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Comparison of Dose Distributions in IMRT Planning Using the Gamma Function

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Intensity-modulated radiotherapy (IMRT) (1) is an advanced form of 3-D conformal radiotherapy. It uses non uniform spatial modifications in the intensity of the beams across the irradiated field. Consequently, it is necessary to develop sophisticated tools to compare measured and calculated dose distributions in order to verify the accuracy of the results of the planned dose distribution. Different methods have been developed to evaluate the accordance between measured and calculated doses, such as the point-to-point dose difference or the evaluation of the distance between two closed points having the same dose value (2-4). The verification method proposed by Low (5-7) seems to be more complete since it takes into account both the dose difference (DD) and the distance to agreement (DTA), allowing to define a "score", the gamma value, at each point of interest. A software tool (DDE: Dose Distribution Evaluator), based on Low's method, to evaluate the agreement between dose distribution matrices has been implemented. In particular, the proposed gamma curve, as a function of the isodose levels, gives real-time information useful for decision making about the treatment plan. The paper describes the software, and reports the obtained results in a simple geometry and in several clinical cases (head-neck and prostate). Comparison between measured data (film and MapCheck) and calculated data (CadPlan) using DDE has shown very good agreements. Thanks to its higher resolution, film dosimetry showed better accuracy than the MapCheck technique. Similar results can be obtained also with the MapCheck technique when proper measurement methods are used.

Key Words: Intensity modulation radiation therapy, Radiotherapy, Treatment planning system, Quality assurance, Gamma function

Considerable advances in radiotherapy dose planning can be performed with the implementation of sophisticated three dimensional dose algorithms. The progress of 3-D dose computations are closely coupled with computer performances. The complexity of the IMRT technique requires a high degree of computational power to assist the physicist in the optimisation process and in the technical implementation of the clinical prescriptions.

It is widely recognized that the correct use of IMRT in the clinical practice necessitates new Quality Assurance (QA) procedures (2, 8). The aim of the QA program is to assure the integrity of the planning and delivery systems. The QA program includes treatment planning software packages, and delivery issues involving MLC mechanics, electronics and software. IMRT requires highly time-consuming techniques, such as inverse planning (IP), because of the high degree of complexity of the clinical cases (the number of OARs and their relative weights in planning the treatment) and other parameters that drive the optimisation process.

IMRT needs, differently from other more conventional techniques, a dedicated quality assurance procedure for each patient. In fact, the steep dose gradients of IMRT plans make the deviation between calculated and delivered dose distributions critical in the region close to OARs. Planning, information transfer, delivery process, organ movement during irradiation and possible planning blunders can introduce approximations that affect the achievement of the therapeutic results. (9)

In the clinical practice, several devices can be used to measure the reference planar isodose distribution, e.g., radiographic films, ionisation chambers, diode arrays, portal imaging devices, etc. The main tools developed to evaluate the calculated planar isodose distribution are:

· DTA tool, to evaluate the distance between a given point of a measured dose matrix and the nearest point having the same dose value in the calculated dose distribution matrix;

· subtraction tool, where a subtraction routine is used to calculate DD, on a pixel-by-pixel basis, between two images;

· gamma function (6), a function that combines DTA and DD parameters to assign a score to the agreement between the dose distributions.

This paper describes a QA procedure to assess treatment plans in IMRT technique using the gamma function. A software tool, the Dose Distribution Evaluator (DDE) was developed after Low's method, to evaluate the agreement between dose distribution matrices. DDE accepts different format files both of calculated and measured dose distributions.

DDE has been tested on simple geometry distributions and applied to the study of some clinical cases (prostate and head-neck).

Materials and Methods

For a fast and objective evaluation of the accordance between calculated and measured dose distributions the method of comparison proposed by Low has been implemented in the DDE software package. Low's method (6, 7) is based on the definition of an ellipsoid in an 3D space where two dimensions are given by DTA and the third one represents the DD. For each point of the measured dose distribution map the distance from the nearest points of the calculated dose distribution map is calculated. This distance, called gamma parameter, is then normalized to the chosen tolerance values of the two parameters DD and DTA. When the gamma value is below the unit an acceptable accordance between the two points of the maps exists. The calculation is done on all points of the measured data so that the agreement with the calculated data is established. Since significant agreements have been obtained by the first two levels of Low's model, these are the only ones that have been implemented.

The DDE software package was implemented, for the Windows platform, in Visual–C using the OpenGl graphic libraries for the graphical output. DDE can manage data from several measurement devices, such as radiographic films digitized with Vidar 16X scanner and processed using RIT 113 software, or the MapCheck™ Model 1175 (Sun Nuclear, Melbourne, FL). The MapCHECK consists of 445 N-type diodes that are in a 22x22 cm^2 2-D array with variable spacing between diodes. Each detector has an active area of 0.8x0.8 mm^2 (10-13).

In this paper the dose matrices have been calculated with CadPlan 6.3.5, equipped with an Inverse Planning Helios 6.3 module, and the experimental measures performed with the Kodak film EDR (Extended Dose Range) and MapCheck. The DDE software gives results in real time (few seconds).

Main characteristics of the software

Notwithstanding the simplicity of the calculation of the gamma function, several questions arose while implementing the program.

DDE compares the dose distribution between two matrices (both in absolute and relative values), but does not distinguish measured from calculated data. Since it is good practice to consider the measurements as reference values, one should check whether the calculated dose agrees with them. Consequently, a distinction between the calculated and measured data has been maintained in the program.

As above stated, the software can read data from different sources and differently sized matrices.

When the measured matrix is greater than the calculated matrix, the former can be sized down to fit the latter; this is the case with data arising from radiographic film. The dose values can be computed by two different methods. Both methods generate a matrix using only the points of the measured matrix closest to the calculated ones. In one method the measured dose value is attributed to each point. In the other method the dose value is the average of the values measured on an area equivalent to the square of the distance between two close calculated points. The choice of resizing needs to account for the different algorithms used to calculate the dose matrix by the TPS.

Finally, according to Low's method, for each measured point, the corresponding points of the calculated matrix inside a district, defined as a square of two times DTA side, have been considered in the calculations. In order to preserve all allowable data in the district, the calculated matrix is not resized.

Should measurements performed in relative modality, the gamma function is calculated using

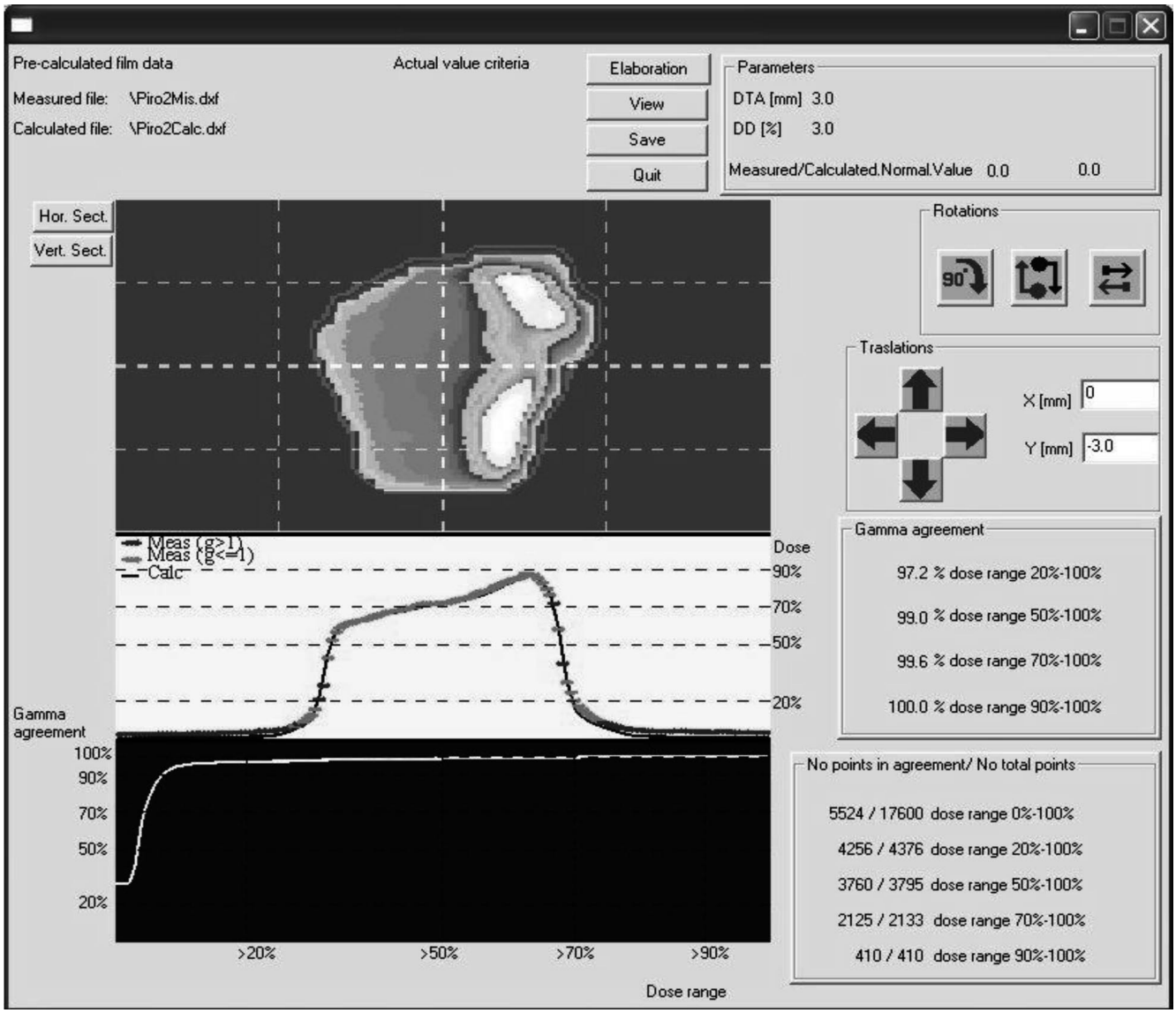

Fig. 1 - Comparison between film and calculated plan. Prostate.

dose distributions normalized to the respective maximum value; alternatively, a comparison between absolute dose distributions without any normalization can be made.

Even if the gamma function value could give an idea of the amount of the discrepancies between the data, a simple yes/no answer, i.e. by the percentage of gamma below or above the unit, was considered a good indicator because it allows a fast decision regarding the possible acceptance of the treatment plan. As a result, the gamma function calculation ends when a value below the unit is obtained - this means that, at the given point, the chosen DTA and DD values are respected. Different values of DTA and DD can be used in the calculation, if necessary.

Since the measured and calculated matrices can have different physical dimensions, some proper algorithms have been implemented to extract only the overlapping data.

The agreement between the two dose distribution data is expressed by the percentage of the measured points in accordance with the calculated ones inside the area defined by a given isodose level. These percentages are presented in a graphical way as a plot and in a numerical way for 4 selected dose levels (20, 50 70 and 90%), Figure 1.

Since the same percentage of agreement can be obtained from a different number of points, depend-

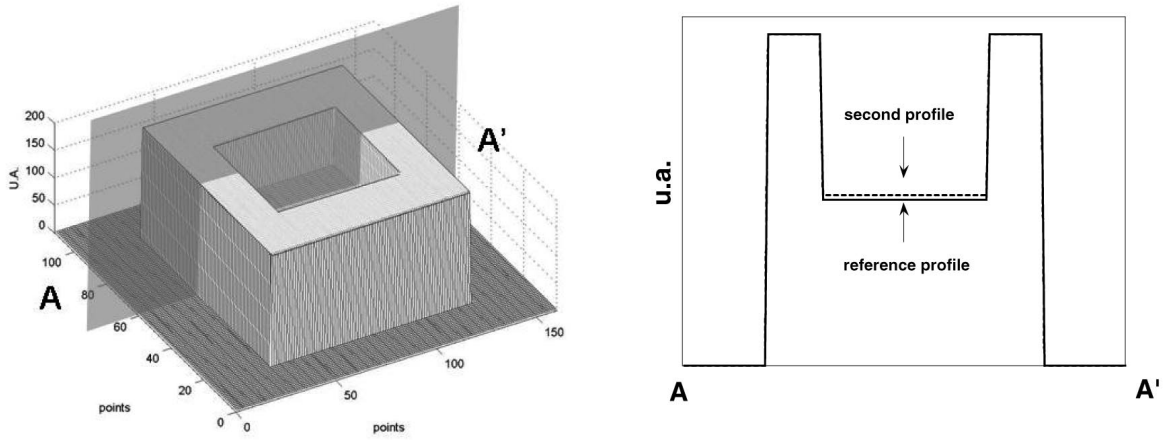

Fig. 2 - Dose distribution used to validate the software.

ing on the size of the measured matrix, the number of points the gamma calculation is based on is also provided.

A graphical view of horizontal or vertical dose profiles comparison is also allowed, the points resulting not in agreement are differently coloured to distinguish them from the others (Fig. 1).

Results

DDE has been tested by comparing the results with the theoretically expected values in the case of matrices of 160x112 points representing a distribution of data having the shape shown in Figure 2. The geometric shape makes steep gradient regions evident. Two tests have been performed: in the first the same measured and calculated data matrix was loaded and the evaluation carried out by entirely translating one matrix over the other along one axis. For each value of the translation the expected and the calculated number of total points and of acceptable gamma values were the same (Fig. 3).

The second test has been performed using two matrices with different dose values only in the central region (Fig. 2). The test has been carried out by varying the DD value in the range from 1% to 5%. As expected, unacceptable gamma values have been found for those points whose dose difference was higher than the chosen DD value.

Then DDE has been applied to some clinical cases of prostate and head-neck cancer. In order to investigate the possible dependence of the gamma agreement on the measurement technique, the same modulation fields have been verified by using both radiographic film and MapCheck.

As expected, due to the different characteristics of the two devices (resolution and detectors spacing), different gamma agreements have been obtained. Table I summarizes all the gamma agreements obtained.

The gamma agreement was found to depend on the measurement technique. Differences between MapCheck and film in the gamma percentage value have been observed at all isodose levels considered. This differences probably arise from different aspect of the experimental set up.

The discrepancy observed at the isodose of 90%

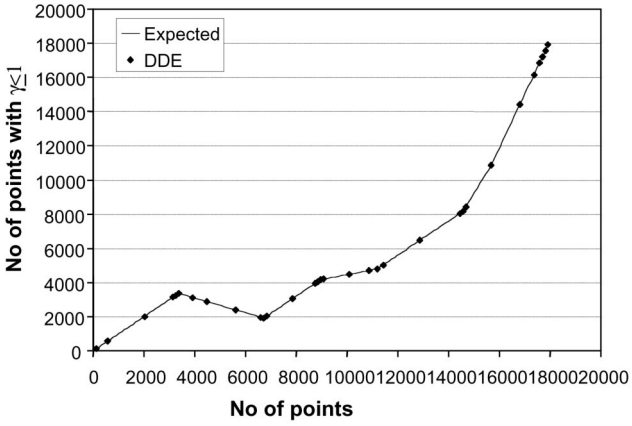

Fig. 3 - Expected and calculated acceptable gamma values.

Table I - Gamma agreement values in the clinical cases

Target	MapCheck				Radiographic Film			
	>20%	>50%	>70%	>90%	>20%	>50%	>70%	>90%
Head – Neck	83.7	89.1	91.4	100.0	80.0	84.1	94.8	100.0
Head - Neck	77.4	75.5	76.7	75.0	78.7	78.8	83.3	96.4
Head - Neck	76.2	82.0	87.8	88.5	83.0	87.6	93.5	99.7
Head - Neck	83.0	84.8	87.5	86.2	70.0	88.9	90.7	80.1
Head - Neck	96.4	98.2	98.4	88.9	76.9	89.2	94.6	100.0
Prostate	78.9	74.8	80.4	60.0	85.8	86.0	80.3	90.8
Prostate	94.4	93.5	91.5	95.7	86.4	92.1	89.8	90.8
Prostate	88.6	87.0	87.3	100.0	94.1	96.1	96.3	95.4
Prostate	91.4	95.8	97.8	100.0	80.5	86.7	88.8	98.0
Prostate	89.4	88.7	86.1	85.0	89.2	90.8	94.6	94.8

has been mainly attributed to the different number of points sampled by the two measurement techniques. As a matter of fact, at the higher dose levels, the gamma values obtained by MapCheck are very sensible to the number of points in agreement because of the reduced number of data available. In fact, in some cases only ten or less data have been detected in regions of isodoses of 90% or higher.

Furthermore, when the gamma evaluation is performed on normalized values, the value of the normalization factor is expected to be important. The MapCheck is expected to be more sensible to this problem because of the detectors spacing. Indeed, the maximun dose point of the delivered dose distribution could not correspond to a specific diode. Consequently, the normalized dose distribution and the isodoses shape depend on the device position, and as a result the gamma agreement also depends on the device position. To quantify this effect, the same field modulation, coming from a 5-field standard prostate treatment, has been delivered and multiple measurements have been performed by varying the MapCheck position along the x and y axis in the range of few centimetres from the reference position (in which the field isocentre is aligned with the device centre). In Figure 4 it is shown the gamma agreement dependence from the measured maximum dose: the agreement inside the 20 %, 50% and 70% isodose ranges from 71% to 89%, 66% to 88%, 76% to 97%. The results obviuosly depend on the particular intensity modulation but the influence of the device position has to be taken into account when the treatment plan verification is performed or when gamma agreements from different devices have to be compared.

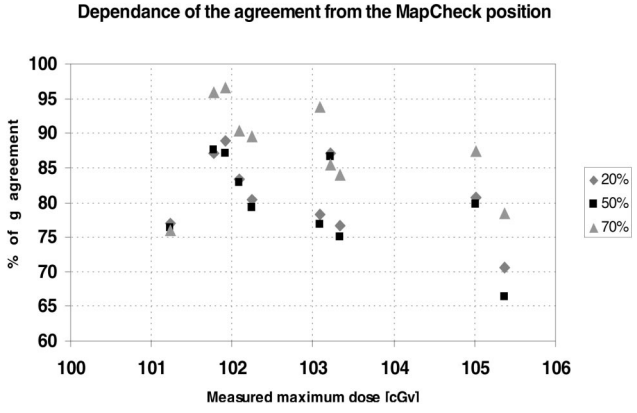

Fig. 4 - Influence of the gamma agreement from MapCheck Position.

The film is expected to be much less sensible to both the two experimental aspects above discussed but, obviously, it is also much more time consuming with respect to the MapCheck. In order to reduce the uncertainties arising from these problems, in our experience, the entire gamma agreement curve from 20% of isodose region should be studied since it gives a more complete information on the quality of the treatment plan under examination.

Discussion

A software package to compare calculated and

measured dose distribution data has been developed, tested and applied to some clinical cases.

As expected, different measurement techniques yield different results in the gamma function evaluation. Sometimes these differences are quite evident and could create problems in the acceptance of the treatment plan. Consequently, the decision should be based not only on a simple value of the gamma function chosen at a given isodose level, but the entire course of the gamma curve agreement should be considered along with the number of points actually processed.

The MapCheck is an interesting alternative to the film technique because it reduces the time required to make the measurements necessary to establish the appropriateness of the treatment plans, even though special attention must be paid to particularly complex plans. These could be more relevant when OARs are close to the zones where steep gradient doses are planned.

The present work aims to demonstrate that it is necessary to know the course of the gamma function through all the isodose ranges and the number of points processed in order to verify a calculated treatment plan.

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