EXPERIMENTAL DOSIMETRIC CHECKUP UNDER POSITIONING ERRORS ACCORDING TO GAMMA CRITERION

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Whereas the number of clinics benefiting from the option to provide radiotherapy treatments using modulated intensity techniques, detrimental to the 3D conformal technique, is significantly increasing, the need to ensure a high-quality treatment plan is also increasing; mainly using the gamma criterion. In order for a treatment plan to pass the gamma criterion analysis, at least 95% of the measured items should pass the gamma analysis for the 3%/3 mm criterion, and at least 90% for the 2%/2mm criterion [1].

This study aims at reviewing the impact of positioning errors in gamma criterion analysis (3%/3mm) on all its 3 axes (longitudinal, lateral and vertical), depending on the complexity of the PTV.

Keywords: positioning errors, dose distribution, IMRT, VMAT, γ analysis, patient QA;

1. Introduction

Modulated intensity techniques have been implemented as a result of the requirement to increase the dose of the target volume and the need to ensure a better protection for organs involved. Once the techniques used in radiotherapy have been improved, the risk related to actual treatment administration has also increased, and implicitly the need to ensure far more complex quality standards, as compared to prior techniques.

In what concerns quality, in the case of modulated intensity techniques, it is vital to ensure a high quality treatment plan, other than the conventional manual calculation used in 3D or 3D conformal radiotherapy. It is possible to verify the dose in accurately determined points, but it does not enable it to verify the leaves position of the multi-leaf collimator [1].

In what the risk associated with patient positioning is concerned, it has recorded a significant increase. Apart from the error according to which there is a risk that the PTV is no longer focused on by the irradiation field, once the modulated intensity techniques have been introduced, the intensity is modulated in

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such a way so as to obtain a homogenous dose throughout the entire irradiated volume, irrespective of the tissue density penetrated by the radiation down to the target volume.

The first technique ever used to modulate the intensity of a radiation beam in the history of radiotherapy, was done with the help of compensators, separately created inside hospitals' melting houses and they displayed a unique design for each particular patient [2].

All the intensity modulated techniques are more prone to errors due to the higher precision in target localization and also more vulnerable to uncertainties, mainly because of the steeper dose gradient and inhomogeneous fluence distribution. After performing acceptance testing and commissioning of the various aspects of the IMRT planning and delivery system separately, each IMRT technique should be checked by measuring the 3D dose distribution in a phantom and comparing its characteristics with the prescribed plan [3][4][5].

Because of the multitude of parameters per plan, for IMRT techniques compared to conventional techniques it is impossible to verify all combinations with the machine-oriented quality assurance (QA) experiments. It is possible to perform a manual calculation for the dose in each point of interest, but it is not relevant, considering that the fluence is modulated and a different dose might be delivered in each voxel involved in the beam [3][4]. Another question that comes out and needs to be verified before each treatment is the correct movement of the leaves. As matching between imaging, planning and plan delivery is a key factor, the patient specific QA is necessary. The image guided radiotherapy (IGRT) protocol which ensures a proper treatment delivery according to the patient's positioning is needed, but also patient specific QA which involves dose verification and the correct leaf movement check, all analyzed according to gamma criterion [6][7].

A γ index method of quantitative evaluation of dose distributions is a comparison between the measured and the calculated plan, both converted into the phantom. Basic idea consists in dose gradients area with higher, larger dose differences being acceptable. The method starts with the certainty that each point included in the plan has both a measured and a calculated dose. Using the formula (1), γ index can be calculated for each point of interest, depending how many detectors the phantom has [8][9][10].

$$\gamma_r = min \sqrt{\left(\frac{|r-r'|}{DTA}\right)^2 + \left(\frac{D_{m(r)}-D_{c(r')}}{DD}\right)^2} \quad (1)$$

Where:

- r = pixel from measured plan;
- r' = correspondent pixel in calculated plan;

- *DTA* = distance to agreement;
- *DD* = dose distribution;
- $D_{m(r)}$ = Measured dose in pixel r;
- $D_{c(r')}$ = Calculated dose in pixel r';

DTA and DD are determined values according to the requirements of each TPS. Most of the TPS requires DTA = 3mm and DD = 3%, values also used in the presented study.

In order for a pixel to pass, the condition is $\gamma \leq 1$. For a patient QA protocol it needs to be established the percentage number of pixels passing that needs to be reached in order for the plan to be accepted and the patient to start the treatment [9].

2. Materials and methods

Treatment plans have been calculated based on Eclipse treatment planning system, the calculus pattern PRO_13026 - Progressive Resolution Optimizer algorithm (Version 13.0.26) being used for optimization purposes, whilst AAA_13026 calculus pattern - the Anisotropic Analytical Algorithm (Version 13.0.26) were used for dose calculation.

The 4D checkup device Arc Check, a helical diode array dosimeter from SUN Nuclear having 1386 diodes and a virtual inclinometer with a 21 cm diameter and 27 cm active length of measurement using the software SNC Patient 6.6, Fig [1].

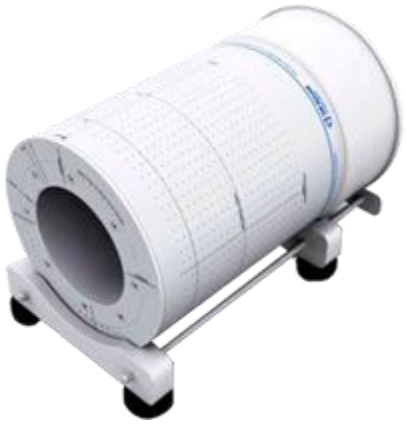


Fig [1] – ArcCheck device

Functions of interest when analyzing a plan according to γ criterion:

- TH – Isodose percentage line that defines the dose area to evaluate;
- Diff (%) – Percent acceptance criterion between set 1 and set 2 dose values;
- Dist. (mm) – Distance to agreement criterion;

- % Pass – Percentage of detector points that passed within the defined threshold with a pass/fail indication;
- Calc. shift – Determines if there is a misalignment between the measured and planed dose maps and automatically corrects for the misalignment if accepted by the user [8];

According to gamma criterion, 2 treatment plans have been reviewed with different PTV sizes.

It is shown in Fig [2] an example of the map dose of a calculated plan which is compared to a map dose the measured dose of the same plan Fig [3]. In order to compare the calculated with the measured plan the maps are overlapped and the mismatching points are taken into account in order to perform the gamma analysis.

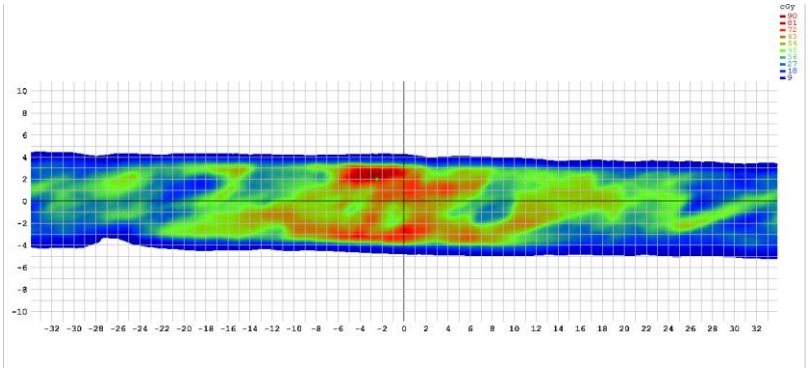


Fig [2] - Calculated dose distribution map

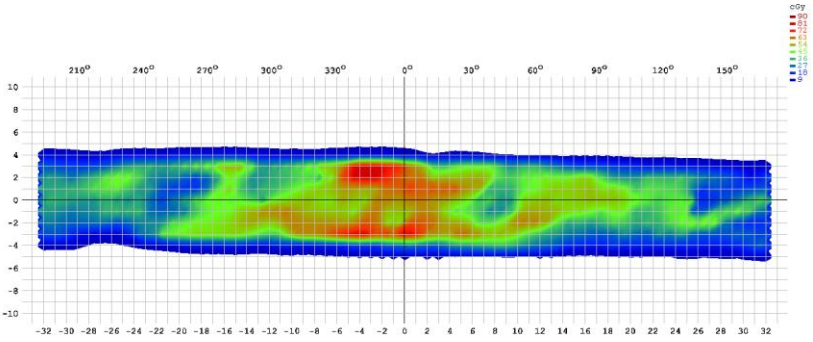


Fig [3] – Measured dose distribution map

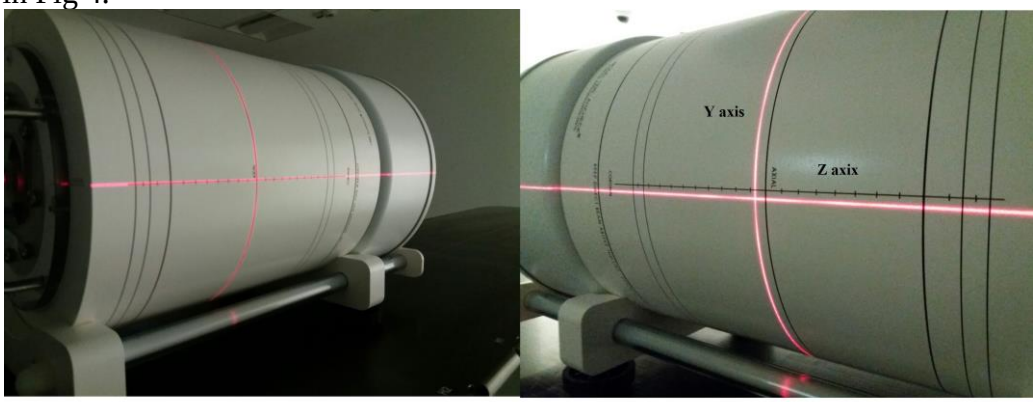
For case A, a treatment plan of a lung case has been carried out, with a PTV of 313.26 cm^3. Also, by using the VMAT technique, 2 half arcs between 30^0 and 181^0 and the second between 181^0 and 30^0 fields measuring 17,1x14 cm, have been performed. Coverage obtained for PTV V95%-D96.6%. The first arc provides 252 MU and the second 243 MU with a dose of 2Gy/fraction.

Case B focuses on irradiating a volume in the pelvis area, with a PTV of 1768.68 cm^3. The treatment plan has been performed with the VMAT technique, 2 full arcs, the first between 179^0 and 181^0 and the second counter-clockwise. The 23.1x26 cm fields and PTV coverage of V95%-D96%. Each of the two arcs provides 243 MU.

Leaving aside the clinical part, strictly from a physical point of view, the major differences between the two cases are conveyed by the size of the PTV on the Y-axis, but also by the electronic density of the irradiated tissue. (In case A the density is relatively homogenous between -40 and 150 HU and in case B the density in PTV varies significantly from -832 HU up to 111 HU).

Both plans were converted into the ArcCheck phantom for measurements. Each of them passed the γ analysis between 98.2% and 100% when proceeding the patient QA with DTA = 3mm and DD = 3%.

To evaluate the accuracy of the dose distribution during the simulated treatment, positioning errors were made for each of the three axis independently (X - lateral, Y - longitudinal and Z - vertical). For each plan, positioning errors from 2 to 2 mm were simulated up to 10 mm. The experimental setup is presented in Fig 4.



Correct positioning according to positioning lasers in treatment room

Positioning missmatching on Y and Z axis

Fig [4] – Experimental setup

3. Results

The results achieved from the measurements performed for case A starting from a correct positioning where 100% of the measured points have passed the gamma criterion, and the measurements were performed by placing the phantom every 2 mm from the origin point on the X-axis up to a positioning error of 10 mm. (An error which may occur in the clinical practice especially, on patients with tumors in the thorax area, mainly in clinics that do not benefit from a

respiratory gating system). Worst case scenario is represented by 32.5% of the measured points not passing gamma criterion.

In the next measurements performed with errors applied on Y-axis (longitudinally) and measurements with positioning errors applied on Z-axis (vertical), it can be observed that a positioning error over 4 mm affects γ passing rate over 5% according to γ criterion, meaning that 5% of the pixels do not achieve the condition of γ≤1. Based on the simulated errors, a major difference between independently measured results on all 3 axis may be noted. For a 10 mm Z axis positioning error, less pixels are not passing the γ criterion (18.7%) comparing to 32.5% pixels on X axis not passing the same γ criterion. The worst case scenario is met when mismatching on the Y axis. In this case only 46.5% of the measured points had passed the γ analysis when simulating a 10 mm positioning error on Y axis, meaning 53.5% pixels are not achieving the γ≤1condition.

The same measurements have been performed for case B, with positioning errors every 2 mm (Fig [7]), alongside all 3 axis (Fig [8]), independently, for the purpose of analyzing the gamma criterion depending on the movement.

By reviewing all data achieved, we may notice that positioning errors influence the analysis of gamma criterion, both depending on the PTV size as well as depending on the electronic density of the irradiated volume.

4. Discussions

A comparison between gamma passing rates for each measurement with positioning errors on all of the three axis are presented in the graphs below. 5th figure is assigned to case A and the 6th one to case B.

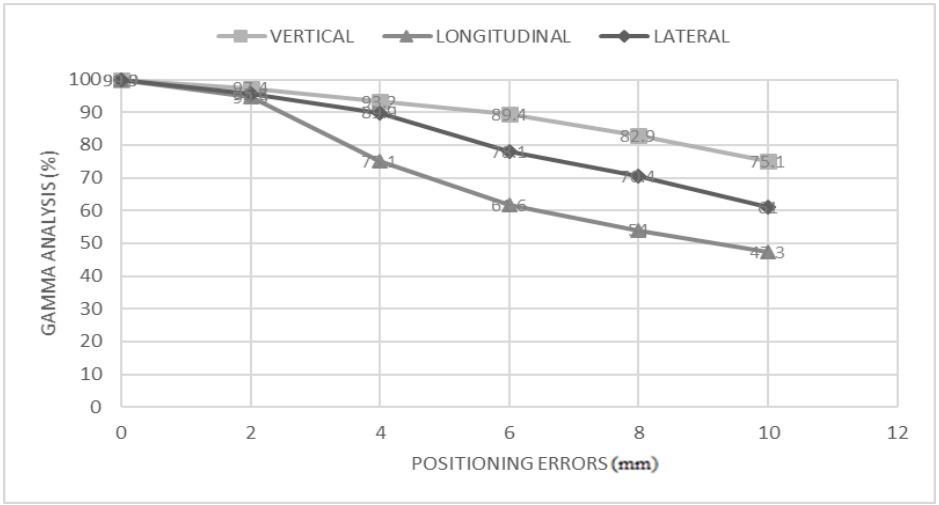


Fig [5] – γ passing rate, lung case (A)

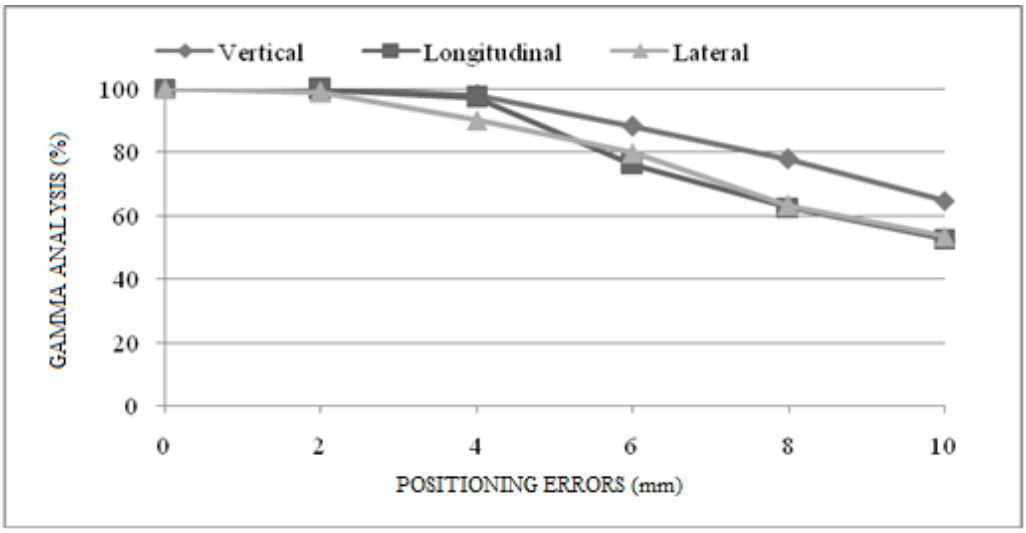


Fig [6] – γ passing rate, Prostate case (B)

Analyzing the two graphs above it can be resumed that: according to γ criterion the less passing rate is met when the positioning error is made on Y axis compared to the passing rate with the same positioning error made on Z axis. When mismatching on X or Z axis, calculated dose is not achieved by all the points. Considering that outside PTV the dose decreases sequentially and achieving a homogenous dose inside the PTV is important, the main problem of mismatching consist in positioning errors on the Y axis. That is the case where one entire slice or more could be completely out of the field. (OAR's are completely excluded from the study; the purpose of the study is to analyze how the positioning errors can influence the delivered dose into the PTV according to gamma analysis). Less passing rate during the performed γ analysis was achieved at case A with only 46.5% γ passing rate with 10 mm positioning error on Y axis.

PTV movements of 10 mm on the Y axis are entirely possible during breathing especially when an inferior lobe of the lung is treated, and no respiratory motion system is used.

In order to check if the number of points not fulfilling gamma criterion grows with the number of axis of mismatching, the dose distribution map with mismatching on 2 axes in the same time and with mismatching up to 10 mm on all of the three axis were measured for case B.

Fig [7] presents the gamma analysis results when mismatching on x and y axis with a constant correct positioning on z axis. In gamma analysis the number of passing points drops significantly from 84.1% when mismatching 2 mm on 2 axis compared to 98.2% when mismatching 2 mm on one axis. This difference is recorded in all analyzed cases.

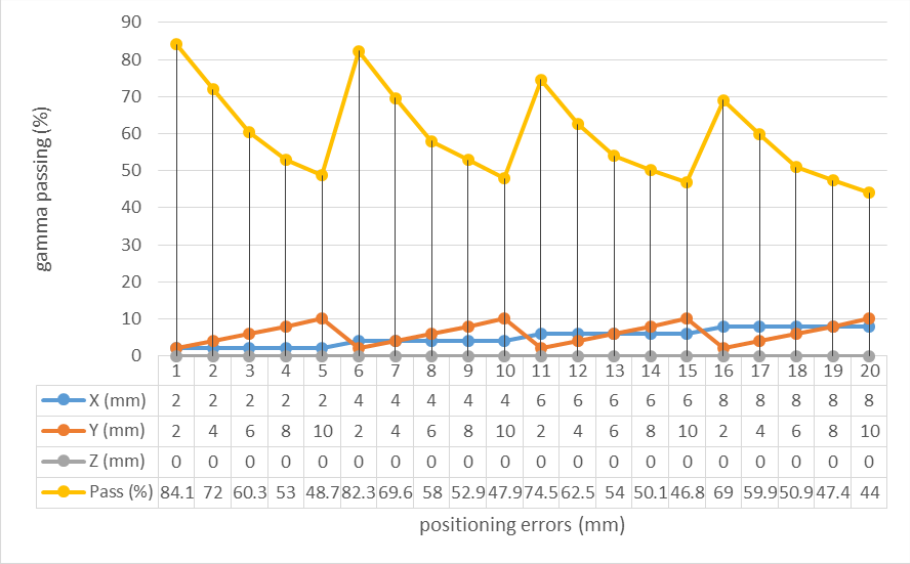


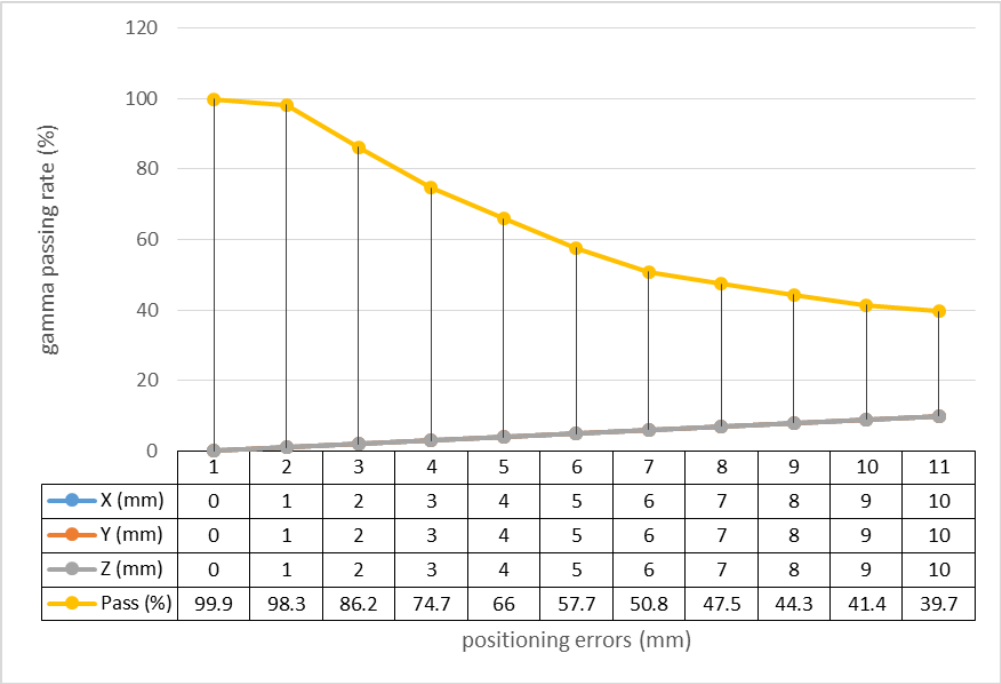
Fig [7] Positioning errors on 2 axis (X and Y)

Gamma analysis results for all three-axis mismatching is presented in Fig [8]. There is an unexpected similarity between mismatching on 2 axes compared to the mismatching on all three axis. For example, 2 mm positioning error on 2 axis gives a smaller gamma passing rate (84.1%) versus 2 mm mismatching on all three axes (86.2%).

This error can occur in cases when two different points (A and B) collect the same amount of radiation using the same intensity of the beam. There is a possibility of a random comparison in gamma analysis, between the measured point A and the calculated point B or the other way around. That would lead to a false positive result in gamma analysis.

The probability of a false positive analysis is higher when the dose distribution in the target is more homogeneous and the electron density in the area is similar. The probability of this error to occur drops with the distance of mismatching from the origin point.

Overall, worst case scenario was recorded when mismatching on all of the three axes, with 39.7% gamma passing rate for 10 mm positioning error



	1	2	3	4	5	6	7	8	9	10	11
X (mm)	0	1	2	3	4	5	6	7	8	9	10
Y (mm)	0	1	2	3	4	5	6	7	8	9	10
Z (mm)	0	1	2	3	4	5	6	7	8	9	10
Pass (%)	99.9	98.3	86.2	74.7	66	57.7	50.8	47.5	44.3	41.4	39.7

Fig [8] – Positioning errors on all of the three axes

In clinical practice random or systematic errors are any time possible. It is important to keep in mind that the patient is physiologically active, not having a regular geometrical shape and nearly impossible to reposition at each treatment session such as each voxel in the patient's body collects exactly the same dose as TPS had been calculated for each voxel. Also, to remember that the bigger the number of axis with positioning errors is, the larger the space between the voxels will be.

Comparing the collected dates is it noticeable that a mismatching on the Z axis will result in a more serious error as the PTV diameter is bigger.

5. Conclusions

Less than 50% of measured points are passing γ criterion when mismatching up to 10 mm, PTV movements entirely possible during breathing especially when an inferior lobe of the lung is treated, and no respiratory motion system is used.

Using the new treatment techniques and having a better precision in the targeted structures doesn't necessarily mean that better treatment is delivered.

As shown in the graphs, worst case scenario when mismatching on one of the three axes is met when the positioning error is made on the Y axis as the dose is more shifted in the detectors.

Worst case scenario in practice is a mismatching on all of the three axis at the same time.

In order to obtain a real correspondence between the theoretical and the real dose distribution it is absolutely necessary a QA system including contention systems, portal imaging and dosimetry checking systems.

R E F E R E N C E S

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