Evaluation of Peripheral Dose for Varian Trilogy Linear Accelerator

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Research

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Abstract

Objective To measure and evaluate the peripheral dose(PD) for Trilogy linear accelerator in different setup condition and investigate the feasibility of the diode dosimetric system to measure the peripheral dose.

Methods Peripheral dose were measured using a CC13 ionization chamber and the diode dosimetric system in a set of solid water phantom. Measurements were performed for different depths, field sizes, physical and virtual wedge, radiation beam energy and up at distance of 1cm to 31cm beyond the field edges. PD is separated into $PD_{leakage}$ and $PD_{scatter}$ by measure peripheral dose with or without scattering phantom. CRIS phantom was used for this research with the diode dosimetric system at the interest points of the breast, thyroid, and lens.

Results All the measure data were normalized to isocenter. The measured PD decreases exponentially as a function of distance up to 31cm from the edge. PD shows no significant relevant to depth and it increases with the increased field size. As the physics wedge angle increase, PD increases about 1%, but enhanced dynamic wedge decreased 2-3% compared with open field. As the beam energy increase, PD decreased. All PD data difference less than 1% between CC13 ionization chamber and diode. The PD of CRIS phantom for Volume Modulated ARC Therapy (VMAT) is minimum and the mean dose for breast、thyroid and lens is 6.72 mGy、2.90 mGy and 2.37 mGy respectively.

Conclusion The diode dosimetric system provides an sufficient assessment in peripheral regions of 6MV X-ray beam. PD changes because of field size、depth、beam energy etc and the assessment of PD would be helpful to evaluate the dose received by the relevant critical structures near the treatment field. Furthermore it is advantaged to use external shielding for critical organs.

Background

In Radiation Therapy, treatment target will be irradiated, spontaneously, organs surrounded receive small amount of radiation dose inevitable. The small amount of radiation dose received are called peripheral dose(PD).Peripheral dose will increase the advent of long-term complications. For example: Primates cataract's threshold dose is 3Gy and for sexual gland is 2Gy,Dörr and Herrmann found that : The majority of secondary carcinoma were within 5 cm margin from the radiation portal edge, this correlated to regions receiving less than 6Gy radiation dose. This research is to determine the peripheral dose(PD) for Varian Trilogy accelerator and investigate the ability of the diode dosimetric system to accurately measure the PD.

Methods And Materials

Instruments:

Varian Trilogy Linear accelerator with beam energy of 6MV and 18MV,60 leaf MLC; Eclipse 8.6 treatment planning system; SunNuclear IVD measurement system ISORAD-p(diameter:9.7mm,length:10.6mm, effective measurement volume:0.023cm^3);IBA Dose1,CC13 ionization chamber(diameter:10mm,length:11.6mm,effective measurement volume:0.13cm^3)and water equivalent phantom; CRIS phantom.

1. Phantom scan:

Two sets of 40cm*40cm*20cm water equivalent phantom is used for PD measurement. The phantom anterior is used for 'scattering phantom' and the posterior one is used for 'measurement phantom' (as show in Figure 1a). All phantoms mentioned above CT scanned by Philips big bore CT scan system, with 5mm CT scan slice thickness. All scan images were imported to Eclipse 8.6 treatment plan system.

2. Experiment 1,constitution of peripheral dose:

Irradiate the scattering phantom with beam energy of 6MV, gantry angle at 0 degree and field size is set to 20cm*20cm,isocenter irradiation with depth of 10cm, isocenter dose is set at 100cGy.Measure the peripheral dose at 1cm, 2cm, 3cm, 4cm, 7cm, 10cm, 13cm, 16cm, 19cm, 22cm, 25cm, 28cm, 31cm outside the edge of field size by CC13 ionization chamber and Diode ionization chamber respectively. All the data acquired by this setup is defined as 'PD_{all}'. Remove the 'scattering phantom' and measure the PD at the same setup as above, define all the acquired data as '$PD_{leakage}$' and the differences between 'PD_{all}' and '$PD_{leakage}$' as '$PD_{scatter}$'. All the peripheral dose are normalized to isocenter.

3. Experiment 2, relationship between irradiation depth and PD:

Under the same setup as Experiment 1, Measure all the PD data at 3cm, 10cm, 15cm depth.

4. Experiment 3, relationship between field size and PD:

Under the same setup as Experiment 1, change the field size at 10cm*10cm, 20cm*20cm, 30cm*30cm and measure all the PD data.

5. Experiment 4, Effects of wedge on PD:

Under the same setup as Experiment 1, add physical wedge and virtual wedge separately, which is w15, w45, vw15, vw45, measure PD as Experiment 1.

6. Experiment 5, relationship between beam energy and PD:

Under the same setup as Experiment 1, change the beam energy to 6MV and 18MV, Measure all the PD data as Experiment 1.

7. Experiment 6, PD measurement on CRIS phantom:

Hybrid treatment plan of postoperative patients with cervical cancer to CRIS tissue equivalent phantom, design VMAT, FF-IMRT step & shoot and FF-IMRT sliding window plan for the patient target, where VMAT plan consists of 2 Arc, FF-IMRT plan consists of 7 radiation fields and level of step shoot is 10[5]. The dose measurement organs are breast, thyroid and lens with and without Lead shielding (0.5 Pb).The distance for three organs of interest to

isocenter are 35cm, 51cm and 62cm and the depth are 3cm, 2cm and 1cm respectively. All doses are normalized to irradiation isocenter dose.

Results

1. PD distribution at isocenter of beam energy of 6MV and 20cm*20cm field size is shown in figure 2, 'PD_{all}' ,'$PD_{leakage}$' and '$PD_{scatter}$' decrease exponentially from 13.41% to 0.25% at the distance 1cm to 31cm from field edge. Measurement of CC13 ionization chamber and Diode ionization chamber shows good conformity and the maximum deviation is less than 1%. The relationship between '$PD_{leakage}$' and '$PD_{scatter}$' is shown in figure 3. '$PD_{scatter}$' dominant in near field edge area while '$PD_{leakage}$' dominant remoteness area. The junction point of these two dominances is at 7cm approximately where the '$PD_{leakage}$' and '$PD_{scatter}$' are equal.

2. Relationship between depth and dose distribution is shown in figure 4. Depth show small impact on PD distribution, the deviation is less than 1% at different depth.

3. Relationship between field size and dose distribution is shown in figure 5. As field size increases, PD value increases significantly.

4. The effect of wedge on PD distribution is shown in figure 6 and figure 7.Virtual wedge decrease PD and physical wedge increase PD compare to open beam setup. As the angle of physical wedge increases, PD increases and as the angle of virtual wedge increases, PD decrease significantly.

5. PD distribution at different beam energy is shown in figure 8. Beam energy increases, PD decrease significantly, for 6MV beam, Diode and CC13 ionization chamber shows good conformity and for high energy beam, they show worse conformity and the maximum deviation is 5% approximately.

6. PD distribution in different radiation technique in breast,thyroid and lens are shown in table 1. MU in sliding window, step & shoot and ARC technique is: 1069, 811 and 413; PD for breast, thyroid and lens in different technique is: 9.17mGy, 4.61mGy and 3.21mGy; 7.39mGy, 4.05mGy and 2.48mGy; 6.72mGy, 2.90mGy and 2.37mGy. Data shows that PD value is positive related to MU value, sliding window technique > step & shoot technique > ARC technique. Organ of interest dose decrease significantly with lead shielding.

Table 1
Mammary gland, thyroid and lens PD distribution in different treatment technique

Organs	Step & shoot		sliding window		VMAT	
	Measurement without shielding (mGy)	Measurement with shielding (mGy)	Measurement without shielding (mGy)	Measurement with shielding (mGy)	Measurement without shielding (mGy)	Measurement with shielding (mGy)
breast L	7.49	5.74	9.07	7.63	6.68	5.51
brest R	7.24	4.20	9.27	7.74	6.76	5.72
Thyroid L	3.84	3.15	4.23	3.71	2.60	2.74
Thyroid R	4.25	3.25	4.98	4.60	3.57	3.06
Lens L	2.61	1.60	3.18	2.91	2.55	1.01
Lens R	2.35	1.44	3.24	2.06	2.18	1.19

Discussion

This research investigate the effect of radiation depth, field size , wedge and beam energy on peripheral dose distribution and discuss the constitution of peripheral dose. We also discussed the feasibility of using diode system to detect peripheral dose and measure breast,thyroid and lens dose using CRIS phantom.

Gopiraj Annamalai et al[6] found that: as depth increases, the peripheral dose increase. At setup of field size 20cm*20cm,distance from edge is 1cm at 1.5cm, 5cm and 10cm depth, the peripheral dose is: 7.8%, 10% and 16%. They show different results from us, which are 13% consistent at different depths. The reason of this difference is unsure but it may cause by the precision of position and the choice of measurement detector in spite of field size changes in MLC for different measurement. These reasons may cause differences especially in measurement near the field edge. R. Balasubramanian[7] found that: PD distribution distance at 5cm – 20cm from field edge in different depth is approximately equal shows similar result with us.

Our results show that as field size increases, phantom scatter factor increase and PD increases accordingly. It shows similar result with most research. This result, however, did not take into account that MLC can form same field size as collimator. Robin L. Stern found that: In same field size condition, field formed by MLC can reduce peripheral dose by 6% to 50%.

Effects of physical wedge and virtual wedge to peripheral dose are complex. For physical wedges, there are four kinds of effects: 1. When physical wedge added, beam quality changes. 2. Physical wedge blocks some of the scattering radiation from collimator. 3. Radiation beam's angle changes when enter the phantom. 4. It takes more MU to deliver same amount of radiation dose. Scrimger et al. and Svensson et al. also found the increases in peripheral dose when adding physical wedges[9][10].

Virtual wedges changes dose distribution by moving jaw, when jaw moving, it blocks parts of scattering radiation generated from collimator and the volume of phantom irradiated are decrease as jaw moving. Accordingly, phantom scatter factor decrease and then the peripheral dose decreases.

Radiation beam will generate Compton effects with phantom, and with beam energy increases, backscatter electron will have more tendency to scatter in front direction. In this case, lower the peripheral dose in more distance area from field edge. And also, in the same dose condition, higher energy radiation beam requires less MU than that of lower energy radiation beam which cause lower the collimator scatter factor in high energy radiation beam. These two reason mentioned above caused higher energy radiation beam have less peripheral dose than lower energy radiation beam. R. Balasubramanian et al. found that: in 15MV and 6MV beam energy, for peripheral dose at 5cm distance from field edge, the peripheral dose is 3.42% and 3.07%[7], which have similar result with us.

Gopiraj Annamalai et al.'s research about Primus linear accelerator found that: at 10cm-20cm distance from radiation field edge, phantom scatter is dominant and at 30cm distance, phantom scatter dose is approximately equal to leakage dose. In our research, '$PD_{scatter}$' dominant in near field edge area while '$PD_{leakage}$' dominant remoteness area. The junction point of these two dominances is at 7cm approximately where the '$PD_{leakage}$' and '$PD_{scatter}$' are equal and '$PD_{leakage}$' dominant in more distance area over 7cm. Steffen Lissner et al.'s research about Tomotherapy accelerator found that: because of its unique principle of operation and shielding design, leakage dose's percentage at 30cm distance is less than 40%. In other words, phantom scatter peripheral dose dominant in any position in Tomotherapy accelerator.

For measurement of peripheral dose, choice of measurement instrument is always a controversial topic. For now, most researchers select TLD, Tilo Wiezorek[13] and E. D'Agostino[2] et al. uses TLD to measure peripheral dose in intensity modulated treatment. TLD have advantages that it has no dose rate response and have large range of measurement, relatively small volume and can repeatedly use makes it widely used for peripheral dose measurement. TLD is hard to operate and cannot read dose timely, however, limit its usage. This research considering using Diode ionization chamber to measure peripheral dose as it's easy to operate, strong timeliness and have high sensitivity response. In this research, when measuring 6MV radiation beam, Diode and CC13 ionization chamber has good conformity, for 18MV radiation beam, however, it does not show good enough conformity in account of high energy radiation beam has a complex energy spectrum and for 18MV diode detector has a narrow range.

Benedick A Fraass et al. found that adding lead shielding outside radiation field can reduce region of interest radiation dose[14]. This research has mentioned that lead shielding can reduce breast, thyroid and lens' radiation dose. It shows a little difference than Ming X Jia et al.'s results[15].The reason of the differences maybe the size difference of radiation target, the distance differences of organs of interest and radiation target.

Conclusion

In conclusion, radiation field size, wedge, radiation beam energy and etc may effects peripheral dose. To lower the chance of complication of surrounding healthy tissue, we recommend using shielding technique. Diode system and CC13 ionization chamber has good conformity, and is feasible in clinic for peripheral dose measurement. In clinical setup, Organs of interest's radiation dose are related to radiation technique, target field size, and need more analysis.

Declarations

1. Ethics approval and consent to participate

This manuscript doesn't report on or involve the use of any animal or human data or tissue so that this section is not applicable.

2. Consent for publication

This manuscript does not contain data from any individual person, hence this section is not applicable.

3. Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

4. Competing interests

The authors declare that they have no competing interests.

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6. Authors' contributions

Bo Yang performed most of the experiments and wrote the manuscript; *Tingtian Pang* performed some experiments and provided the discussion. *Xiansong Sun, Tingting Dong, Rui Li* and *KeHu* provided the discussion. wrote and edited the manuscript; *Fuquan Zhang* and *Jie Qiu* conceived the presented idea, designed experiments, wrote research grant. All authors read and approved the final manuscript.

7. Acknowledgements

Not applicable

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Figures

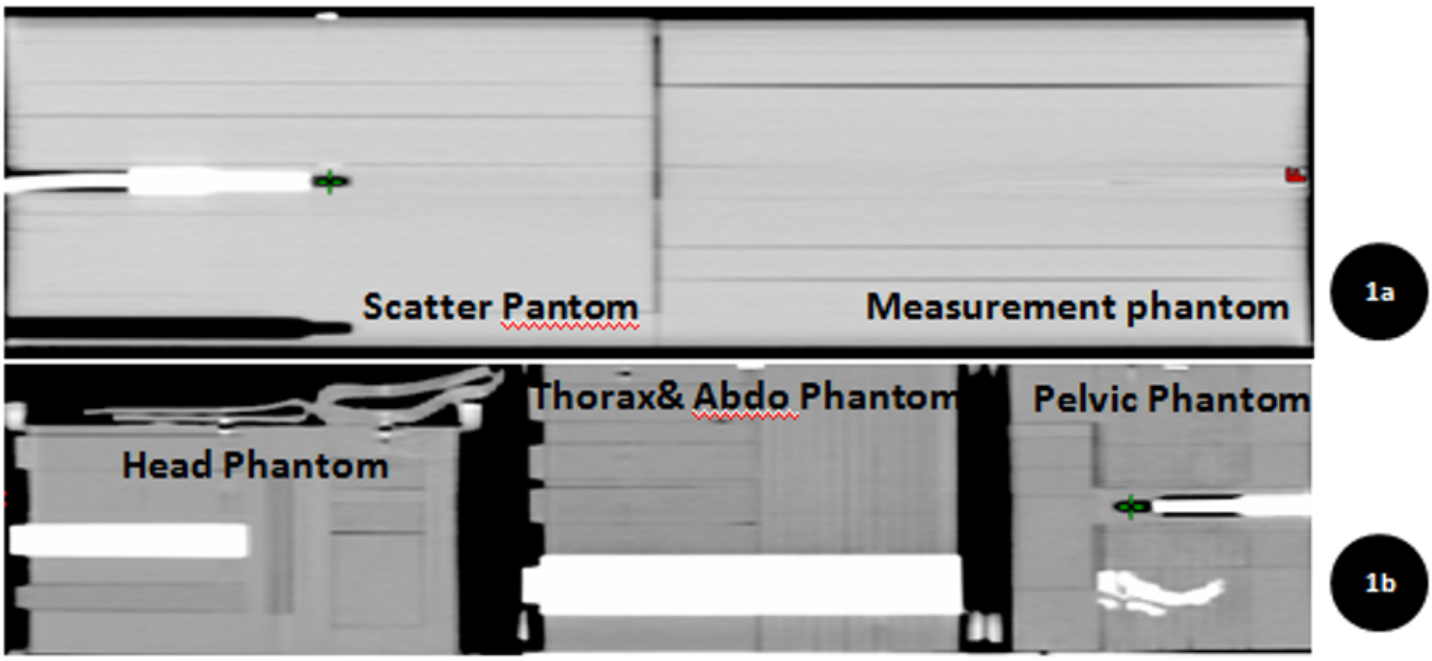

Figure 1

Sagittal plane of water equivalent phantom (1a) and CRIS phantom (1b).

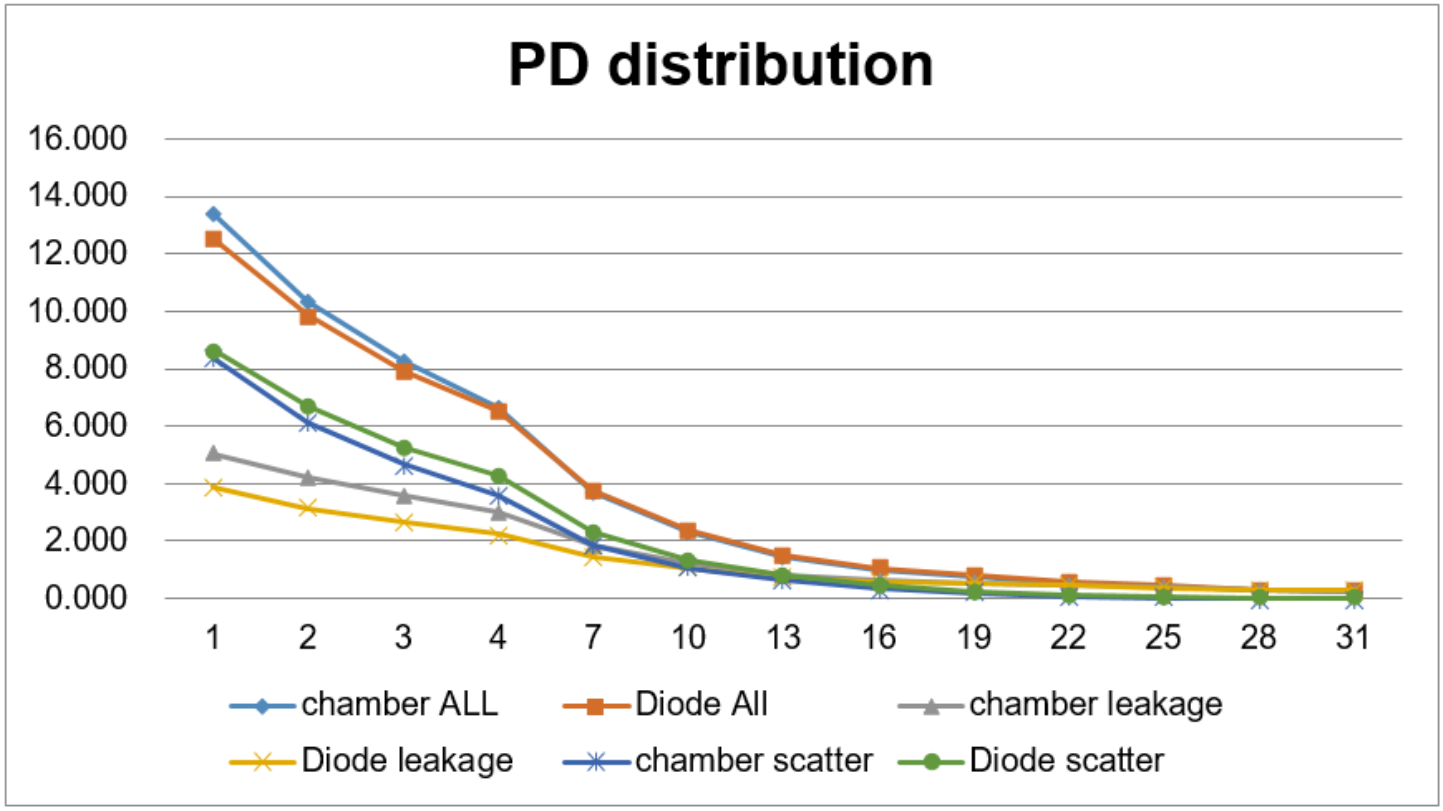

Figure 2

'PDall' ,'PDleakage' and 'PDscatter' at different distances

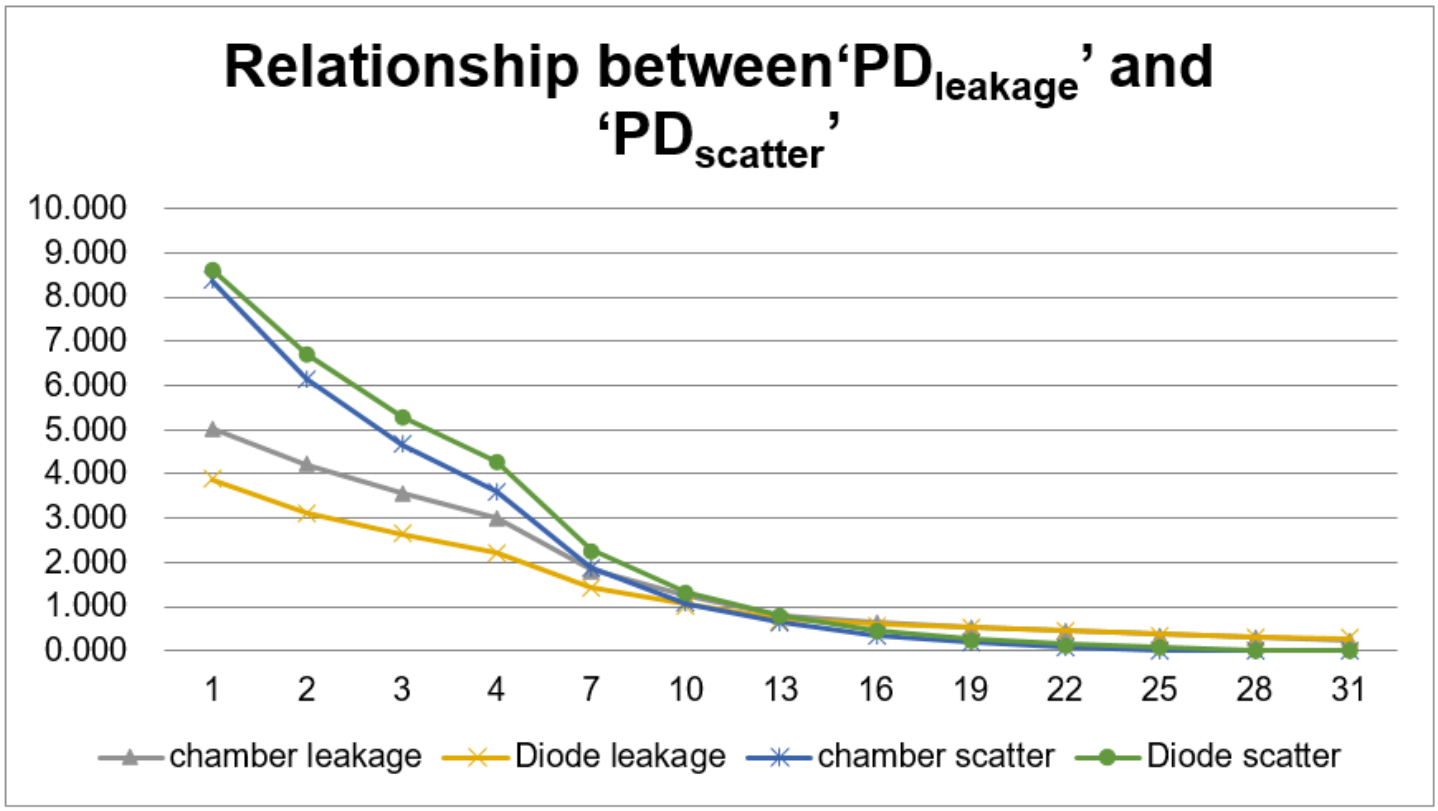

Figure 3

Relationship between ‘PDleakage’ and ‘PDscatter’

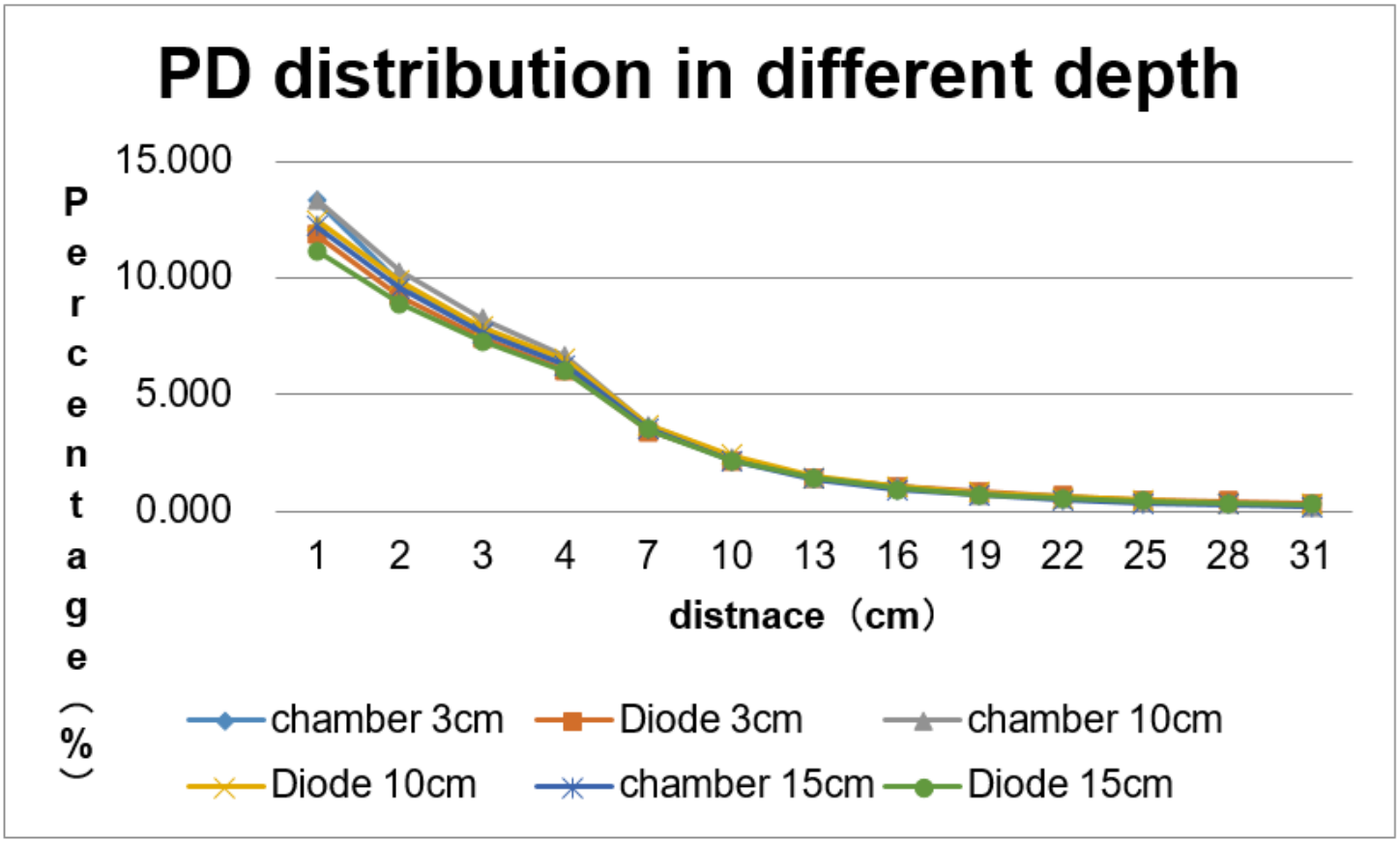

Figure 4

Relationship between depth and dose distribution

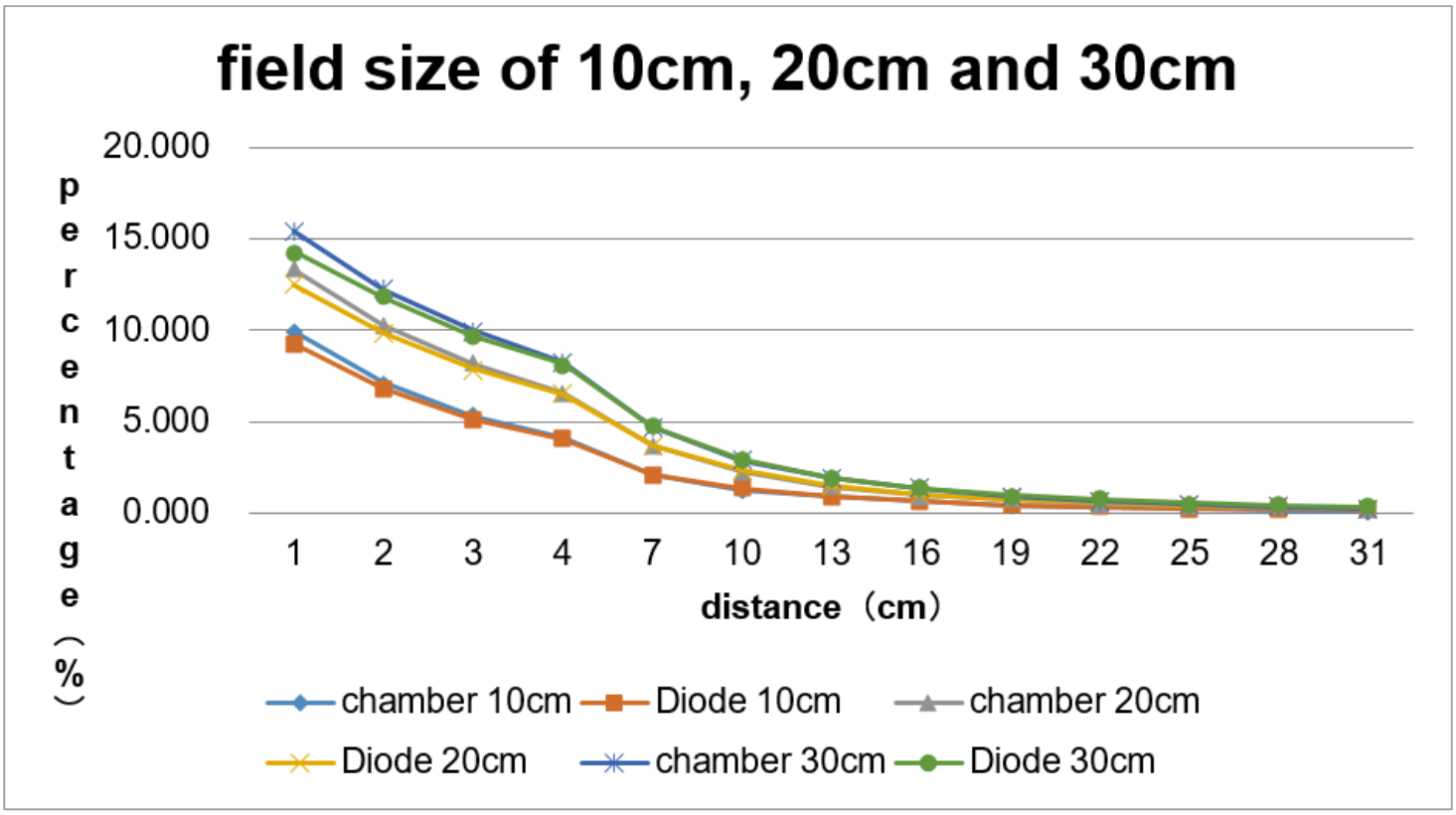

Figure 5

Relationship between field size and dose distribution

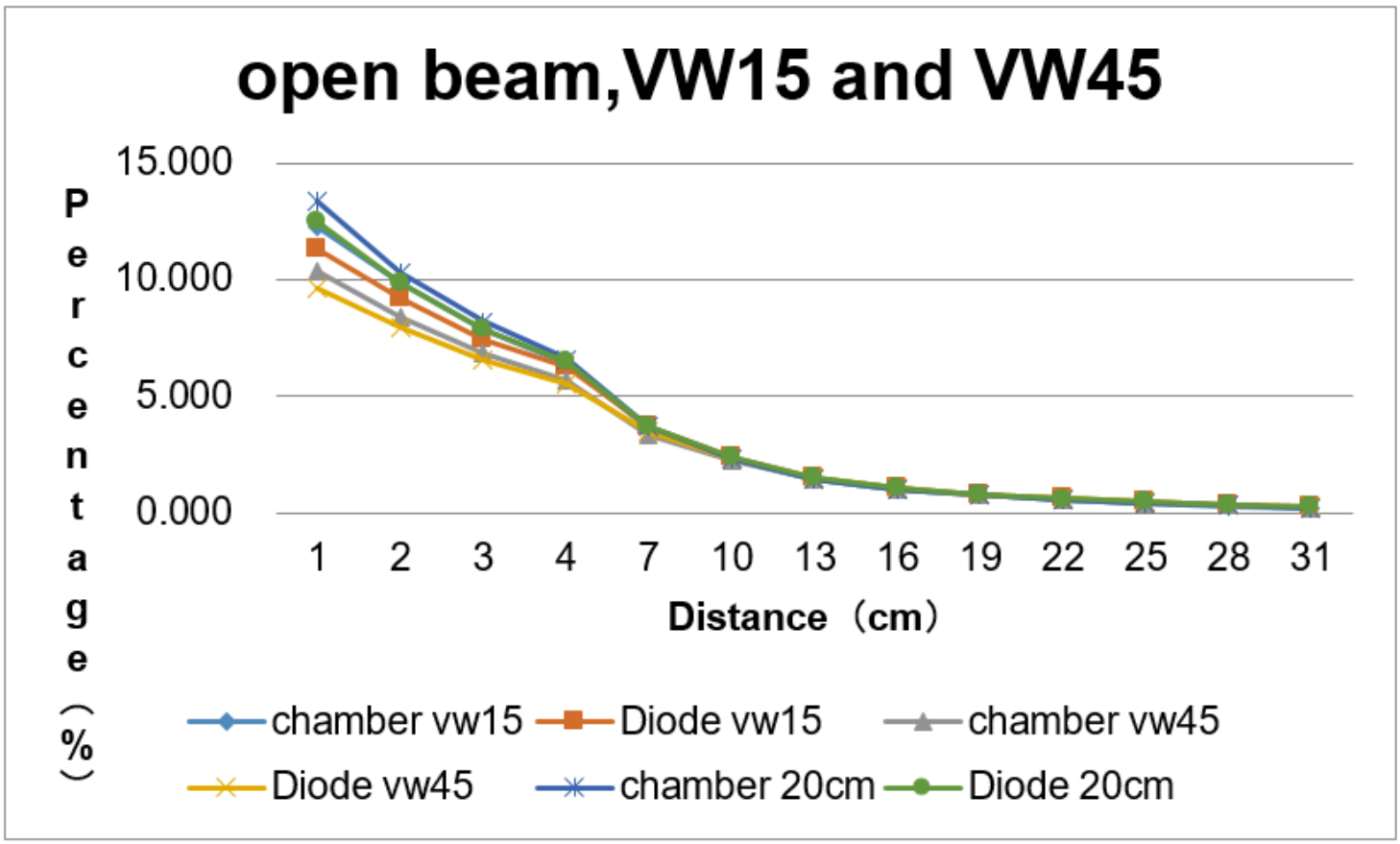

Figure 6

Dose distribution of virtual wedge

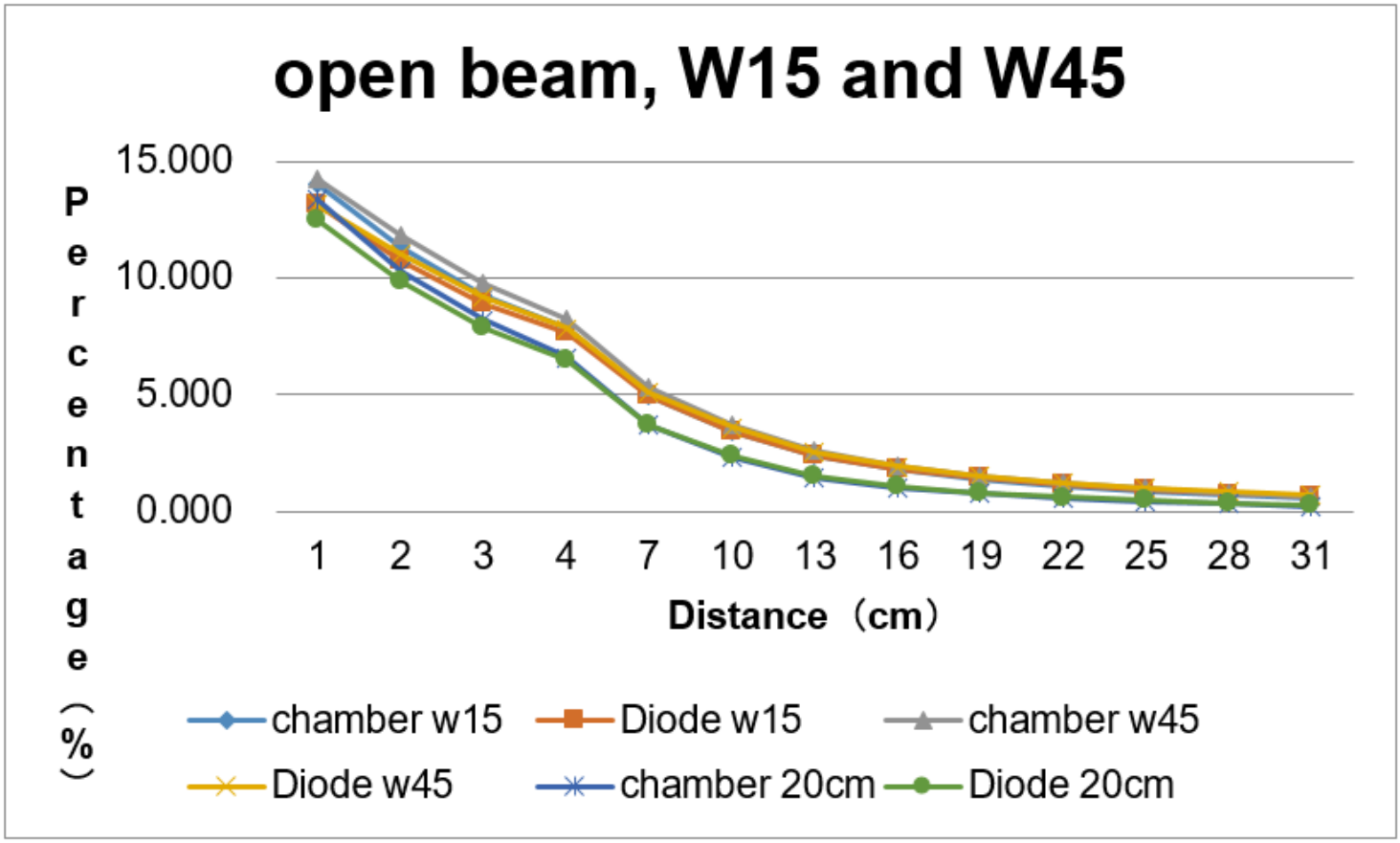

Figure 7

Dose distribution of physical wedge

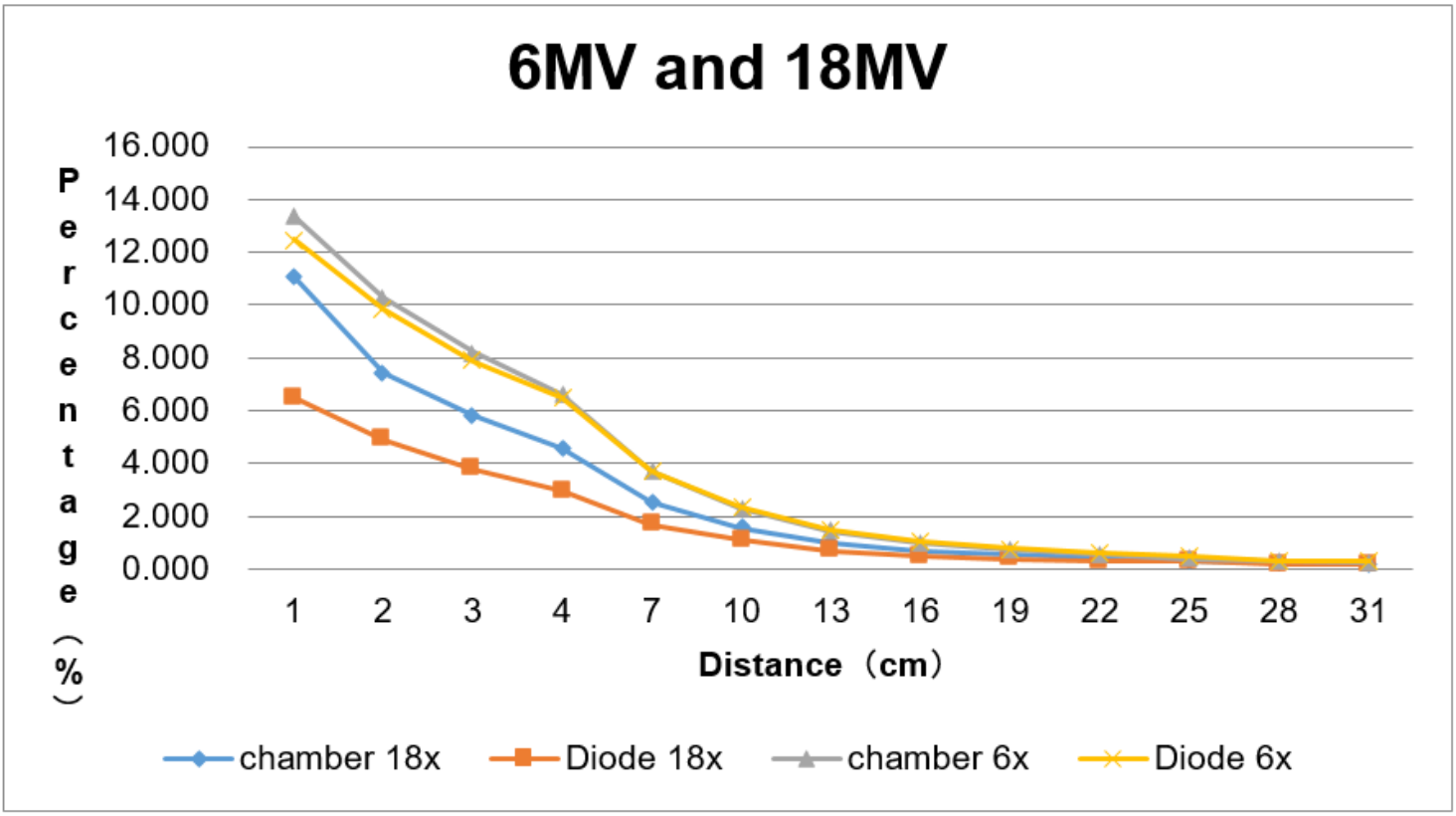

Figure 8

PD distribution at different beam energy