Reference Electron Beam Dosimetry Data Set: A Preliminary Analysis

José A. Bencomo§, Rita Weathers*, Marilyn Stovall*, and Geoffrey S. Ibbott§
Department of Radiation Physics
University of Texas M. D. Anderson Cancer Center

Abstract

A sample of 136 machines with a total of 760 electron beam PDD tables was selected from the Radiation Dosimetry Services (RDS) database. For each beam, a set of data points was extracted from the tables for a 10x10 cm^2 cone if available and a 15x15 cm^2 cone otherwise. The depths selected for the fitting ranged from 0.4 cm from the surface to the depth of 10% to 20% of the maximum dose. A sixth order polynomial was fitted to the data for each set of beam data using MicroSoft Excel™ software. For all data sets evaluated the regression coefficient was larger than 0.998.

Data were stratified by machine manufacturer, model and beam energy for all analyses. Outliers were discarded and not included in the standard calculations. Most outliers were found to be ionization data instead of PDD data.

For this study we investigated the feasibility of developing a set of standard curves (average curves). These standard curves were developed to facilitate the analysis of TLD irradiated with an electron beam energy when the institution monitored did not provide complete PDD data for that beam, also for reviewing new beam data submitted by institutions to RDS, and to provide PDD shape information when reported data are sparse. The standard curves proposed can be used as a reference when commissioning a new linear accelerator.

Introduction

It is critical to know the characteristics of individual beams so clinicians can select the appropriate beam energy for any treatment. Radiation Dosimetry Services (RDS) and the Radiological Physics Center (RPC) of the department of Radiation Physics at U.T. M.D. Anderson Cancer Center have provided mailed quality assurance (QA) services for external photon and electron beams for more than 35 years. RDS provides the service for a fee at the request of physicists at institutions and the RPC provides the service to institutions participating in NCI clinical protocols that include radiation treatment.

Specific aims of this project

- To provide clinical physicists with a set of reference data to verify manufacturer and model specific electron PDD data and serve as reference data when determining expected PDD shape during commissioning of new equipment.
- To promote the efficient interpretation of the information obtained from TLD measurements at participating institutions.
- To compare to published data by the British Journal of Radiology Supplement 25 (BJR25), Lillicrap (1996) and by Followill et al. (2004).

Method and Materials

- PDD data have been collected from more than 900 machines as a part of the RDS and RPC QA service. Figure 1 shows the distribution of machine manufacturers and figure 2 shows the distribution of Varian models currently in the database.
- For this study the data were restricted to Varian Clinac 2100C, 21EX and Siemens MD and Primus machines with data sets for 5-6 electron beam energies for 10x10 cm^2 cones current data in the RDS database.
- Curve fitting:
  - A sixth order polynomial was selected because the least squares fitting routine was readily available in MicroSoft Excel™ and the polynomial provides excellent fit for all data in the desired depth range, ~4 mm depth and to a depth corresponding to 10-20% of maximum dose, for energies ranging from 6 to 21 MeV.
  - Outliers were defined as >2 standard deviations from the mean depth of 50% of maximum dose (d_{50}) for a machine model and energy. The 30 curves (<5%) declared outliers were not used in calculating average curves.
  - The curves generated by the polynomials were compared for shape and location on the depth scale for selected values such as the depth of 50% (d_{50}) and depth of 80% (d_{80}) for each beam energy and for each machine model.

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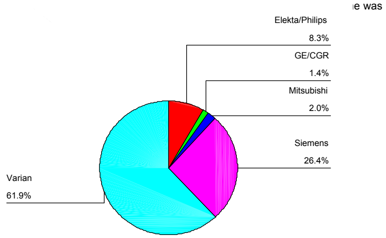

Fig. 1 Machine manufacturers included in the RDS database.

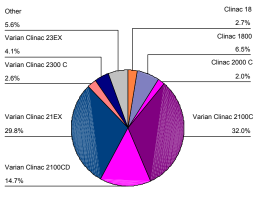

Figure 2. Distribution of Varian Models

Results

- An average curve was estimated from the parameters of the sample of curve fits. The curves were grouped by machine model and nominal energy.
- It was estimated that in order to have a 95% power of prediction of PDD from depth, a sample of at least 20 PDD curves was needed.
- Agreement was found to be ± 1 mm of the "average" curve for all depths between 100% and 20% of maximum dose for 74% of the beams, 93% of PDD curves for particular beam energy, make, and model accelerator were within ± 2 mm of their mean curve. The remaining 7% of curves were >2 to 5 mm of their mean curve.
- Curves were aligned at d_{50} in figure 3 to observe differences in shape. Figure 4 shows the distribution of the shift from the average curve.
- The main source of outliers in the data set studied was percentage ionization data being used as PDD data by institutions. Figure 5 shows the unshifted curves for Clinac 2100C 9 MeV beams.

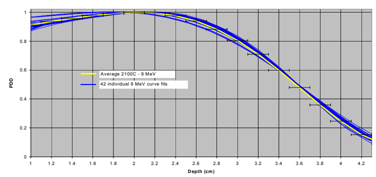

Figure 3. A plot of fitted curves for 42 Varian Clinac 2100C 9 MeV beams shifted so that d_{50} aligns. The thick yellow line is the average of the 42 curves.

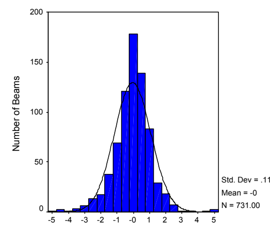

Figure 4. Distribution of shift from manufacturer, model and energy specific standard curve for all beams.

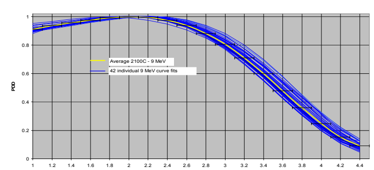

Figure 5. A plot of fitted curves for 42 Varian Clinac 2100C 9 MeV beams. The thick yellow line is the average of the 42 curves.

- We found an excellent fit to central axis electron PDD data from a depth of <0.4 cm to a depth corresponding to 10-20% of maximum dose using a sixth-order polynomial. R^2 for the curve fits ranged from 0.998 to 1.000. Figure 6 shows a set of clinical data for a Varian Clinac 2100C plotted with the curves generated by the polynomial fit.
- Figure 7 shows the set of standards generated for the Varian Clinac 2100C and the standard error bars.

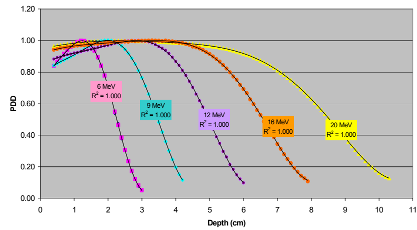

Figure 6. Fitted data for one Varian 21 EX machine.

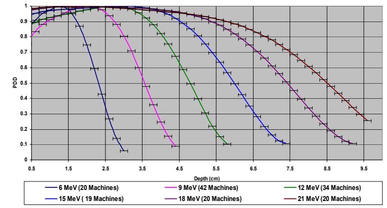

Figure 7. A plot of the average fitted polynomial for 6 energies for the Siemens Primus machine with error bars at 1 standard deviation or approximately ± 1 mm. (The number of machines analyzed is shown within parenthesis)

- The British Journal of Radiology Supplement 25 (BJR25), Lillicrap (1996), presents average electron PDD data from 24 institutions or manufacturers. This is the most comprehensive publication of standard PDD data for electrons. The average are not typical of any particular machine and are not suitable for clinical use. In figure 8 the average curves for the Varian and Siemens machines combined are plotted with BJR25 curves for corresponding energies. As seen in the figure there is a significant difference in the shape of the curves at all energies. There is also a shift of 4 mm for energies below 16 MeV and 2 mm or less for higher energies.

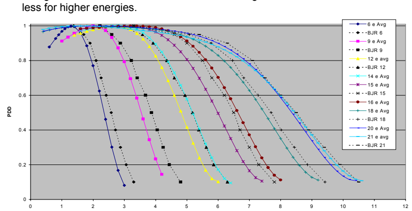

Figure 8. Combined average Varian 2100C, Varian 21 EX, Siemens MD and Siemens Primus curves for selected energies compared to BJR25 data.

- When we evaluated the curve shape and location by manufacturer and model the standard deviation of d_{80} and d_{50} was approximately 1 mm with a range of 0.9 to 1.4 mm. These results are consistent with Followill et al. (2004) results. Although our set of data is very different from those used in publications by Followill et al. (2004) and Kirby et al. (1985), we agreed with their conclusions.
- Figure 9 shows a plot of d_{80} vs. d_{50} generated from our fittings together with Followill et al. (2004) results.
- Table 1 summarizes the parameters of the linear fitting to each set of data. As seen in the figure and table there is no significant difference between the fitted lines and Followill et al. (2004) results. This confirmed that a standard set of data has been developed with a high degree confidence (± 1 mm).

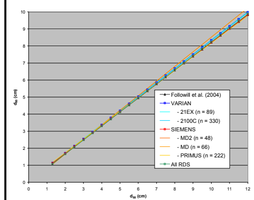

Figure 10. Comparison to Followill d_{50} to d_{80} relationship.

Table 1. Parameters for linear fit of d_{80} vs. d_{50}

Model: $d_{80} = m * d_{50} + b$				
Machine	m	b	R2	# of beams
Followill et al. (all models)	0.81480	0.06070	0.995	2000
Varian 21EX	0.82405	0.08076	0.998	89
Varian 2100C	0.82867	0.05152	0.995	330
Siemens MD	0.85895	-0.07020	0.999	66
Siemens MD2	0.85819	-0.06183	1.000	48
Siemens Primus	0.80492	0.12578	0.998	222

Discussion

The concept of standard percentage depth dose (PDD) data for electron beams has been considered by other authors. Kirby et al. (1985) used RPC measurements at selected depths in 120 beams to demonstrate that depths associated with PDD below 90% and above 10% were reproducible to ±2 mm with a standard deviation of < 1 mm for selected beams on several different accelerators. His data consisted of RPC measured data for d_{max}, d_{99}, d_{95}, d_{90}, d_{80}, d_{50} and d_{20} for 11 different machines from 9 manufacturers and found agreement within 1-2 mm when machines were grouped by scattering foil design. Similarly Followill et al. (2004) analyzed measurements acquired by RPC staff during institution audits for more than 2000 beams. They concluded that nominal energy was not a precise indicator of the beam penetration and recommended that clinicians should be familiar with the PDD characteristics of beams in their clinic when planning treatments. Average depths for d_{max}, d_{80} and d_{50} were tabulated in addition to an analysis of the functional relationship between beam quality R_{50} and depth of d_{80}, d_{50} and d_{max}.

Conclusions

- The large database of PDD data at the RDS and RPC organizations contain data that have been measured independently by physicists at many institutions on different machines in clinical use. The measurements at selected clinically significant depths show small standard deviations ($\leq$ 1mm) providing strong evidence that standard curves can be developed for electron beams from linear accelerators when the data are separated by manufacturer and model.
- PDD standards are useful for the RDS and RPC to streamline QA activities. They can be used as a screening tool to identify potential problems in PDD data submitted by institutions.
- The reference data can be used by the medical physics community when commissioning electron beams in new accelerators.

Strengths and limitations of this data

- The primary strength of this study is the size of the database analyzed and the fact that individuals following standard practices independently collected the data. This is also a limitation of the study because methods and data are not verified. Selected PDD point measurements taken by an expert group like the RPC in the Followill et al.(2004) or Kirby et al. (1985) publications are more easily verified, however we used complete sets of PDD data for our analysis and agreed very well with the RPC results.
- The data included in this database are from modern machines in clinical use. Data analyzed by the RPC included many older models no longer in clinical use.
- The curves estimated are entirely mathematical and are valid only for interpolation, not extrapolation. They are not suitable for clinical use without verification. However, the standards can be used for QA activities and for comparison among machines.
- The accuracy of the developed standards allow us to identify differences between the standards and TLD results within ±3 mm. The RPC uses a ±5 mm acceptance criterion for the difference between the TLD measured depth at a particular PDD and the depth for the same PDD from the institution's PDD data.

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*Radiation Dosimetry Services, §Radiological Physics Center

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