Comparison of beam energy metrics for acceptance of Halcyon Linac

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INTRODUCTION

Photon beam energy metrics based on off-axis ratio (OAR) have been shown to more sensitive than those based on percentage-depth dose (PDD) measurements.[1] Beam energy was verified with beam profiles measured on the largest available field size with an IC Profiler (ICP). The diagonal off-axis ratio (F_{DN}) was measured to determine beam energy. Another method for determining photon beam energy with an ICP is the quad-wedge (QW) which uses two pairs of copper, wedge-shaped, attenuators placed on top of the diagonal detector axes of the ICP. The energy metric from the QW is the area ratio (AR) which is defined as the sum of measurement points under the wedges (attenuated profiles along two diagonal axes) normalized to the sum of measurement points from a similar detector set on the X and Y axes (open field profiles).

We were able to change the beam energy by adjusting the magnetron current in Halcyon. At each magnetron current setting we obtained ICP measurements with and without the quad wedge as well as PDDs with a 1D water scanner (1DS) allowing us to compare F_{DN}, AR and changes in D10 (PDD at 10 cm depth) in water as a function of changes in beam energy.

AIM

To determine if beam profile energy metrics are better than percent depth doses (PDD) for ensuring that the beam matches the treatment planning system (TPS) for the Halcyon and to compare these metrics with the TPS across 5 Halcyon linacs from multiple institutions.

METHOD

Energy metrics were tested with three methods as a function of change in beam energy:

(1) PDDs measured with a 1DS,

(2) F_{DN} from profiles measured with an ICP,

(3) Area ratios (AR) measured with a photon QW on an ICP.

Each energy metric was measured at the nominal energy and five intentional changes from nominal (0%): –10.0%, –5.0%, –2.5%, +2.5% and +5.0%. We then investigated the relationships between the F_{DN} and D10 from PDD at depth 10 cm, as well as the AR from the QW profile and D10. Once these relationships are established, the D10 can be either calculated from F_{DN} or directly reported from the ICP/QW system, depending on the use of open profile or QW profile. Following the adjusted beam energy comparison of the three methods on the single Halcyon "calibration linac", five nominal energy Halcyons were compared with results from TPS D10 values and the D10 values using the F_{DN} method and the QW method.

RESULTS

Calibration:

Five beam energy changes were made from the nominal (0%) energy: –10.0%, –5.0%, –2.5%, +2.5% and +5.0%. The PDD data were measured for 10 × 10 cm² field size with a 1D water scanning system. The PDD curves were normalized to the d_{max} depth for each energy and D10 values were calculated for every adjusted energy. The F_{DN} values were obtained from the open profiles using the IC Profiler software for each beam energy. The relationship between F_{DN} and D10 was linear at the adjusted beam energies for four different off-axis distances (Fig. 1). We developed a calibration by fitting the D10 vs F_{DN} data to a line using a least squares fit. From this calibration linear fit equation, We can calculate the D10 from the F_{DN} values measured with ICP at fixed off-axis distances and compared to those values with the D10 values measured from the 1DS for each adjusted beam energy (Table 1).

From the quad-wedge (QW) (profiles measured using ICP with QW plate, we also established a linear relationship between area ratio from QW profiles and D10 values scanned from 1DS at the adjusted beam energies(Fig. 2). The ICP software includes the functionality to report the D10 values from the quad-wedge profiles for all energies based on this calibration. The D10 determined from the quad-wedge profiles measured with ICP were compared with those scanned in 1DS (Table 1).

Evaluation:

The D10 values of five Halcyon linacs from multiple institutions determined from the diagonal normalized flatness (F_{DN}) and from quad-wedge profile (QW) under the same measurement condition are compared to the D10 values determined from the Eclipse treatment planning system (TPS) as well as the water tank scanned data (Table 2). The differences of D10 between F_{DN} and treatment planning (TPS) calculations [D10(TPS) – D10(F_{DN})] indicated that the average ± standard deviation was –0.16 ± 0.24%, with a range from –0.47% to 0.20%. The differences of D10 between F_{DN} and water scans [D10(water) – D10(F_{DN})] indicated that was –0.22± 0.20%, with a range from –0.60% to 0.46%.

Comparing D10 values determined from quad-wedge profile (QW) to TPS calculations and in water scanned data, between quad wedge (QW) and treatment planning (TPS) calculations [D10(TPS) – D10(QW)] indicated that the average ± standard deviation was –0.82 ± 1.27%, with a range from –2.43% to 0.6%. The differences of D10 between QW and water scans [D10(water) – D10(QW)] indicated that was –0.22 ± 0.20%, with a range from –2.24% to 0.98%.

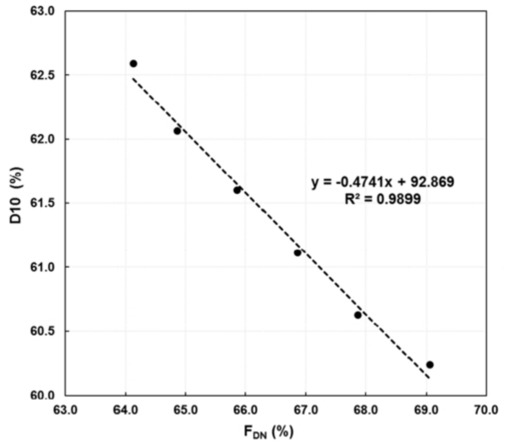

Fig. 1. The linear relationship between the PDD at 10 cm depth D10 scanned using the 1D water tank scanner (1DS) and the diagonal normalized flatness (F_{DN}) measured from the beam profile with the ionization chamber array for beam energies off the nominal beam energy by –10.0%, –5.0%, –2.5%, +2.5% and +5.0%.

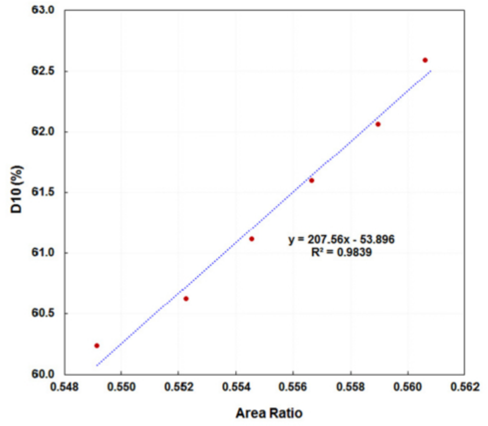

Fig. 2. The linear relationship between the percent depth dose at 10 cm depth D10 scanned using the 1DS and the area ratio from the quad wedge profile measured with the ionization chamber Profiler (ICP) and quad wedge plate for beam energies off the nominal beam energy by –10.0%, –5.0%, –2.5%, +2.5% and +5.0%.

Table 1. For beam energies off from the nominal beam energy by –10.0%, –5.0%, –2.5%, 0%, +2.5% and +5.0%: The percent depth dose at a depth of 10 cm, (D10), scanned with a 1D water scanning system (1DS), the D10 values determined from the diagonal off-axis ratio (F_{DN}). The difference of D10 between F_{DN} and 1DS. The D10 determined from quad wedge profile (QW) and difference of D10 between QW and 1DS.

Change in energy (%)	5.0%	2.5%	0.0%	-2.5%	-5.0%	-10.0%
D10 (1DS) (%)	62.59	62.07	61.60	61.12	60.63	60.24
D10 (F_{DN}) (%)	62.49	62.11	61.64	61.17	60.69	60.14
δD10(1DS-F_{DN})	0.10	-0.05	-0.04	-0.05	-0.06	0.10
D10 (QW) (%)	62.43	62.08	61.61	61.17	60.69	60.04
δD10(1DS-QW)	0.16	-0.02	-0.01	-0.05	-0.06	0.20

Table 2. The percent depth dose at a depth of 10 cm, (D10), determined from the diagonal off-axis ratio (F_{DN}) and from quad wedge profile (QW) of five Halcyons from multiple institutions. The difference of D10 between F_{DN} and TPS (also QW and TPS), and the difference of D10 between F_{DN} and water scans (also QW and water scans); their averages and standard deviations (σ).

Method	Off-axis ratio (F_{DN})			Quad Wedge (QW)		
Machine	D_{10} (F_{DN})	δD_{10} (TPS-F_{DN})	δD_{10} (water-F_{DN})	D_{10} (QW)	δD_{10} (TPS-QW)	δD_{10} (water-QW)
M1	61.74	-0.32	-0.13	61.74	-0.32	-0.14
M2	61.89	-0.47	-0.07	63.85	-2.43	-2.00
M3	61.64	-0.22	-0.30	63.64	-2.22	-2.24
M4	61.43	-0.01	-0.60	61.12	0.30	-0.22
M5	61.22	0.20	0.46	60.82	0.60	0.98
Average	61.58	-0.16	-0.22	62.24	-0.82	-0.22
σ	0.24	0.24	0.20	1.27	1.27	0.20

CONCLUSIONS

The beam energy of the Halcyon/Eclipse system can be accepted and commissioned with the profile based energy metric measured using an ionization chamber array. The measurement results of five Halcyons from multiple institutions indicated that: The percent depth dose at depth 10 cm, D10, measured with the off-axis ratio (F_{DN}) based energy metric is better matched to D10 from TPS and PDD scans than those measured with the quad-wedge profile based energy metric.

REFERENCES

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