RADIOPROTECTION OF PATIENTS IN RADIOTHERAPY: THE GONADAL DOSES RESULTING FROM TREATMENTS AT ELECTRON ACCELERATORS.

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1. INTRODUCTION

Since the time electron accelerators have been used in radiotherapy for several kinds of malignant diseases the survival rates were enhanced significantly. Therefore, it is necessary to draw even more attention on the radioprotection of the patient, particularly, when children or young patients are treated.
The dose absorbed by the patient in regions outside the primary beam may be separated in three components, the leakage radiation of the accelerator, the stray radiation from the treatment room and the scatter in the patient. All parts interfere in a complicated manner. So, it is necessary to study the influence of some factors on the dose distribution in the whole body of the patient. In this paper results will be presented when variing the following parameters: the beam quality, the beam energy, the protection effect of lead shielding, the spatial orientation of the phantom and the field size. Due to the fact that betatrons and linear acclerators are the machines most frequently used in radiotherapy centers today, the secondary radiation field of either accelerator type was investigated.

2. METHOD AND RESULTS

In a systematic study dose profiles were measured in a phantom of polystyrene (75x25x20 cm) using LiF-dosemeters. The maximum lateral distance to the beam axis was 50 cm, the distance between the measuring points was 6 cm. The phantom was fixed on the treatment couch and it was irradiated with the gantry being in vertical position. Experimental details are given elsewhere (1).

2.1 Measurements at the betatron

The phantom was irradiated at a 45 MeV betatron (Siemens) with 45 MV X-rays, 10 MeV, 18 MeV and 45 MeV electrons. Adequate compensating filters and scattering foils were used for beam flattening. The X-ray field size was 10x10 cm at 100 cm SSD, the electron field was defined by a cone of 12 cm diameter at 120 SSD. The results are summarized in table 1.

Beam quality and energy

Due to the small side scattering of high energy photons D^e (x)

falls more rapid with the lateral distance x than in the case of the electron beam of the same energy: at 45 MeV the ratio of the slopes dlogD/dx is about 3. However, with respect to the maximum dose in the beam center axis the dose at the X-ray field edge is 20 times as high as for the electron beam. At large lateral distances this difference is smoothed. Comparing the dose distributions at different electron energies the slopes of the profiles do not change, whereas the relative dose decreases with primary beam energy.

energy	lead (mm)	D^e_{10} (%)	D^e_{40} (%)	D^c_c (%)	D^c_{40} (%)	dlogD/dx
45 MV X	0	28	1	63	0.65	0.046
45 MV X	1	16	0.35	80	0.28	0.055
45 MeV e^-	0	46	13	2.6	0.32	0.017
45 MeV e^-	1	28	5.7	3.7	0.22	0.020
18 MeV e^-	0	27	8.7	1.2	0.12	0.017
18 MeV e^-	1	20	4.5	1.2	0.05	0.022
10 MeV e^-	0	12	3.1	0.73	0.02	0.022
10 MeV e^-	1	5.4	0.5	0.73	0.007	0.034

Tab.1: Dose profiles at the betatron. D^e_x =relative dose normalized at the field edge; D^c_x =relative dose normalized at the beam center line; x = lateral distance to the field edge.

Protection effect of lead shielding

Dose distributions were measured with the phantom covered with lead sheets of 1 to 3 mm thickness against stray and leakage radiation outside the primary beam. The penetrating power of the radiation measured by means of the HVL in lead was found to decrease by a factor up to 0.3 over the whole lateral distance. The efficacy of the lead shielding depends on the distance from the field edge, mainly. At high energies the build-up is shifted from the phantom into the lead cover causing a rise in dose near the field edge. At greater distances, however, a dose reduction by an amount up to 0.35 was found by covering with 1 mm Pb, only. Because with greater depths in the phantom corresponding to the localization of the female gonads the phantom scatter becomes dominant, protection with lead is more effective in the treatment of male patients.

Spatial orientation of the phantom

The dose in the phantom measured at greater distances to the beam center line varies significantly with the orientation of the treatment couch. As exspected from the technique of beam generation in this betatron dose minima were observed in the plane normal to the electron orbit. The maximum values in the electron and in the photon mode were measured in the plane of the electron orbit at opposite directions. By positioning the patient properly it is possible to reduce the gonadal dose to 1/2 of the value obtained at the 0°- and 180°- direction, respectively.

Field size

A variation of the field size modifies the dose profiles significantly in the electron mode, only. The influence of the field size becomes important with decreasing electron energy and increasing lateral distance.

2.2 Measurements at the linear accelerator

A second series of dose profiles were measured at the Clinac-18 (Varian) using flattened beams of 10 MV X-rays, 6 MeV and 18 MeV electrons. The field size was 10x10 cm^2 at 100 cm SSD. In the electron mode a cone was used. Some results are given in table 2.

energy	lead (mm)	D^e_{10} (%)	D^e_{40} (%)	D^c_0 (%)	D^c_{40} (%)	dlogD/dx
10 MV X	0	29	3.0	25	0.75	0.046
10 MV X	1	10	0.55	39	0.22	0.042
18 MeV e^-	0	12	0.8	12	0.12	0.038
18 MeV e^-	1	9.5	0.75	6.5	0.05	0.038
6 MeV e^-	0	1.2	0.13	22.5	0.03	0.032

Tab.2: Dose profiles at the linac. Same symbols as in tab.1.

Beam quality and energy

Comparing the photon beams of both accelerators the dose profiles of the linac are less steep, but with respect to the center axis maximum dose the dose at the field edge is more favourable. This is a consequence of the quite different beam energies, mainly. Contrarily, the profiles at 18 MeV electron energy show an inverse behaviour. Compared to the betatron the dose at the field edge is now about 10 times higher. This may be caused by the different construction of the electron cones used at either accelerator.

Protection effect of lead shielding

In the photon mode the HVL of the leakage and stray radiation spectrum decreases with the distance to the field edge by more than 1/4, whereas at electron radiation the HVL varies over the same distance by 1/2, only. The dose sparing effect of 1 mm lead covering the phantom amounts up to about 1/3.

Spatial orientation of the phantom

Because the electrons in the Clinac-18 are deflected by a 270°-magnet before hitting the bremsstrahltarget the leakage radiation in the photon mode has maxima both in the 0°- and in the 180°- direction of the treatment couch. The difference in the dose at large distances to the primary beam with the couch being parallel or normal to the tube axis, respectively, amounts to about a factor 2. In the electron mode,

particularly, at 6 MeV incident energy, in the 180 direction the dose profile decreases surprisingly slow, probably indicating an additional leakage radiation component from the clystron.

3. DETERMINATION OF THE GONADAL DOSES

One of the aims of these measurements was to estimate the gonadal load of a patient treated at either accelerator type. Therefore, the dose absorbed by the gonads during treatment was measured using the man-like Alderson-Rando phantom.

region	energy	$D_{♀}$ (‰)	$D_{♂}$ (‰)	$D_{♀}$ (mGy)	$D_{♂}$ (mGy)
mediastinum	45 MV X	1.5	2.0	68	90
	10 MV X	2.0	2.4	90	110
	45 MeV e^-	3.0	2.0	135	90
	18 MeV e^-	0.5	0.9	23	41
paraaortal lymph nodes	45 MV X	4.0	1.0	180	45
	10 MV X	6.0	4.0	270	180
	45 MeV e^-	1.5	0.7	68	32
	18 MeV e^-	0.3	0.2	14	9

Tab.3: The gonadal load resulting from treatments at accelerators. Relative doses are normalized against the maximum dose. Last two columns: Gonadal load resulting irradiation with 45 Gy maximum dose for femal (f) and male (m) patients, respectively.

Table 3 shows the gonadal load measured at two different field localizations. The figures given in the last two columns are doses absorbed by the gonads during a radiation treatment with 45 Gy maximum dose. Comparing these data to the values estimated on the basis of the dose distribution measurements no remarkable discrepancies were be found.

REFERENCE

(1) NUESSLIN,F., HASSENSTEIN,E. 'Die Gonadenbelastung bei der Strahlentherapie gutartiger Erkrankungen', Strahlentherapie 151 5 (1976) 409