that of Sandilos *et al*.[16]

In test case 2, open rectangular fields were investigated. The minimum and maximum deviations are found to be –0.08% and 2.38% [Figure 2]. Except in two points, all of the test points satisfy the tolerance level of 2%. This finding, combined with the dosimetric verification of calculations for rectangular fields, supports the adequacy of the equivalent square method. Moreover, a trend of TPS dose underestimation with increasing field size is also observed for rectangular fields.

In test case 3, the influence of SSD variation on TPS dose calculations was investigated. The maximum and minimum deviations are found to be 0.15% and –1.44% [Figure 3]. None of the 13 test point measurements exceeded the tolerance level of 3%. As SSD decreases, absolute deviations were found to increase for all field sizes, being within the acceptable tolerance level. TPS dose calculations were smaller than measured values for most of the points.

In test case 4, the influence of introduction of wedge filters in the field were investigated. A minimum deviation of 0.24% and a maximum of 4.09% were observed [Figure 4]. Four of the 12 test points, the deviation are found to be more than the prescribed limit of 3% by Venselaar *et al*.[15] TPS was found to overestimate dose and also the deviation between the measured and calculated values were increasing with the wedge angles. In test case 5 the influence of introduction of central block in the beam was investigated. Four test points were measured in the inner beam and [9] maximum and minimum deviations of 0.13% and –1.92% were observed [Figure 5]. The results for all test points presented positive deviation, which were well within the recommended tolerance limit of 3%. This implies proper configuration of the TPS shielding block.

In test case 6, the accuracy of dose calculation in the off-centred plane were investigated, presenting a maximum and minimum deviation of 0.4% and –2.64%. Except in two points all other points are well within the tolerance level of 3%. The deviations are presented in Figure 6. The test case 7 investigates the influence oblique incidence of beam in the dose calculation algorithm, the deviations were found to be a minimum of –0.92% and a maximum of 0.81% [Figure 7], which is well within the acceptance limit of 3%. The deviations were found to increase with an oblique angle.

The test case 8 investigates the accountability of density

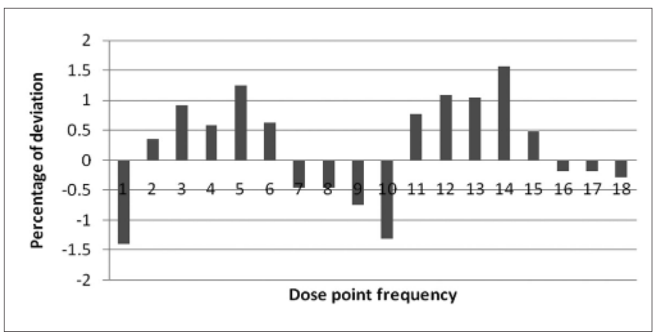


**Figure 1: Dose comparisons: Histograms of the differences between calculated and measured values in percentage for test case 1.**

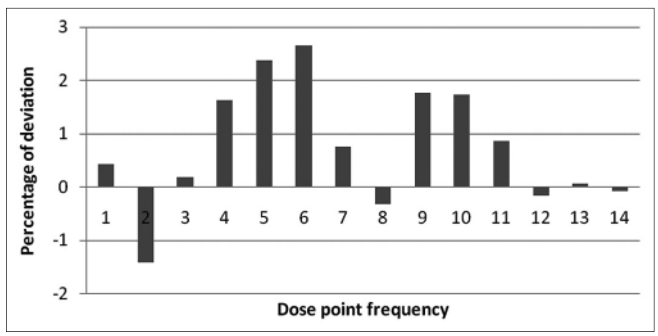


**Figure 2: Dose comparisons: Histograms of the differences between calculated and measured values in percentage for test case 2**

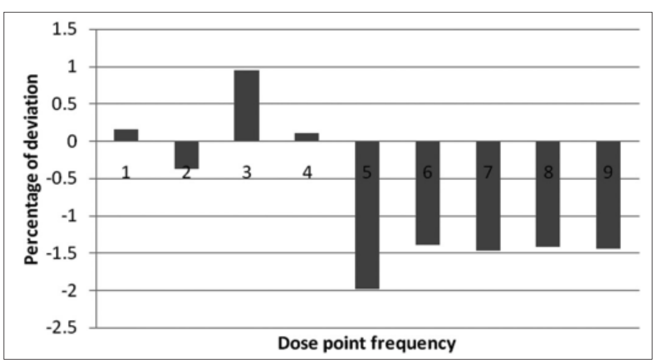


**Figure 3: Dose comparisons: Histograms of the differences between calculated and measured values in percentage for test case 3**

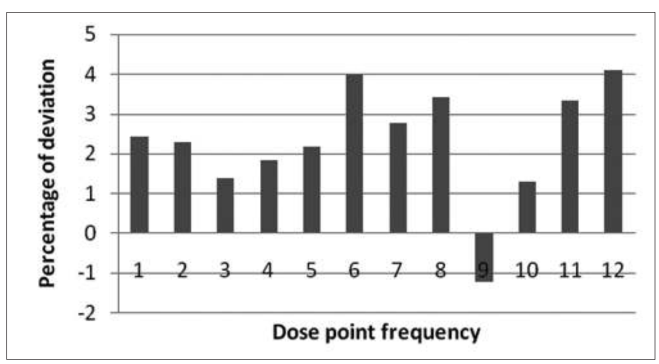


**Figure 4: Dose comparisons: Histograms of the differences between calculated and measured values in percentage for test case 4**

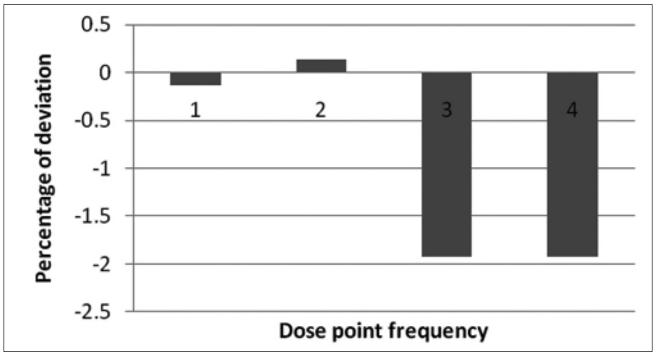


Figure 5: Dose comparisons: Histograms of the differences between calculated and measured values in percentage for test case 5

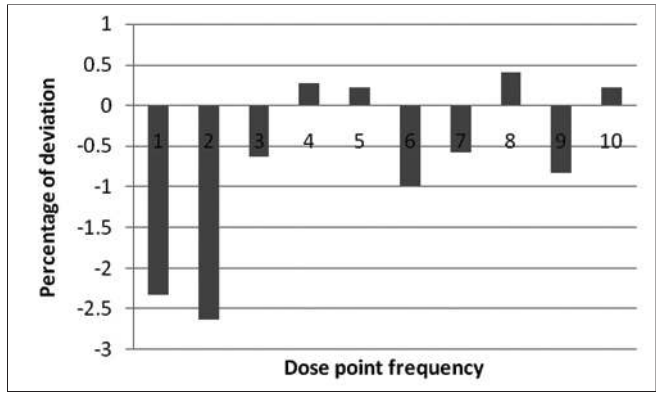


Figure 6: Dose comparisons: Histograms of the differences between calculated and measured values in percentage for test case 6

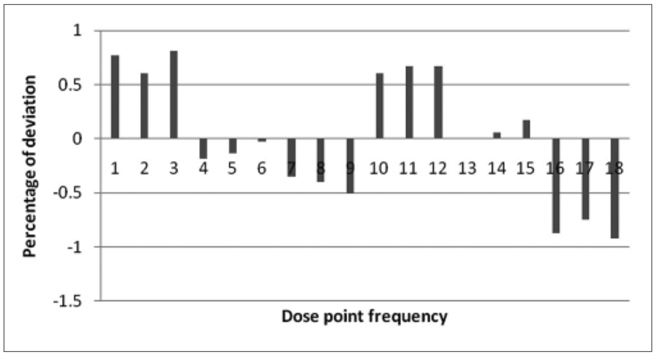


Figure 7: Dose comparisons: Histograms of the differences between calculated and measured values in percentage for test case 7

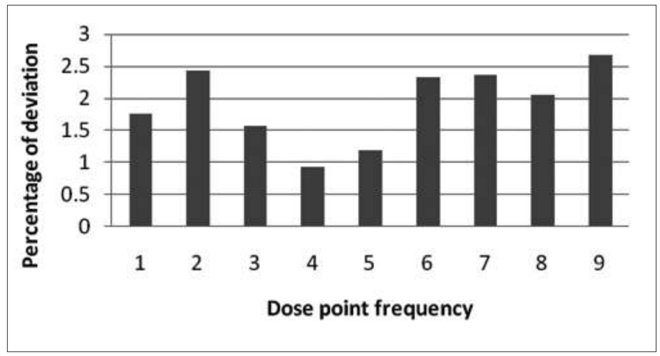


Figure 8: Dose comparisons: Histograms of the differences between calculated and measured values in percentage for test case 8

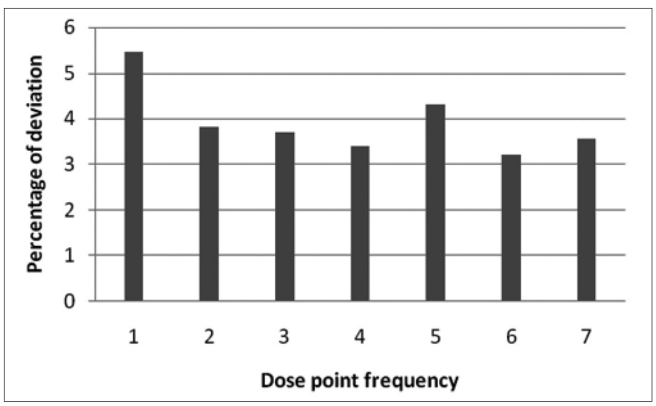


Figure 9: Dose comparisons: Histograms of the differences between calculated and measured values in percentage for test case 9

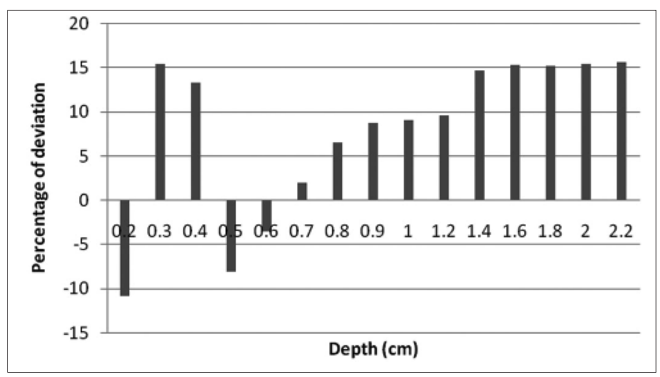


Figure 10: Dose comparisons: Histograms of the differences between calculated and measured values in percentage at different depths for 10 cm2 field size for test case 10

correction by the treatment planning system; the deviations were found to be in the range of 0.93% to 2.67% [Figure 8]. None of the test points exceeded the criterion of 3%. In test case 9, the influence of wedge filters in the asymmetric field were investigated, except in 2 test points of small field sizes all other point the deviations are well within the tolerance level of 4% as shown in the Figure 9.

In test case 10, the build-up region behavior was analyzed by measuring dose at 75 test points for open, wedged and shielding tray fields using the parallel plate chamber (PPC40, Scanditronix-Wellhofer, Germany). The build-up region has been divided into three parts as 20-30%, 30-80%, and 80-100% dose regions. In the region of 0.2 cm to 0.5 cm (20-30% dose), a maximum deviation of 14.28% and a minimum deviation of –10.82% is observed, and from 0.6 cm to 1.2 cm (30-80% dose region) of build-up region a maximum deviation of 13.16% and a minimum deviation of –3.51% is observed, in the region of 1.2 cm to 1.6 cm a maximum deviation of 15.63% and a minimum deviation of 13.16% is observed for the field size of 10 $cm^2$ [Figure 10]. The same pattern is observed for 5 and 20 $cm^2$ field sizes. The deviation were less only in the region of 30% to 80% of build-up dose region. All the deviations are within the tolerance limit of 20%.[9] The introduction of shielding

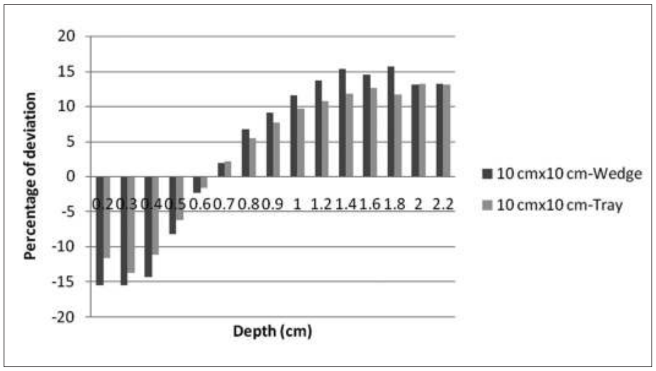


**Figure 11: Dose comparisons: Histograms of the differences between calculated and measured values in percentage at different depths for 10 cm2 field size with Shielding tray and wedge for test case 10**

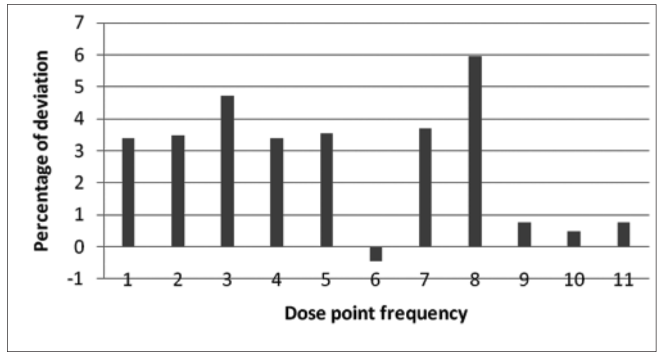


**Figure 12: Dose comparisons: Histograms of the differences between calculated and measured values in percentage for test case 11**

tray increases the deviation in the 20-30% dose region, and the deviations were found to be in the negative side. In the wedge field, at 30-80% of build-up dose region a maximum deviation of 12.61% and a minimum deviation of –1.68% is observed [Figure 11]; it may be due to the beam hardening. The deviations are found to be well below the tolerance limit of 50%.[9] In test case 11, cerrobend block-shaped field were used, a minimum deviation of –0.44% and a maximum deviation of 5.94% are absorbed [Figure 12], and the maximum deviation is absorbed in the complex geometry.[9] All other points are well within the tolerance limit of 2%.

## Discussion

The first criteria published by Van Dyk *et al.* in 1993[10] are characterized by increased tolerance limits due to the fact that most of the TPS were using two-dimensional algorithms at the time. The recommendations of AAPM TG53 report in 1998,[17] report 7 of the Swiss Society for Radiobiology and Medical Physics (SSRMP) in 1997[14] and Venselaar *et al.* in 2001[15] are generally more strict, but realistic for a properly functioning dose calculation algorithm. When the complexity of the geometry increases, however, tolerance limits may have to be less strict relative to beam modelling geometry. In this work the set of tolerance limits proposed by Venselaar *et al.* and TRS 430 is followed. The test cases used can be divided in three groups in terms of increasing complexity of the test configuration. The first group includes simple geometrical test cases (square and rectangular fields, SSD variation, off centre plane and oblique incidence) where dose calculations are performed in a homogeneous phantom for fields without special accessories. The second group includes complex geometrical test cases (wedge, central block, and in-homogeneities). The third group consists of more complex geometries which include combination of first and second groups. The first group of checks (test cases 1, 2, 3, 6, 7 and 11) has also been studied by Alam *et al.*,[1] Venselaar *et al.*,[15] and Sandilos *et al.*[16] for the older PLATO versions 1.21, 2.01, and 2.2.3, respectively. The Nucletron Plato version 1.21 employs a two-dimensional dose calculation algorithm, while versions 2.01 (Venselaar *et al.*), 2.2.3 (Sandilos *et al.*), and 2.7.2 (present study) employ a 3D dose calculation algorithm. Comparing results of these previous studies[1,15,16] with those of the present work for version 2.7.2, a continuous improvement of the system is evident. Although older TPS versions also met the tolerance limit for these test cases, a reduction of calculated to measured dose deviations is reported here. The above conclusion assumes ideal modeling of these systems.

In the second group of checks (test cases 4, 5 and 8), differences between the calculated and measured values are well within the tolerance limit of ±3% except for some points in the wedged fields. The present results are comparable with that of Sandilos *et al.*[16] Third group of check (Test case 9) examines more complex geometries, and most of the test point results fall within ±4% of tolerance.

However, it should be noted that only the accuracy of the dose calculation algorithm has been investigated without examining other potential inaccuracies associated with the geometry in the TPS (CT image acquisition and transfer, graphical display of 3D radiation beams, etc.). In addition, results of this work are limited to the 6 MV of the Linear accelerator photon beams.

## Conclusion

An attempt has been made to study the performance of the TPS (PLATO V 2.7.2) by using 11 numbers of test cases and 201-point dose measurements for a 6 MV photon beam. The measured- and TPS-calculated point doses are well within the tolerance of ±5%. The study concludes that (i) for higher field sizes the TPS tends to underestimate the dose for both square and rectangular field sizes, (ii) for smaller SSDs the deviations were found to increase, (iii) TPS was found to overestimate the dose for increasing wedge angles, (iv) the deviation were found to increase with an increase of obliquity of a beam angle, (v) in the build-up region analysis, the deviation were less only in the 30--80% of build-up dose region, the deviation were found to be less in wedged fields when compared with open fields and this may be due to the beam hardening effect.

The study has ensured the correctness of the beam data entered in the TPS during the commissioning. The usefulness of test data provided by TRS 430 and Venselaar *et al*. are verified for QA and inter-comparison of new radiotherapy treatment planning systems. Nevertheless, the beam modelling and basic data entered in each system depend on the user and the particular features of each system. This present methodology may be used to inter compare TPS, in various hospitals. This study also ensures that dosimetric calculations performed by the TPS is very accurate and enables the user to achieve the accuracy of ±5%, which is very much warranted in patient dose delivery.

## Acknowledgement

We acknowledge and thank the Dr. Kamakshi Memorial Hospital and the management for the providing the facility to carry out the work.

## References

1. Alam R, Ibbott GS, Pourang R, Nath R. Application of AAPM Radiation Therapy Committee Task Group 23 test package for comparison of two treatment planning systems for photon external beam radiotherapy. Med Phys 1997;24:2043-54.
2. International Commission on Radiation Units and Measurements (ICRU). Dose specifications for reporting external beam therapy with photons and electrons. ICRU Report 29, Baltimore, MD: ICRU Bethesda, MD; 1978.
3. Mijnheer BJ, Battermann JJ, Wambersie A. What degree of accuracy is required and can be achieved in photon and neuron therapy? Radiother Oncol 1987;8:237-52.
4. IEC 1217: "Radiotherapy equipment - Coordinates movements and scales 1996".
5. Bortfeld T, Schlegel W, Rhein B. Decomposition of pencil beam kernels for fast dose calculations in three-dimensional treatment planning. Med Phys 1993;20:311-8.
6. Sontag M, Cunningham JR. The equivalent tissue-air ratio method for making absorbed dose calculations in a heterogeneous medium. Radiology 1978;129:787-94.
7. Yu CX, Wong JW. Implementation of the ETAR method for 3D inhomogeneity correction using FFT. Med Phys 1993;20:627-32.
8. Andreo P, Burns DT, Hohlfeld K, Huq MS, Kanai T, Laitano F, *et al*. Absorbed dose determination in external beam radiotherapy: an international code of practice for dosimetry based on standards of absorbed dose to water. IAEA Technical Report Series no 398. Vienna: International Atomic Energy Agency; 2000.
9. Andreo P, Cramb J, Fraass BA, Ionescu-Farca F, Izewska J, Levin V, *et al*. Commissioning and quality assurance of computerised planning systems for radiation treatment of cancer. IAEA Technical Report Series no 430. Vienna: International Atomic Energy Agency; 2004.
10. Van Dyk J, Barnett R, Cygler J, Shragge P. Commissioning and quality assurance of treatment planning computers. Int J Radiat Oncol Biol Phys 1993;26:261-73.
11. Jacky J, White C. Testing a 3-D radiation therapy planning program. Int J Radiat Oncol Biol Phys 1990;18:253-61.
12. Ramsey CR, Cordrey IL, Spencer KM, Oliver AL. Dosimetric verification of two commercially available three-dimensional treatment planning systems using the TG23 test package. Med Phys 1999;26:1188-95.
13. Declich F, Fumasoni K, Mangili P, Cattaneo GM, Iori M. Dosimetric evaluation of a commercial 3-D treatment planning system using Report 55 by AAPM Task Group 23. Radiother Oncol 1999;52:69-77.
14. Swiss Society for Radiobiology and Medical Physics (SGSMP/SSRPM/SSRFM). Quality control of treatment planning systems for teletherapy. SGSMP Report 7, 1997.
15. Venselaar J, Welleweerd H, Mijnheer BJ. Tolerances for the accuracy of photon beam dose calculations of treatment planning systems. Radiother Oncol 2001;60:191-201.
16. Sandilos P, Seferlis S, Antypas C, Karaiskos P, Dardoufas C, Vlahos L. Evaluation of dosimetric performance in a commercial 3D treatment planning system. Br J Radiol 2005;78:899-905.
17. Fraas B, Doppke K, Hunt M, Kutcher G, Starkschall G, Stern R, *et al*. American Association of Physicists in Medicine Radiation Therapy Committee Task Group 53: Quality assurance for clinical radiotherapy treatment planning. Med Phys 1998;25:1773-829.

**Source of Support:** Nil, **Conflict of Interest:** None declared.