Clinical implementation of the Delta^4 Phantom+ MR for patient-specific QA in 0.35T MR-Linac

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Delta^4
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1. Introduction

Magnetic Resonance Imaging Guided Linear Accelerator (MR-Linac) uses magnetic resonance (MR) imaging together with a linear accelerator to treat tumors, taking advantage of the soft-tissues visualization. The radiation delivery is synchronized with the MR imaging. The MR-Linac allows adaptation of the radiation treatment plan based on the movement of the tumor or surrounding critical structures, and also track the motion of the tumor and control accordingly the radiation beams.

This new technology requires development of MR-compatible equipment for machine and patient-specific quality assurance (QA). This includes ionization chambers, 2D and 3D detectors arrays, water tanks, etc. The way the equipment manufacturers are addressing this new paradigm is through the update of their non-MR compatible products to MR-compatibles. That is the case of the ArcCheck from SunNuclear, Octavius from PTW and Delta^4 from ScandiDos.

This white paper will cover a general description of the process of implementation of the Delta^4 Phantom+ MR for patient-specific QA in a MRIdian Linac from ViewRay.

The main characteristics of the MRIdian Linac are listed below;

- 6FFF MVLinac
- Step-and-shoot delivered mode
- 0.35T magnet
- Real-time MR imaging
- Adaptive planning and delivery

2. Equipment for patient-specific quality assurance. Options in the current market.

General characteristics of existing devices for patient-specific QA in MR-linacs:

- ArcCheck MR. The measurements are performed for the entrance dose in a 360 degrees geometry. No measurement result for comparison with the calculated dose at the isocenter is provided. The device uses 1386 diodes as detectors with 10mm spacing. Because of the measurement geometry, there is almost no directional dependence with the beams angles

- Octavius 1500: The dose measurements are performed in only one plane using 1405 vented plane-parallel ionization chambers as detectors with 7.1mm spacing. High directional dependence is present if the 4D model is not used (the MR compatible 4D model is planned to be released this year according to the manufacturer).

- Delta^4 Phantom+ MR: The dose measurement is performed for two orthogonal planes using 1069 p-diodes as detectors. The resolution is 5mm at the isocenter and it can be increased to 2.5mm by merging. It has a minimal directional dependence. The analysis can be performed field by field or for the composite dose.

3. Delta^4 Phantom+ MR commissioning process

3.1 Handling

The Delta^4 Phantom+ MR was designed with the user´s comfort in mind. The system comes with a portable table which allows easy placement of the phantom onto the linac couch, as seen in Fig.1 and Fig.2, with minimal effort for the user. The cables that connect the device to the control unit have the needed length for a quick and reliable connection.

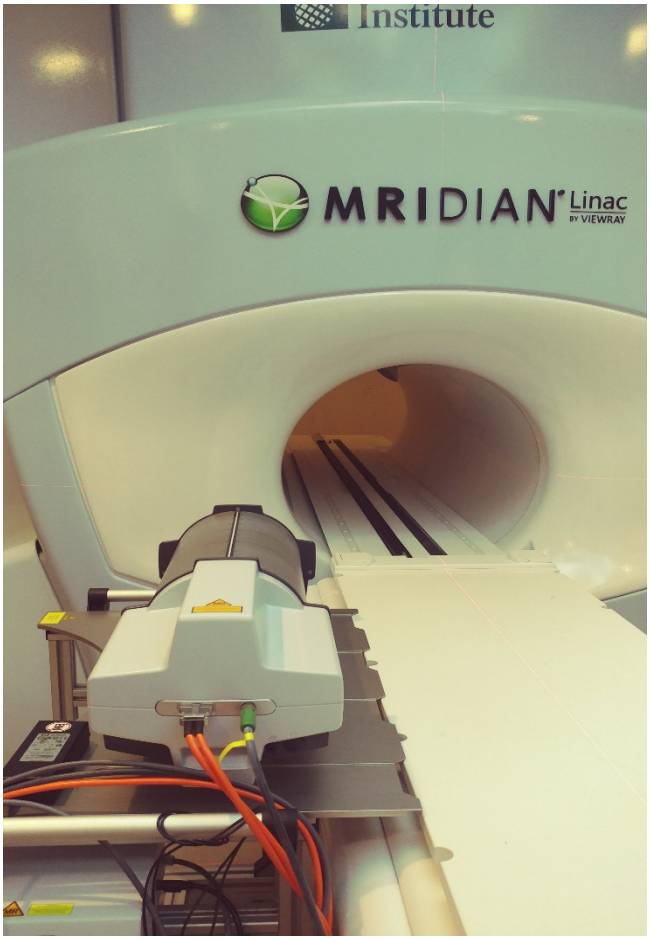

Figure 1. Delta^4 Phantom+ MR. A portable table is included for transportation and easy placement onto the LINAC couch.

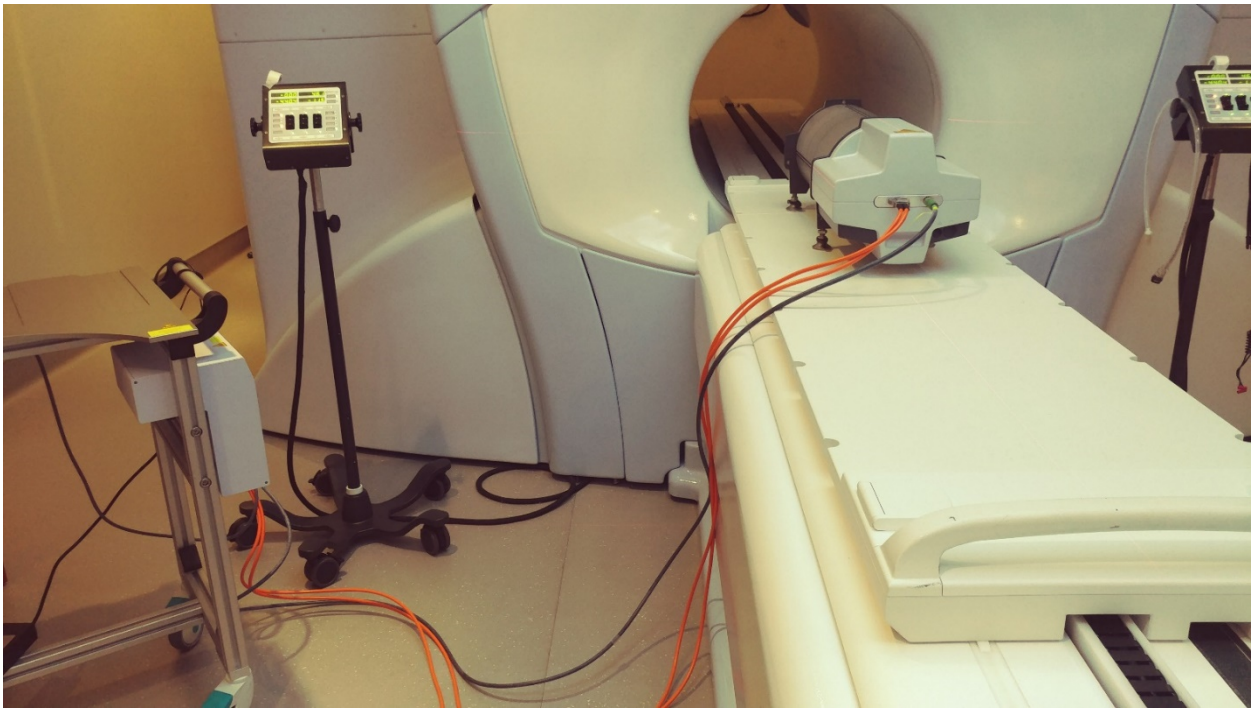

Figure 2. Delta^4 system setup for measurement

3.2 Calibration

The Delta^4 calibration is straightforward. The system asks for reference measurements for two field sizes at two gantry angles (at 0 and 90 degrees). The calibration window that needs to be filled up is shown in Fig.3. For the absolute calibration, only one extra measurement at 45 degrees needs to be performed.

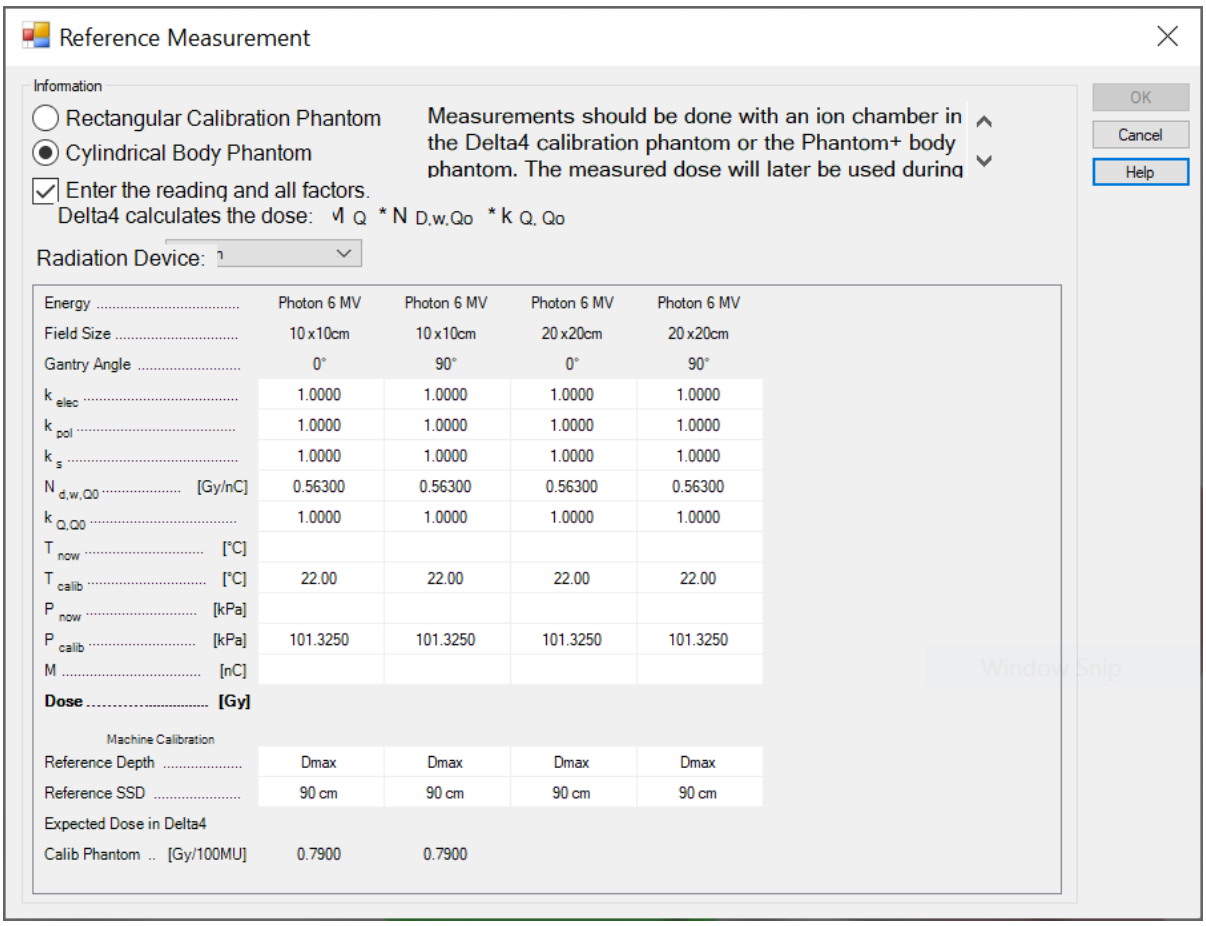

Figure 3. Delta^4 calibration window

After the Delta^4 calibration is done, ScandiDos recommends checking its validity using a simple plan developed with the treatment planning system (TPS). For that purpose, a four open fields plan without modulation can be used. The dose distribution through an axial plane and the dose-volume-histogram (DVH) for such a plan is shown in Fig.4. The ViewRay TPS was used to generate this plan. The gantry angles and beam weights are included at the figure's bottom part.

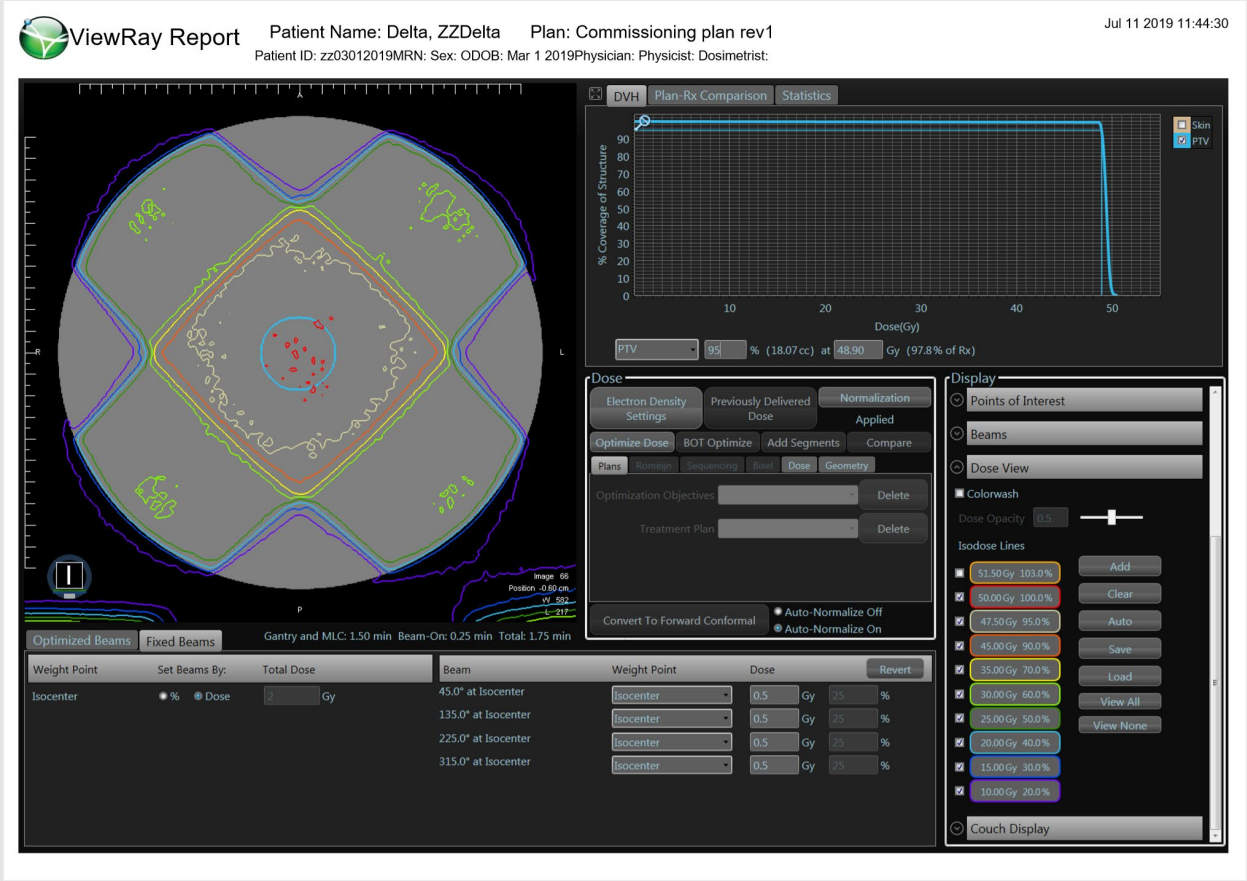

Figure 4. Four fields plan to check Delta^4 calibration

4. Delta^4 Software presentation

The main advantage over competitors is the Delta^4´s capability of dose measurement in two planes crossing the isocenter or the planning target volume (PTV). The spacing between detectors is 5mm, but the resolution can be increased to 2.5mm if two measurements are merged.

Another important competitive advantage is the powerful yet user-friendly analysis software offered. In Fig.5 the Delta^4 software main window shows the results of the analysis for the absolute dose deviation for a pancreas plan using 15 beams.

The Delta^4 software allows for correction of the phantom misplacement and for the linac's daily output variations. At the bottom, three histograms are presented that correspond to the fraction's statistics. The first histogram shows the frequency of the dose deviation (in percentage), the second one shows the frequency of the Distance to Agreement (DTA) occurrences and the third one shows the frequency of the Gamma Index occurrences. In this

particular case, the Gamma Index criteria used was 2% for the absolute dose analysis and 2mm for the DTA.

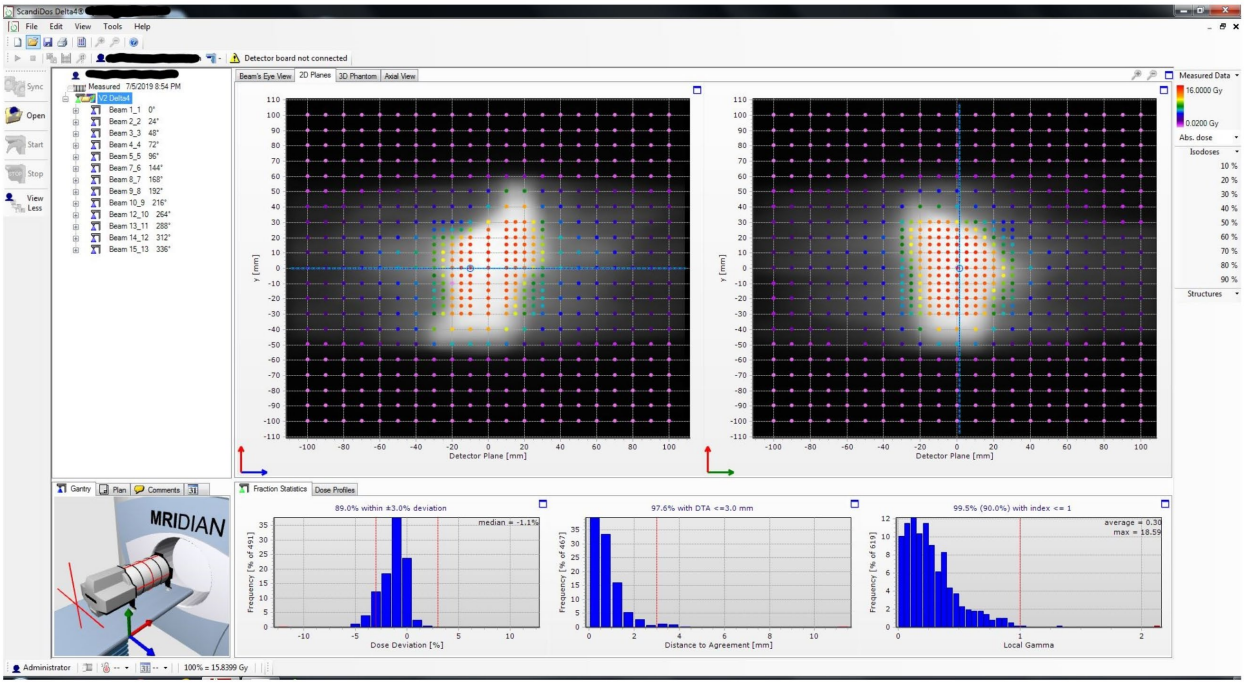

Figure 5. Delta[4] main window showing the pass rates histograms for the absolute dose, Distance-to-Agreement (DTA) and Gamma Index

In Fig.6, the dose profile comparison between the planned and measured dose is presented. On the bottom, the left information corresponds to the X-axis (axial plane). On the right, the results for the Y-axis (sagittal plane) are presented. The dots correspond to the Gamma index for a particular detector. In this case, it was elected to present the Gamma index, but the user can instead elect to have the results displayed for the absolute dose or the relative dose instead.

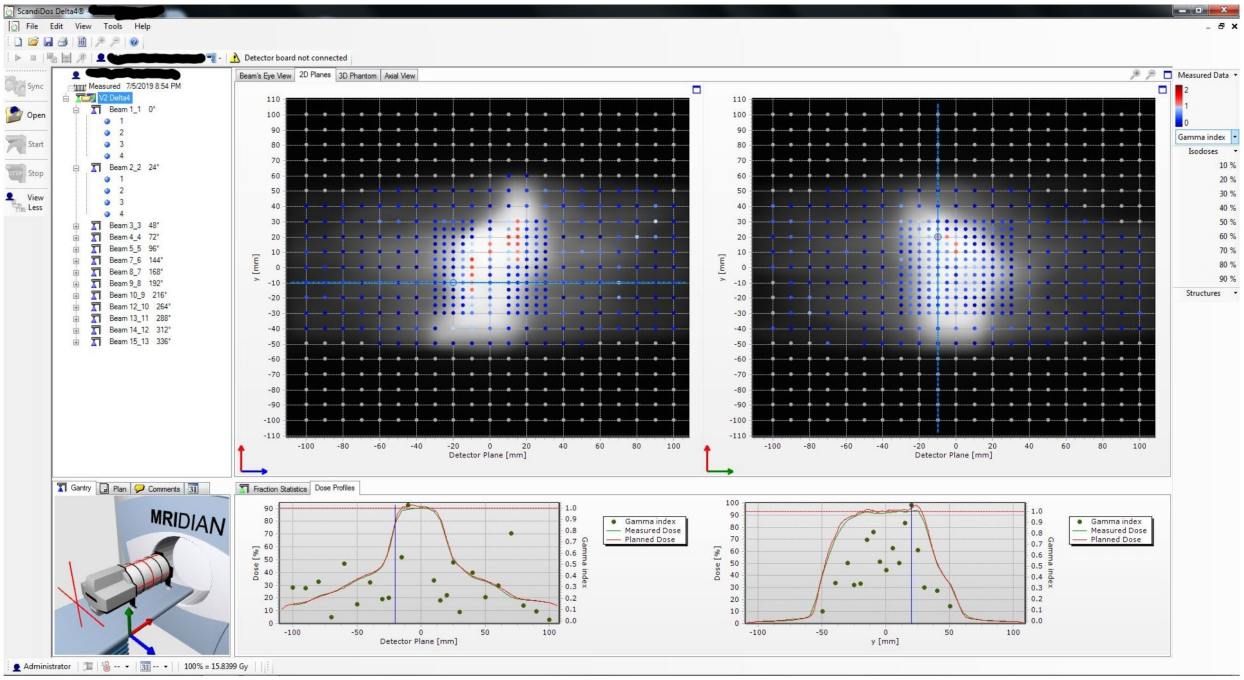

Figure 6. Delta^4 main windows showing for each detector plane ("X"-plane on the left, "Y"-plane on the right). The comparison between the measured dose and the planned dose is showed. The dots represent the value of the Gamma Index according to the right ordinate axis values.

In Fig.7 an example of the analysis report is presented. The report is fully customizable. The Gamma Index Evaluations in form of a table is included. The X-axis corresponds to different dose criteria in percentage and the Y-axis corresponds to DTA criteria in mm. Each cell in the table corresponds to the Gamma Index Evaluation result according to the selected values for the dose and DTA criteria. In this report, a 90% threshold for the Gamma Index Evaluation pass rate was selected. All combinations of dose criteria and DTA for which the Gamma Index Evaluation will be equal or greater than 90%, will be displayed in green in the table. At the bottom of the report, the absolute dose profiles comparison is presented.

The Delta^4 software is indeed powerful and customizable. Multiple Gamma Index Evaluations can instantly be presented without the need for running the software multiple times with different criteria.

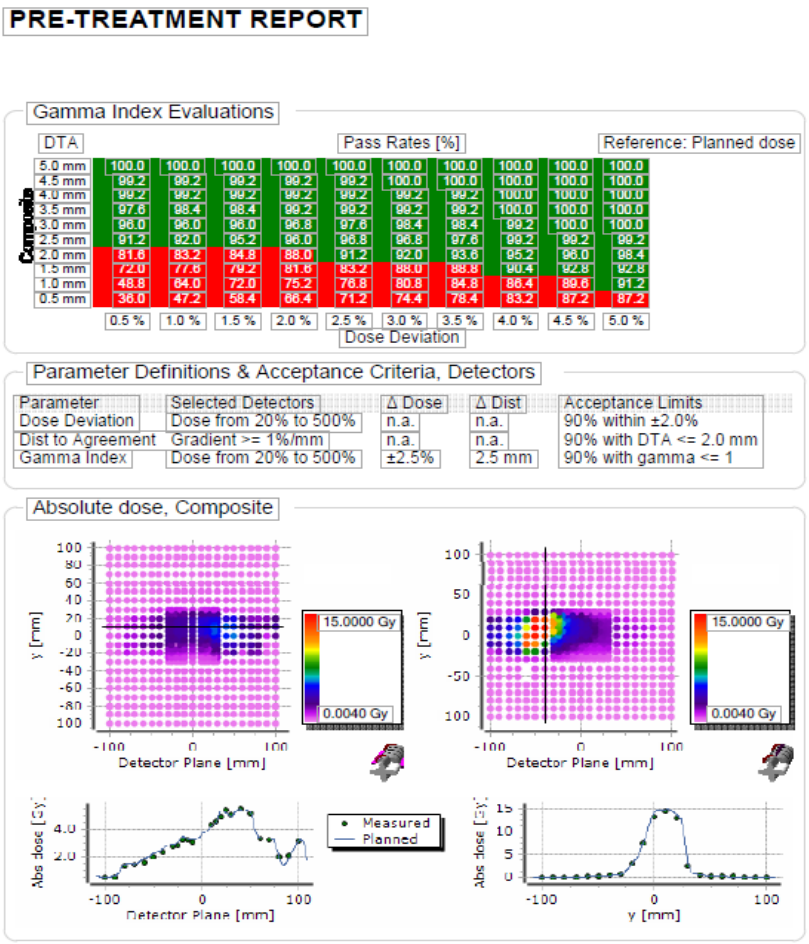

Figure 7. Example of the report generated by the Delta^4 software

5. Advantages of the use of the Delta^4 Phantom+ MR over its competitors

The ArcCheck does not perform a direct measurement across the isocenter or other volumes of interest. The user needs to rely on the indirect measurement of the entrance dose.

The Octavius1500 measures the dose in only one plane. In some cases, to catch the dose distribution by the detector plane, the requested couch position falls outside the allowable range. Some plans may have beams that hit the detector plane at angles close to zero degrees. In those cases, a Region of Interest (ROI) for the analysis needs to be selected. The defined ROI should exclude the peripheral detectors. The latter can be avoided if the 4D version is used, but at that moment of writing this white paper, the MR-compatible version is not yet on the market.

Compared to the Octavius 1500, the smaller Delta^4 dimensions and the use of two detector planes allow a wider range of couch positions. That means more flexibility for the isocenter

placement. The two-plane geometry is also more comprehensive for the dose analysis and less dependent on the gantry angles.

6. Results of the use of the Delta^4 Phantom+ MR in the clinic

The Delta^4 has been extensively tested with clinical plans at different centers. It has been adopted as the primary patient quality assurance (QA) device at Miami Cancer Institute in Miami, Florida, United States. In this section, the results of its use for QA of 14 patients with different treatment sites are presented. The plans represent a wide selection of isocenter placements, gantry angles used for treatment, and beam modulations (beams segment sizes). In table 1 the results for the Gamma Index evaluation using 3% as the criterion for the dose absolute deviation and 3mm for the DTA are presented. In table 2 the 2%/2mm criteria are shown.

The same patients' plans were checked using the Octavius 1500. To get similar results compared to the Delta^4 phantom, the analysis needed to be limited to a region of interest (ROI) excluding the peripheral detectors for the reason previously mentioned. That means that the analysis is limited to a certain number of detectors only.

Patient Number	Site	Pass rate for dose deviation < 3%	Pass rate for DTA < 3mm	Gamma Index pass rate for Gamma <= 1
1	Adrenal SBRT	93.50%	96.80%	98.00%
2	LT Adrenal SBRT	87.20%	98.40%	99.40%
3	SBRT Pancreas	89.20%	97.90%	100.00%
4	Lung LT SBRT	92.60%	97.90%	98.80%
5	Pancreas IMRT	89.30%	96.90%	97.40%
6	Liver SBRT	77.10%	98.70%	100.00%
7	Abdomen 35Gy	91.60%	99.30%	99.80%
8	Main Bronchus	82.10%	96.50%	98.70%
9	Pancreas	84.10%	95.50%	97.80%
10	Pancreas SBRT	75.00%	93.50%	98.80%
11	LT Abdominal Wall	89.70%	97.00%	97.90%
12	Pancreas SBRT	81.90%	97.60%	98.90%
13	Pancreas Boost	52.60%	94.70%	98.10%
14	Pancreas	76.30%	95.60%	97.60%

Table 1. Results of the patients´ QA for different treatment sites using 3%/3mm criteria for the Gamma Index with threshold of 90%.

Patient Number	Site	Pass rate for dose deviation < 2%	Pass rate for DTA < 2mm	Gamma Index pass rate for Gamma <= 1
1	Adrenal SBRT	76.60%	91.30%	93.80%
2	LT Adrenal SBRT	71.00%	94.90%	98.50%
3	SBRT Pancreas	74.30%	94.40%	97.20%
4	Lung LT SBRT	79.80%	95.60%	97.90%
5	Pancreas IMRT	72.50%	92.40%	94.50%
6	Liver SBRT	67.30%	89.00%	99.30%
7	Abdomen 35Gy	74.50%	92.00%	99.30%
8	Main Bronchus	62.40%	86.50%	97.60%
9	Pancreas	64.50%	86.20%	92.40%
10	Pancreas SBRT	58.30%	82.20%	95.20%
11	LT Abdominal Wall	77.00%	84.80%	96.40%
12	Pancreas SBRT	62.00%	89.40%	97.80%
13	Pancreas Boost	34.10%	82.70%	95.90%
14	Pancreas	62.20%	82.40%	94.70%

Table 2. Results of the patients´ QA for different treatment sites using 2%/2mm criteria for the Gamma Index with threshold of 90%

7. Conclusions

A summary of the advantages of the use of the Delta^4 Phantom+ MR for patient QA in 0.35T MR-Linac:

- Solid system that offers reliable results in any operation conditions
- Excellent handling for positioning and alignment
- Simultaneous measurement and analysis for two orthogonal planes
- Higher measurement resolution compared to the competitors
- Easy and solid calibration procedure
- Low directional dependence
- Very powerful software analysis. The parameters that conform to the gamma index can be analyzed and displayed point by point. Besides the gamma index evaluation, the user has access to the absolute, relative dose and the DTA analysis independently as shown in Fig.6 and Fig.7.

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FURTHER READINGS ABOUT THE DELTA^4 PHANTOM+ MR

WEBINAR with Wilfred de Vries, UMC Utrecht
Delta4 Phantom+ MR

PRODUCT PAGE
Delta^4 Phantom+ MR

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