Original Article

Validation of Microionization Chambers in Small-field Dosimetry

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Abstract

Aim: This study aims to validate the Razor Nano Chamber (RNC) and Razor Chamber (RC) dosimetric characteristics in a small field. The dosimetric parameters of the two chambers were compared. **Materials and Methods:** The chamber characteristics of leakage (pre and post), stability, energy dependency, dose linearity, dose rate effect, stem effect, angular dependency, ion recombination effect, and polarity effect were studied. Relative dose measurements of the percentage depth dose, profile measurement, and output factor (OF) measurements were performed for small fields. All measurements were performed in a Theratron 780E telecobalt unit and an Elekta Versa HD™ Linear Accelerator. **Results and Discussion:** The measured pre- and postirradiation leakage and energy dependency were within 0.5% of the acceptable limit. In the stability check, the standard error and standard error of mean were 0.047% and 0.068%, respectively, for both RNC and RC. The deviation in the angular responses of the RNC and RC ion chambers was negligible. In the ion recombination measurements, both the RNC and RC were overestimated for the 10 flattening filter-free photon beam. In small fields, there were no significant differences in the k_{pol} values for either chamber. The RNC showed good agreement in the relative dose measurements compared to the RC. **Conclusion:** RNC and RC showed good agreement in small-field dosimetry. The RNC angular dependency and OF showed a superior response compared to the RC because of the small volume spherical shape and high spatial resolution, which gives a reduced penumbra and no volume averaging effect.

Keywords: Microionization chamber, Razor chamber, Razor Nano chamber, small-field dosimetry, validation of ion chamber

Received on: 15-01-2024 **Review completed on: 21-02-2024** **Accepted on: 03-03-2024** **Published on: 25-06-2024**

Introduction

In advanced radiotherapy techniques, small-field segments are created using a multileaf collimator (MLC), micro-MLC, stereotactic cones for stereotactic radiosurgery, stereotactic radiotherapy, and stereotactic body radiotherapy. These techniques deliver a highly conformal dose to the tumor and minimize the dose to the surrounding healthy tissues.[1-3] In particular, these techniques utilize flattening filter (FF) and flattening filter-free (FFF) photon beams to deliver a larger dose over a shorter period.[4,5] One of the key tasks in the treatment planning system commissioning data measurements is to ensure that patients receive high-quality treatment outcomes. For small-field dosimetry to succeed, the measurement data must be extremely precise and accurate.[6-8]

Radiotherapy dosimetry frequently uses ion chambers.[9] The primary restriction of the ion chamber became apparent when measuring beams that had a width <2 cm or at the beam penumbra.[10] The active volumes were generally not constructed with sizes smaller than 2–3 mm due to the low sensitivity of air. In small-field dosimetry, this results in volume averaging.[11,12] Chamber materials have the potential to significantly disturb these small fields.[13] Other restrictions include the reliance on the polarity impact on the field magnitude and other electric phenomena linked to low signal-to-noise ratios, such as the stem/cable effect and signal instability.[11,13,14] Ion recombination is an issue, especially in FFF beams for ionization chambers. Limited precision in these domains has been demonstrated by early small active volume chambers.[15] Early solid-state detectors experienced significant total ionizing radiation damage and poor tissue equivalence and demonstrated differences in detector response from similar dosimeters.[16] Number of publications available

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Access this article online

Quick Response Code:

Website: www.jmp.org.in

DOI: 10.4103/jmp.jmp_9_24

How to cite this article: Kannan M, Saminathan S, Shwetha B, Chandraraj V, Raj DG, Ganesh KM. Validation of microionization chambers in small-field dosimetry. J Med Phys 2024;49:285-93.

in detectors were air-filled ionization chambers, and solid-state detectors used in small field measurements. New construction techniques for ion chambers and solid-state detectors may be necessary in light of current developments in radiotherapy.[5,17] The IBA dosimeter was available as a small-volume Razor Nano Chamber™ (RNC), IBA, Germany, with a volume of 3 mm^3 and the Razor Chamber™ (RC), IBA, Germany, with a volume of 10 mm^3.

Reggiori *et al*. investigated the characteristics of RNC ion-chamber with 6MVFF, 6MVFFF, and 10MVFFF photon beams.[18] The study did not include the energy dependency and stability of the chambers. Furthermore, the 10MV photon beam was not included in this study. Partanen M *et al*. (2021), determine the output correction factor of RNC ion-chamber in 6MVFF, 6MVFFF, and 10MVFF photon beams.[19] In this study, the characteristics of the RNC and RC were investigated and compared for 6MV and 10MV (FF and FFF) photon beams.

Materials and Methods

Materials

Physical characteristics of chambers

The physical characteristics of the RNC and RC are listed in Table 1.

Figure 1 shows physical and radiographic images of the chambers.

Treatment units

A Theratron 780E telecobalt unit and Elekta Versa HD™ linear accelerator (Elekta AB, Stockholm, Sweden) machines were used for dosimetric measurements. The Elekta Versa HD™ linear accelerator is capable of delivering a 6MV FF, 6MV FFF, 10MV FF, and 10MV FFF photons, and five electron beam energies the secondary collimator jaw is replaced with Agility™ (Elekta AB, Stockholm, Sweden) MLC, which incorporates 80 pairs of tungsten leaves with 5 mm projected leaf width at isocenter.

Dosimetric equipment

The chamber characteristics and various dosimetric parameters were evaluated for the small-volume ionization chambers, RNC and RC. A radiation field analyzer (RFA), IBA Blue phantom™ (IBA, Germany), and calibrated dose 1 electrometer (IBA, Germany) were used for all the dosimetric measurements.

Methods

Pre- and post-irradiation leakage

To achieve the thermal stability of the chambers and electrical stability of the electrometer, the ionization chambers were connected to the electrometer in a powered-on condition and maintained for an hour. The factors including unclean couplings, moist desiccators, insufficient time given for the instrument to stabilize, and no preirradiation dose delivered to the chamber can contribute to natural (preirradiation) leakage. The preirradiation leakage of the chamber was evaluated for 5 min, with measurements taken five times. Leakage caused by radiation can be detected only after the chamber has been exposed to radiation. If radiation-induced leakage occurs, then the charge continues to accumulate even after the beam is switched off.

Stability and energy dependency

Ionization chamber stability checks are essential because they are relatively delicate and may show little or no obvious signs

Table 1: Physical characteristics of chambers

	RNC	RC
Active volume (cm^3)	0.003	0.01
Diameter of active volume/length (mm)	2.0	3.6
Wall thickness	0.5 mm (88 mg/cm^2)	0.5 mm (88 mg/cm^2)
Outer electrode (g/cm^3)	Shonka (C-552) (P=1.76)	Shonka (C-552) (P=1.76)
Inner electrode (g/cm^3)	Graphite-EDM3 (P=1.81)	Graphite-EDM3 (P=1.6)

RNC: Razor Nano chamber, RC: Razor chamber, EDM3: Electrical discharge machining 3

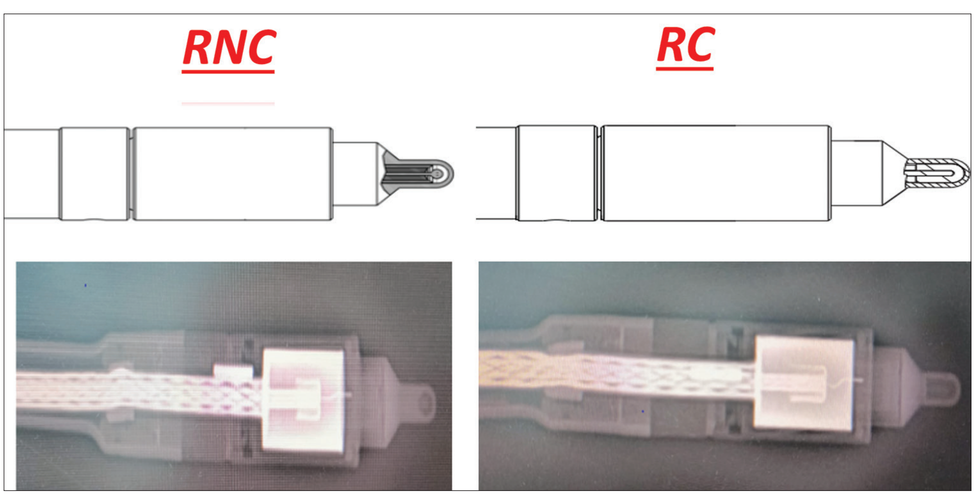

Figure 1: Physical and radiographical images. RNC: Razor Nano chamber, RC: Razor chamber

of deterioration. The check source, strontium-90 (Sr^{90}) was used to evaluate the ionization efficiency, overall sensitivity, and stability. The activity of the source is 140MBq as of July 2023. The source, chamber, and measuring assembly had been placed in the measuring room an hour before the measurement, to ensure the thermal stability. The measurement was performed ten times, and pressure and temperature corrections were applied to the measured readings. The standard uncertainty and standard error of the mean were calculated from measurements. To check the energy dependence, the calculated 2 Gy was delivered in ^{60}Co, 6MV, and 10MV (FF and FFF) photon beams with 10 cm × 10 cm field size at 5 cm depth for both the RNC and RC chambers.

Dose linearity and dose rate effect

The chamber was positioned at 5 cm with a 95 cm Source to surface distance (SSD) and a field size of 10 cm × 10 cm for all measurements. Chamber linearity was checked for monitor units ranging from 10 to 1000 MU with photon energies of 6MV and 10MV (FF and FFF). During the measurement, a dose rate of 600 MU/min was maintained and the measurement was repeated five times. In addition, the chamber response for different dose rates ranging from 100 to 1200 MU/min was checked for the dose of 200 MU. It was normalized to 600 MU/min for FF beam and 1000 MU/min for FFF photon beam.

Stem effect and angular dependency

To check the stem effect of the chambers, the chambers were exposed to a 6MV photon beam at depth of 5 cm for field size setting 3 cm × 10 cm (width × length) and 10 cm × 3 cm (width × length). The percentage variation in the response of the chamber for the above-mentioned field size reflects the stem effect, and to find the angular dependency in-air measurements with a suitable build-up cap were performed in ^{60}Co photon beams. The source-to-chamber axis distance was maintained at 80 cm for gantry angles between 0° and 360° in increments of 30°. The 5 cm × 5 cm field size was used for this measurement.

Ion recombination effect

When the chamber receives a sufficiently high voltage, the charge generated during the irradiation will be completely collected if sufficient high voltage is applied to the chamber. If the chamber is operated below the saturation voltage, few charges generated on irradiation recombine, which results in a loss of the dosimetric signal. The chamber response was studied by varying the bias voltages from 50 to 400 V, with an increment of 50 V for all the energies used in this study. The field size was 10 cm × 10 cm at a depth of 5 cm for all measurements. Ion recombination was analyzed using two methods: the two-voltage method and saturation curve method.[20,21]

Two voltage methods used the following Equation (1):

$$\text{(High energy) } k_s = a_0 + a_1(M_1/M_2) + a_2(M_1/M_2)^2 \quad (1)$$

where,

M_1 and M_2 are meter readings for the polarizing voltages V_1 = +300 V and V_2 = +150 V.

a_0, a_1, a_2 - quadratic fit coefficients.

Agostinelli *et al*. proposed a J_{sat} for 1/Q v_s 1/V saturation curve for the polarity effect, where Q is the polarity-corrected charge and V is the bias voltages from 50V to 400V.[21] To obtain the stabilized output of the chamber, approximately a gap of 30 min was given between the measurements while bias voltages were changed.

The J_{sat} method used the following Equation (2).

$$J_{sat} = \frac{Q_{SAT}}{Q_{300}} \quad (2)$$

where,

Q_{SAT} – Saturation charge.

Q_{300} – Charge collected for +300V.

Polarity effect (k_{pol})

Polarity correction factors for the RNC and RC were evaluated for the 6MV, 10MV (FF and FFF) photon beams. The measurements were performed for field sizes ranging from 1 cm × 1 cm to 10 cm × 10 cm for all photon beams. The polarity was checked for M+ (+300V) and M^- (−300 V) bias voltages. Equation (3) was used to calculate the polarity effect.

$$k_{pol} = \frac{|M^+| + |M^-|}{2M} \quad (3)$$

where M^+ and M− are the electrometer reading sat the positive and negative potentials, respectively, and M is the route polarity electrometer reading.

Relative dose measurements

Relative dose measurements, such as dose profile, percentage depth dose (PDD), and output factors (OF), were measured using the RNC and RC with RFA. The Profile and OFs were measured at a depth of 10 cm with a source-to-detector distance of 90 cm. The step-by-step scanning method was performed with a 0.1 cm step size from a depth of 0.05 cm to 15 cm for the PDD measurement, and the SSD was maintained at 100 cm. Profile measurements were performed for field sizes of 3 cm × 3 cm, 5 cm × 5 cm, and 10 cm × 10 cm for 6MV and 10MV (FF and FFF) photon beams. The OF measurement was carried for the field sizes 0.5 cm × 0.5 cm, 1 cm × 1 cm, 1.5 cm × 1.5 cm, 2 cm × 2 cm, 2.5 cm × 2.5 cm, 3 cm × 3 cm, 4 cm × 4 cm, 5 cm × 5 cm, and 10 cm × 10 cm.

Results and Discussion

Pre- and post-irradiation leakage

The pre- and postirradiation leakage currents for the RNC and RC were 2fA, 1.1fA, and 3.2fA, 2.2fA, respectively. RNC and RC measurements indicate that the constructed ionization chamber's pre- and postirradiation leakage current was within 0.5% acceptable limit.[22]

Stability and energy dependency

The stability of the chamber was tested using ^{90}Sr check source. The standard error and standard error of mean were 0.047% and 0.068% for the RNC and RC, respectively. The stability of the chamber was compatible with the International Electrotechnical Commission-60731 recommendations.[22] Energy dependency was checked for both the RNC and RC. Figure 2 depicts the energy responses of the RNC and RC ionization chambers. All the energy values were normalized to Co^{60} photon beam. No significant variations were observed in the detector's energy dependency (<0.5%) and the results were within acceptable measurement errors. The chamber response was found to be independent of energy.

Dose linearity and dose rate effect

A good linear response was observed with both chambers for monitor units ranging from 10 to 1000MU with photon beam energies of 6MV and 10MV (FF and FFF). Figure 3 shows the linearity of the RNC and RC for different monitor units. The variation in linearity was <0.5% and 0.4% in RNC and RC, respectively. Reggiori *et al*. reported a dose linearity of 0.4% for RNC with lowest MU (5–10 MU).[18] The maximum deviation was observed at the lowest dose value of 10 MU, which could be related to the larger uncertainty of the low measured signal (<0.1 nC).

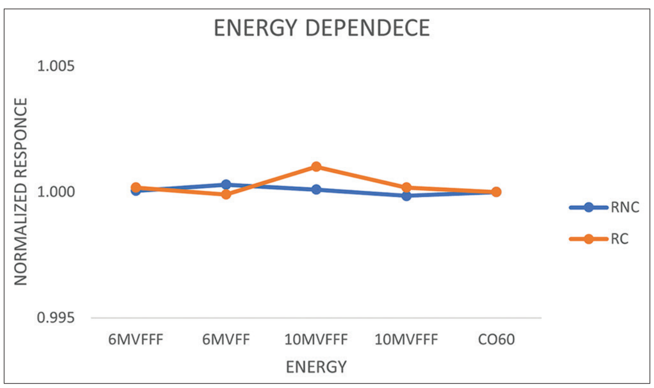

Figure 2: Energy response of the Razor Nano chamber and Razor chamber. RNC: Razor Nano chamber, RC: Razor chamber, FFF: Flattening filter free, FF: Flattening filter

The response of the RNC and RC for dose rates ranging from 100 to 1200 MU/min for photon beam energies of 6MV and 10MV (FF and FFF) were checked. Figure 4 shows the dose rate effect for the RNC and RC. The 6MVFFF photon beam shows a maximum deviation of −0.57% and 0.55% for RNC and RC, respectively. The data show that both chambers were independent of the dose rate for all energies.

Stem effect and angular dependency

The stem effects of the RNC and RC ionization chambers were measured for field sizes of 10 cm × 3 cm (width × length) and 3 cm × 10 cm (width × length). The percentage variations in the response were 0.45% and 0.35% for RNC and RC, respectively.

The angular response of the RNC and RC was checked in a ^{60}Co beam as an in-air measurement with a field size of 5 cm × 5 cm. The response is shown in Figure 5; the measurement shows the maximum deviations of 0.13% and 0.40% at 90°gantry angle. The deviation was due to the stem and cable effects in the irradiation field area. Reggiori *et al*. (2018) reported an angular response for RNC with deviations <0.5% for all angles (from 0° to 360°).[18] The angular responses of the RNC and RC ion chambers were negligible for all angles.

Ion recombination effect (k_s)

The ion recombination correction factor for the 6MV and 10MV (FF and FFF) photon beams with a field size of 10 cm × 10 cm were checked. Figure 6 shows the saturation curves. For all the energies, the J_{sat} value was calculated from the Q_{sat} value. Table 2 shows the ion recombination for the RNC and RC using the Jeff plot and the two voltage methods. Several authors[21,23-25] have mentioned that the small-volume chamber two-voltage method overestimates the ion recombination values. Similarly, our results also show that J_{sat} for 10MVFFF photon beam in RNC and RC have been overestimated by a maximum of 1.37% and 1.14%. Figure 7 shows the variation in ion recombination for both methods.

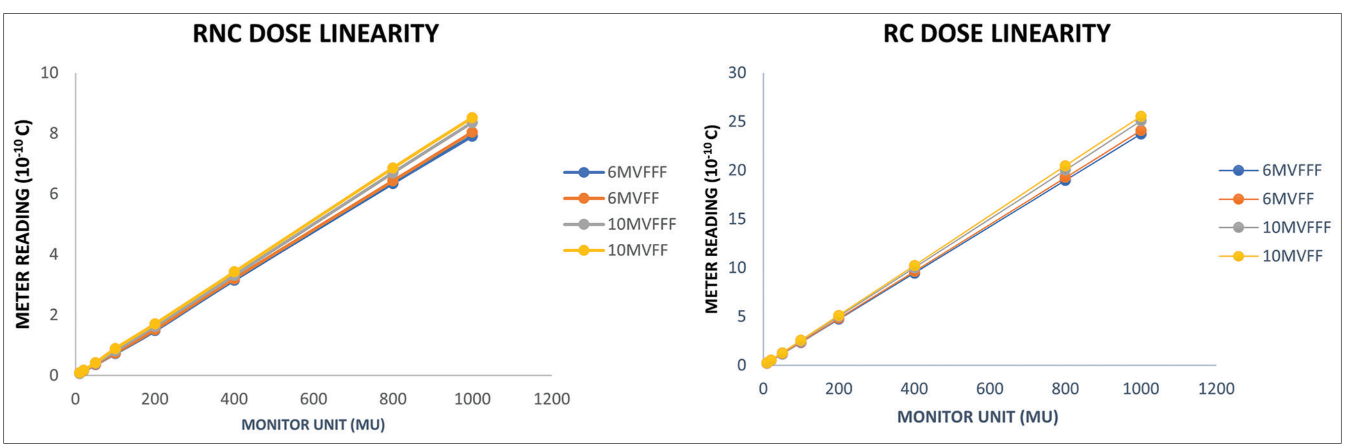

Figure 3: Dose linearity of Razor Nano chamber and Razor chamber. RNC: Razor Nano chamber, RC: Razor chamber, FFF: Flattening filter free, FF: Flattening filter

Table 2: Ion recombination for Razor Nano chamber and Razor chamber

Energy	RNC		RC	
	Two voltage method	Agostinelli J_{sat} method	Two voltage method	Agostinelli J_{sat} method
6 MV FFF	1.0168	1.0045	1.0117	1.0013
6 MV FF	1.0068	1.0039	1.0057	1.0041
10 MV FFF	1.0154	1.0040	1.0160	1.0045
10 MV FF	1.0168	1.0017	1.0090	1.0030

RNC: Razor Nano chamber, RC: Razor chamber, FF: Flattening filter, FFF: Flattening filter free

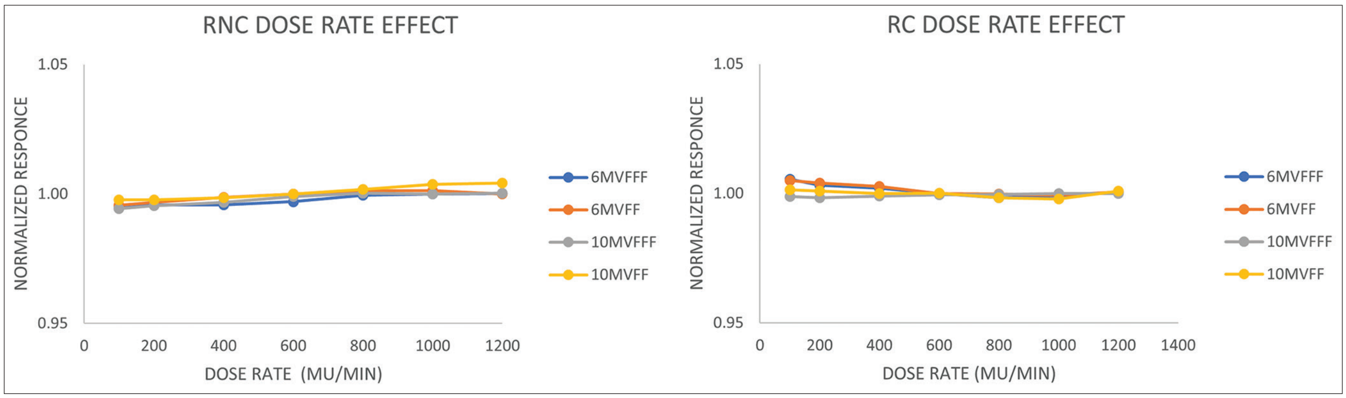

Figure 4: Dose rate effect of Razor Nano chamber and Razor chamber. RNC: Razor Nano chamber, RC: Razor chamber, FFF: Flattening filter free, FF: Flattening filter

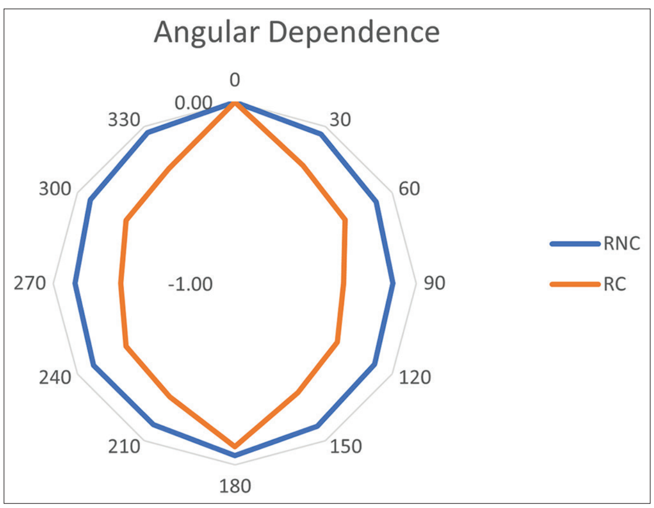

Figure 5: Angular response for Razor Nano chamber and Razor chamber. RNC: Razor Nano chamber, RC: Razor chamber

Polarity effect (k_{Pol})

The polarity effect with the field size was observed for both the 6MV and 10MV (FF and FFF) photon beams. The k_{pol} values are shown in Table 3 for a reference field size of 10 cm × 10 cm. Pasquino *et al*. (2017) observed that the polarity effect strongly depended on the field size for smaller fields. The variation was <1% compared with the reference field size 10 cm × 10 cm. This behavior is also similar to that of the PTW (COMPANY NAME (TN)) Pin-Point and Standard Imaging A26 chambers.[24] In our study, we observed a maximum deviation of 0.5% for RNC and 1.0% for RC in the k_{pol} value. Figure 8 shows the polarity effect for the RNC and RC.

Relative dose measurements

The PDD measurements were performed in 6MV and 10MV (FF and FFF) photon beams with field sizes of 3 × 3, 5 × 5, and 10 cm × 10 cm. The PDD curves of the RNC and RC are compared, and the results are shown in Figure 9. The RNC gives the overresponse with depth for all energies, the effect also varies with field sizes 10 × 10 (1.7 ± 0.15%), 5 × 5 (1.0 ± 0.2%), 3 × 3 (0.7 ± 0.1%) cm^2 compared to RC. Similarly, Reggiori *et al*. reported that the RNC showed a slight over response with increasing depth. The maximum difference was observed for the 6 MV photon beam, where this effect increased with increasing field size. Maximum values observed were 1.9%, 0.9%, and 0.7% for the field sizes 10 cm × 10 cm, 5 cm × 5 cm, and 3 cm × 3 cm, respectively.[18]

Profile measurements were performed for all energies using RNC and RC. The 10 FFF photon-beam crossline and inline profiles are shown in Figure 10. Reggiori *et al*. compared RNC and CC01 chambers and observed a penumbra of 0.5 mm for a 5 cm x 5 cm field size.[18] Similarly, in our study, the small-volume RNC showed good spatial resolution in the penumbra region compared to the RC. For all energies, the penumbral variation between the RNC and RC was <0.4 mm. The penumbral effect was greater in smaller fields than in larger fields.

The OF was measured for both chambers with field sizes 0.5 cm × 0.5 cm, 1 cm × 1 cm, 1.5 cm × 1.5 cm, 2 cm × 2 cm,

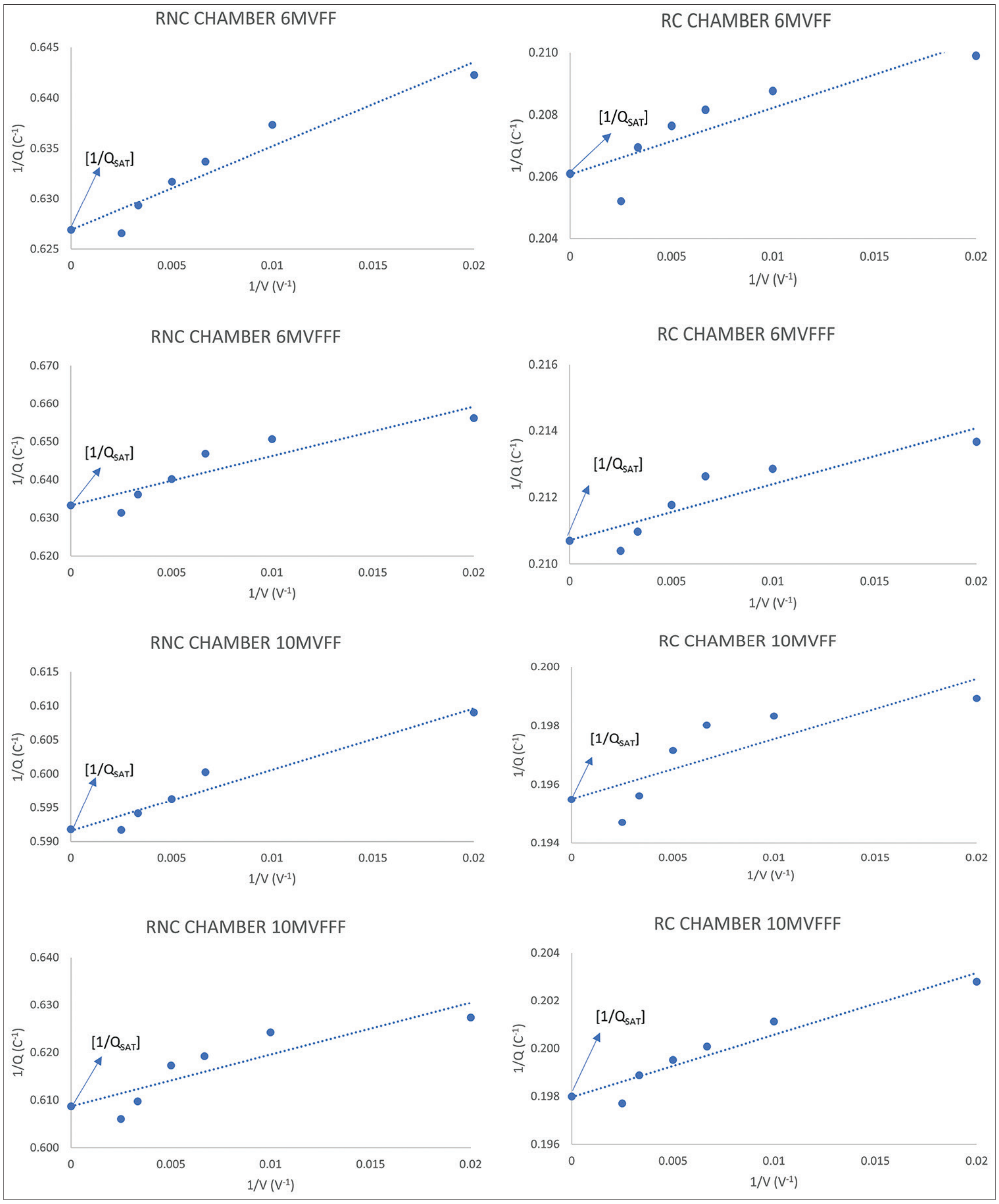

Figure 6: Saturation curve for Razor Nano chamber and Razor chamber. RNC: Razor Nano chamber, RC: Razor chamber, FFF: Flattening filter free, FF: Flattening filter

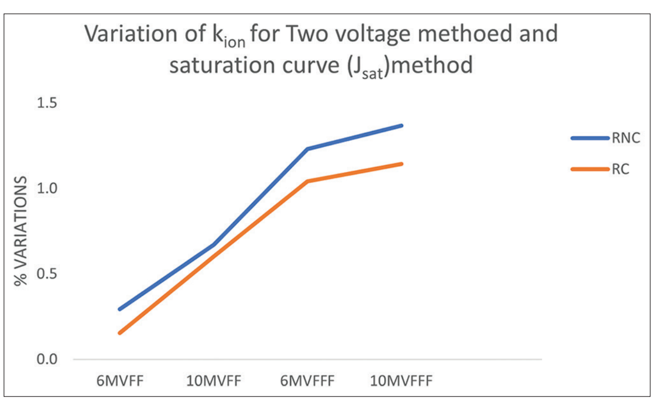

Figure 7: Variation of k_{ion} between two voltage method and J_{sat} method for Razor Nano chamber and Razor chamber. RNC: Razor Nano chamber, RC: Razor chamber, FFF: Flattening filter free, FF: Flattening filter

Table 3: Polarity correction factor values for Razor Nano chamber and Razor chamber

Energy	RNC	RC
6 MV FFF	0.9942±0.002	0.9931±0.003
6 MV FF	0.9941±0.001	0.9929±0.002
10 MV FFF	0.9953±0.003	0.9941±0.003
10 MV FF	0.9956±0.002	0.9931±0.001

RNC: Razor Nano chamber, RC: Razor chamber, FF: Flattening filter, FFF: Flattening filter free

2.5 cm × 2.5 cm, 3 cm × 3 cm, 4 cm × 4 cm, 5 cm × 5 cm, and 10 cm × 10 cm for all photon energies used in this study. The OF results are shown in Table 4 and the percentage of variation between the OF for the RNC and RC is shown in Figure 11. Reggiori *et al*. compared the OFs of micro-diamond

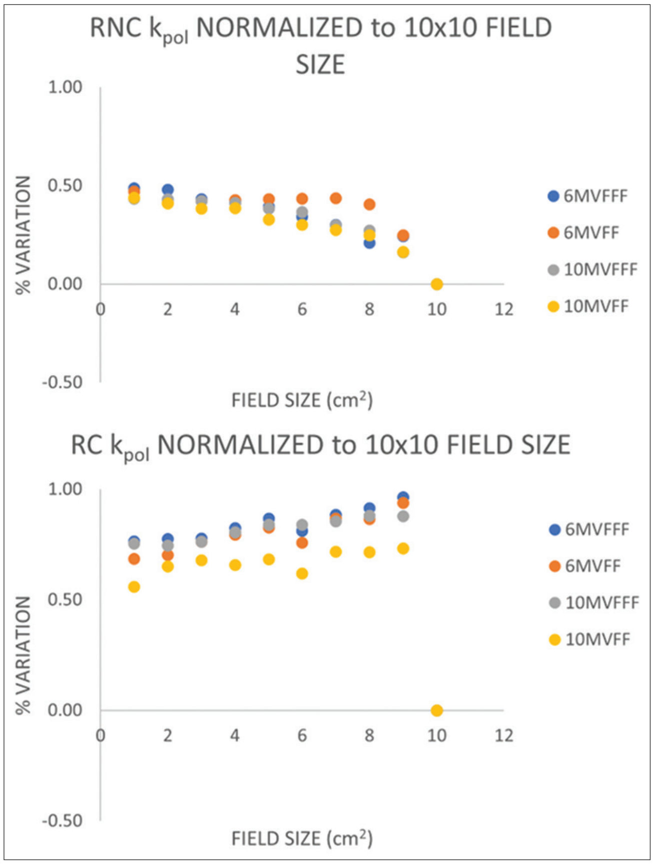

Figure 8: Polarity effect for Razor Nano chamber and Razor chamber. RNC: Razor Nano chamber, RC: Razor chamber, FFF: Flattening filter free, FF: Flattening filter

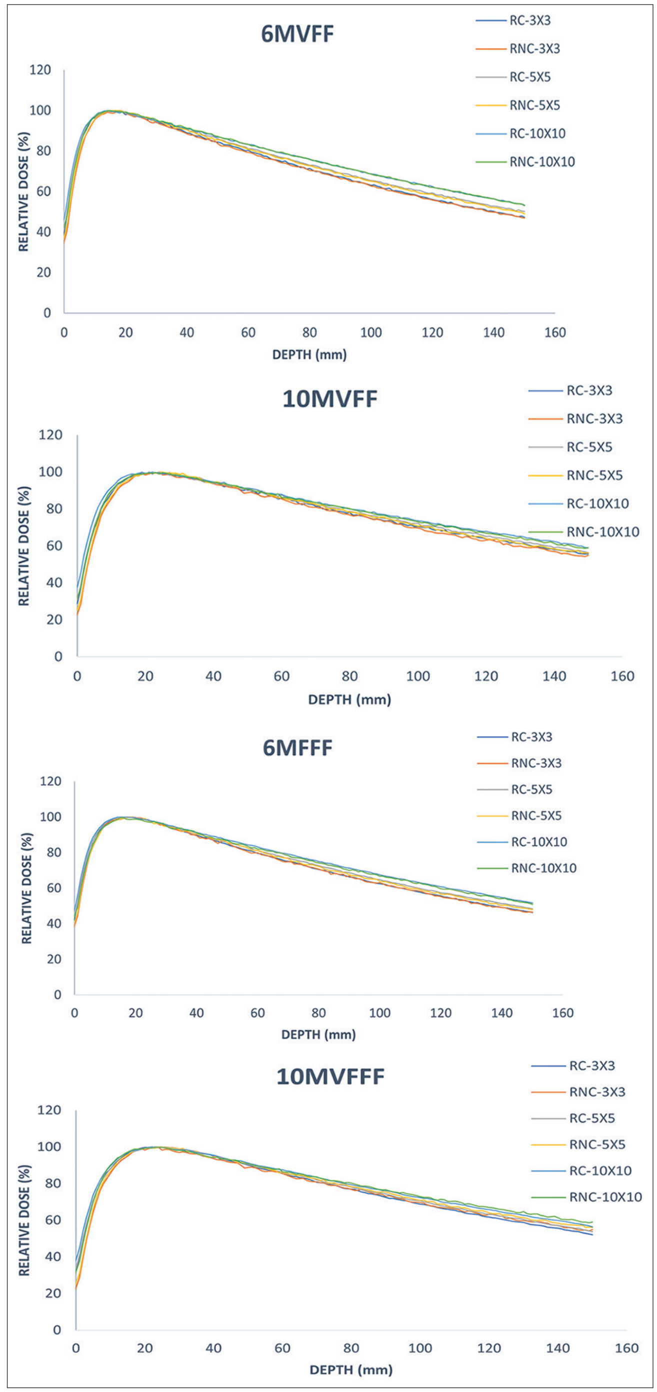

Figure 9: The comparison of percentage depth dose curves for Razor Nano chamber and Razor chamber. RNC: Razor Nano chamber, RC: Razor chamber, FFF: Flattening filter free, FF: Flattening filter

and razor-diode detectors. The RNC showed a good agreement 0.4% without applying the volume average correction.[18] Similarly, in our study, the RNC showed good agreement for the smaller field size <1.5 cm × 1.5 cm compared to RC. The variation between OF for the RNC and RC is <1% for a field size >1.5 cm × 1.5 cm for all photon energies whereas, the maximum variations were −4.02%, −4.50%, −4.0%, and −4.46% for 6MVFF, 6MVFFF, 10MVFF, and 10MVFFF photon energies, respectively, for the field size 0.5 cm × 0.5 cm. Table 4 shows the OF variation with an increase in field size for both chambers. The maximum of RNC and RC, the variation was −4.02%, −4.50%, −4.0%, and −4.46% for 6MVFF, 6MVFFF, 10MVFF, and 10MVFFF photon energies, respectively.

Conclusion

The RC (0.01 cm^3) and RNC (0.003 cm^3) are potential alternatives to classical vented ionization chambers for small-field dosimetry. Despite the similarities in their phenomena, the application of RC and RNC in radiotherapy has been hindered by the lack of studies on the dosimetric characteristics of high-energy beams in radiotherapy for small fields. In this study, the dosimetric characteristics of RC and RNC were examined for different photon energies. The dose-response behavior is independent of dosimetric parameters, such as leakage, stability, linearity, dose rate, directional dependency, stem effect, polarity effect, and ion recombination effect. The pre-and postirradiation leakage currents for the RNC and the RC were within acceptable limits. As the active volume of the RC and RNC is very small, they can be used for measurements in very small fields. As the volume is small, there is no volume-average effect, and it is more

Table 4: Output factor for Razor Nano chamber and Razor chamber

Field size (cm^2)	6 MV FF		6 MV FFF		10 MV FF		10 MV FFF	
	RNC	RC	RNC	RC	RNC	RC	RNC	RC
0.5×0.5	0.4140	0.3974	0.4165	0.3978	0.3550	0.3408	0.3264	0.3118
1.0×1.0	0.6850	0.6632	0.7075	0.6827	0.6555	0.6356	0.6650	0.6442
1.5×1.5	0.7703	0.7592	0.7980	0.7841	0.7550	0.7450	0.7850	0.7705
2.0×2.0	0.8040	0.8012	0.8320	0.8265	0.8020	0.7972	0.8380	0.8320
2.5×2.5	0.8255	0.8274	0.8450	0.8508	0.8300	0.8339	0.8700	0.8687
3.0×3.0	0.8476	0.8490	0.8711	0.8739	0.8570	0.8595	0.8925	0.8931
4.0×4.0	0.8820	0.8830	0.9020	0.9038	0.8930	0.8951	0.9230	0.9248
5.0×5.0	0.9075	0.9077	0.9241	0.9256	0.9200	0.9207	0.9435	0.9465
10.0×10.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

RNC: Razor Nano chamber, RC: Razor chamber, FF: Flattening filter, FFF: Flattening filter free

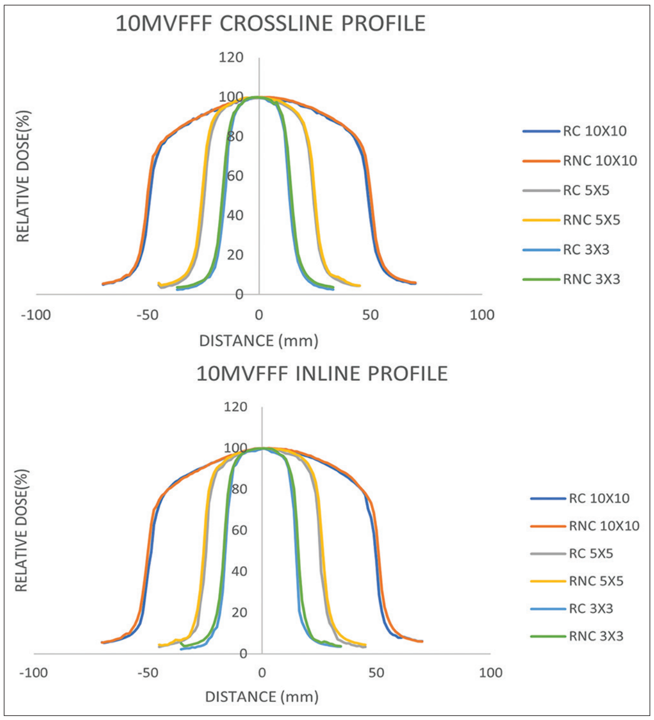

Figure 10: The 10 flattening filter free photon beam crossline and inline profile for Razor Nano chamber and Razor chamber. RNC: Razor Nano chamber, RC: Razor chamber, FFF: Flattening filter free, FF: Flattening filter

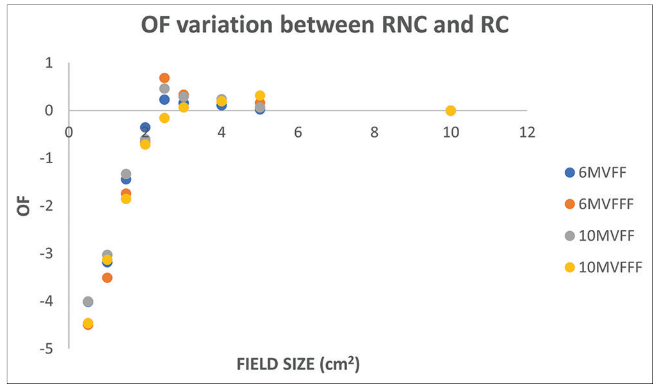

Figure 11: Comparison output factor variation between the Razor Nano chamber and Razor chamber. RNC: Razor Nano chamber, RC: Razor chamber, FFF: Flattening filter free, FF: Flattening filter, OF: Output factor

accurate. The good stability of both chambers demonstrated that they could be conveniently reused several times, providing less leakage before and after irradiation.

Acknowledgment

The authors are also grateful to Mr. Sandeep B S and Mr. Prabhu K for their contribution while doing the measurement. The authors would like to thank Mr. Sakthichelvam R. R IBA Dosimetry India Pvt Ltd. for the support related to experimental work.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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