COMPARISON *OF* TWO PRE-TREATMENT VERIFICATION METHODS *FOR* ARC – IMRT PLANS

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ABSTRACT

In radiotherapy, the application of the IMRT arc technique, a special technique of external beam irradiation, while providing greater ballistic accuracy and personalization of treatment, as well as better speed of execution, requires special attention to the development of the treatment plan and its verification.
Therefore, tools and methods of physical-health analysis that allow verification of the accuracy of the delivery of the radiant beam in the stages prior to treatment are essential. At the unit of Medical Physics at Dimiccoli Hospital Barletta, a prospective experimental study was conducted based on the comparison of two different methods of pre-treatment verification in patients treated for prostate cancer with the aim of increasing the performance of the treatment workflow.
A comparative evaluation of gamma analysis results on images acquired with a 2D flat panel detector EPID (Electronic Portal Imaging Device) on the one hand and a 2D ionizing chambers detector on the other hand was conducted. The study sample included 38 patients undergoing radiotherapy with IMRT between December 2021 and October 2022, and each subject was studied and verified with both methods.
The results of gamma analysis conducted with the two methods of pre-treatment verification of patients with prostate cancer are superimposable. In addition, with EPID we have a significant saving of machine time and thus allows an increase in the number of patients undergoing daily radiotherapy.
In light of internationally accepted dosimetric and radiation protection accuracy standards according to Decree 101/2020, pre-treatment verification of dose distributions, using a 2D flat panel detection system (EPID), was found to be in line with waiting list reduction goals.

INTRODUCTION

Radiation therapy over the years has developed more efficient techniques that have made possible to treat patients with tumors of complex geometries, ensuring eradication of the disease and sparing of organs adjacent to it. The technique that allows us to irradiate by conforming the dose to the target in the best possible way is arc IMRT. Given the complexity of this treatment technique, it becomes essential to verify patient's plans, which is done through a direct measurement that is known as quality assurance (QA), aimed at verifying the agreement between prescribed dose and delivered dose to the patient. The aim of the analysis performed is to find the match between the two dose distributions through the gamma index calculation.
The 2018 AAPM Task Group 218 report provides a comprehensive review aimed at improving the understanding of tolerance limits and the methodology by which these checks are done.
Different RT facilties have implemented tolerance criteria guidelines, but the procedures and devices that can be used to perform these checks differ.
Thus, our study stems from the need to assess whether the effectiveness of the various methods is superimposable or whether there are methods that might prove for some reasons to be better to use.
The two detectors considered are the EPID system and the MatriXX system.

MATERIALS AND METHODS

The measurements were carried out at the Medical Physics Unit of the "M. Dimiccoli" Hospital in Barletta. The sample included 38 male subjects with prostate cancer. All patients were treated with radiotherapy with an arc IMRT technique between December 2021 and October 2022 in the Radiotherapy Unit in Barletta. RT plans included 1 or 2 PTVs corresponding to prostate and lymph nodes: eleven plans with 1 arc and twenty-seven with 2 arcs. The linear accelerator used to deliver treatment and perform testing was the CLINAC 2100 VARIAN (Varian medical Systems Inc, Palo
Alto, USA) equipped with wall-mounted laser centering 49 systems, a four-degree-of-freedom treatment couch, EPID and OBI for imaging in the kilovoltage range.
The EPID integrated into the LINAC on which plan checks were delivered is the Varian aS1000 (PortalVision, Varian Medical Systems, Palo Alto, CA). It is an amorphous silicon flat-panel imaging device mounted on a robotic arm. The other detector used to

Fig. 1 - *MatriXX in operation*

deliver the treatment plans is the IBA MatriXX EVOLUTION.
The software used to conduct gamma analysis are: - Varian's Treatment Planning software ECLIPSE v1.01, Portal Dosimetry, for the EPID system; - OmniPro-I'mRT program (IBA Dosimetry) for the MatriXX sytem.
The first step to proceed in the study was to enroll radiotherapy plans from patients who had treated their prostate with arc IMRT. For each one, we created verification plans for both methods, which were approved and scheduled for the LINAC. It was of main importance to deliver the two plan verifications on the same day to break down differences in LINAC performance that would not have allowed us to make an appropriate comparison between the two methods. The checks were conducted during the machine slot time dedicated to Medical Physics QA, following the daily LINAC QC. Procedures to set-up the phantom connected to MatriXX detector must be done precisely and millimeter-wise to ensure that the center of the detector corresponds with the isocenter of the target and that the measurement is correct. During the delivery, the MatriXX is placed under the gantry header on the treatment table, embedded in a Multi cube phantom, which consists of two plates, one reconstruction plate and one backscatter plate, so that the scattering can be measured to resemble that of the human body.

Fig. 2 - *Arc IMRT angular correction sensor*

Fig. 3 - *EPID integrated in the linac*

When using backscattering plates, the center of mass is on the side of the electronics, so we have to support the electronic part of the device to eliminate the risk of the MatriXX tipping over. To overcome this we use an immobilization device for the patient's head that will give us the proper support. The detector is then connected to the PC in the control room via an Ethernet cable or via an existing LAN. Next, the gantry angle sensor is placed. Its purpose is the in-line detection of the gantry angle during
irradiation for treatment verification. The sensor should 75 be attached to the gantry using powertrips and tape. Measurement parameters are set in the software and the first measurement can be acquired after measuring the detector background. Then, the 2D dose distribution delivered on the MatriXX and the calculated dose distribution are available for comparison in the OmniPro I'mRT software.
Before proceeding with dose comparison with MATRIXX, we also delivered the verification plans created for EPID system in order to obtain similar LINAC beam characteristics and consequently a more realistic comparison of the methods. For the preparation of EPID verification we need to use a remote control that allow us to extract the EPID and to position it thanks to its robotic arm at 100cm from the header LINAC. This allow us to simplify the execution of the verification and to preserve adequate spatial resolution. Planar maps of delivered fluence will then be recorded in terms of fluence (for EPID system) and dose (for MATRIXX system), which will later be compared with those predicted in the plan calculated by the TPS.
The 2D maps comparison was conducted with gamma analysis where we compared calculated and measured dose distribution. To do this analysis, the software uses Dose Agreement (DA%) and Distance To Agreement (DTA) as main parameters to be used for gamma calculation. DA% is defined as the percent-

age difference between calculated and measured dose values.
The DTA is resolved as the minimum spatial distance between a pixel in the calculated distribution and a pixel in the delivered distribution to be evaluated with the same dose value.
The use of only these two parameters for the comparison of the two dose maps, however, is not exhaustive in areas where the dose gradient is intermediate, because they process a qualitative analysis rather than quantitative analysis. This problem is solved by introducing the γ-analysis, which includes a combination of the two parameters presented above, but generates one.
The most basic quantitative analysis consists of punctually examining the differences in dose values between the calculated and measured maps and allows us to visualize regions of over- and under-dose with coloured maps. A method of investigation to takes this into account is that of 'differences over region of interest': given a dose point on the calculated matrix and an ellipsoid radius defined by the two tolerances Δd spatial displacement and ΔD dose difference, a point is found in the measured dose matrix that satisfies the condition GAMMA ≤1 (Gamma is the two dimensional deviation over dose and distance); in formula.

$$\gamma = \sqrt{\frac{(D_m - D_c)^2}{\Delta D^2} + \frac{(d_m - d_c)^2}{\Delta d^2}}$$

Fig. 4 - *Mathematical formula of gamma analysis*

From this calculation we derive the percentages that are useful in determining whether the plan is acceptable. Tolerance limits are defined as the limits within which a process is considered to function normally, i.e. subject only to random errors. From AAPM 218, defining the Area in which the gamma index between the two dose distribution maps is calculated, it must be verified that: -Tolerance limit: the gamma index must be less than 1 in an area ≥95%, assuming 3% ΔD and 2mm DTA, with a dose threshold of 10%. -Action limit: the gamma index must be less than 1 in an area ≥90%, assuming 3% ΔD and 2 mm DTA, with a dose threshold of 10%.
For each plan, we calculated the resulting gamma index with MatriXX and EPID, using the corresponding software and we noted down all the values of ΔD, DTA and the percentage gamma index value.
The dose threshold we used wis 10% and represents the dose range within which the gamma index must be calculated. It is set at 10% for both methods in order to ensure a more truthful comparative analysis and is also recommended by the AAPM report TG 218.

RESULTS AND DISCUSSIONS

In table number 1 we display the gamma index results obtained from pre-treatment
testing with EPID and MatriXX. To arrive at this result, the threshold dose of 10% and the
tolerance criteria ΔD of 3% and DTA of 2mm were set for all gamma analyses corresponding to
each patient and both methods. By setting these values we were able to make a closer comparison of the two detectors and calculated for each plane whether the gamma index was less than 1 in an area < or > 90%.
For all planes with gamma ≤1 in areas < 90%, 127 the physicists reviewed the treatment plan at the TPS in order to exclude gross optimization errors. In the second instance, the distribution of areas with gamma >1 was analyzed jointly with the radiotherapist in order to identify in detail the corresponding anatomical areas and in particular whether these areas included or were in the proximity of critical OARs. Plans in which this condition was excluded were accepted and delivered to patients.
The main result of this analysis is that for 18 out of 22 plans, the outcome of the checks agrees in both methods. In the remaining 4 plans we find a difference, as shown in table 2.
For patient no. 14, we checked the output of the machine on the day of the verification delivery and we found that the LINAC output was higher than the reference output. We then repeated the gamma analysis

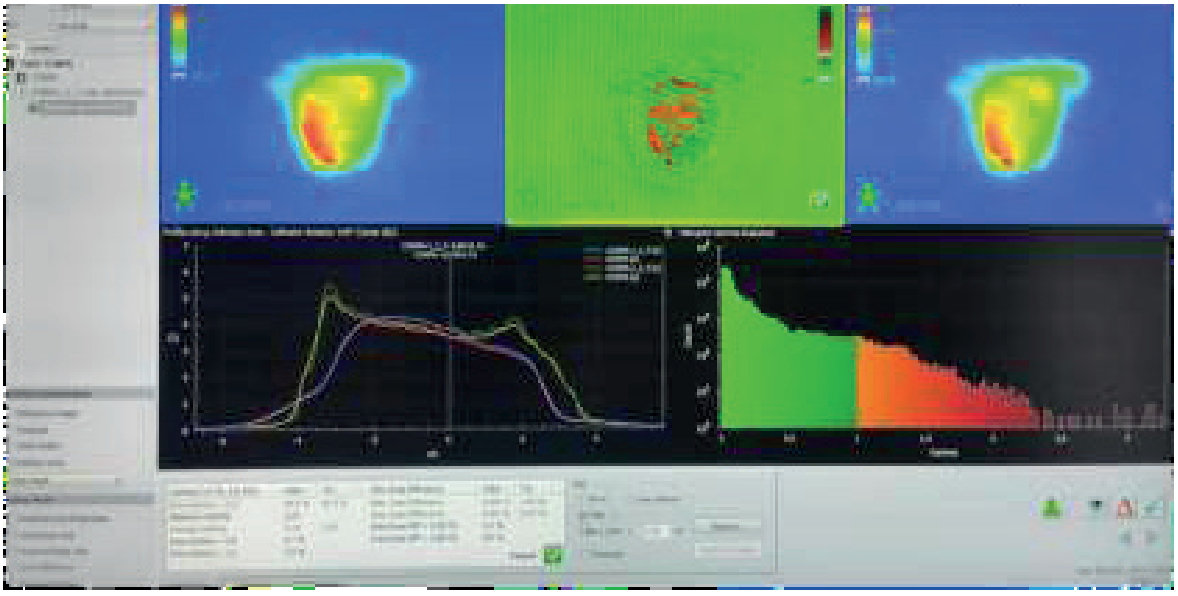

Fig. 5 - *Portal Dosimetry screen of the EPID detector software*

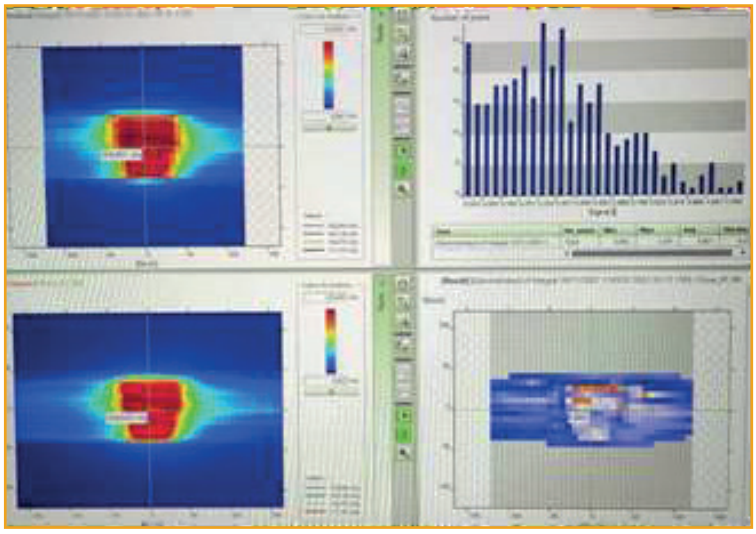

Fig. 6 - *Comparison of the two fluences from OmniPro-219 I'mRT software (IBA Dosimetry)*

using ΔD tolerance criteria of 4% and DTA of 2mm, using a less stringent dose difference criterion and in this way the area where the gamma index was ≤1 became ≥ 90%.
Patients No.3, No.19 and No.20 passed the test with EPID using criteria of ΔD of 3% and DTA of 3mm.
In addition to the above-mentioned 22 patients, we also analyzed the verifications with both methods for a further 16 patients, albeit on different days. The results are shown in table 3.

			MatriXX	EPID
n.pz	DATA misura	ARCO	% area con γ<1	% area con γ<1
1	13/12/2021	CCW	>90	>90
		CW	>90	>90
2	13/12/2021	CCW	>90	>90
		CW	>90	>90
3	17/10/2022	CCW	>90	<90
		CW	>90	<90
4	10/05/2022	CCW	>90	>90
		CW	>90	>90
5	24/02/2022	CCW	<90	<90
		CW	<90	<90
6	07/02/2022	CCW	<90	<90
		CW	<90	<90
7	20/10/2022	CCW	<90	<90
		CW	<90	<90
8	14/12/2021	CCW	>90	>90
		CW	>90	>90
9	17/08/2022	CCW	<90	<90
		CW	<90	<90
10	17/08/2022	CCW	<90	<90
		CW	<90	<90
11	19/10/2022	CCW	>90	>90
12	11/10/2022	CCW	>90	>90
13	19/08/2022	CCW	>90	>90
14	19/08/2022	CCW	<90	>90
15	12/09/2022	CCW	>90	>90
16	17/10/2022	CCW	>90	>95
17	12/09/2022	CCW	<90	<90
18	21/09/2022	CCW	<90	<90
19	21/09/2022	CCW	>90	<90
20	21/09/2022	CCW	>90	<90
21	03/11/2022	CCW	>95	>90
		CW	>95	>90

Tab. 1 - *Comparison data table of the percentage gamma index from MatriXX and EPID audits*

			MatriXX	EPID
n.pz	Data misura	Arco	% area con γ<1	% area con γ<1
3	17/10/2022	CCW	93,5	84,1
		CW	94	74,6
14	19/08/2022	CCW	86,4*	94,5
19	21/09/2022	CCW	90,7	86,1
20	21/09/2022	CCW	90,2	87,2

Tab. 2 -*Table of plans where we notice a difference in the two methods*

			MatriXX	EPID
n.pz	Δt	ARCO	% area con γ<1	% area con γ<1
23	10	CCW	>90	>90
		CW	>90	>90
24	4	CCW	>90	>95
		CW	>90	>90
25	5	CCW	>90	>90
		CW	>90	>90
26	10	CCW	<90	>90
		CW	<90	>90
27	3	CCW	<90	<90
		CW	<90	<90
28	6	CCW	>90	<90
		CW	>90	<90
29	2	CCW	>95	>90
		CW	>90	>90
30	2	CCW	>90	>90
		CW	>90	>90
31	7	CCW	>95	>90
		CW	>90	>90
32	3	CCW	<90	<90
		CW	<90	<90
33	7	CCW	>90	>90
		CW	>90	>90
34	4	CCW	>95	>95
		CW	>90	>90
35	2	CCW	>95	>90
		CW	>90	>90
36	2	CCW	<90	<90
		CW	<90	<90
37	4	CCW	<90	<90
		CW	<90	<90
38	6	CCW	<90	<90
		CW	<90	<90

Tab. 3 - *Data table comparing the percentage gamma index from audits with MatriXX and EPID delivered on different days*

			MatriXX	EPID
n.pz	Δt	ARCO	% area con γ<1	% area con γ<1
26	10	CCW	83,5	92,5
		CW	74	90,1
28	6	CCW	93,2	86,6
		CW	92,8	88,5

Tab. 4 - *Table of plans where we find a difference between EPID and MatriXX*

The comparison was carried out with dose threshold and tolerance criteria ΔD and DTA the same as the previous comparison; the Δt value represents how many days elapsed between the delivery of the verifications with the two methods. In this case for 14 out of 16 plans, the outcome of the verifications agrees in both methods, and in the remaining 2 plans we find a difference, as shown in Table 4.

The performance of the LINAC on the day of the pre-treatment verification with MatriXX of patient no. 26 was 0.9% higher than in our reference. For this reason, we repeated the gamma analysis of the same patient by only enlarging the ΔD tolerance criterion from 3% to 4% and in this way the area where the gamma index is ≤1 becomes ≥ 90%.
The plan of patient no. 28 passes the verification for 153 both arcs using the criteria ΔD of 3% and DTA of 3mm on the EPID.
From the data sets obtained from this evaluation, we found that the pre-treatment result for 32 out of 38 treatment plans (84%) agreed in both verification methods. Only in 6 treatment plans did we obtain a discordant result, so the two methods overlap.
In 2 out of the 6 plans where we notice a difference, the different verification result (positive with EPID and negative with MatriXX) can be attributed to a performance overshoot of the LINAC affecting the response of the MatriXX detector and thus a higher measured dose distribution than calculated that worst the gamma analysis. By repeating the gamma analysis and increasing the tolerance in the dose difference from 3 to 4 per cent (ΔD), the two plans also passed the test with the MatriXX.
For the other 4 plans that had negative verification outcomes for EPID, we found that by expanding the spatial tolerance (DTA) on EPID by 1 mm, the verification outcomes came back.
This could be attributable to errors in the positioning of the MLC, which EPID suffers more from because it has a better spatial resolution than MatriXX. The matrix of the EPID detectors is in fact composed of 1024x768 elements distributed over an area of 40 x 30 cm2 (pixels of 3 x 4 mm2), while that of the MatriXX is composed of 1020, arranged in a grid of 32x32 cm2 (pixels of approximately 1cm2). Consequently, this results in more precise verifications, as the fine matrix of the EPID detectors registers even small spatial differences in the delivered fluence compared to the calculated fluence in a more detailed manner.
Concerning the verification method with the MatriXX detector with ionization chambers, we have noticed that a lack of correction of the angular sensor and the set-up errors that can occur when
aligning the detector + phantom on the couch, could lead to an incorrect outcome of the plan verification. In fact, we have found during testing that the angle sensor can give electrical contact problems, disconnecting during arc delivery. It should also be considered that the sensor itself carries an uncertainty in the dose reading correction as a function of the angle of dispensing. This uncertainty does not arise with the EPID verification system because the detector itself is integral with the LINAC and moves with it during delivery.
Regarding the verification method with the EPID flat panel type detector, we must consider that the EPID provides a measurement proportional to fluence, not directly a dose, as it has no absorber phatom to attenuate the energy before detection. However, this is compensated for by periodic calibration of the detector as a function of dose.
An important advantage in the pre-treatment verification with EPID is the time saving in the technical preparation of the verifications. Monitoring the time used to assemble the MatriXX detector, to warm it up and to set-up the image acquisition software, it takes about 20 minutes, not including the time to deliver the plan, which varies depending on the monitor units used (about 5 minutes). To this time is added that of creating the verification plan at the TPS (about 15 minutes), by the Physicist, against the 5-minute calculation time for the verification plan for EPID. The time for setting up the EPID and changing the angle of the gantry is a maximum of 2 minutes. The time to uninstall the detectors must also be considered: about 4 minutes for the MatriXX and 1 minute for the EPID.
As a result of the above analysis, we can estimate that the exclusive use of the system with EPID in the pre-treatment checks of the arc treatment plans for the prostate district would result in a time saving of more than 20 minutes and this would increase the machine time dedicated to the treatment sessions (one more patient per day), with the same quality check of the plan.
As we know, in fact, the time factor is important in the management of radiotherapy patients: the schedules assigned for daily treatment are very strict, in order to be able to treat as many patients as possible, precisely because the cancer patient must be treated promptly. On the other hand, it is essential to carefully position the patient before the session, having the right time frame for the TSRM staff.
In conclusion, the results of the gamma analysis conducted for the same plans for prostate cancer patients with both the EPID and MatriXX systems allow us to routinely use the EPID detector as a
pre-treatment verification system instead of 205 the MatriXX, also in light of the considerable time saving in preparing the verification plan, setting up the instrumentation and for the ease of dispensing the treatment plans on the detector.

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