THE ANALYSIS OF SOME PHYSICAL ASPECTS OF INTRACAVITARY IRRADIATION WITH SELECTRON LDR. CALCULATION OF PHYSICAL CORRECTION FACTORS BASED ON THE L-Q MODEL

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Received 25 May 1998; revision received 23 November 1998; accepted 8 January 1999.

SUMMARY

This paper determines the influence of physical parameters of intracavitary irradiation, such as the length of the intrauterine tube, the size of vaginal ovoids, the distance between them and the arrangement of the active sources in the ovoids, on the physical dose at reference points in the bladder and rectum. The biological equivalence of irradiation with the use of the Selectron LDR in relation to the Manchester method, with reference to early and late reactions were calculated on the basis of the L-Q model.

INTRODUCTION

Intracavitary irradiation allows administration of a sufficient dose to the neoplasmatic tumour, but on the other hand, leads to a considerable exposure to radiation of the critical organs such as rectum and bladder. The knowledge of the influence of physical parameters of irradiation on the dose at reference points, makes it possible to optimize the dose distribution, in such a way that the administration of the planned dose at point A would not be associated with the excess of the tolerance dose in the rectum and bladder. The physical parameters of the irradiation with the Selectron LDR were defined according to the modified Manchester method used in our Clinic for over 30 years, in which radium was replaced by 13.5 mm long caesium - 137 sources filtrated by 0.5 mm Pt. (Lewocki, 1994) The influence of the length of the intrauterine tube and the size of active sources in the ovoids on the physical dose at reference points was analysed. Intrauterine applications were performed with the use of standard applicators and caesium - 137 sources of the nominal activity of 40 mCi. The correction of the total dose associated with higher activity of the Selectron sources was calculated using the L-Q model.

MATERIAL AND METHOD

In order to perform intracavitary irradiation with Selectron LDR, a selectron standard applicators set has been used. Positioning of the sources in the applicators has been determined experimentally on the basis of the analysis of the isodose curves and the dose at point A. The long intrauterine tubes contains 7 radioactive spherical sources in positions 1,3,5,8,13,16,21. In each vaginal ovoid 2.5 mm in diameter, four sources were placed in positions 3,4,6,7. The remaining positions contain dummy sources. For this set of applicators, the dose rate at point A is 1.67 Gy/h. The dose of 75 Gy is obtained at this point in 45 hours. In the medium uterine tube, the active sources are placed in position 1,3,5,8,13. (Lewocki, 1994)

Since all sources have the same activity, the differences in the quantity of radium used in the classical Manchester method, associated with the size of vaginal ovoids, were replaced by different times of irradiation. The correction of the irradiation times correlated with the different size of the ovoids, was calculated on the basis of the ratios of the radium sources used in the Manchester method. (Tab.1)

Type of ovoid	Number of mg radium in classical Manchester method	Time correction factors in irradiation for Selectron
Smallest ovoid	15,0 mg	0,75
Small ovoid	17,5 mg	0,875
Medium ovoid	20,0 mg	1
Large ovoid	22,5 mg	1,125

Table 1. Time correction factors for Selectron irradiation equal activity sources depending on the ovoid size.

THE BIOLOGICAL EQUIVALENCE OF IRRADIATION USING THE MODIFIED MANCHESTER METHOD WITH SELECTRON LDR

The linear - quadratic model L-Q was used to calculate the biologically equivalent dose administered in the modified Manchester method employing Selectron (Barendsen, 1982).

$$ERDc = Dc (1+2r/\alpha/\beta),$$

where r is the dose rate in Gy/h, and Dc is the total dose during continuous irradiation.

This equation can be applied on the assumption that the time of application is much longer than the sublethal damage repair half-times, i.e. 1.5 - 2 hours. According to some authors, the values of the ERDc (Extrapolated Response Dose in continuos irradiation) are calculated (Barendsen, 1982; Fowler, 1989), assuming that the α/β ratio is 10 for early reacting tissues and the tumour, and 3 for late reacting tissues. The equivalent doses for the early reacting tissues and the tumour are shown in Table 2, and these for late responding tissues in Table 3.

Method of irradiation				Decrease in physical dose [%]
Modified Manchester method dose rate = 0,535 Gy/h		Selectron, dose rate = 1,67 Gy/h		
D(A) [Gy] (1)	ERDc (2)	D(A) [Gy]	ERDc	
75,0	77,5	62,25	77,5	17 %
60,0	66,44	49,82	66,44	17 %
55,0	60,9	45,66	60,9	17 %
50,0	55,32	41,52	55,32	17 %

Table 2 Biological equivalence for acute radiation reaction of the tissues and tumour response α/β=10. (1) D(A) - dose in point A, (2) ERDc - extrapolated response dose during continuous irradiation.

Method of irradiation				Decrease in physical dose [%]
Modified Manchester Method dose rate = 0,535 Gy/h		Selectron, dose rate = 1,67 Gy/h		
D(A) [Gy]	ERDc	D(A) [Gy]	ERDc	
75,0	95,02	48,23	95,02	35,7 %
60,0	81,44	38,58	81,44	35,7 %
55,0	74,66	35,36	74,66	35,7 %
50,0	67,86	32,14	67,86	35,7 %

Table 3 Biological equivalence for late radiation reaction of the tissues α/β = 3. (1) D(A) - dose at point A, (2) ERDc - extrapolated response dose during continuous irradiation.

The analysis of the physical parameters of irradiation with the modified Manchester method using Selectron was based on clinical data comprising 126 gynaecological brachytherapy applications. The reference point doses were normalised to the dose of 75 Gy at point A, and than compared. Table 4 illustrates the dose at point A which in the applications performed with Selectron is 3.2 % greater than that in the applications performed with the modified Manchester method. The mean absorbed dose at this point, calculated for the group of 126 applications is 77.4 Gy. The deviation from the mean calculated value is 6.5 % (5.03 Gy).

Method of irradiation				
Modified Manchester method		Irradiation with Selectron		
Reference points	Reference dose	Equivalent dose by ERDc(1) α/β=10	Physical dose [Gy]	Decrease in physical dose [%]
Point A	75,0 Gy	77,4 Gy	64,2 Gy	13,5 %
Point B	22,1 Gy	22,5 Gy	19,41 Gy	12,2 %
Lymph nodes				
External iliac	14,4 Gy	15,3 Gy	12,7 Gy	11,8 %
Commoniliac	10,1 Gy	11,0 Gy	9,2 Gy	8,9 %
Para-aortic	3,2 Gy	3,4 Gy	2,9 Gy	9,4 %

Table 4. The doses at reference points in conventional intracavitary irradiation with a modified Manchester method and by Selectron. (1) ERDc - Extrapolated response dose in continuous irradiation.

The bladder and rectum reference points doses were 97.2% ± 33.7% and 68.4% ± 31.9 %, respectively, in relation to the dose at point A. The influence of the length of the uterine tube on the dose at point A, as well as in the rectum and bladder, was also estimated (Fig. 1).

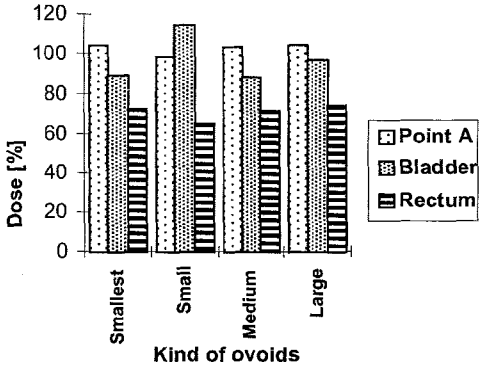

Fig.1. The doses at reference points depending on the length of the intrauterine probe.

The doses were normalised to a model application with the use of a long uterine tube, which was also the basis to calculate the table of application times, when irradiating using Selectron. Fig. 1 shows that the length of the intrauterine tube has no significant influence on the dose at point A. The highest dose at the bladder reference point was observed using the 4 cm long uterine tube (113.7 %) and the lowest dose using 6 cm long tube (96.4%). Similarly, at the rectum reference point the highest dose was observed when the 4 cm long tube was used (77.2 %), and the lowest dose when the 6 cm long tube was used (68.1 %).

The mean doses calculated at point A, and those in the bladder and rectum, were normalised to the dose at point A in the model application, where the ovoids of different size were used (Fig.2).

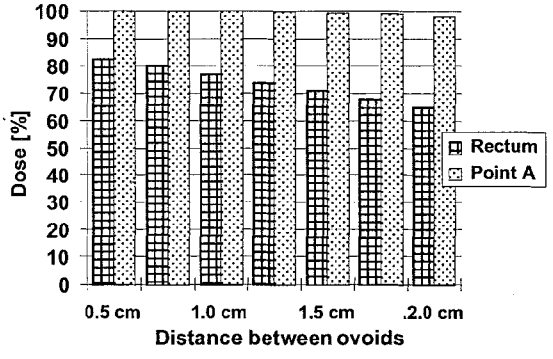

Fig.2. The doses at reference points depending on the size of the ovoids.

The highest dose at point A was obtained using large ovoids (104.3 %), and the lowest dose-using small ovoids (88.4 %). At the bladder reference point, the highest dose was observed when small ovoids were applied (114 %), whereas the smallest dose was found for medium size ovoids. At the rectum reference point, the dose increased from 64.4 % when small ovoids were used, to 74.5 % for large ovoids.

The impact of the position of active sources in the ovoids on the doses at point A, the bladder and rectum reference points was estimated. The dose at point A in the application with the use of a long intrauterine tube and the ovoids containing active sources in positions 3,4,6,7 was estimated to be 100%. It was a typical configuration of active sources in the ovoids used in our Clinic. The results shown in Fig. 3 indicate that the most favourable dose distribution in the rectum was obtained with the location of active sources in positions 3,4,6,7. However, this occurs at the cost of a greater burden to the bladder. All other configurations of active sources in the ovoids increases the dose in the rectum and diminishes the dose in the bladder.

On the basis of the model application, the dependence of the dose at point A and rectum on the distance between the ovoids was established. The rectum reference point was defined at the distance of 0.5 cm from the posterior surface of the ovoids. The dose at point A in the application with the use of a long intracavitary tube and the medium size ovoids spaced 1 cm apart, was defined as 100 %. Fig. 3 indicates that an increase in the distance between the ovoids by 0.25 cm decreases the dose in the rectum by about 3 %. The distance between the ovoids has practically no influence on the absorbed dose at point A.

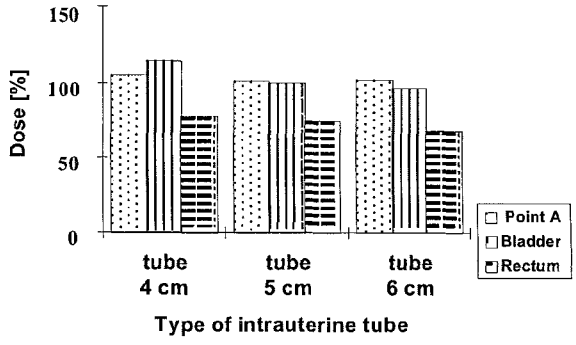

Fig.3. The doses at reference points depending on the positioning of the sources in the ovoids.

DISCUSSION

Physical doses which should be administered with Selectron in order to obtain the same biological equivalence of irradiation as that with the modified Manchester method, were calculated using the ERD equation. The same ERD values for early reactions (α/β=10) were obtained with the reduction of the physical dose by 17%, whereas for the late reactions (α/β=3) the reduction of 36% was necessary. The use of the 17% correction of the physical dose when calculating the time of irradiation with Selectron can be justified by the following explanation:

- clinical experience of some authors (Akine et al., 1980;Hunter, 1985; Hunter, 1992) shows that by applying a dose-rate of 1.5-1.8 Gy/h to point A during intracavitary irradiation similar results of the treatment are achieved, as those using the Manchester method, when the physical dose is reduced by 10 - 20%,
- the vaginal tamponing during the application effectively moves the rectum away from the vaginal ovoids. In this way, the dose in

the rectum and the risk of late effects in this organ can greatly be reduced,

- although in later years attention was drawn to the lack of correlation between the early and late reactions in some organs including the rectum, this correlation has been confirmed by several clinical studies and cellular models (Klimek, 1993).

The dependence of the dose at point A and that in the bladder and rectum reference points upon such parameters as the length of the intrauterine tube the size of the ovoids, the distance between them and the arrangement of active sources in the ovoids was analysed. A very small influence of these parameters on the dose at point A was found, whereas the exposure of the bladder and the rectum clearly depends on the size of the ovoids and the distance between them. Unfavourable anatomical conditions in the vagina, which allow only the insertion of the small and smallest ovoids, cause an increase in the dose in the bladder and rectum. The possibility of an individualised optimisation of the dose distribution by different arrangement of active sources in the ovoids, permits administration of a lower dose to these organs. The analysis of some aspects of the dosimetry during irradiation with Selectron, was carried out by Szymczyk et al. [8]. In their study, experimental configuration of active sources in the applicators was similar to that applied in our own study. The mean dose in the rectum (52%) in relation to the dose at point A was lower than that in our study (68.4%). This is probably due to the employiment of a different method of defining the dose in the rectum. The influence of the distance between the ovoids on the dose in the rectum shown by Szymczyk et al. to be a line of regression, is similar to our results presented in Fig. 4. Similar results were also obtained in relation to the most favourable arrangement of active sources in the vaginal ovoids.

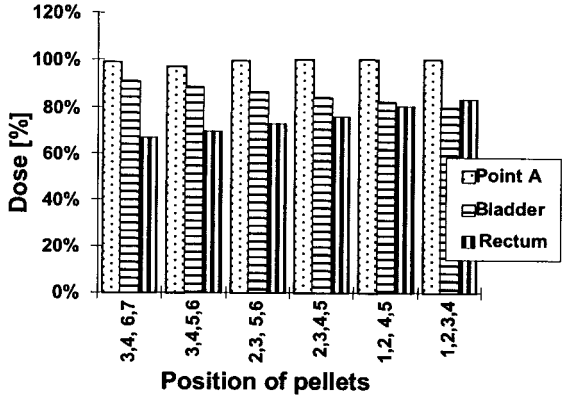

Fig.4. The doses at reference points depending on the distance between ovoids.

CONCLUSIONS

1. The L-Q model can be a useful tool for the estimation of a biologically equivalent dose in intracavitary irradiation performed with different dose rate sources.
2. The knowledge of the influence of physical parameters of intracavitary irradiation on the dose of reference points permits optimisation of the dose distribution in such a way that the administration of the planned dose at point A would not be associated with the excess of the tolerance dose in the rectum and bladder.

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