On the dose linearity of detectors for small field dosimetry

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Background and Objective

The guidance for dose linearity in the TRS-483 CoP stipulates it to be ***"better than 0.1% over an absorbed dose range of at least three orders of magnitude"***. TRS-483 did not provide any methodology for the measurement of dose linearity. The aim of our multicenter experimental study was to verify that guidance for dose linearity applying two alternative methods, using a large number of suitable detectors recommended in TRS-483 for small field dosimetry.

Methods

- A strict study protocol was followed at each of the nine participating centers;
- Twenty different types of detectors (10 ionization chambers, 9 diodes, and 1 micro diamond detector) were used for testing the dose linearity; 49 detectors in total;
- All measurements were performed using an isocentric set-up with SSD = 90 cm, a depth of 10 cm, gantry 0°, and field size of 4 x 4 cm^2
- 6 and 10 MV photon beams with (WFF) and without (FFF) flattening filter were used on either Elekta Versa HD™ or Varian TrueBeam™ linear accelerators;
- Detectors were irradiated with 5, 10, 20, 30, 50, 100, 200, 300, 500, and 1000 MUs, covering an approximate absorbed dose range of three orders of magnitude.

Dose Linearity A: Adapted formalism from IEC 60731

Dose Linearity was calculated as shown in Eq. (1), where $M_i = m_i/m_{i,ref}$; m_i denotes a single, *i-th* measurement (data point) performed at a particular center, for a selected detector, energy, and number of MUs, while $m_{i,ref}$ stands for the corresponding measurement with reference ionization chamber done at the same time. M_{ref} was defined as shown in Eq. (2), where indices 50, 100, and 200 denote number of MUs.

$$\text{Dose Linearity A} = 100 \cdot \left(\frac{M_i}{M_{ref}} - 1\right) \quad (1)$$

$$M_{ref} = \frac{1}{3}(M_{50} + M_{100} + M_{200}) \quad (2)$$

Dose Linearity B: Coefficient of determination R^2

R^2 indicates the proportion of the variation of the data explained by the best-fit linear function, where mi,ref and mi were considered as the independent and dependent variables, respectively. We also considered that the pass criteria of 0.1% is satisfied if $R^2 > 0.999$.

Results and Discussion

Dose Linearity A: the TRS-483 criterion on dose linearity (0.1%) was not met for the majority of the 1960 analyzed data points (Table 1). In particular, the dose linearity criterion was not satisfied for low number of MUs.

Dose Linearity B: The coefficient of determination R^2 was higher than 0.999 for all analyzed data sets (196) for the entire range of MUs investigated in this study.

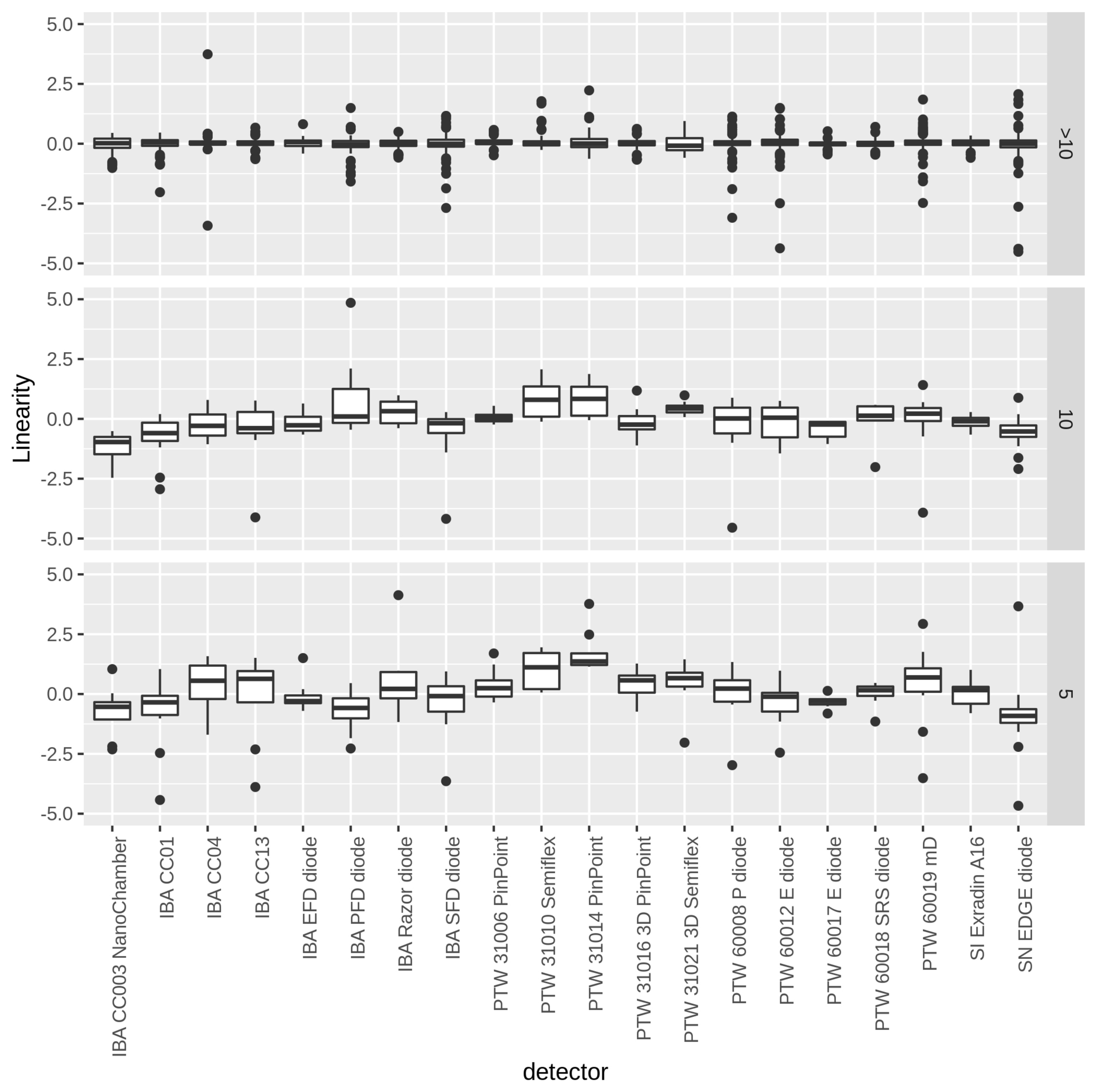
We tested dose linearity for 49 detectors (20 different types) using two methods.

The present results show that the 0.1% tolerance for dose linearity cannot be met for the selected range of doses (MUs) if the first method is used (adapted methodology from IEC 60731) for the determination of dose linearity. If we adopt that methodology, a less stringent acceptability criterion is needed, especially for very small numbers of MUs. For instance, if the tolerance in dose linearity is set at 1.0%, then more than 90% of the data points with 20 or more MUs comply (Table 1).

Table 1. Percentage of analyzed data points that satisfy different dose linearity criteria/tolerances ranging from 0.1 to 2.0% using the approach "Dose Linearity A" as described in the Methods section.

	Dose linearity tolerances			
t[MU]	0.1%	0.5%	1.0%	2.0%
	Data within tolerances [%]			
5	10.2	41.3	64.8	86.2
10	13.8	51.5	81.6	92.3
20	21.4	69.9	92.9	95.9
30	30.1	87.8	94.4	98.0
50	49.0	96.4	99.0	100.0
100	82.7	99.0	100.0	100.0
200	63.3	97.4	99.5	100.0
300	44.4	95.4	98.5	100.0
500	41.3	93.4	98.0	100.0
1000	33.2	88.3	95.9	99.5

Table 2. Distribution of "Dose Linearity A": values for twenty different types of detectors as a function of irradiated MU (≥5 MU, ≥10 MU or >10MU), which were included in the analysis.



Alternatively, if we assume that $R^2 = 0.999$ corresponds to 0.1% linearity criterion from TRS-483, the dose linearity acceptability criterion can be met with 100% of the data points for the whole range of MUs investigated in this study. In our opinion, method B is an acceptable method for the determination of dose linearity of detectors for small field dosimetry. Therefore, we recommend reporting dose linearity in terms of the coefficient of determination R^2. To avoid any potential ambiguity, the methodology for the determination of dose linearity should be specified along with the corresponding acceptability criterion in an eventual update of the TRS-483.

Conclusions

- Dose linearity has been tested for 49 detectors (20 different types) recommended in TRS-483 using two methods: adapted methodology from IEC 60731 and the approach using the coefficient of determination R^2.
- Study results show that the 0.1% tolerance for dose linearity cannot be met if the adapted methodology from IEC 60731 is utilized.
- Assuming that $R^2 = 0.999$ corresponds to 0.1% linearity criterion, the criterion is fulfilled for all analysed data points. To avoid any ambiguity, regarding the methodology for the determination of dose linearity, we recommend, that the methodology is explicitly specified in terms of the coefficient of determination R^2 in an eventual update of the TRS-483.

References

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