Corrected relationship between $\%dd(10)_x$ and stopping-power ratios

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Kosunen and Rogers [Med. Phys. **20**, 1181–1188 (1993)] presented a linear equation relating the Spencer–Attix water/air stopping power ratio to $\%dd(10)_x$, the photon component of the percentage depth-dose at 10 cm depth for a $10\times 10\,\mathrm{cm}^2$ field on the surface of a phantom at SSD=100 cm. This relationship has been used to calculate extensive tables of k_Q factors for use with dosimetry protocols based on absorbed-dose calibration factors. Unfortunately, the original paper contained an error which has recently been assessed (Yang *et al.*). The present paper presents a corrected form of this relationship, viz.: $(\overline{L}/\rho)^{\mathrm{water}}_{\mathrm{air}} = 1.275 - 0.00231[\%dd(10)_x]$ which is based on corrected values of $\%dd(10)_x$. It is shown that despite changes of up to 2% in calculated values of $\%dd(10)_x$, the net effect on calculated values of k_Q is less than 0.2%. [S0094-2405(99)01204-3]

Key words: Monte Carlo, stopping-power ratio, beam quality, ion chamber dosimetry

I. INTRODUCTION

In the forthcoming AAPM TG-51 dosimetry protocol,[1,2] the photon beam quality specifier is $\%dd(10)_x$, the photon component of the percentage depth-dose at 10 cm depth for a $10\times 10\,\mathrm{cm}^2$ field on the surface of a phantom at an SSD of 100 cm. The rationale for using this beam quality specifier has been discussed in detail by Kosunen and Rogers.[3] They also presented a linear relationship between $\%dd(10)_x$ and the Spencer–Attix water to air restricted stopping power ratio, $(\overline{L}/\rho)^{\mathrm{water}}_{\mathrm{air}}$, which is of fundamental importance in clinical photon beam dosimetry. Their relationship is:

$$\left(\frac{\overline{L}}{\rho}\right)^{\mathrm{water}}_{\mathrm{air}} = 1.2676 - 0.002224(\%dd(10)). \tag{1}$$

This relationship has been used as the basis of calculations of the quality conversion factor, k_Q, which plays a central role in the TG-51 protocol's approach to photon beam dosimetry based on absorbed-dose calibration factors.[4] The quantity k_Q is discussed in detail elsewhere.[4–7]

Yang *et al.*[8,9] have recently highlighted the fact that it is inappropriate just to use a simple $1/r^2$ correction to convert depth-dose curves calculated for parallel beams into those for a fixed SSD. It has been well known for many years that there are scatter corrections needed as well as the $1/r^2$ corrections,[10,11] but Kosunen and Rogers just used the $1/r^2$ correction. Yang *et al.*'s data suggest changes in the value of $\%dd(10)_x$ of up to nearly 2% at low energies but no significant change for beams with $\%dd(10)_x$ greater than 80%. [Note that by a 2% change in $\%dd(10)_x$ we mean 50% goes to 51%.]

The purpose of this paper is to document a revision to the relationship between $\%dd(10)_x$ and $(\overline{L}/\rho)^{\mathrm{water}}_{\mathrm{air}}$ and to show the size of the effects expected in calculated values for k_Q as used in TG-51.[2,4]

II. CORRECTED DATA AT SSD=100 CM

In the original paper,[3] depth-dose curves were calculated with EGS4[12] for 100 cm^2 circular parallel beams for many different bremsstrahlung spectra. These depth-dose curves were then $1/r^2$ corrected to SSD=100 cm. Table I presents a summary of the 23 beams used in that work and the present work, and compares the values of $\%dd(10)_x$ obtained by doing a $1/r^2$ correction of the parallel beam data to the proper values of $\%dd(10)_x$ calculated for a point source. These latter values are obtained either by a direct calculation for a point source (for a $10\times 10\,\mathrm{cm}^2$ beam from a point 100 cm away from the phantom surface in a vacuum) or by using the correction curve calculated by Yang *et al.*[8] which relates the true point source value of $\%dd(10)_x$ to that obtained by doing a $1/r^2$ correction of the parallel beam data. The original paper contains a description of the spectra used.[3]

It is worth noting that the previous parallel beam calculations[3] for the ^{60}Co and 6 MV beams seem to be inaccurate (low by 2.0% and high by 0.9%, respectively). In the ^{60}Co case it appears that a transcription error occurred since the original raw data are consistent with the current results. The 6 MV case can only be explained as a statistical anomaly.

Table I also contains the values reported for $\%dd(10)$ in Supplement 25 of the British Journal of Radiology[13] and the values given in the report of Task Group 46 of the Radiation Therapy Committee of the AAPM.[14] The measured values of $\%dd(10)$ include any effects of electron contamination, whereas $\%dd(10)_x$ is for the photon component only of the beam. It is important to recognize that the BJR data are averaged over many machine types whereas the TG-46 data are machine specific and have been selected to match the Varian machines modeled when calculating the spectra used in the present calculations.[15]

Given the above consideration, the measured data for beams below 15 MV are in good agreement with the calcu-

TABLE I. Revised data relating stopping-power ratio to $\%dd(10)_x$. The stopping-power ratios and ''original'' data are from Kosunen and Rogers (Ref. 3) and are based on parallel beam calculations which were $1/r^2$ corrected to SSD=100 cm. The ''point source'' data are either calculated directly (shown with a*) or use the correction factors calculated by Yang *et al.* (Ref. 8) to correct the original data. Experimental data from BJR Supplement 25 (Ref. 13) and AAPM's TG-46 (Ref. 14) are shown in the last two columns. The TG-46 data are specific to machine type whereas the BJR25 data average over many machines.

Spectrum	$\left(\frac{\bar{L}}{\rho}\right)^{\text{water}}_{\text{air}}$	$\%dd(10)_x$ Original	Point source	BJR25	TG46
Co 60	1.1335	56.26	58.40*	58.7	···
Mohan *et al.*					
4 MV	1.1277	62.33	63.35	63.0	63.3
6 MV	1.1206	66.54	66.71*	67.5	66.6[a]
10 MV	1.1071	72.40	73.0	73.0	73.2
15 MV	1.0946	77.91	78.22	77.0	76.9
24 MV	1.0745	86.06	86.06	83.0	NA
Aluminum					
10 MeV	1.1126	69.89	70.58		
15 MeV	1.0958	77.28	77.67		
20 MeV	1.0855	81.88	81.88		
25 MeV	1.0769	85.97	85.97		
30 MeV	1.0685	89.55	89.55		
Lead					
10 MeV	1.1114	70.63	71.33		
15 MeV	1.0988	76.63	77.01		
20 MeV	1.0882	80.83	80.83		
25 MeV	1.0796	84.57	84.57		
30 MeV	1.0747	88.01	88.01		
Beryllium					
15 MV	1.0972	76.17	76.62		
Filtered					
10 MV 14 cm Al	1.1021	74.42	74.94		
20 MV 14 cm Al	1.0771	84.84	84.84		
NRC					
10 MeV NRC Al	1.1101	69.96	70.65		
20 MeV NRC Al	1.0868	81.15	81.15		
MSKCC racetrack					
30 MeV	1.0725	88.00	88.00		
50 MeV	1.0538	95.36	95.15*		

[a]This is for Clinac 6 which is what Mohan *et al.*'s spectrum refers to. The Clinac 2100C is 67.1; Siemens KD is 67.7; Philips SL75 is 67.9; SL25 is 67.9.

lations since electron contamination has little effect on $\%dd(10)$. For the higher energy beams, the electron contamination reduces the value of $\%dd(10)$ and hence the measured value of $\%dd(10)$ is not directly comparable to $\%dd(10)_x$. Using a general relationship presented earlier[4] to estimate the effect of electron contamination on $\%dd(10)$, the discrepancies for the 15 and 24 MV beams are reduced, respectively, from 1.6% and 3.7% to 0.9% in both cases.

Figure 1 presents the revised data along with the revised fit to the data for the bremsstrahlung beams. The revised relationship is:

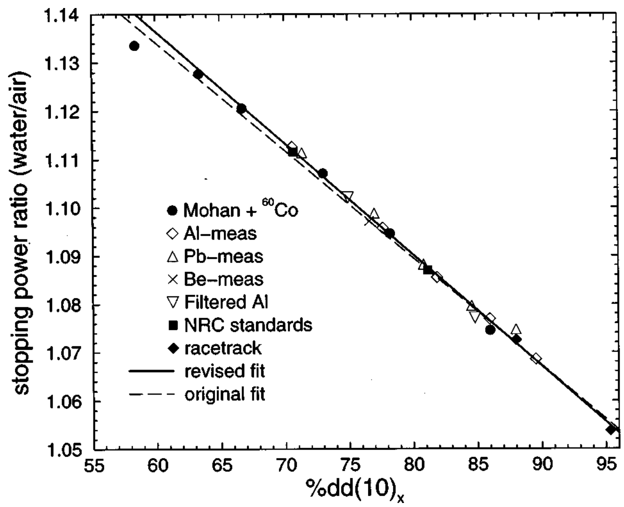

FIG. 1. Calculated Spencer–Attix water to air stopping-power ratios (based on ICRU 37 stopping powers, Ref. 16) vs revised $\%dd(10)_x$ for the same spectra as studied by Kosunen and Rogers. (Ref. 3) The solid straight line is the linear fit [Eq. (2)] to the revised data for all the bremsstrahlung beams whereas the dashed line is the fit to the original data.

$$\left(\frac{\bar{L}}{\rho}\right)^{\text{water}}_{\text{air}} = 1.275 - 0.00231(\%dd(10)_x). \tag{2}$$

The effect of the revision is to change the fitted line slightly and improve the quality of the fit. The rms deviation about the fitted line is now 0.0011 (previously 0.0013).

The figure also shows the linear fit to the original data. The major change is for low energy beams. The biggest practical change would be for a 4 MV beam where the stopping-power ratio assigned based on a value of $\%dd(10)_x$ of 63.4 would change by 0.20%. Thus although the values of $\%dd(10)_x$ for the 4 MV beam changed by 2%, the variation in stopping-power ratio is much reduced because the relationship between stopping-power ratio and $\%dd(10)_x$ has such a small slope.

III. CHANGES TO CALCULATED k_Q FACTORS

For photon dosimetry based on absorbed-dose calibration factors for ^{60}Co beams, one calculates values of k_Q using the relationship between stopping-power ratios and $\%dd(10)_x$. See Ref. 4 for a detailed description of the calculations. The linear fit is used above $\%dd(10)_x = 63.35\%$ and below that a linear interpolation to the ^{60}Co datapoint is used and for $\%dd(10)_x$ below 58.4%, the ^{60}Co value of the stopping-power ratio is used. Figure 2 presents a comparison of the k_Q values as a function of $\%dd(10)_x$ values calculated with the revised versus original relationship. The differences mirror the change in the stopping-power ratio versus $\%dd(10)_x$ curves since the k_Q values are dominated by these curves. There is also a second order effect in the calculation of k_Q since there is a slight change in the relationship between TPR and $\%dd(10)_x$.[4] This relationship is used to access some of the data used in the calculation and these data are available as a function of TPR [e.g., (μ_{en}/ρ)], but the effects of these changes are insignificant.

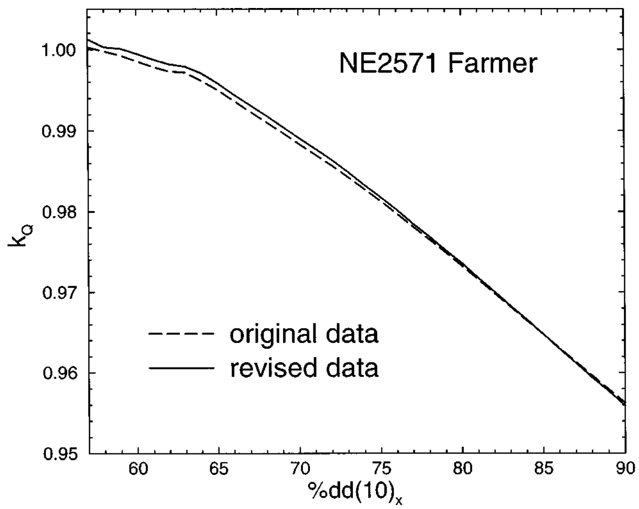

FIG. 2. Values of k_Q for an NE2571 Farmer-like chamber as calculated with the revised or original stopping-power ratio vs $\%dd(10)_x$ data.

IV. CONCLUSIONS

Although the changes caused by properly calculating the values of $\%dd(10)_x$ are nearly 2% for low energy photon beams, these changes translate into much smaller changes in the values of stopping-power ratio for a given value of $\%dd(10)_x$. Although the maximum change of 0.20% in the stopping-power ratio and hence k_Q for a given value of $\%dd(10)_x$ is not clinically important, it is worthwhile to use the correct procedure for the new TG-51 protocol.

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