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Characterization of a Commercial PIN Diode for Stereotactic Radiosurgery Dosimetry

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ABSTRACT

The stereotactic radiosurgery (SRS) is a technique that uses multiple beams extremely collimated of ionizing radiation to treat intracranial lesions and functional abnormalities, with high geometric precision and dosimetric accuracy. The use of small fields is already a reality in modern radiotherapy techniques. However, the accuracy in small-field dosimetry is challenging because of several process physics and aspects related to the detector. The aim of this paper is to evaluate the response of a dosimetric system developed by Nuclear Energy Department of Federal University of Pernambuco (DEN/UFPE) for small field dosimetry. Measurements of, output factor (OF), off-axis ratio (OAR) and percentage depth dose (PDP) were performed with this dosimetric system and compared with the results obtained with a commercial diode and treatment planning system data. The results showed that the Diode-DEN presents a reliable and economical alternative for small fields dosimetry used in treatments of SRS. This detector can be used for validation of dates obtained in commissioning of linear accelerator and inserted in Treatment Planning Systems (TPS).

Keywords: **diode, small fields, dosimetry, circular cones. radiosurgery**

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1. INTRODUCTION

The Small-field dosimetry has become increasingly important as modern radiotherapy techniques including intensity-modulated radiotherapy (IMRT), volumetrically modulated arc therapy (VMAT), Stereotactic Body Radiosurgery (SBRT), and Stereotactic Radiosurgery (SRS) are commonly used throughout the world.

By definition, stereotactic radiosurgery (SRS) is an irradiation method used to deliver high absorbed doses of radiation in one to five fractions. This technique uses small and highly-collimated beams (Multileaf–MLC or circular cone collimator) to irradiate intracranial lesions and functional abnormalities with high geometric precision, high conformity, and dosimetric accuracy. For this technique, the use of small fields is always associated.

However, it is known that accuracy in small-field dosimetry is challenging because of several process physics, such as the loss of lateral electronic equilibrium, partial occlusion of the source, and perturbation of the charged-particle fluence by the detector size used for their measurement. To minimize these effects, various types of detectors with small sensitive volumes (e.g. diodes and diamond) have been developed and characterized [1]. The aim of this study is to evaluate the characteristics of the dosimetric system developed by Nuclear Energy Department of UFPE (DEN) for small-field photon beam dosimetry under conditions of SRS.

2. MATERIALS AND METHODS

The dosimetric system is composed by a diode (Diode-DEN) and an electrometer, named EL- DEN, both developed by the DEN/UFPE. The detector has a sensitive area of 0.35 mm^2 and a sensitive volume of 0.021 mm^3. The detector is a Si diode type PIN, operating in the photovoltaic mode. A holder for the diode was modeled in software CAD and 3D printed with a black resin that presented a density close to water. This holder was created to make the diode waterproof. Therefore, according to TRS 483 the Diode-DEN is a type of Unshielded diode. Shielded diodes contain high-density material (e.g. tungsten). In small fields, the use of unshielded diodes is advised [3]. Figure 1 present Diode-DEN and its electrometer.

All irradiations were performed with a 10 MV-FFF (Flattening filter free) photon beam produced by TrueBeam STx 2.7 Linac (Varian Medical System), present at Real Hospital Português, in Recife-PE. This Linac is already installed and in use for treatment, therefore all acceptance and commissioning tests have been performed. Measurements were carried out for cones with field diameters from 4.0 to 17.5 mm, that are part of the Intracranial SRS package (Varian), as show in Figure 2-a. These collimators were coupled to the output of the Linac beam. A 5x5 cm^2 field in Linac collimators (primary and secondary, X and Y) was adjusted to ensure a constant radiation beam scattering for all configurations used.

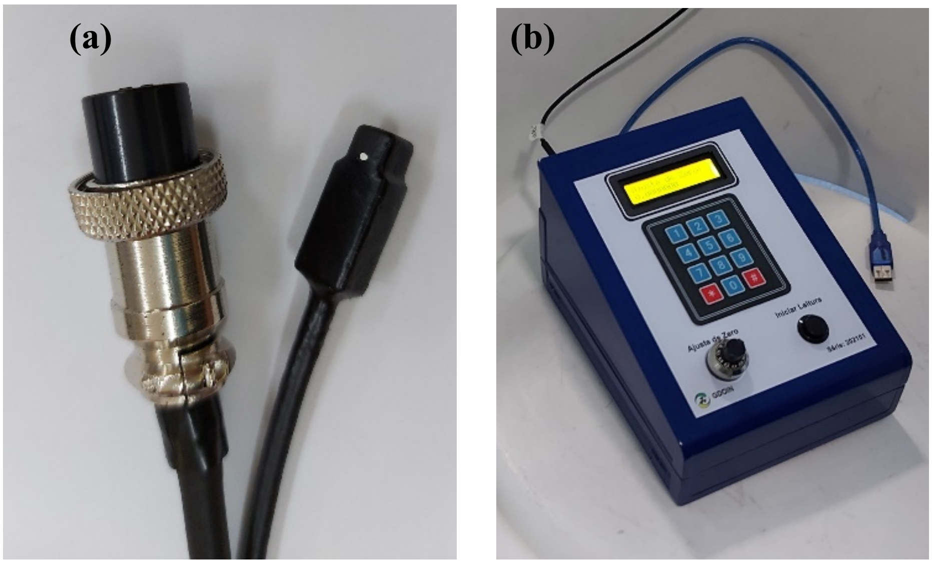


Figure 1: *Dosimetric system: (a) Diode-DEN and its connector, (b) electrometer*

The main dosimetric characteristics, such as response repeatability, dose-response curve, and dependence on dose rate were evaluated. The setup for these measurements was the same, where the diode was positioned at the center of solid water phantom with size 30x30 cm^2 (Figure 2-b) at a depth of 5 cm and surface source distance (SSD) at 95 cm. For these analyses, the dose rate was set at 2400 MU/min for the irradiations, which is the maximum dose rate value for this energy and is usually most used, except in the study of the dependence of the detector response on the dose rate.

Initially, the study of the repeatability of the diode-DEN response for a given value of radiation dose was carried out. The radiation field was fixed with a conical collimator measuring 7.5 mm in diameter, and the applied dose was 10 Gy. Four consecutive measurements were performed and the arithmetic means, standard deviation, and coefficient of variation of the obtained measurements were calculated. To study the linearity of the diode response with the dose, keeping the same setup described above, irradiations with doses of 3, 5, 10, 15, 20 and 25 Gy were carried out. For each dose value, three measurements were taken, and the mean reading was used to plot the curve of the detector response as a function of the dose and to analyze the linearity of the Diode-DEN response with the applied radiation dose.

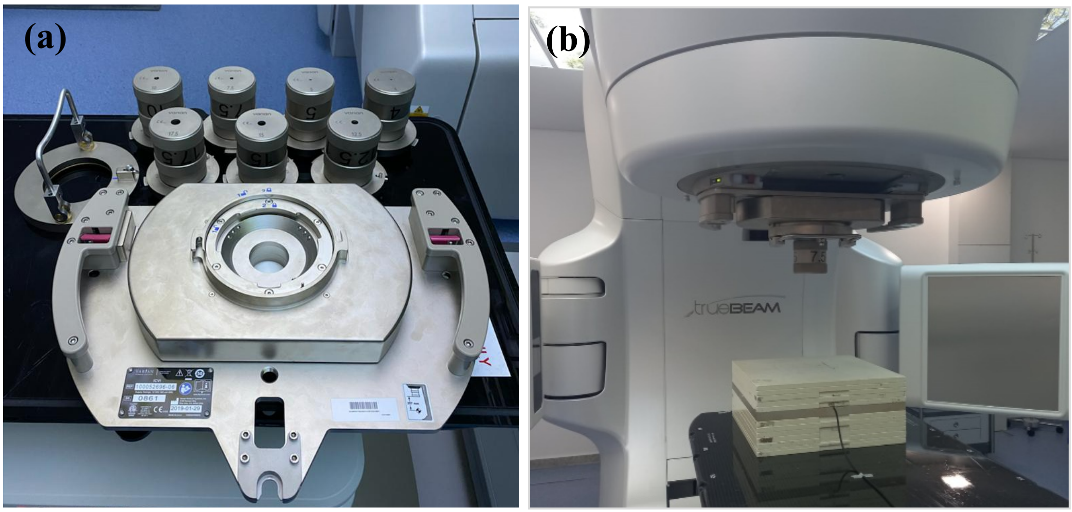


Figure 2: (a) *Intracranial SRS Package, (b) Setup of irradiation on solid water phantom*
Source: (a) [2].

To evaluate the dependence of the Diode-DEN response with the applied dose rate, the previously described geometry, and a conical collimator with 7.5 mm in diameter was used again, and measurements were performed with a dose rate of 800, 1200, 1600, 2000, and 2400 MU/min, keeping fixed a dose of 3 Gy. For each dose rate value, three measurements were carried out and the mean reading was used to evaluate the dependence of the diode response on the dose rate. The measurements were normalized to Diode-DEN response when irradiated with a doses rate of 2400 MU/min.

2.1. Validation of Diode-DEN response

For benchmarking, the measurement of output factors (OF), off axis ratios (OAR) and percentage depth dose (PDD) was carried. The results of these parameters were compared with those obtained with commercial diodes EDGE (SUN NUCLEAR) and RAZOR (IBA Dosimetry) in the same conditions. These measurements were performed using an automated scanning phantom, model BluePhantom2, from the company IBA Dosimetry. This phantom consists of a 48x48x41 cm^3 reservoir, filled with water.

For the Output factor measurements, the detector was positioned on the BluePhantom2 support, at a source surface distance of 95 cm, on the central axis of the radiation field, and a depth of 5 cm for all output measurements. The OF is obtained by the ratio of the detector's response at an arbitrary cone size to the reference field, which was 10 cm x 10 cm. Three irradiations were carried out with a dose of 3 Gy for each size of a circular cone, as follows: 4.0, 5.0, 7.5, 10.0, 12.5, 15.0 and 17.5 mm in diameter. The output correction factors recommended by TRS 483 (2017) [3] were applied, which considers the effect of the mean volume of the detector during the measurement. These factors are dependent on the size of the clinical field of treatment. The size of the clinical field of each cone had already been determined during its commissioning, through radiochromic film, and was used to obtain these correction factors. The OF measurements were repeated with commercial diodes EDGE and RAZOR, in the same conditions for comparison.

To evaluate off axis ratio, 4.0 and 7.5 mm diameter cones were used. The measurements were taken in step-by-step scanning mode, with a step of 0.5 mm between each measurement point, in the lateral range of -2 cm to 2 cm along the center of the radiation field in the cross-plane direction. For each cone size, three dose profiles were collected, varying the source-surface distance (80, 90 and 100 cm) and keeping the detector depth fixed at 5 cm. This parameter was obtained for comparison using the detectors: Diode-DEN, RAZOR, and EDGE.

For PDP measurements, the detector was first positioned on the BluePhantom2 support, at an SSD of 100 cm, in the central axis of the radiation field, and varying its position vertically in 0.5 mm steps. Continuous irradiation was carried out with a dose rate of 2400 MU/min, using a cone size of 4.0 and 7.5 mm of diameter. The reading was obtained in real-time by OmniPRO Accept software, which automatically plotted the PDP curve.

3. RESULTS AND DISCUSSION

The result of the repeatability of the Diode-DEN response showed a coefficient of variation lower than 0.05% for the four consecutive measurements under the same conditions. Figure 3 shows the Diode-DEN response curve as a function of radiation dose, with the standard deviation at each point. Unable to observe error bars due to low coefficient of variation of measurements. This same behavior was observed in all graphs plotted in this work.

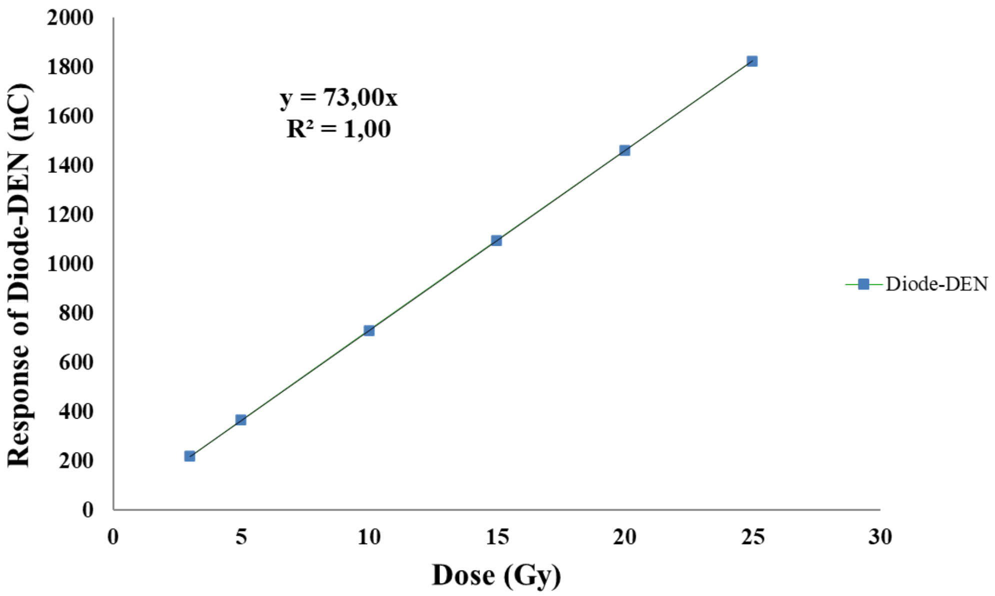


Figure 3: *Dose-response curve for Diode-DEN*

Note that the Diode-DEN response was linear within the measured dose range, between 3 Gy and 25 Gy. This dose range includes the dose values generally prescribed for cases of stereotaxic radiosurgery. The sensitivity factor of Diode-DEN was 73 nC/Gy. This value shows that the sensitivity of the Diode-DEN is greater than the 2 commercial stereotactic diodes compared in this study. The sensitivity for diodes EDGE and RAZOR were 32 nC/Gy and 30 nC/Gy, respectively. The fact that the Diode-DEN is the PIN-type explains its greater sensitivity because has an intrinsic region in its composition, which increases its depletion region.

The Figure 4 shows the Diode-DEN response as a function of the dose rate between 800 and 2400 MU/min. Each point on the graph corresponds to the average of three readings carried out for an absorbed dose of 3 Gy in each dose rate and normalized to the value corresponding to a dose rate of 2400 MU/min. The variation of the relative response in the analyzed dose rate range is less than 0.85%. For comparison, Kumar et al. evaluated the dosimetric characteristics of PIN-type diode for radiotherapy applications. The diode named BARC showed a dose rate dependence of 2.5 % for 6 MV and 15 MV photon beam for the dose rate range in 100 MU/min and 300 MU/min [4].

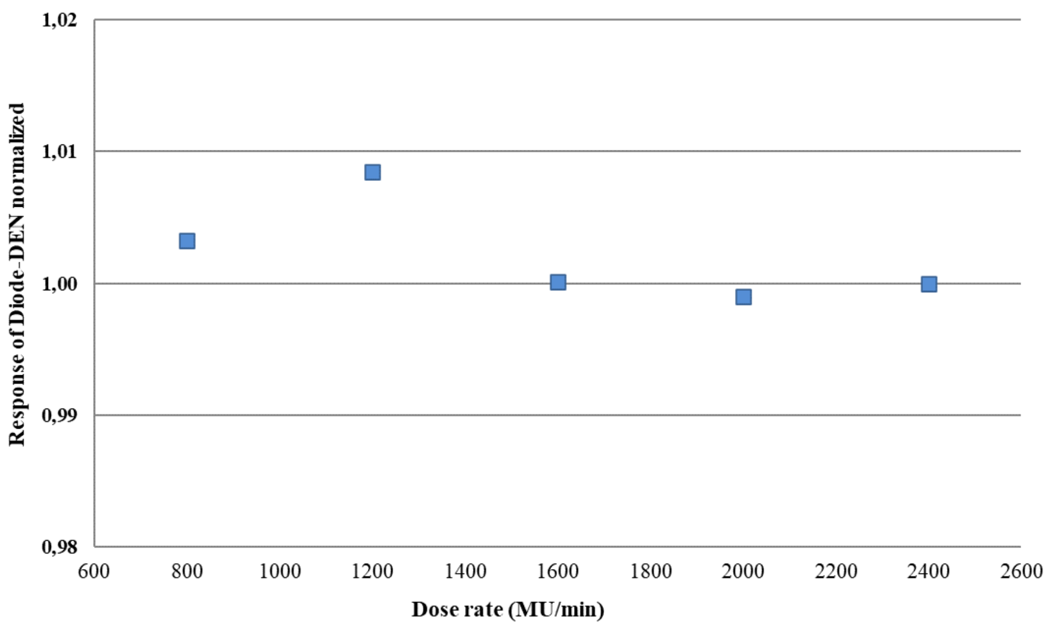


Figure 4: *Dependence of response with dose rate*

3.1. Validation of Diode-DEN response

Figure 5 shows the output factor plotted for the 7 cone sizes, normalized to the 10 x 10 cm^2 reference field, obtained with the Diode-DEN, EDGE, and RAZOR, and compared to the manufacturer reference data for the energy of 10 MV-FFF.

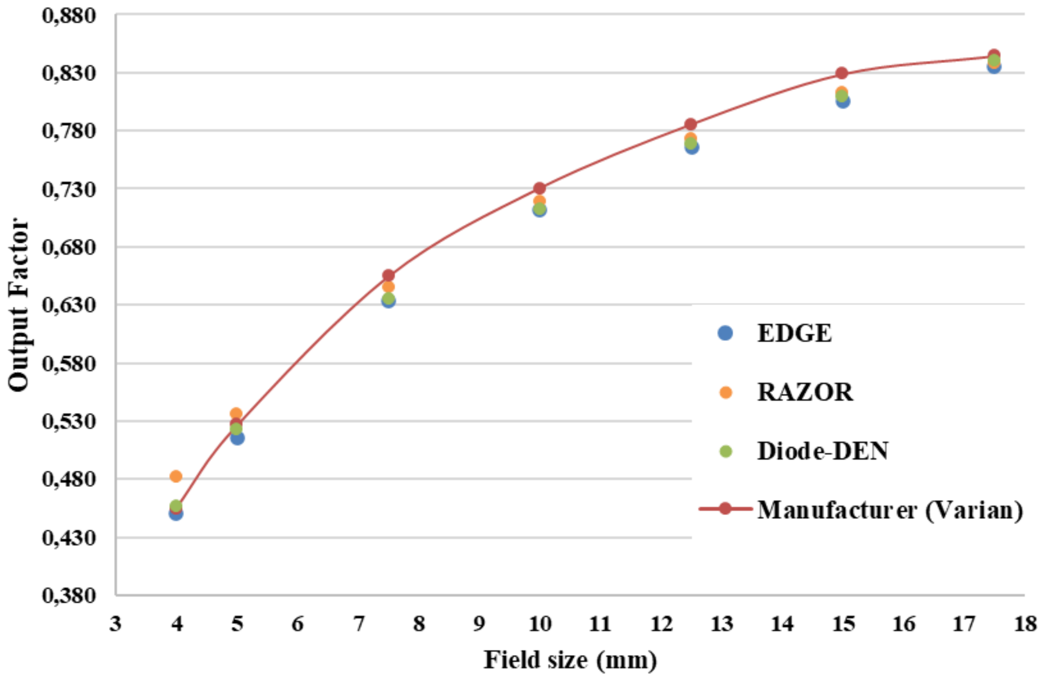


Figure 5: *Output factor for all cone sizes with difference detectors*

The larger difference found for the output factor when compared to the manufacturer's data was for the RAZOR diode and 4.0 mm cone, obtaining a difference of 5.7%. For the EDGE diode, the larger difference found was for the 7.5 mm cone, with a difference of -3,3%. Coincidentally, the larger difference found between the output factor determined with the Diode-DEN was also for the 7.5 mm cone, obtaining a difference of -3.0%.

For the calculation of dose in radiotherapy, the output factor is one of the most important parameters. In small fields, the dispersion in obtaining these factors can reach 20% depending on the type of detector [3]. The results found were compared with the literature and presented similar results, according to Fontana and Galvan et al. that used in their studies the EDGE diode commercial to commission the Varian cone radiosurgery integrated system, with the same TrueBeam Linear Accelerator model [2,5]. Cheng et al. performed a comparison of measured output factors with Edge diode and Monte Carlo simulation for the same TrueBeam cone radiosurgery platform. The output factors found in these studies are plotted in Figure 6 for comparison with manufacturer data. There is variability in the results, mainly related to the type of detector [6]. Fontana performed output measurements with 8 different detectors, 6 commercial diodes and 2 small volume ionization chambers. An alternative in view of this variability is to assume the average of the readings of the detector that performed best in the measurements, that is, those that came closest to the manufacturer data [2].

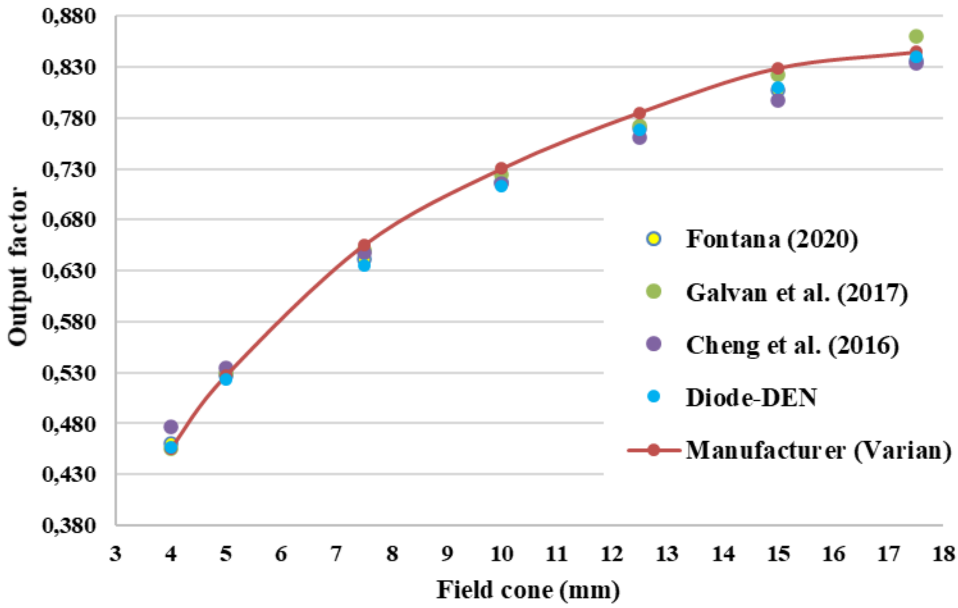


Figure 6: *Comparison between different authors for measurements of output factors for 10 MV-FFF photon beam.*

Figure 7 illustrates the measured off-axis ratio for the 4 and 7.5 mm cones in the 80, 90, and 100 cm of SSD. Measures for EDGE, RAZOR, Diode-DEN, and manufacturer reference data are plotted simultaneously. The curves for the three detectors practically overlap along with the field profile, for the 3 SSD's. The larger differences found were in the penumbra region, a range of the field where there will naturally be differences due to the variety of volumes of the detectors used. In the literature, it is mentioned that the detectors with the best performance in the characterization of OARs are radiochromic films and diodes. Analogously in the determination of output factors, an alternative to minimize this effect of volume when determining a parameter is to assume the average of the readings from different detectors.

Because they are small fields conditions, we can assume the geometry as complex according to Venselaar et al., who suggests as tolerance the value of 3% variation inside the field, 15% in the penumbra region, and 4% outside the radiation field [7].

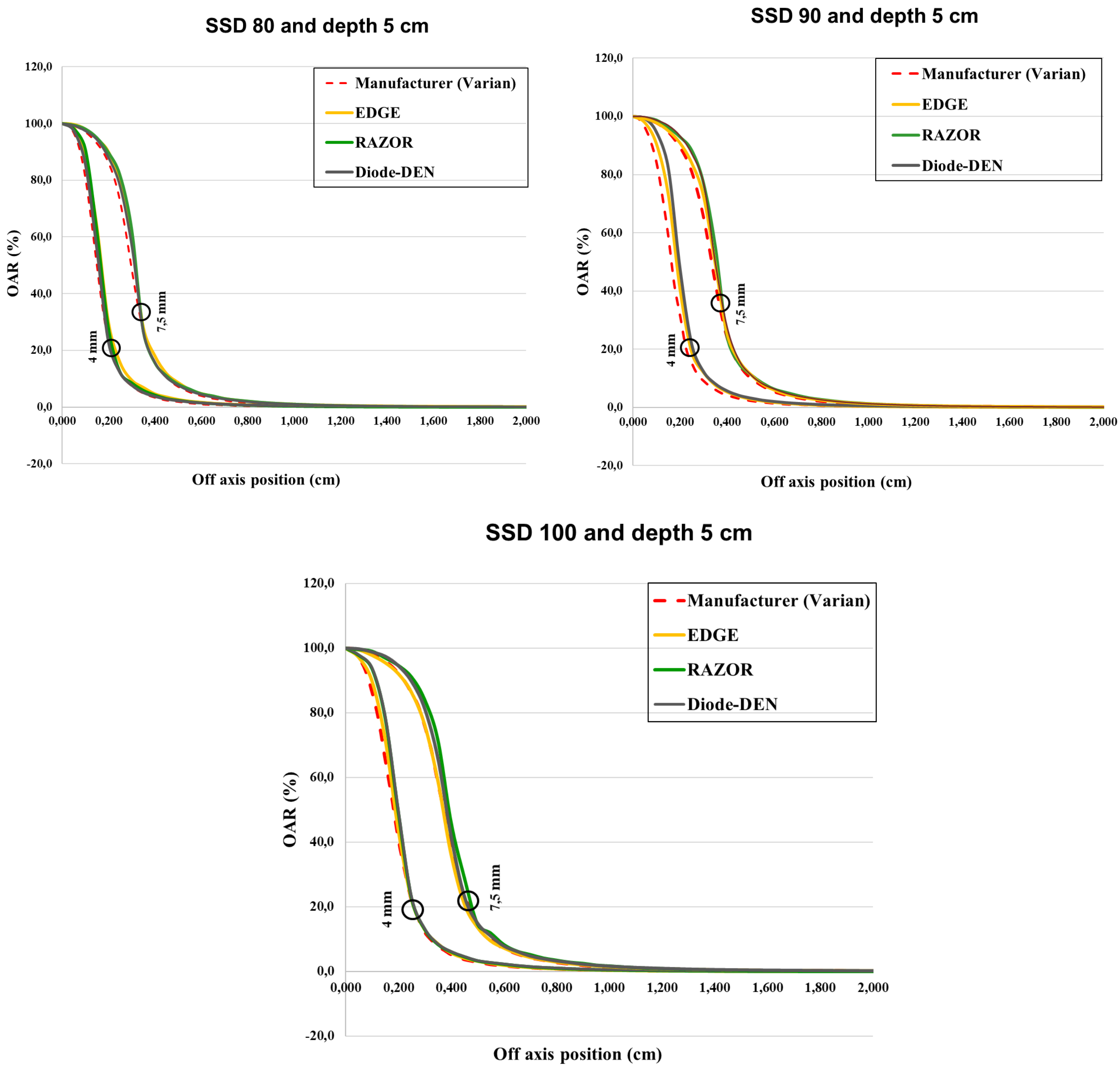
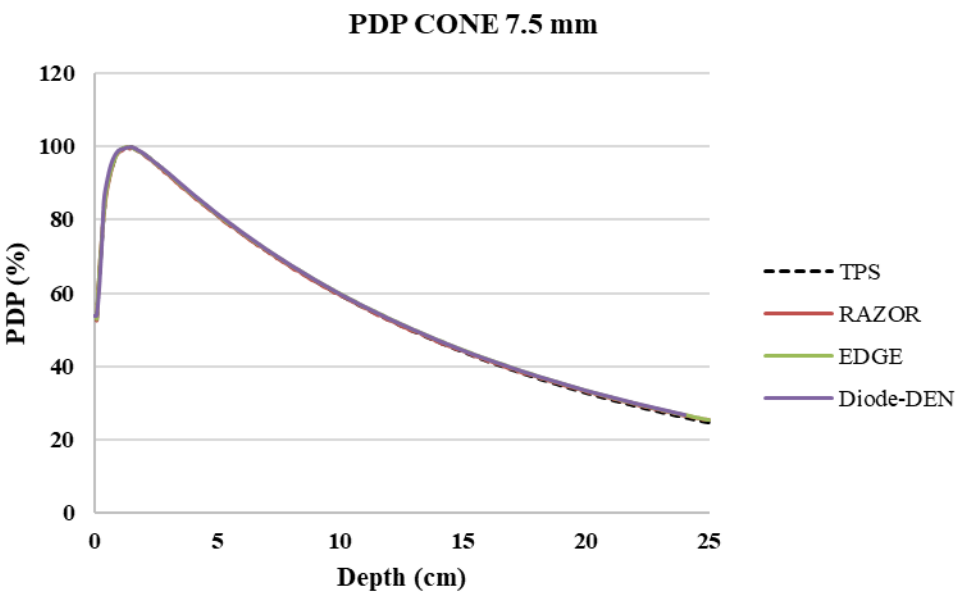


Figure 7: *OAR for cones 4.0 and 7.5 mm in SSD's: 80, 90 and 100 cm for 10 MV-FFF photon beam*

Figure 8 shows the PDP results obtained with EDGE, RAZOR, and Diode-DEN diodes for 7.5 and 4 mm diameter cones. The measurements were compared with the manufacturer's reference data contained in the treatment planning system (TPS). This is a complex geometry, where the author Venselaar et al. suggests as a tolerance the value of 15% variation in the build-up region and 3% after the build-up [7].



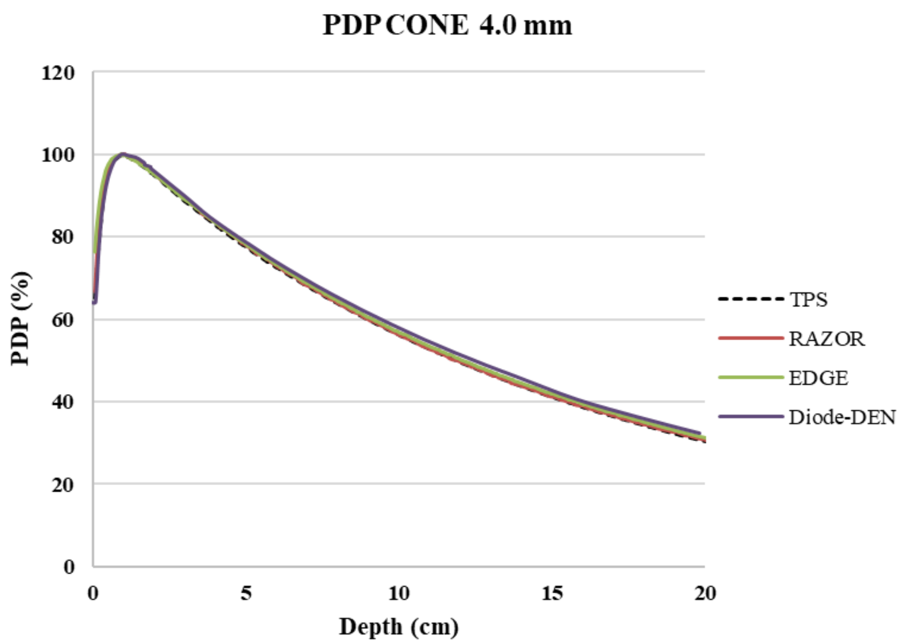


Figure 8: *PDP for cones of 7.5 and 4.0mm, and 10 MV-FFF photon beam*

Analyzing the difference in the PDP between the three detectors compared with the data from the TPS, there is a variation and can reach up to 3%, except for the build-up region. The maximum variation found was for the Diode-DEN, obtaining a value of -7.93 in the build-up region for the 7.5 mm diameter cone. Considering that this region presents greater uncertainty in the measurement process, the PDP obtained with the Diode-DEN presents variation within the tolerable limits, as described by Venselaar et al. [7].

For the 4.0 mm diameter cone, the variation in the PDP measurement for the three diodes was greater. This is the smallest cone size in the set, which makes the measurement process difficult, as it is extremely dependent on the setup arrangement and detector alignment. For the build-up region, only the Razor detector and the Diode-DEN had variations smaller than 15%. For the remainder of the curve, the Diode-DEN presents a variation greater than 3% at depths greater than 10 cm. After the build-up region, the Razor and Edge diodes performed with smaller variations

4. CONCLUSIONS

The evaluated dosimetric characteristics of the dosimetric Den system, such as the response repeatability of showed variations smaller than 0.05 %, which allows its use for dosimetry. Regarding the dose response the results showed a linear response with a correlation coefficient equal to 1. The effect of the dose rate on the diode-DEN response provides a variation less than 0.85% in the analyzed range of 800 to 2400 MU/min.

The results showed that Diode-DEN has a sensitivity about twice that of other commercial diodes used in small fields of radiosurgery. This fact allows us to suggest that the Diode-DEN can also be used to measure doses in smaller ranges.

From this study, it was concluded that Diode-DEN presents a reliable and economical alternative for small fields dosimetry used in treatments of SRS. Thus, this system can be used for validation of dates obtained in commissioning of linear accelerator and inserted in Treatment Planning Systems (TPS).

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