

# Methodology for Quality Control of Treatment Planning Systems for Use in Radiation Teletherapy

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**Abstract:** Radiation oncology requires appropriate planning of both target volume and location. The correct calculation of the target volume as well as the precise location of critical anatomic structures is vitally important to ensure the success of treatment. Treatment planning systems (TPS) are used in radiation teletherapy to simulate the projection of the field, its shape and the distribution of the absorbed dose over the volume of interest. This allows maximization of the absorbed dose in the target tumor and minimizes unnecessary exposure to other tissues. A quality assurance program is also important to ensure the effectiveness of treatment. In Brazil, in 2000, the Ministry of Health instituted a protocol to optimize the quality control associated with radiation oncology. In 2004, the International Atomic Energy Agency established a specific protocol for quality control procedures for TPS. However, an appropriate methodology to comply with these quality control procedures is needed. We propose a methodology for assessing the quality control tasks used in treatment planning systems. This methodology will evaluate the capacity of TPS to use the data generated by computed tomography and the table scanner to determine the appropriate distribution of the absorbed dose over the volume of interest.

## 1. INTRODUCTION

The location and definition of the target volume are fundamental to radiation teletherapy because they make possible the liberation of a larger dose inside the tumor while minimizing unnecessary exposure to the adjacent tissues [1].

Compared to the manual method of treatment planning, treatment planning systems (TPS) are more complex and involve the development of software that simulates the penetration, distribution and the deposition of energy (absorbed dose) inside the patient, thereby determining the best form of treatment [2].

The purpose of TPS is to delineate the target volume and to apply parameters such as field size to alter the dose distribution in the diseased tissue. For the treatment to be successful, the planned dose distribution to the target volume (as established by the TPS) should coincide with acceptance and commissioning data in each linear accelerator (LINAC). A mistake in the dose planning favors cancer recurrence and decreases patient survival [3, 4].

During the past few years, regulation agencies such as the International Atomic Energy Agency (IAEA) and American Association of Physicists in Medicine [5] have developed viable protocols that guarantee teletherapy treatment quality. In Brazil, in 2001, the Ministry of Health initiated the quality control (QC) protocol for radiation oncology, TEC DOC 1151 [6], in accordance at the International Atomic Energy Agency.

The aim of this protocol is to standardize the basic parameters associated with TPS used in teletherapy and

brachytherapy. In 2004, the International Atomic Energy Agency published another document, the IAEA Technical Report Series 430 (TRS 430) [2], entitled *Commissioning and quality assurance of computerized planning systems for radiation treatment of cancer*. The TRS 430 formalized the parameters for quality assurance. More recently, IAEA has published the *Protocol for specification and acceptance testing of radiation treatment planning systems*, TECDOC 1540 [7]. Others institutions have developed reports for acceptance testing of TPS.

According to Van Dyk [8], the TRS 430 is the most comprehensive of all these reports, because it attempts to provide a guide for the entire gamut of TPS worldwide. The TRS 430 and TEC DOC 1151 protocols establish the acceptance parameters associated with QC, but they do not provide the necessary methodology to implement the QC.

Several authors have analyzed the importance of quality control of TPS. As example, in Brazil, Camargo *et al.* [9] implanted a QC for TPS through the application of TRS 430. The acceptance criteria for that TPS were in conformity with the established protocol. However, the authors noted that most radiation oncology services in Brazil do not perform TPS quality control. In France, Denis *et al.* [10] observed that classical methods to assess the quality of TPS are to use physical test objects that are acquired with a CT installation by the system in place of the patient; however, quality assessment can be more accurate using digital test objects that can be analyze directly by the TPS. In Greece, a national comprehensive study of dosimetry quality audit of high energy external photon beams in all radiotherapy centers was carried out during 2002 and 2006, including the treatment planning systems (TPS) that were evaluated with respect to irradiation time calculations [11].

Our objective is to develop an improved methodology for TPS quality control that is applicable to many different

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**Table 1. Specifications of the Scanners Tables and CT**

Equipment	Hospital 1		Hospital 2	
	Manufacturer	Model	Manufacturer	Model
Scanner Table	Alket Corporation	ACT18028-1BL	Numonics Accugrid	-
Tomography	General Eletric	Hispeed NX/I	Toshiba	Aukelet

manufacturers, based on protocols TRS 430 and TEC DOC 1151. We propose a set of simple tests that provide exact results which can be adapted to any radiotherapy setup. We also identify the minimum number of tests necessary to evaluate the ability of TPS to acquire and process the data generated by the CT scanner, the scanner table and the dose distribution calculated from a homogeneous phantom.

## 2. MATERIALS AND METHODOLOGY

TPS was evaluated through the application of integrity tests to check the functionality of the software and hardware systems.

In order to evaluate the proposed methodology, two TPS set ups were tested. Two radiation oncology services that use these TPS in Northeast Brazil were designated as Hospital #1 and Hospital #2.

The data acquired by TPS were compared with those generated by the image acquisition facilities and the data obtained from the treatment machines, making possible the determination of the uncertainties associated with the use of TPS in the planning teletherapy treatment.

### 2.1. Performance of the Hardware, Software and Data Transfer

The performance of the hardware, software and data transfer were evaluated using computers at the radiation oncology service of Hospital #1 (PC-Hewlett-Packard; Server TC 21002.07; Processor, P-Intel Pentium (R) III CPU Family) and the radiation oncology service at Hospital #2 (Com-pag; Evo W8000; Processor, XEON™).

During all stages of the integrity tests, we attempted to verify the incidence of error messages and operational problems shown by the software at the two hospitals. Such verifications were related to the data transferred from both the table scanner and the CT to the two TPSs. The data from the table scanner and the CT are shown in Table 1.

Initially, the TPS exit data was verified at the dedicated HP Laser Jet 1329 printer at Hospital #1 and at the HP Business Injet 2600 printer used at Hospital #2.

The following sequence of integrity tests was performed on the collection systems that manipulate the data referred to the TPS:

1. Memory: We noted the time taken to process data used to calculate dose distribution generated by the TPS and thus evaluated the memory performance of the PC used;

2. Hand Disk (HD): a series of CT image slices were transferred to the TPS for the purpose of analyzing the storage capacity of the hard disc drive;

3. Operating system: the PC was restarted in order to detect flaws and error messages in the initialization program of the operating system;

4. Back-up: the acquired data from tests of dose distribution were saved in a pen drive in order to verify the reconstruction of this data by visual inspection;

5. Scanner table: the transfer region of the scanner table was verified using twenty random demarcations or digitalized points in the transfer region of scanner table;

6. Computed Tomography: the CT images obtained were selected as points. After processing by the TPS, the points were visually counted on the PC screen in order to quantitatively analyze the reproducibility of the TPS;

7. Printing of data: flaws in the TPS exit data were evaluated by printing test pages from each printer.

### 2.2. Performance of Contour Acquisition

Evaluation of the contour acquisition performance was made by means of entry, editing and display of the contours of regular geometric figures. To accomplish this, three geometric figures (a rectangle, a circle and a triangle) of known dimensions were drawn, digitalized and printed on each service. The dimensions of the rectangle were  $X_R = 12$  cm,  $Y_R = 6$  cm; the circle had a radius of 4 cm and was divided into 36 sectors; and the sides of the triangle were  $X_T = 12$  cm,  $Y_T = 6$  cm.

A physicist from each hospital transcribed the figure contours for TPS through all points. The points were individually united for the vertices of each figure in the scanner, except for the circle that had its transcription done through the binding of the 36 points corresponding to the circumference contour. The images were digitalized and printed using a scale of 1:1. The original and digitalized figures were overlapped to check accuracy. As specified by TRS 430, the variation in the measures did not exceed a difference of 0.2 cm between the entry and exiting data.

A phantom was used to verify the accuracy in the reference and reproduction of the anatomic data from the CT scanner and the definition of the contours by the TPS. The phantom was a cylindrical object composed of nylon with a density equal to 70 CT numbers (Hounsefield units), a diameter of  $4.17 \pm 0.03$  cm and a volume of  $204.89 \pm 0.05$  cm<sup>3</sup>. The images from this object were acquired using axial CT scanning technique. In Hospital #1, 162 slices with a thickness of 1.0 mm were acquired using 120 kV and 100

**Table 2. Parameters Used in the Tests of Dose Distribution During the QC Evaluation of TPS from Hospitals 1 and 2 [6]**

Tests	Field (cm <sup>2</sup> )	Descriptions
Punctual dose for squared field	5x5 10x10 35x35	PDD under isocentric conditions
Calculation of the inverse square law	10x10	PDD with the SSD of 95 cm, 100 cm and 105 cm
Field profile for squared field	5x5 10x10 30x30	To the depth of 1.5 cm, 5 cm and 10 cm
Field profile with filters	10x10	Filters of 30°, 45° and 60° to the depth of 10 cm
Field profile with central block	10x10	Block with 2 cm of width placed at nominal isocentre distance
Correction of contour	10x10	Field profile with 20° gantry angulation

mA. In Hospital #2, 54 slices with a thickness of 3 mm were acquired using 120 kV and 120 mA. The slices were transferred by a DICOM system at each hospital and reconstructed in their respective TPS. The TPS phantom reconstructions provided a comparison between the reproduced diameters and the actual diameters.

### 2.3. Evaluation of Dose Distribution

The tests to evaluate the dose distribution were divided into two groups. The first group tested the acquisition of the data by the TPS using a percentage of depth dose (PDD) and isodose curves. The second group tested acquisition using dosimetry performed in the treatment facilities, using depths of  $D_{max}$  equal to 5 cm and 10 cm. All the parameters used for the tests of dose distribution are presented in Table 2.

For the acquisition of data in the first group, a homogeneous water phantom with acrylic walls measuring 35 x 40 x 40 cm<sup>3</sup> was used for each TPS. This phantom is identical in size to the one belonging to the radiation oncology services (Medintec and CNMC). This phantom was sectioned into 40 slices, simulating the CT image slices. The dose distributions were obtained assuming a beam perpendicular to the phantom.

A table of data was created for each TPS, reproducing the beam attenuation in the water phantom. The data was compared with that obtained from the dosimetry for the various cases.

As a second step in the dose evaluation, the data acquisitions were performed using a photon beam of 6 MV, according to the IAEA TRS 398 [12]. Some dosimetric data, such as the PDD curves, beam profiles of square fields, dose distributions using compensating filters and data of Tissue

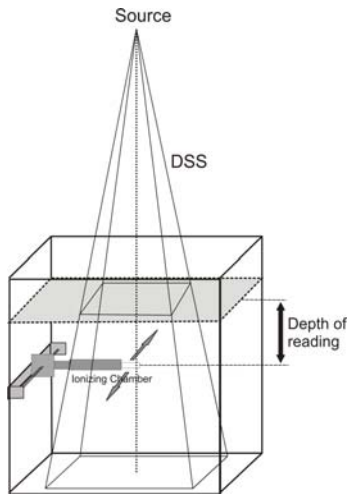
Phantom-Ratio (TPR) were obtained according to the commissioning measurements.

In all procedures, the source to surface distance (SSD) was 100 cm and the LINAC was adjusted to liberate a relative dose of 30 cGy at the depth of dose maximum. The measurements were repeated three times for every point of interest. The specifications of the ionization chambers used in the research are presented in the Table 3.

**Table 3. Characteristics of the Ionization Chamber Used in the Radiation Measurements in the Hospitals 1 and 2**

Specifications	Hospital 1	Hospital 2
Manufacturer	PTW	Wellhofer
Type	Parallel Plates	Parallel Plates
Model	Markus	PPC05
Volume	55 mm <sup>3</sup>	46 mm <sup>3</sup>
Wall of the chamber	0.03 mm	0.6 mm
Layer of electronic balance	1 mm	0.99 mm
Voltage Interval	±400 V	±300 V

For the dose distribution measurements, the ionization chamber was positioned on the beam central axis and was moved to the positive and negative side, as shown in Fig. (1). The ionization chamber was positioned on the dose plateau region at increments of 0.5 cm after each measurement. In the region where the increase in dose gradient was higher than 30, the readings were performed at intervals less than



**Fig. (1).** Dose distribution measurement procedures.

0.3 cm. The results for each measurement are described in Table 2.

The test of the inverse square distance correction used data from the TPR. For every SSD described in Table 2, the PDD was calculated using Equation 1,

$$PDD = TPR \times 100 \times (SSD + d_m)^2 / (SSD + d)^2 \quad (1)$$

In this equation,  $d_m$  is the depth of dose maximum (1.5 cm) and  $d$  is the depth of interest.

### 3. RESULTS AND DISCUSSIONS

#### 3.1. Performance of the Hardware, Software and Data Transfer

In the sequence of integrity tests on the collection systems, the manipulation and exit of the referring data to TPS were satisfactory. In the test processing, the TPS of Hospital #1 used an average of 2 minutes and 42 seconds for the implementation of each evaluation. In Hospital #2, this interval was 38 seconds and remained below 3 minutes, in accordance with criteria established by TRS 430. The difference in the times of processing between the two hospitals may be due to factors such as the type of processor used in the hardware, the method used by the program to calculate the dose distribution and the data storage capacity of the TPS.

#### 3.2. Performance of Contour Acquisition

The mistakes related to scanner table position, obtained from the QC tests, were compared with the initial values and the experimental results of the figures generated by the hospitals' printers. The results proved that the TPS was accurate in both acquisition and reconstruction of the data from the scanner table because they were in close agreement with the established criterion in TRS 430. The largest differences found between the entrance dimensions and the exit contours of the geometric figures were  $0.15 \pm 0.07$  cm for Hospital #1 TPS and  $0.05 \pm 0.07$  cm for Hospital #2 TPS.

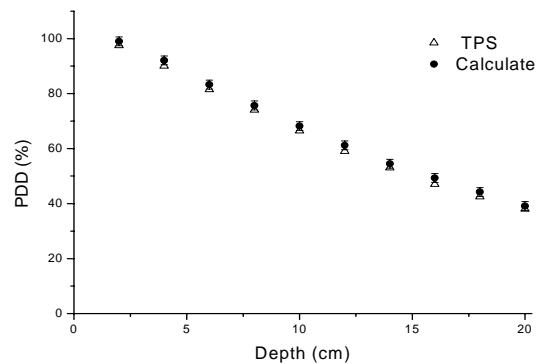
The difference in the virtual measurements obtained during the acquisition of the CT images (using the diameter of

the nylon simulator object) was  $0.04 \pm 0.03$  cm for Hospital #1 and  $0.06 \pm 0.02$  cm for Hospital #2. These values are in the satisfactory range for TPS accuracy according to established criteria.

#### 3.3. Evaluation of Dose Distribution

The results of the evaluation of punctual doses of squared fields were in agreement with the descriptions of the tests presented in the Table 2. They were, however, only partially satisfactory since a significant variation was seen in the acceptance criteria (a maximum 2% after the build-up region) for the  $35 \times 35$  cm<sup>2</sup> field used at Hospital #1. An increase of the relative error was also observed for TPS at Hospital #2. A maximum relative error of 1.3% was observed at a depth of 17 cm for the points confronted after the build-up region. Despite the increase in relative error observed, the results from Hospital #2 were in agreement with the established limits of TEC DOC 1151.

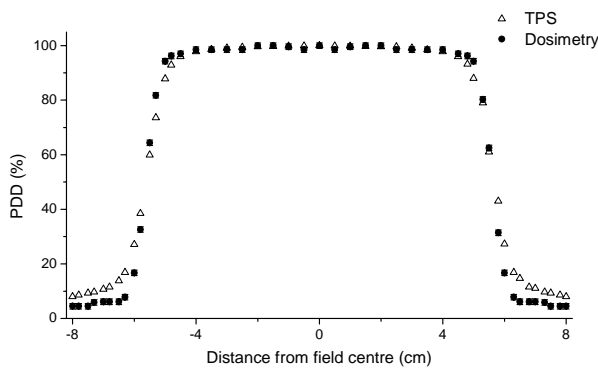
In agreement with the applied methodology for the calculation of the inverse square law, a 2.3% error was observed for the SSD at 105 cm in Hospital #1, which exceeded the acceptance criterion of 2%. That error can be visualized in Fig. (2) which shows the PDD distribution starting from a depth of 2 cm. At the three distances from the surface of the source at which the TPS of Hospital #2 was tested, the results obtained were in conformity with the expected results. The convergence of hospital #2, however, was still larger in relation to Hospital #1 and thus the results were satisfactory for both radiation oncology services.



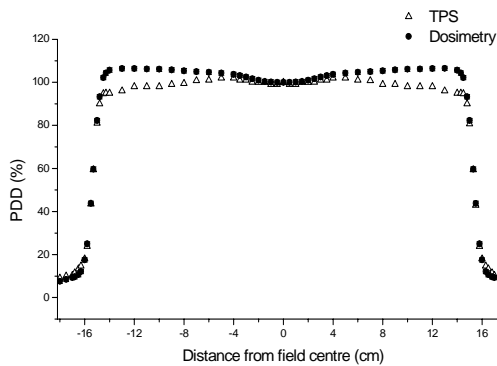
**Fig. (2).** PDD distribution generated by the TPS using dosimetric procedures with LINAC at Hospital #1 for a  $10 \times 10$  cm<sup>2</sup> field at an SSD of 105 cm.

When compared to the acceptance criteria, several discrepancies in the evaluation of the dose distributions were observed in the curves obtained from the TPS of Hospital #1. The result which was in greatest disagreement was acquired for the  $5 \times 5$  cm<sup>2</sup> field size at a depth of 5 cm. In this case, a deviation of 3.6 mm was observed for a distance of -3.3 cm from field center, exceeding the criterion of 4.0 mm established for the lateral region of the field.

Discrepancies in the dose distribution for  $10 \times 10$  cm<sup>2</sup> field were also observed in the measurement performed at the depth of 10 cm using the water phantom from Hospital #1, as shown in Fig. (3). That distribution exhibits relative



**Fig. (3).** Comparison between the dose distributions obtained from the TPS and of the dosimetric procedures at Hospital #1 for the 10x10 cm<sup>2</sup> field at a depth of 10 cm.



**Fig. (4).** Comparison between the dose distributions obtained from the TPS and of the dosimetric procedures at Hospital #1 for the 30 x 30 cm<sup>2</sup> field at a depth of 1.5 cm.

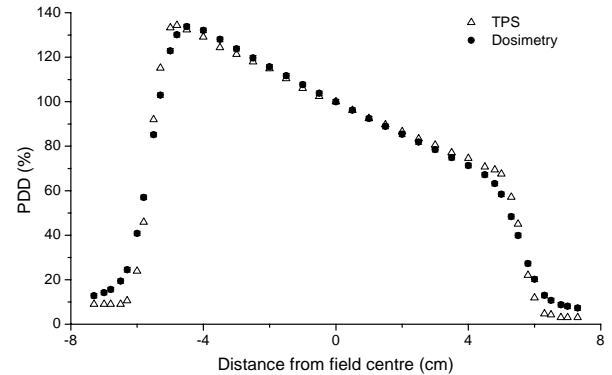
errors of 5.4% in the penumbra region. Moreover, this difference reaches 18 mm between the TPS and the dosimetry results at a distance of -6.3 cm from the central axis. According to established criteria, the maximum acceptable variations are 3% and 4 mm, respectively. Consequently, it is expected that these differences can provoke considerable errors in the dose within the target volume.

The largest difference observed for the dose distribution tests at Hospital #1 were in the plateau dose region using the 30 x 30 cm<sup>2</sup> field. That result was incompatible with the acceptance criterion which accommodates an error up to only 3%. According to Fig. (4), that relative error is observed at the ends of the dose plateau regions, making the dose prescribed by TPS lower than the dose emitted by the linear accelerator up to 10.7% at distances of -14.3 cm and 14 cm from the central axis.

Regarding Hospital #2, all results were in agreement with the acceptance criterion which was within 3% of the dose plateau region, 4 mm on the side of the field and 3% for the penumbra.

Significant differences were also observed in the placement of the wedge filters in the beam with the angles of 30°, 45° and 60° that were used to produce a gradient dose region. An error of 4.2% at -4.8 cm from the central axis and a dif-

ference of 15 mm between the side regions of the dose distribution for the 60° wedge was observed at Hospital #1 (Fig. 5). An error of 6.2% was verified in the penumbra region when a 45° wedge was used. In addition a lower dose was generated by the TPS compared to the one measured in dosimetric procedures. Therefore, the PDD curves generated by the TPS of Hospital #1 underestimated the dose up to 6.2% for the 45° wedge, which generates a higher dose distribution in the tissues adjacent to the target volume.

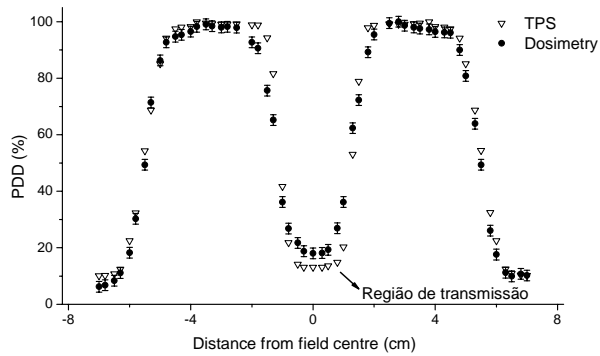


**Fig. (5).** Comparison between the dose distributions obtained from the TPS and of the dosimetric procedures using a 60° wedge at Hospital #1 for a 10 x 10 cm<sup>2</sup> field at a depth of 1.5 cm.

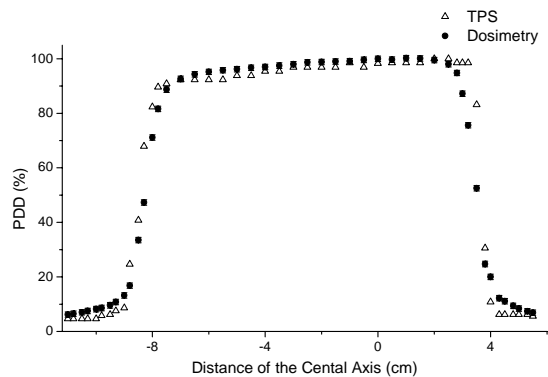
For the results obtained in the TPS of Hospital #2, a quick increase up to 7.6% in the peak of the inclined region of the plane dose was shown by the TPS using the 30° and 60° wedges. The dose increase attributed to TPS can also prejudice the therapy results, because the real dose values released in the target tumor by the accelerator do not reach the dose value prescribed.

The results obtained in the test performed with the alloy block attenuator showed the same variations in relation to the acceptance criteria of 4% for the dose plateau region, specifically, 4.0 mm on the side of the field and 3% for the penumbra region. The differences observed in Hospital #1 overestimate the relative dose attributed to TPS by the attenuator. In Fig. (6), the dose distribution generated by the TPS of Hospital #2 is compared with the isodose generated by dosimetric measurements of the therapeutic beam. TPS underestimated the dose by 5.7% in the transmission region in the centre of the block. An overdose was observed in the data obtained from LINAC, allowing an excess of absorbed dose in the organs in order to protect the block.

Fig. (7) compares the dose distribution from TPS and the profile generated by the dosimetric results from Hospital #1 using a 20° gantry angulation. From the figure, it is possible to perceive an underdose up to 4.9% at a distance of 4.5 cm in the penumbra region in relation to the central axis beam. Once the acceptance criterion for the penumbra region is over 3%, as established for TEC DOC 1151, the obtained result is not satisfactory for TPS of Hospital #1. A relative error of 6.8 mm is observed on the side of the field region near the PDD of 82.2% in relation of the points generated by the dosimetric procedures. This variation also contributes to



**Fig. (6).** Comparison between the dose distributions obtained from the TPS at Hospital #2 and the dosimetric procedures using an alloy block attenuator for a  $10 \times 10 \text{ cm}^2$  field at a depth of 10 cm.



**Fig. (7).** Comparison between the dose distributions obtained from the TPS at Hospital #1 and the dosimetric procedures using a  $20^\circ$  gantry angulation for a  $10 \times 10 \text{ cm}^2$  field of radiation at a depth of 10 cm.

the dose liberated in the target volume, as well as in the penumbra region.

The gantry angulations for the test of contour correction were appropriate for Hospital #2.

#### 4. CONCLUSIONS

We have improved the quality controls of the TPS by developing a method that analyzes the capacity of the TPS to process the data generated by the CT and scanner table, as well as to evaluate the dose distribution in a dedicated water phantom. In conformity with the protocols TRS 430 and TEC DOC 1151, this upgraded methodology makes available a group of simple tests that provide exact results. In addition, these tests, which are essential to the quality control of TPS, can be performed quickly and accurately thus

ensuring reliable results. The results obtained using our proposed tests allow the entire planned therapy dose to be liberated inside the target volume. Our quality control also minimizes the failures that can be associated with TPS in radiotherapy treatment. Therefore, from the conclusion of other authors and regulatory documents, it is correct to affirm that quality assurance programs, maintenance service and periodic quality control tests play an important role for achieving accuracy and safe operation in radiotherapy.

#### CONFLICT OF INTEREST

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