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APPLICATORS FOR REMOTE AFTERLOADING TECHNIQUE FOR OPTIMUM PELVIC DOSE DISTRIBUTION IN CARCINOMA OF THE UTERINE CERVIX

by

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Attempts at reaching optimum dose distribution in the pelvis from intracavitary radiation for carcinoma of the uterine cervix have interested the clinician for many years, and a wealth of literature is available on the subject. Traditionally an improved dose distribution is aimed at by an increase in the source surface distance, an elongation of the intra-uterine source and by using multiple radiation sources preferably spread out in the superior part of the vagina. Lack of space often imposes limitations, and difficulties are encountered regarding the maintenance of the position of the sources during the treatment time both in their interrelationship and to the anatomic configurations of the patient.

The design by NEARY (1947) of a combined intra-uterine and intravaginal high activity irradiator, employing specific screens in the direction of the bladder and the rectum, represents one attempt to achieve improvement in the dose at

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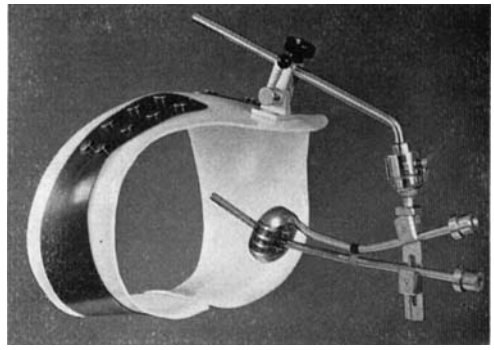

Fig. 1. The intracavitary applicators of the remote afterloading unit are held in place by a fiberglas corset.

the pelvic wall. More recently proposals have suggested the incorporation of specific shields of high Z-metal in the applicators of the current Stockholm method, in combination with the use of medium or low energy gamma radiation sources (KOTTMEIER & WALSTAM 1962). The introduction of the remote afterloading technique opened further prospects. WALSTAM (1965) utilized lateral placement of ^{137}Cs sources surrounded by tungsten absorbers in an early version of an afterloaded vaginal applicator in order to extend the dose distribution laterally. The vaginal applicator was used, however, together with an intra-uterine steel sound loaded with radium; it was anticipated that the resulting dose distribution in the pelvis would not differ considerably from that of the current Stockholm technique. Development of an applicator with increased shielding, particularly of the bladder and rectum, has therefore continued. One of these applicator models has been introduced into the routine clinical work after determination of the dose distribution in a phantom. The relationship between the doses at the pelvic wall and the dose at the posterior part of the bladder and the anterior wall of the rectum has been established in a series of patients.

Intracavitary applicators. With the Stockholm afterloading technique the intracavitary applicators are attached to the patient by means of a special corset (Fig. 1). This arrangement decreases the risk of tissue damage due to pressure even if the applicator is heavy; in addition, the gamma radiation from ^{137}Cs is of fairly low energy, i.e. 0.66 MeV, which reduces the necessary thickness of the material used for shielding purposes. The bar and ball-joint system also allows the final adjustment of applicator site to be made after the patient is released from the lithotomy position.

Two separate sets of intracavitary applicators were used; one of these consisted of the ring-shaped vaginal applicator described by WALSTAM (1965) together with an intra-uterine stainless steel sound. The source activity for this set has

Table 1

Physical characteristics of various materials for the attenuation of radiation from ^{137}Cs

	Z-number	Atomic weight	Density	First HVL in mm (^{137}Cs)
Uranium	92	238	18.8	2.9*
Tungsten	74	184	18.6—19.3	4.0*and **
Lead	82	207	11.0	5.5*
Platinum	78	195	21.4	3.2***
Gold (pure)	79	197	19.3	3.6***
Gold (18 carat)	71****		16.7	4.2***

* According to THORAEUS 1965
** Tungsten alloy, density 17.7
*** Calculated from values in GRODSTEIN 1967
**** Calculated in accordance with MAYNEORD 1937

been stepwise increased from the previously used content of 120 to 140 mg radium, to three times this amount. The vaginal applicator was loaded with a cesium source train of 600 mCi activity. Distribution of the sources at lateral parts of the ring together with tungsten absorbers at selected locations resulted in a dose reduction in the direction of the urinary bladder and the rectum. A radium source train of variable activity (100 to 250 mg Ra) was used for the intra-uterine sound; this applicator combination will be referred to as system No. 1. The recently constructed vaginal applicator model, utilizing additional shielding material, was employed together with an intra-uterine steel sound, both tubes being equipped with cesium source trains. The activity of the sources in each applicator was 600 mCi. This applicator combination will be called system No. 2.

In the design of the vaginal applicator of the No. 2 system various high Z-materials were considered (Table 1). Uranium was disregarded because of its high reactivity. Lead had a too high HVL figure and platinum was too costly. Tungsten, manufactured in sintered form and used as an alloy with copper and nickel, was unsuitable because of difficulties encountered in machining it. Eighteen carat gold, which has a high restistance to corrosion and is easy to machine, was therefore chosen.

The vaginal applicator of the No. 2 system, was intended to be so designed as to reduce the doses in the ventral and dorsal directions, thereby shielding the bladder base and the anterior wall of the rectum. It was decided not to change the arrangement of sources and absorbers from the previous design by WALSTAM. It had been found, however, in a study in 4 patients with the

Table 2

Doses in rad (mean values and limits of observations in 4 patients) in three parts of 19 mm length and in one part of 6 mm length (under the inguinal ligament) of the right iliac vein during intracavitary radiation treatment with the remote afterloading technique, applicator system No. 1

	Parts of iliac vein			Under inguinal ligament
	Cranial	Middle	Caudal	
Limits	250—370	336—430	213—410	230—302
Mean	314	400	357	277

intracavitary applicator combination No. 1 that the radiation doses in the right common and external iliac veins, determined by thermoluminescence dosimetry, reached a maximum of 400 rad during one course of treatment (Table 2). The mean dose during the same treatment on the posterior wall of the bladder was 2 500 rad and on the anterior wall of the rectum 2 000 rad. The relationship is the same as for the current Stockholm technique. Additional gold shielding was therefore applied to the anterior and posterior parts of the ring of the vaginal applicator of the No. 2 system. The gold shielding was shaped into the form of a part collar around the stainless steel sound to produce a sufficiently wide zone of protection. Care was taken to adjust the gold shield as close to the radiation sources as possible in order to increase the space angle it occupied. Discs of gold were also attached to the periphery of the steel sound between each radiation source. The sizes of the discs were chosen to allow only narrow beams of radiation to reach the surrounding regions. Thus, in the lateral direction close to the applicator, a reduced surface dose was obtained since small tissue volumes received radiation from only one radiation source. At greater distance from the ring, arbitrarily chosen tissue volumes were found to receive irradiation from all three radiation sources.

The vaginal applicator with the gold shields was covered with araldite. The total diameter of the applicator was 54 mm and the outer diameter of the stainless steel tube was 8 mm (Fig. 2).

The isodose curves around the vaginal applicator were determined by means of an automatic isodose recorder (LARSSON et coll. 1963) with some modifications. The instrument was equipped with an anthracene crystal placed inside an aluminium tube connected to a photomultiplier. The dependence of the dose response on radiation quality for this crystal was found to be within $\pm$ 5 % in the actual photon energy range. The dose rates were measured with thermoluminescence detectors placed in a perspex fixture firmly attached to the ap-

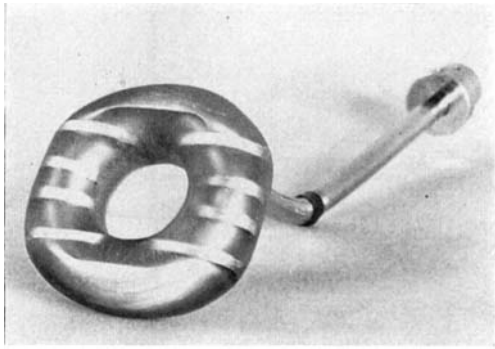

Fig. 2. The vaginal applicator of the remote afterloading unit. The gold screens and flanges are covered with araldite.

plicators. The accuracy of this determination was ± 8 % (standard deviation as percentage of the mean).

It was observed that in a section through the ring the 25 rad/h isodose rate was 78 mm lateral from the center, but only 35 mm ventral and dorsal from the center (Fig. 3, upper diagram). Ten millimeters ventral or dorsal from the outer surface of the ring the dose rate was less than 25 rad/h, while at the same distance lateral from the surface of the ring the dose rate was 125 rad/h. The factor of dose reduction in the ventral and dorsal directions was between 5 and 6.

The 25 rad/h isodose curve was 35 mm ventrally or dorsally to the center of the applicator and 64 mm cranially or caudally to the center in a section perpendicular to the ring (through the shaft of the vaginal applicator). Ten millimeters ventrally from the outer surface the isodose rate was still less than 25 rad/h while 10 mm cranially to the outer surface of the ring the isodose rate was about 150 rad/h. In this plane the factor of dose reduction in the direction of the bladder and the rectum was approximately 6 (see Fig. 3, lower diagram).

In clinical practice the vaginal applicator is used in combination with the uterine stainless steel sound which has an outer diameter of 8 mm and a wall thickness of 1 mm. The intra-uterine activity (600 mCi ^{137}Cs) is distributed over a length of 58 mm, 6 cesium sources, each measuring 8 mm × 3 mm, separated into three sections by two spacers, each measuring 5 mm × 3 mm. Uterine steel sounds are available in lengths between 7 and 9 cm, measured from the 35° bend (always placed in the center of the vaginal sound) to the distal end. The dose distribution around the combined vaginal and intra-uterine applicators was measured in the section perpendicular to the ring through the center of the uterine sound. The dose rates along the bisectrix of the anterior angle between the vaginal ring and the uterine sound were 600, 400 and about 200 rad/h at 10, 20 and 40 mm respectively, with corresponding figures posteriorly of 700, 450 and 200 rad/h (Fig. 4, upper diagram). The 50 rad/h isodose rate curve was

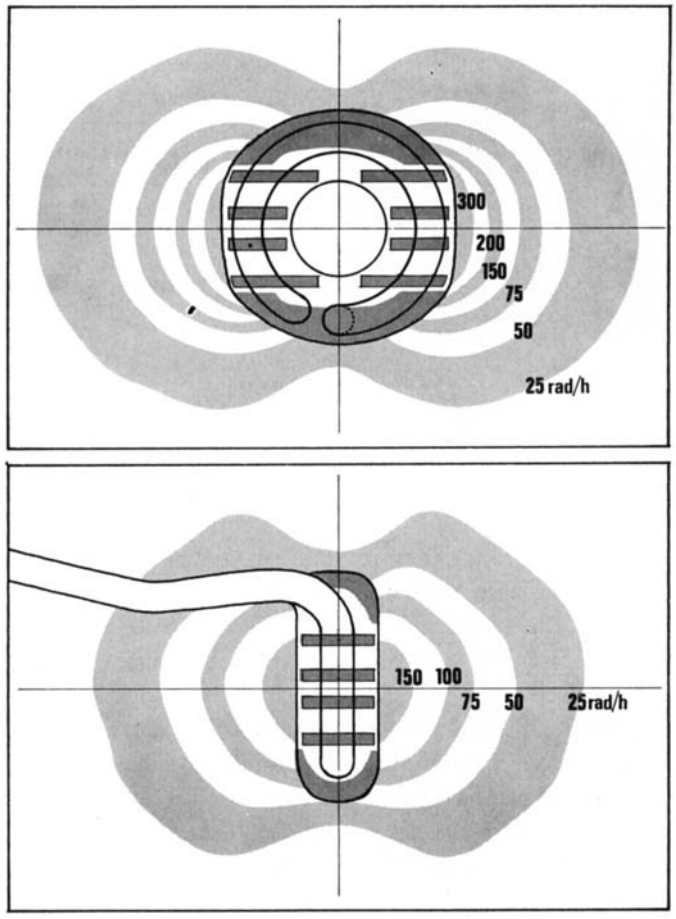

Fig. 3. Dose distribution in the plane of the ring of the vaginal applicator (upper diagram) and in a plane perpendicular to the ring of the vaginal applicator (lower diagram) of the No. 2 system.

45 mm lateral to the outer surface of the vaginal applicator in the section through the intra-uterine steel sound which forms an oblique angle with the ring; at a level 20 mm cranial to the external os 700, 310, 200 and 100 rad/h dose rates were recorded 10, 20, 30 and 50 mm, respectively, lateral to the center of the intra-uterine sound (Fig. 4, lower diagram).

Methods. Eight patients with I b or II a lesions were subjected to lymphography, phlebography and bilateral placement of thermoluminescence radiation detectors in accordance with techniques described in detail elsewhere (JOELSSON

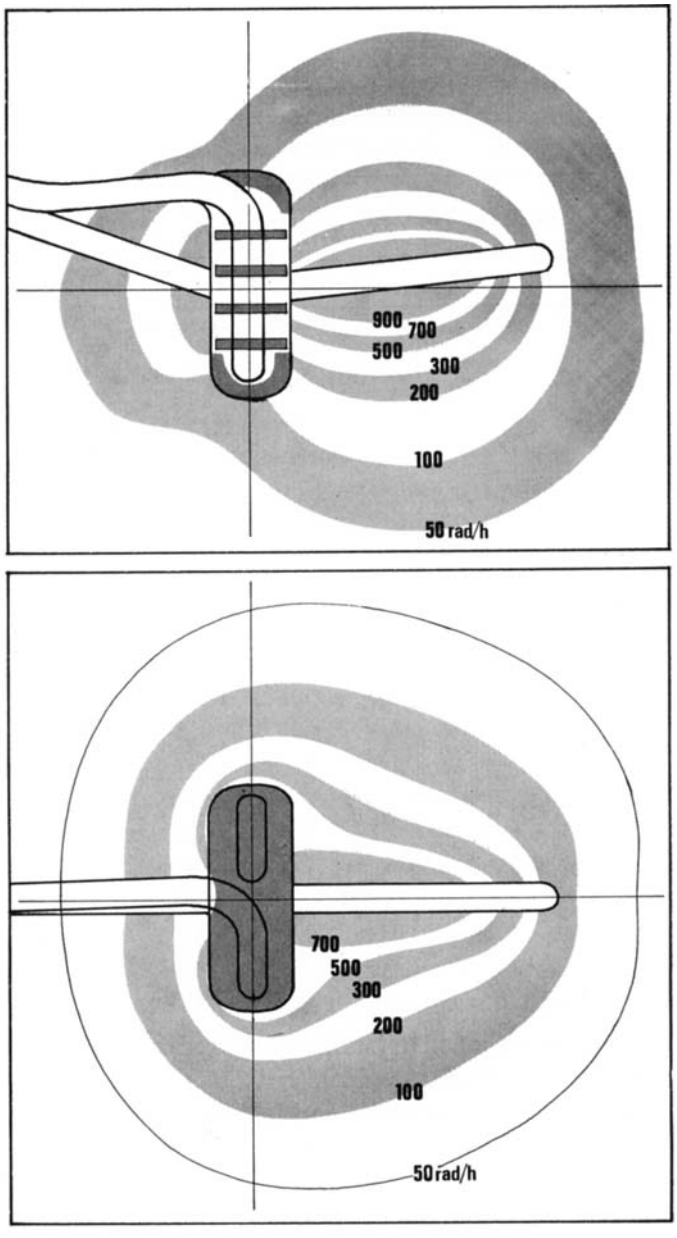

Fig. 4. Dose distribution in the 'sagittal' section through the center of the intra-uterine sound (upper diagram) and in a 'frontal-oblique' plane through the intra-uterine applicator (lower diagram) of the combined applicator of the No. 2 system.

Table 3

Individual differences in dose rates between measurements in lithotomy and supine positions as percentages of values obtained with the patient in lithotomy position. Remote afterloading technique.

	Difference in dose rate as percentage of lithotomy position value	
	Urinary bladder	Rectum
	+ 1	—21
	—27	0
	+22	—12
	+ 2	— 1
	—19	+10
	+ 9	+14
	+ 1	+72
	+ 2	— 4
	+ 4	+46
	—19	+75
	+ 7	+12
	+13	+94
	— 9	+ 6
	+ 2	—30
	0	— 3
	+19	— 1
	+ 9	+32
	+14	+33
Limits	—27 and +22	—30 and +94
Mean	+ 2	+18
S. E.	±3.1	±8.1

et coll. 1969). Primary radiation treatment consisted of two courses of intra-uterine (^{137}Cs, 600 mCi) and intravaginal (^{137}Cs, 600 mCi) applications, three weeks apart. The combined intravaginal and intra-uterine applicators were connected to the remote afterloading unit, Cervitron 7S (manufactured by Nuclesa). The dose rates at the posterior wall of the bladder and the anterior wall of the rectum, with the treatment sources in position, were measured with the Siemens Gammameter immediately after final fixation of the applicators to the patient. This was done with the patient supine, in which position the dose rates were also measured. This was considered necessary because in a separate study in 18 patients, treated with the applicator combination No. 1, considerable differences

occurred between the dose rates at the anterior wall of the rectum measured in lithotomy and supine positions (Table 3). The range of differences was large with a minimum of — 30 % and a maximum of + 94 % with a mean of + 18 %. Six of the 18 patients exhibited differences of over + 20 % and for 4 of them the difference amounted to more than + 40 %. The mean difference of + 18 % cannot be explained by inaccuracies in measurements, but suggests a true difference between dose rates in the two positions; no such differences were observed in dose rates on the posterior wall of the urinary bladder. For the detailed description of the procedure of dose rate measurement the reader is referred to a previous paper by JOELSSON & BÄCKSTRÖM (1969).

Results

The mean values of the doses over one course of intracavitary treatment were 2 900 rad at the base of the bladder and 2 000 rad at the anterior wall of the rectum. The Siemens Gammameter is 6 % more sensitive for radium than for cesium within 30 mm of the source and the values were correspondingly corrected; correction for decreased sensitivity of the instrument with an increase in temperature was also attempted (JOELSSON & BÄCKSTRÖM 1969).

The radiation doses in the common and external iliac veins during one course of treatment are given as mean values of the absorbed dose in pairs of LiF detectors and referred to the anatomy of the vessels. Anatomic inequalities necessitate the values from right and left side being presented separately.

The dose varied between 71 and 215 with a mean of 155 rad in the cranial part of the right common iliac vein with values of 138 to 691, mean 344 rad, in the caudal portion of the same vein. The lowest value was 246 and the highest 1 044, mean 470 rad, in the cranial part of the external iliac vein, while in the caudal part the variation lay between 292 and 1 031, mean 426 rad. The dose in the cranial part of the left common iliac vein was between 78 and 273 with a mean of 158 rad. The dose ranged between 204 and 491, mean 334 rad, in the caudal part of the vein. The dose varied between 302 and 699, mean 467 rad, in the cranial part of the external iliac vein and in the caudal part of the external iliac vein the corresponding values were 312 to 664 with a mean of 445 rad. The one detector, located exactly beneath the inguinal ligament, was always treated separately; dose variation on the right side was 245 to 646, mean 321 rad, and on the left side 242 to 465, mean 348 rad. Detectors were sometimes placed in the inferior vena cava and doses averaging about 100 rad were registered. One or two detectors were introduced in 6 patients into the middle part of the common iliac vein on the left side and in 4 patients into the right side; the mean doses amounted to 260 to 280 rad. Detectors were also, dependent on anatomic variations, put into the middle part of the external iliac vein, i.e. 9

Table 4

The radiation doses in rad (mean values and limits) during one course of intracavitary radiation treatment with the gold-screened vaginal applicator of the afterloading unit together with an intra-uterine stainless steel sound. Bilateral catheters with thermoluminescence LiF detectors were employed in 8 patients.

	Inferior vena cava	Common iliac vein			External iliac vein			Under inguinal ligament
		Cranial	Middle	Caudal	Cranial	Middle	Caudal	
Right side								
Mean	93	155	282	344	470	526	426	321
Limits	44—123	71—215	217—323	138—691	246—1 044	344—1 043	292—1 031	245—646
Left side								
Mean	98	158	263	334	467	507	445	348
Limits	54—134	78—273	165—339	204—491	302—699	357—676	312—664	242—465

detectors (6 patients) on the right and 10 detectors (8 patients) on the left side. On the right side the doses were 344 to 1 043, mean 526 rad, and on the left side 357 to 676, mean 507 rad. The dose contribution from diagnostic roentgen procedures amounted to 2 to 3 rad. It should be emphasized that the accuracy of the thermoluminescence technique was about ± 8 % (standard deviation as percentage of the mean). A complete list of the dose determinations is given in Table 4.

Discussion

A critical review of the factors influencing the dose distribution in intracavitary radiation treatment of carcinoma of the uterine cervix has been given by NEARY (1943, 1947). He concludes that little fundamental improvement in the distribution of the radiation dose can be expected from any variation of the basic Paris or Stockholm methods. The broad features of dose distribution are similar in most existing techniques. The only way to increase the dose in the regions of spread of disease near the pelvic wall is to increase greatly the irradiator activity in the uterus and the vagina. This makes the protection of the rectum and bladder from overdosage of great importance. NEARY used radium sources centrally in the vagina with platinum screens. More recently FLEMING has introduced a similar central source vaginal applicator utilizing ^{60}Co radiation sources and heavy alloy metal (90 to 97 % tungsten) to shield the rectum (FLEMING & WIERNIK 1963). It appears that the lateral decline of doses is little inferior to that of the Manchester technique (BATES et coll. 1968).

The vaginal applicator, which is used in connection with the remote after-

loading unit at Radiumhemmet, is ring-shaped. The radiation sources in the form of a source train can be dispersed mechanically to the lateral parts of the vagina, ^{137}Cs with a gamma energy of 0.66 MeV is used and the activity of the sources is 600 mCi, corresponding to 240 mg radium. In the latest version of the vaginal applicator 18 carat gold screens are adapted to the anterior and posterior surfaces of the ring, gold flanges are placed between the separate cesium sources, and the sintered tungsten absorbers are maintained in the source train. The dose distribution from the vaginal ring itself appears extremely satisfactory, but when the intra-uterine tube with its central sources is added to the system the dose distribution appears to be less satisfactory.

The individual variation of absorbed doses is in general less marked with the afterloading technique than with the current Stockholm method. The reasons are associated with the conformity in relation to the individual anatomy and the stability during treatment time, achieved by attaching applicators to the patients with a bar and corset system. The traction exercised by the flexible tubes connecting the intracavitary sounds with the storage container of the afterloading unit might be thought to cause changes in the position of the vaginal and uterine ends of the sounds; no such changes were however observed. The ball-joint can be locked very firmly, which prevents it from acting as a fulcrum on which the lever can turn. In the current Stockholm technique the vaginal applicator is held in position by gauze packing in the vagina only and is not connected to the intra-uterine applicator. The fallacy of relying upon the gauze pack as an invariable spacer between the source and the rectum has been commented upon elsewhere (JOELSSON & BÄCKSTRÖM 1969).

A striking similarity in doses in the afterloading technique was evident on the right compared to the left side of the pelvis, the highest mean value on the latter being less than 10 % higher than the corresponding value on the right side. In the series of patients studied with thermoluminescence dosimetry during treatment according to the current Stockholm technique a 50 % difference in dosage from one side to the other was occasionally registered.

Doses at the pelvic wall are often given in the literature relative to the dose in the middle of the paracervical triangle. Careful determination of dose rates of clinical significance at the bladder base and anterior rectal wall is always performed at Radiumhemmet. The dose values at these locations are therefore measured doses and are available for a comparison.

The devices for securing the applicators in the afterloading technique interfere however with the introduction and movements of the probe of the Siemens Gammameter. As the ball-joint is located in the medial sagittal plane, the Gammameter probe will invariably be directed either obliquely or be displaced laterally. This obstacle causes difficulties in finding the small area of maximum

dose rate. The significance may be considerable as the dose rates are measured close to irradiators of high activity where the dose rate gradient is steep. Only about 5 mm displacement of the cadmium sulphide crystal of the Gammameter sound can give rise to differences in dose rates of 30 to 40 %.

It has been demonstrated earlier that the highest doses attained at the pelvic wall during radium irradiation according to the current Stockholm method were 22 % of the bladder dose and 20 % of the rectal dose (JOELSSON et coll. 1969). The dose on the pelvic side wall in the present study was 18 % of the bladder dose and 26 % of the rectal dose. This is a reflection of the fact that gold screens adapted to the vaginal applicator considerably reduce the dose rate at the anterior wall of the rectum. At the base of the bladder, however, the contribution from the intra-uterine radiation sources dominates because of the angulation of the uterine sound.

Reference doses other than those in the bladder and rectum are not clinically available. A comparison of the absolute figures of doses over one course of treatment is not to be recommended because of the differences in activities, duration of treatment and the use of absorbing metal screens. In the current Stockholm technique the amount of radium in the uterine applicator varies between 53 and 74 mg, and in the vaginal applicator between 60 and 80 mg. The irradiation time is between 25 and 28 hours for each course. With the afterloading technique 600 mCi ^{137}Cs is applied both in the uterus and in the vagina and the treatment time is between 6 and 8 hours. This means that the activity is increased by a factor of 3.6 and the treatment time is decreased by a factor of 3.8. If the data for the relationship between total dose and treatment time, published by LIVERSAGE (1969) on the basis of information given by MITCHELL (1960), MCWHIRTER (1936) and COWELL (1938) be taken into account, the treatment time should have been still further reduced. Such a reduction must be weighed against the reduced radiation dose to part of the tumor and surrounding tissue effected by the gold screens. When continuing the comparison between the two series referred to above, it is interesting to find that the mean dose at the anterior wall of the rectum for the patients in the afterloading series was 20 % less than the corresponding dose over one course of treatment by the current Stockholm technique. This figure is in accordance with LIVERSAGE's recommended reduction in the "tumor lethal dose" upon change of treatment time from 28 to 8 hours.

Even if shielding devices, inbuilt into the applicators can indeed be used as means of reducing the sharp decline in doses in lateral directions, this would mean that individualization of the treatment would be rendered considerably more difficult. A great number of applicators of different sizes would have to be available.

The use of heavier shields therefore appears to be of doubtful value. The

employment of radiation sources with lower gamma energies, e.g. ^{192}Ir, would on the other hand change the situation. The effective energy of 17 gamma ray lines is about 380 keV and the half value layer 2.2 mm in lead in comparison with 5.5 mm for ^{137}Cs. These favourable data might outweigh the drawback of a rapid decay with a half life of 75 days.

SUMMARY

Selective shielding with gold screens considerably increased the pelvic dose in relation to the rectal dose in the treatment of carcinoma of the cervix uteri with two different intracavitary afterloading applicator systems. The vaginal part of the present applicator device represents one phase in continued efforts towards optimum dose distribution. Different types and sizes must become available so as to facilitate individualized treatment by the remote afterloading technique.

ZUSAMMENFASSUNG

Es konnte gezeigt werden, dass die selektive Abschirmung mit Goldschirmen die Tiefendose im Becken wesentlich verbessert im Vergleich mit der Dose, die das Rektum erhält, wenn man das Cervixcarcinom des Uterus mit zwei verschiedenen Hinterladermodellen von Applikatoren bestrahlt. Der verbesserte, in der Scheide liegende Anteil des Applikators bedeutet ein Fortschritt in der besseren Dosenverteilung im Becken. Verschiedene Grössen und modifizierte Modelle müssen geschaffen werden, um in jedem individuellen Fall die Hinterladungstechnik mittels Fernkontrolle durchzuführen.

RÉSUMÉ

La protection sélective par des écrans en or augmente considérablement la dose pelvienne par rapport à la dose rectale dans le traitement du cancer du col de l'utérus par deux systèmes différents d'applicateurs intracavitaires chargés après leur mise en place. La partie vaginale de cet applicateur représente un des éléments d'une série continuée de perfectionnements en vue d'une distribution de dose optimale. Il faut créer différents types et différentes tailles d'applicateurs pour faciliter l'adaptation à chaque malade du traitement par applicateurs chargés à distance après leur mise en place.

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