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Short Communication

The Effect of 220 kVp X-Rays with Different Spectra on the Dose Response of Chromosome Aberrations in Human Lymphocytes

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There are numerous published data on the dependence of chromosome aberrations in human lymphocytes on radiation quality [for reviews see 2, 6]. The effect of dose rate and fractionation is a well known phenomenon from experiments with sparsely ionizing radiations. Applying the linear-quadratic model $Y = b(0) + b(1)D + b(2)D^2$ to describe the dose response-relationship of dicentrics, a reduction in dose rate is reflected by a reduction of the quadratic coefficient, whereas the linear term remains unchanged. The present study reports on two experiments with 220 kVp X-rays carried out with different filter combinations (Table 1). The irradiation and culture procedures for whole blood from two healthy male donors are described elsewhere [5, 11]. In exp. 1 absorbed dose was measured with a Fricke dosemeter [9] whilst the dosimetry of exp. 2 was performed with an ionizing chamber. The dose-effect relationship was determined for dicentrics and excess acentrics (sum of terminal and interstitial deletions and acentric rings) analysed exclusively in complete first division metaphases (M_1) stained by the fluorescence plus Giemsa technique, FPG [1]. Due to their small number (about 10% of dicentrics) ring chromosomes were not included in the quantitative analysis. Our standard control data are used as zero dose and comprise 24,000 M_1-cells with nine dicentrics and 71 acentrics. Tables 2

Table 1. Characteristic of radiation qualities

X-ray beam	Experiment 1	Experiment 2
Tube voltage [kVp]	220	220
Tube current [mA]	14	12.5
Dose rate [Gy · min^{-1}]	0.16	0.5
Filter [mm]	2.0 Al + 3.35 Cu	4.05 Al + 0.5 Cu
HVL [mm Cu]	2.76	1.32
Mean energy [keV] of:		
Photon fluence	129.2	94.0
Exposure rate	140.4	106.9
Energy fluence	139.3	110.8

Table 2. Intercellular distribution of dicentrics for different doses of 220 kVp X-rays with different spectra

Experiment no.	Dose (Gy)	Cells scored	Dicentrics per cell (Y)	Distribution							Dispersion Index σ^2/Y ± SE	u
				0	1	2	3	4	5	6		
1	0.05	2,000	0.001	1,998	2						1.00 ± 0.02	−0.02
	0.10	2,000	0.0035	1,993	7						1.00 ± 0.03	−0.10
	0.20	1,000	0.009	991	9						0.99 ± 0.04	−0.19
	0.40	1,000	0.014	986	14						0.99 ± 0.04	−0.30
	0.50	1,000	0.025	975	25						0.98 ± 0.04	−0.55
	1.0	1,300	0.070	1,213	83	4					1.02 ± 0.04	0.48
	2.0	700	0.200	569	122	9					0.93 ± 0.05	−1.32
	4.0	500	0.806	226	174	77	17	6			1.01 ± 0.06	0.16
2	0.05	3,000	0.002	2,993	7						1.00 ± 0.02	−0.08
	0.10	3,000	0.005	2,985	15						1.00 ± 0.02	−0.19
	0.20	2,000	0.013	1,975	25						0.99 ± 0.03	−0.39
	0.40	2,000	0.026	1,949	51						0.97 ± 0.03	−0.80
	0.50	2,000	0.032	1,938	61	1					1.00 ± 0.03	0.02
	1.0	1,300	0.109	1,164	131	4	1				0.99 ± 0.04	−0.25
	2.0	700	0.324	537	163	26	4				1.01 ± 0.05	0.22
	3.0	600	0.663	304	216	62	14	4			0.98 ± 0.06	−0.32
	4.0	500	1.104	154	199	103	34	7	1	2	0.94 ± 0.06	−0.98

Table 3. Intercellular distribution of excess acentrics for different doses of 220 kVp X-rays with different spectra

Experiment no.	Dose (Gy)	Cells scored	Acentrics per cell (Y)	Distribution							Dispersion Index σ^2/Y ± SE	u
				0	1	2	3	4	5	6		
1	0.05	2,000	0.005	1,990	10						1.00 ± 0.03	−0.15
	0.10	2,000	0.011	1,979	21						0.99 ± 0.03	−0.32
	0.20	1,000	0.017	983	17						0.98 ± 0.04	−0.37
	0.40	1,000	0.040	961	38	1					1.01 ± 0.04	0.25
	0.50	1,000	0.046	956	42	2					1.04 ± 0.04	0.95
	1.0	1,300	0.095	1,186	105	9					1.05 ± 0.04	1.34
	2.0	700	0.230	559	123	17	0	1			1.06 ± 0.05	1.07
	4.0	500	0.762	250	145	87	12	4	2		1.12 ± 0.06	1.85
2	0.05	3,000	0.007	2,983	14	3					1.29 ± 0.03	11.67
	0.10	3,000	0.010	2,971	29						0.99 ± 0.03	−0.37
	0.20	2,000	0.016	1,971	27	2					1.11 ± 0.03	3.67
	0.40	2,000	0.030	1,942	56	2					1.04 ± 0.03	1.19
	0.50	2,000	0.037	1,933	62	4	1				1.16 ± 0.03	4.96
	1.0	1,300	0.120	1,166	113	20	1				1.18 ± 0.04	4.49
	2.0	700	0.331	507	156	35	2				1.02 ± 0.05	0.44
	3.0	600	0.643	309	216	56	18	1			0.96 ± 0.06	−0.71
	4.0	500	0.992	199	169	89	29	9	4	1	1.16 ± 0.06	2.52

Table 4. Estimated parameters for the linear-quadratic model $Y = b(0) + b(1)D + b(2)D^2$ for dicentrics and excess acentrics

Experiment No.	Aberration type	b(0) ± SE $\times 10^{-4}$ 95% confidence intervals $\times 10^{-4}$	b(1) ± SE $\times 10^{-1}$ Gy^{-1} 95% confidence intervals $\times 10^{-1}$	b(2) ± SE $\times 10^{-2}$ Gy^{-2} 95% confidence intervals $\times 10^{-2}$	Level of significance
1	Dicentrics	3.7 ± 1.0 1.2 ; 6.1	0.22 ± 0.04 0.12 ; 0.32	4.36 ± 0.24 3.77 ; 4.94	P = 0.68
	Acentrics	29.4 ± 2.7 22.8 ; 36.0	0.64 ± 0.06 0.50 ; 0.78	2.99 ± 0.27 2.32 ; 3.66	P = 0.71
2	Dicentrics	3.7 ± 0.8 1.9 ; 5.5	0.40 ± 0.03 0.33 ; 0.48	5.98 ± 0.17 5.57 ; 6.38	P = 0.92
	Acentrics	29.9 ± 3.1 22.6 ; 37.3	0.53 ± 0.06 0.40 ; 0.66	5.15 ± 0.28 4.49 ; 5.82	P = 0.56

and 3 give the intercellular distribution of dicentrics and acentrics in both experiments. For dicentrics the dispersion index (variance, σ^2/mean, Y) equals 1 and the magnitude of the test quantity, u, is < 1.96 (between -0.02 and 0.48), indicating a distribution according to Poisson [4, 7, 8] in both experiments. Acentrics follow the Poisson distribution in exp. 1 but show overdispersion (dispersion index > 1) at 5 of 9 doses (values of u between 2.52 and 11.67) of exp. 2.

Estimated parameters of a weighted (reciprocal sample mean variance n/σ^2) least squares approximation for the linear-quadratic model are presented in Table 4. It is evident from the application of a weighted identity test [10] that the dose-effect relationships for either dicentrics ($i_{3,13} = 49.28$) or acentrics ($i_{3,13} = 15.95$) established from exp. 1 or exp. 2 differ significantly at the 5% level.

Figure 1 shows the 95% confidence ellipsoids for the parameters b(1) and b(2) of the linear quadratic relations for dicentrics and acentrics. It is apparent that the observed differences in the dose-response are mainly due to differences in the quadratic component. This was confirmed by the identity test for dicentrics ($i_{2,13} = 15.73$) and for acentrics ($i_{2,13} = 14.91$).

If only the lower doses up to 0.4 Gy [i.e., below b(1)/b(2)] are considered and the dose response is analysed in terms of the linear model (exp. 1, $Y = 3.5 \pm 1.1 \times 10^{-4} + 0.31 \pm 0.06 \times 10^{-1}$ Gy^{-1}; $P = 0.48$. Exp. 2, $Y = 3.5 \pm 1.1 \times 10^{-4} + 0.56 \pm 0.05 \times 10^{-1}$ Gy^{-1}; $P = 0.53$), a significant difference ($i_{2,6} = 5.67$) is also evident for b(1) at least for dicentrics. Dose effect coefficients for dicentrics for acute exposure (< 20 min) to 180–250 kVp X-rays determined from different laboratories show a variation within about a factor 2 [6]. As already noted, several factors can cause these variations. Intercomparison of published data mostly disregard the applied filter conditions. Thus for existing interlaboratory differences an additional factor, namely the influence of the X-ray spectrum, should be considered.

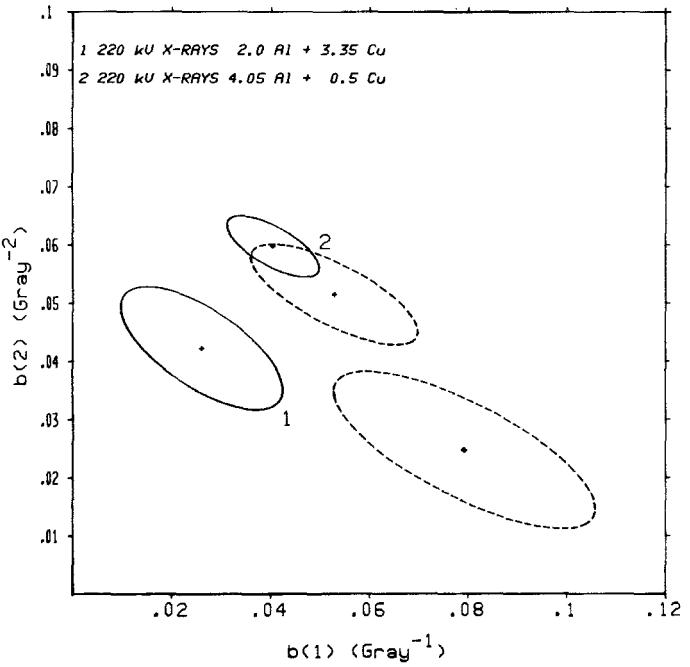

Fig. 1. Ninety-five per cent confidence regions for the parameters b(1) and b(2) of the linear-quadratic relation for dicentrics (full line) and acentrics (broken line) in exp. 1 and exp. 2

In exp. 1 the exposure time at 4.0 Gy was 25 min (0.16 Gy · min^{-1}). This is about three times longer than in exp. 2 (0.5 Gy · min^{-1}). Although the former is slightly above 20 min which is usually accepted as the limit for acute exposure a dose rate effect cannot be fully excluded. However, when compared to our recent findings with ^{60}Co γ-rays no strong influence should be expected. In the gamma-experiments the dose rate differed by about a factor 30 (0.5 and 0.017 Gy · min^{-1}) and b(2)D^2 for dicentric production was found to decrease by 25%, whereas the linear component remained unchanged [3]. It seems unlikely that a dose rate effect of the same order of magnitude should result from the exposure times used in exp. 1 of the present study. In contrast to the experiments with γ-rays the linear component was simultaneously reduced. Therefore the observed differences in the dose-effect curves appear to be mainly a consequence of different X-ray bremsstrahlung spectra rather than of dose rate.

Provided that standardized procedures for irradiation (temperature, dosimetry), scoring (exclusively first division metaphases) and curve fitting (weighting method) are used changes in the dose-effect coefficients can be also detected for X-rays generated at identical tube voltage but having different bremsstrahlung spectra.

For a confirmation and a physical interpretation of the present findings we have performed experiments with 250 kVp X-rays at a constant dose rate of 0.5 Gy · min^{-1} and varying filter combinations. The chromosome analyses are in progress.

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