Introduction

In a previous paper (Olch A, "Evaluation of a computed radiography system for megavoltage photon beam dosimetry". Medical Physics 32(9), 2987-2999, 2005), the Kodak 2000RT computed radiography (CR) scanner system was characterized for its ability to perform quantitative dosimetry for 6 MV x-rays for a variety of tests, including composite IMRT QA. In this study, electron beam dosimetry is explored with the same scanner but with a different model CR plate. With either film or CR, photon beam dosimetry is predicted to be more challenging than electron dosimetry due to the over-response of either type of detector to low energy x-rays created by scatter, an affect that worsens with increasing field size and depth. Film dosimetry has been used for decades for electron beam dosimetry with applications including beam profiles, isodoses, and output factor determination. Both perpendicular and parallel irradiation geometries are used for these tests. This study will characterize the Kodak 2000RT system's dose response for parallel and perpendicular irradiation geometry and its ability to measure profiles and isodoses for a range of electron beam energies and field sizes.

Materials:

Varian 2100C, 6, 9, 12, 16, and 20 MeV electrons
Kodak 2000RT CR scanner
Kodak HR (high resolution) CR plate in ready-pack envelope
Kodak dosimetry software
Radiological Imaging Technology (R.I.T.) analysis software v 4.3
Scanditronix radiosurgery diode in Multidata water tank

Methods:

1) Dose response for perpendicular irradiation for 6, 12, and 20 MeV electron energies:
The CR plate was placed inside a ready-pack envelope that was then placed in a solid water phantom at the depth of d-max for each energy. The 10 cm x 10 cm applicator was used to irradiate the plate sequentially with 5, 30 and 60 cGy. The plate was scanned and then the image file was opened in R.I.T. A 1 cm x 1 cm square region of interest (ROI) was placed at the center of each square field and the mean scanner units were read. These three data points for each energy were used in the R.I.T. software routine specially designed for CR perpendicular calibration. This routine expects the dose-response to be semilog linear rather than not assuming a relationship as for film. A correlation coefficient for the straight line through the three data points was always higher than .999.

2) Dose response for parallel irradiation for 6, 9, 12, 16, and 20 MeV electron energies:
The CR plate was placed inside a ready-pack envelope that was then placed in a solid water phantom such that the surface of the CR plate was aligned with the surface of the phantom. The phantom was placed on the linac couch so that the CR plate was parallel to it and the gantry was rotated to 270 degrees. Sixty cGy was delivered to dmax for each energy using a 10 cm x 10 cm applicator. The CR plate was scanned and the image was read into R.I.T. A set of 13-16 depth points through the central axis of the beam with known doses from maximum to 1% of maximum were used to create a calibration curve for each energy.

3) Isodose and profile agreement with diode measurements in water scanner:
Each of the parallel irradiation images from #2 was calibrated using the central axis dose calibration data for that energy. Isodoses were then generated. These isodoses could be compared to isodoses obtained using a diode scanned in water. In addition, for the 20 MeV beam, an iso-scanner units plot was generated showing the high dose area as well as the x-ray contamination zone beyond and outside the range of the electrons. Also, a horizontal beam profile at d-max for the 12 MeV beam was generated by applying the perpendicular calibration file for that energy to the 30 cGy perpendicular image.

4) Dose-response dependence on field size and energy (perpendicular geometry):
The 6, 12, and 20 MeV electron energies were used to irradiate the CR plate placed at dmax for each energy. Fifty cGy (monitor units adjusted based on output factors) was used for 6x6, 15x15, and 25x25 applicators. Each image was scanned and read into R.I.T. A 1 cm x 1 cm ROI was placed at the center of each image and the mean scanner units were read. Dose differences were computed based on the data from #1.

Discussion and Conclusions

Using film for electron beam dosimetry is usually thought of as fairly simple, without major limitations, while photon beam film dosimetry was more difficult. However, as Gerbi et al. (Med Phys (30), p 2703, 2003) point out, there haven't been papers studying electron energy dependence of EDR2 film nor have we found much data on field size or beam direction effects on film response. This study looks at the response of a CR plate to varying the electron energy, field size, and angle of incidence. The findings for dose response by angle of incidence, either parallel or perpendicular, show a similar result as for photon beams with the MD10 plate, i.e., the CR plate will look lighter (higher scanner units) for parallel incidence for the same dose as for perpendicular incidence. One difference from the photon results is that the parallel dose response appears not to be semilog linear. There appears to be two regions of these curves: for higher doses, the curves are nearly semilog linear with a slope that approximates the perpendicular results. However, for lower doses obtained beyond the electron range, the response is much higher (scanner units below the extrapolated high dose straight line). This may be attributed to the higher absorption of low energy scatted photons from the x-ray contamination in the beam. This effect is also seen in Gerbi's percent depth dose data to some degree. The curves are separated from one another, indicating that electron energy is a factor in sensitivity in this geometry where it is not a factor for perpendicular geometry. Perhaps the high Z material in the phosphor causes multiplication of scattering that reduces the electron fluence with increasing depth and decreasing energy through the plate. Practically, this means that an energy-specific calibration curve should be generated for each energy that will be used in the parallel geometry while a single calibration curve would suffice in the perpendicular geometry.

In the paper by Gerbi, et al., they report seeing an energy dependence of EDR2 film for electron beam dosimetry for a 10 cm x 10 cm field. Their data show that as the energy increases, the sensitivity of EDR2 film increases for a given dose and this effect is further increased with increasing dose. The data in table I show a similar pattern for CR for a dose of 50 cGy. The scanner units for 6 and 12 MeV are within about 2% in dose for smallest to largest field sizes but the dose for 20 MeV was 6.5 to 11.4% higher than the lower energies. Higher doses were not explored in this study. In this study, dose-response dependence on field size and energy was explored, and it appears that for 20 MeV and a 25x25 applicator, there was a noticeable increase in sensitivity to 50 cGy compared the smaller applicators and to the 6 and 12 MeV energies for any field size. Gerbi et al. did not offer any explanation for the energy effects they saw. However, one logical possibility is that the presence of contaminating x-rays present in the electron beam and further generated in the phantom are responsible for these findings. This explanation is plausible because both film and CR are detectors that tend to over-respond to low energy scattered x-rays. The higher energy electron beam contains more x-ray contamination than lower energies. Beyond the range of the electrons, the 6 MeV beam has a dose of 1% vs 5.5% for the 20 MeV beam. The larger field size would also permit more scattered photons to reach central axis.

In summary, the Kodak HR CR plate acts similarly to EDR2 film in many respects when irradiated with electron beams. For perpendicular irradiation, a single calibration curve could be used while energy-specific curves are required for parallel irradiation. Isodoses and profiles can accurately be measured with CR. Thus, the CR system is a useful tool for electron beam dosimetry when proper calibration procedures are performed, taking into account beam direction, energy, and for the higher energies, field size as well.

Figure 1

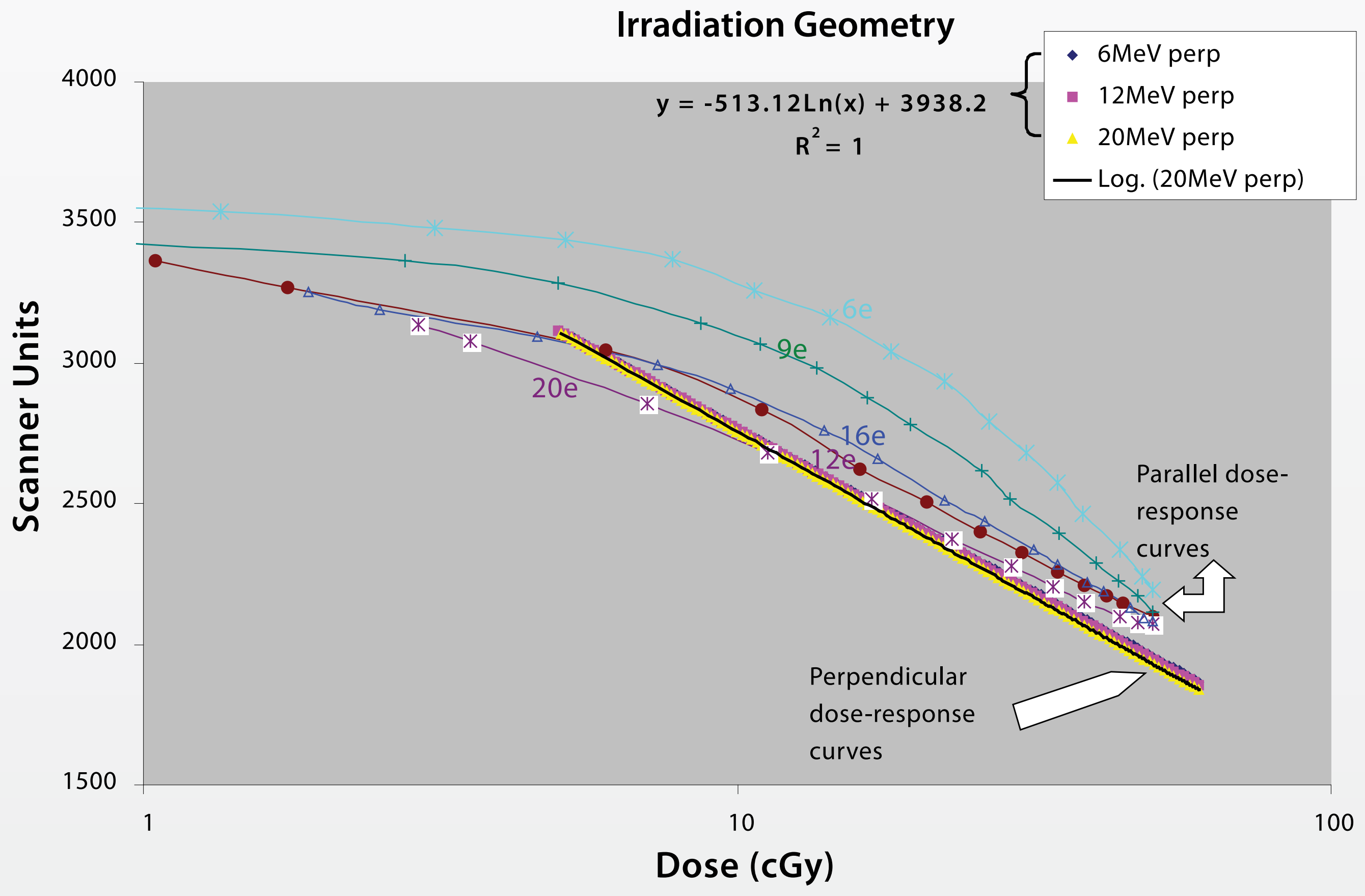

Electron Dose-Response: Perpendicular vs. Parallel Irradiation Geometry

Figure 2a

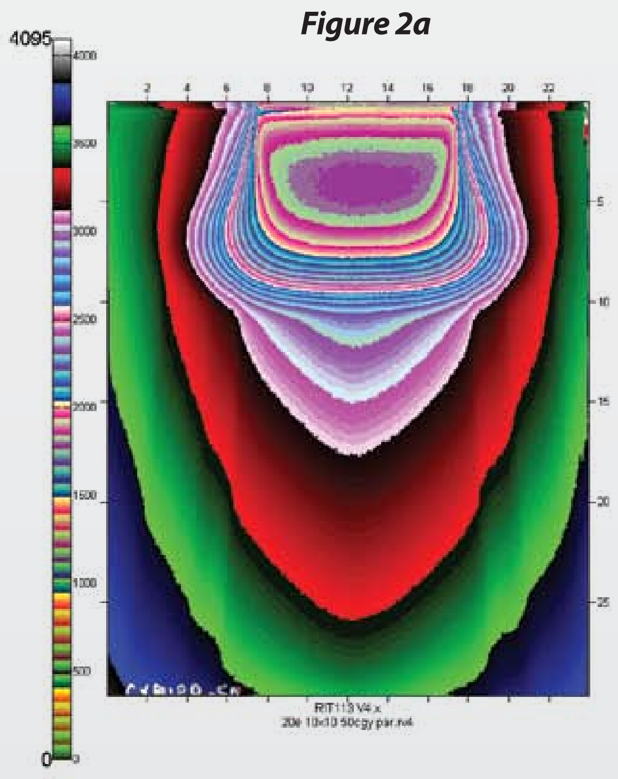


Figure 2b

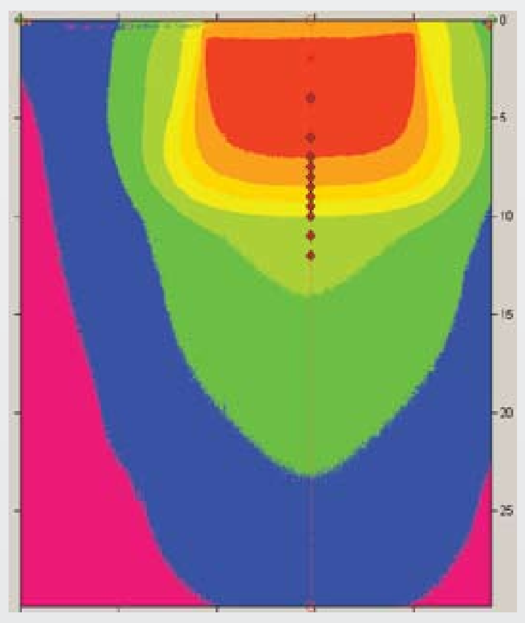
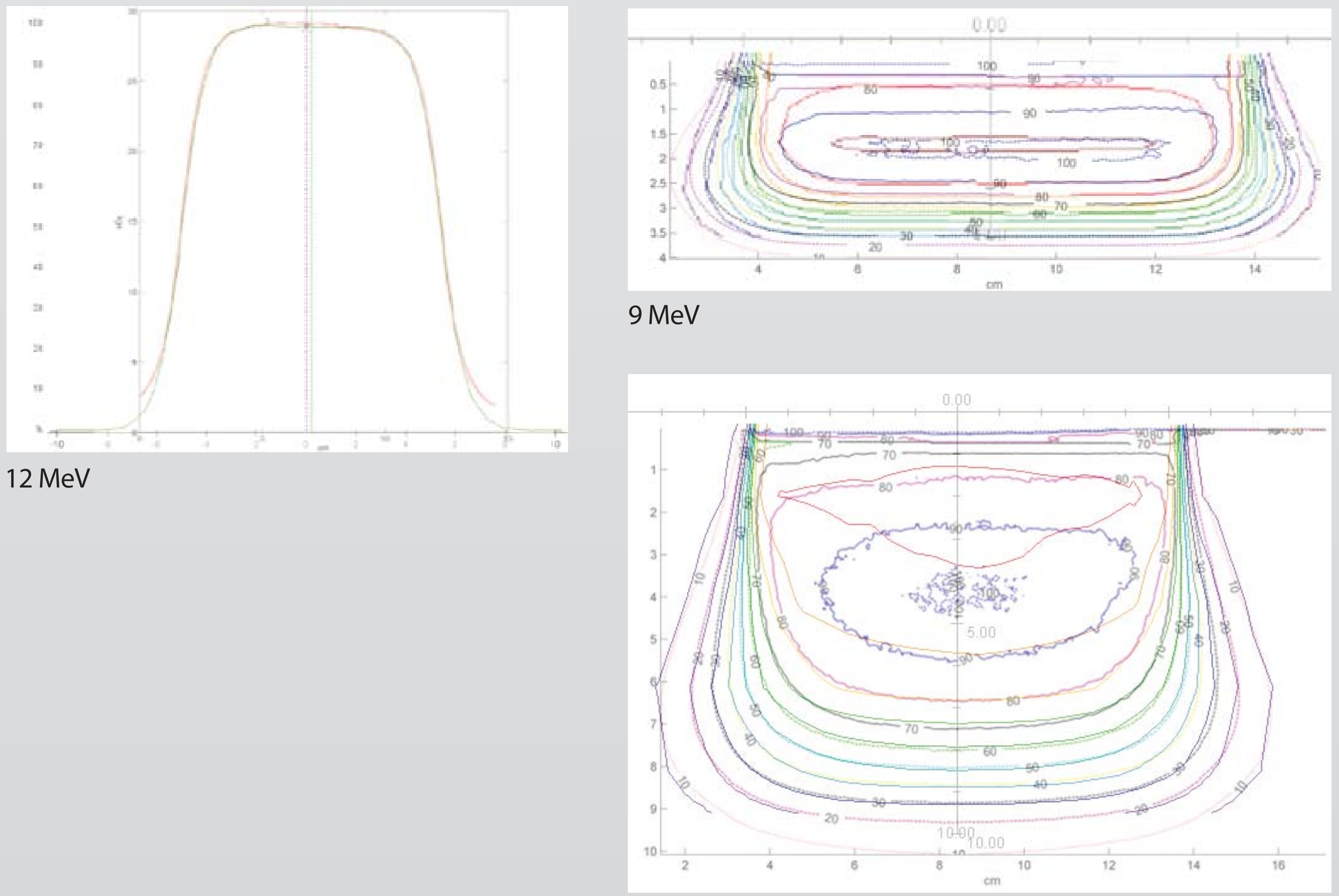


Table 1

Scanner Units and dose differences for 50 cGy to dmax (perpendicular)						
	6e	dose diff	12e	dose diff	20e	dose diff
Applicator						
6x6	1970 ±3	1.000 *	1983 ±2	1.025	1938 ±4	1.065
15x15	1977 ±1	1.015	1971 ±2	1.002	1931 ±2	1.082
25x25	1970 ±1	1	1968 ±1	0.996	1916 ±4	1.114

**Dose difference values are normalized to 6MeV 6x6 applicator value.*
The standard deviation of each scanner unit value from 3 measurements is shown as well.

Figures 3 a, b, c


12 MeV
9 MeV
20 MeV

3) Isodose and profile agreement with diode measurements in water scanner:
Figure 2a,b shows a color wash for the 20 MeV beam in scanner units. In the 2a, one can clearly see the photon contamination component including beam edges beyond the range of electrons. Figure 2b shows the central axis line and the depth points chosen for calibration curve generation. Figure 3a shows the horizontal profile overlay for 12 MeV and 3 b and c show isodose overlays for 9 and 20 MeV electrons. The dashed lines are from CR and the solid from diode measurements in water. Agreement is excellent except in the isodose build-up region (surface to 100%) and below the 20% dose for the profile. Other energies showed similar agreement.

4) Dose-response dependence on field size and energy (perpendicular geometry):
Table 1 shows the scanner unit data for 6, 12, and 20 MeV electrons for 6x6, 15x15, and 25x25 applicators. The dose differences have been normalized to the 6 MeV 6x6 applicator. These data show that the CR plate tested was about equally responsive to 6 or 12 MeV electrons for all three field sizes but responded more to the 20 MeV electron energy. Also, for 20 MeV, the plate response increased with field size.

1) Dose response for perpendicular irradiation for 6, 12, and 20 MeV electron energies:

Figure 1 shows the scanner units vs. dose plotted semi logarithmically. The three lines are nearly indistinguishable indicating that the CR plate responds equally to these energies. A representative equation of the line is shown as well.

2) Dose response for parallel irradiation for 6, 9, 12, 16, and 20 MeV electron energies:

Figure 1 also shows the scanner units vs. dose for parallel irradiation from all 5 electron energies. These plot not as lines but as curves and are separated from each other. All are above the lines from perpendicular irradiation, indicating that the CR plate responds less for the same dose in this geometry than in perpendicular geometry (higher scanner units means lighter image). This finding is consistent with that found with 6 MV x-rays and the MD-10 Agfa CR plate. Future research will include retesting the HR plate with photons for obliquity effects. Note that the curves flatten out at the lowest doses (occurring just at or beyond the electron range). Also note that the slopes of the 6 and 9 MeV curves are larger, 12 and 16 MeV are about the same, and 20 MeV appears smaller than the perpendicular geometry slope for doses above about 10 cGy.