Original Article

Low dose rate caesium-137 implant time of intracavitary brachytherapy source of a selected oncology center in Ghana

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ABSTRACT

Background: The treatment time taken for a radioactive source is found to be very important in intracavitary brachytherapy treatment. The duration of the treatment time depends on the prescribed dose requested to a reference point and the calculated dose rate to the same point. The duration of the treatment time of source is found to depend on the tumour stage. In this work, the treatment time of implant has been calculated for a Caesium-137 low dose rate brachytherapy source at an oncology facility in Ghana. **Objective:** The objective was to determine how the treatment time of tumours depends on the dose rate to the reference point prescribed by the Oncologists and the dose rate determined by the dosimetrists at the facility. **Materials and Method:** Depending upon the stage of the cancer, the Oncologist determines the type of treatment modality, source configuration for the cancer patient and positions of both tandem and ovoids in the cervix. Depending also on the tumour stage, two orthogonal radiographic X-ray films are taken using a simulator machine. The treatment machine used in the study is AMRA-Curietron. The maximum activity of the source was 259GBq. It has five channels which is a manual remote afterloader. In clinical practice, the treatment time t is very short(only some few days) for such low dose rate brachytherapy source like Cs-137 which lasts only for some few days in comparison with the half life of the Cs-137 source. The mathematical equation for the calculation of treatment time is written as $t = \frac{D}{\dot{D}}$. Hence t is the treatment time of the radioactive source of patients undergoing intracavitary brachytherapy treatment, D is prescribed dose to a reference point and $\dot{D}^{\infty}$ is the dose rate to the same reference point. **Results:** The calculated treatment time of the Cs-137 brachytherapy source for different source arrangements or channels used in clinical practice at the brachytherapy Centre have been determined. Also provided, are the prescribed doses to the reference point and the calculated dose rate to the same point. The source arrangements in the channels are (1-2-5), (1-3-5), (1-4-5) and (1-5) respectively. **Conclusion:** The treatment time of Cs-137 low dose rate radioactive source for intracavitary brachytherapy treatment has been determined using the Manchester System. The results show that the treatment time depends on the dose prescribed to a reference point, which is usually set up by the oncologist at the Oncology center and the dose rate to the same point, which is determined by the dosimetrists using the Treatment Planning System (TPS) at the facility. The treatment time for advanced stages of the tumors were found to be much higher than the early stages of tumours.

Key words: Dose rate, intracavitary brachytherapy, prescribed dose, treatment planning system, treatment time

INTRODUCTION

Intracavitary brachytherapy (ICBT) is one of the most efficient radiotherapy techniques widely used for the treatment of cervix carcinoma. This is mainly due to two reasons; namely the anatomical conditions that allow insertion of both intrauterine and intravaginal radioactive sources in close contact with the treatment volume and secondly, because of the inverse square law effects, the dose decreases steeply as a function of distance from the source and this dose gradient is steepest closer to the sources.[1]

The ICBT is a treatment procedure in which radioactive sources are placed in the body cavities close to the tumor volume to deliver radiation at short distances.[2] In this mode of treatment, high radiation dose can be delivered to the

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tumor volume with rapid fall-off in the surrounding normal tissues. ICBT treatments are always temporary which lasts only for some few days. In this case, the prescribed radiation dose is delivered over a short period of time, and the radioactive sources are removed after the prescribed dose has been delivered to the patient. In the ICBT treatment of cancer of the cervix, the time taken for the radioactive source implant is a function of the dose prescribed to a reference point.[3,4] The required dose to a reference point is usually prescribed by the radiation Oncologist at the radiotherapy facility. Depending on the source arrangements which are usually classified as channels (e.g., channels 1-4-5), the dose rate to a reference point is determined using a computerized treatment planning system (TPS).[5] The time of implant of the radioactive source used in this model of calculation is based on the Manchester system.

The ICBT is mostly used for the treatment of cancers of the uterine cervix, uterine body, and vagina. Different forms of applicators are available for clinical use that holds the radioactive sources in an appropriate configuration. Normally, a cervix applicator consists of a tandem and ovoid.[4,6] One of the most widely used radioactive source for gynecological cancer treatment is caesium-137 which is a low dose rate (LDR) source. In this case, it is necessary to use sources of different source strengths in order to achieve the required dose distribution.

In modern remote after loading devices, a high dose rate of Ir-192 radioactive source is used for the same type of treatment. Different systems based on clinical practice like the Paris, Manchester and Stockholm systems have been used for dose specifications in the treatment of cancer of the cervix but of these, the most commonly used system is the Manchester system. In the Manchester system it is characterized by doses to only four points, namely point A, point B, bladder and rectum as shown in Figure 1. The

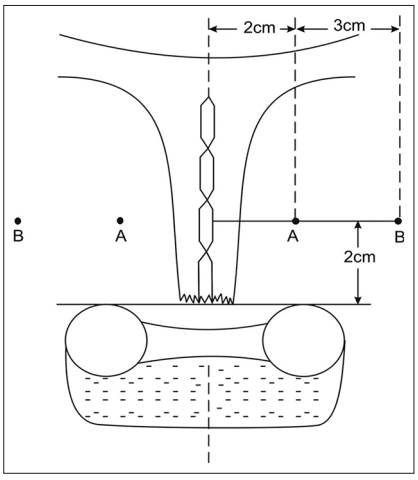

Figure 1: Definition of reference points A and B according to the Manchester system

treatment time of a radioactive source is dependent on the dose rate to point A or point B depending on the reference point adopted at the oncology center. The significance of the point A or B is that the duration of treatment time of a radioactive source depends on the dose rate calculated at point A or point B. Clinically, point A represents the location where the uterine vessel crosses the ureter and also relates to the position of the sources.[7] The prescribed dose at point A is very sensitive to the position of the ovoid source relative to the tandem. Point A is defined as 2 cm superior to the external cervical end of the tandem and also 2 cm lateral to the cervical canal. Point B is defined as 3 cm lateral to point A or 5 cm from the midline of the tandem.[3,8]

In ICBT treatment of cervical cancer, strict quality assurance rules are observed during the placement of a radioactive source into the target volume and surrounding organs at risk such as the bladder and rectum. The clinical guidelines are usually followed resulting in adequate dose delivery to the paracervical tissues and avoidance of under dosage or over dosage in regions around the cervix or high radiation doses to the sensitive organs.

The most frequent clinical complications of ICBT treatment of cervical cancer result from high doses delivered to portions of the rectum and bladder, which are in close proximity to the brachytherapy sources. The dose to bladder and rectum depends on the distribution of sources in a given application. If a dose is assessed to be too high either by measurement or calculation, the radiation oncologist has the option of changing the geometry of the sources. Although various instruments including intracavitary ionization chambers, thermoluminescent dosimeters are available for such measurements, but the calculational or mathematical method has been found to be more reliable and accurate.[8,9]

Applicator placement with respect to the location of rectum and bladder is very important, and the doses to the critical structures should be kept as low as reasonably achievable. In the clinical situations, surgical gauze is used to displace these critical structures away from the applicators. The localization of bladder and rectum can be visualized using two orthogonal radiographic X-ray films taken with a contrast media such as barium in the bladder and the rectum. The maximum dose to the bladder and the rectum should be as far as possible, less than the dose to the point A (e.g., 80% or less of the dose to point A).[8,10] The type of applicators used for the treatment of cervical cancer is the Fletcher-Suit-Delcos System.

Calculations of the absorbed dose to medium were done according to the following equations:

$$D_{air} = \left(\frac{W_{air}}{e} \right) X \quad (1)$$

Where, D_{air} = is the absorbed dose in air, e = electronic charge, W_{air} = ion charge in air and X = exposure rate in the air.

Then absorbed dose to tissue/medium is given by,

$$D_{\text{med}} = D_{\text{air}} \left(\frac{\mu_{\text{en}}}{\rho} \right)_{air}^{med} \quad (2)$$

or

$$D_{\text{med}} = X \left(\frac{W_{\text{air}}}{e} \right) \left(\frac{\mu_{\text{en}}}{\rho} \right)_{air}^{med} \quad (3)$$

Where, $\frac{W_{\text{air}}}{e} = 33.97$ J/C ; $\left(\frac{\mu_{\text{en}}}{\rho} \right)$ is the mass energy absorption coefficient, and X is the exposure rate in the air.

The mathematical equation for the treatment time is written as,

$$t = \frac{D}{\dot{D}} \quad (4)$$

Hence, t is the treatment time of the radioactive source of patients undergoing ICBT treatment, D is prescribed dose to a reference point and $\dot{D}$ is the dose rate to the same reference point.

In this study, the Manchester system has been used to determine the dose rates at the reference points and consequently the treatment time of the source is calculated. The study was carried out in a brachytherapy Centre of a Teaching Hospital in Ghana.

METHOD OF ANALYSIS

Depending upon the stage of the cancer, the oncologist determines the type of treatment modality, source configuration for the cancer patient and positions both tandem and ovoids in the cervix. Depending also on the tumor stage, two orthogonal radiographic X-ray films are taken using a simulator machine.

Figure 1 shows the descriptive distances of 2 cm and 5 cm which are relevant points in ICBT using the Manchester system.

The treatment machine used in the study is AMRA-Curietron with model number CA: 9610 which is an LDR brachytherapy machine and manufactured by Cis-Bio International. The age group of adult patients for the study was between 25 and 60 years all being females with the tumor stages I-IV. The maximum activity of the source was 259GBq. It has five channels which is a manual remote afterloader as shown schematically in Figure 2

For this treatment machine, the ovoids are marked by the letter "V" which represents channels 1 and 5, respectively. For the tandem, there are only three channels which are marked by the letter "U." In this case, there are three channels for "U"; these are 2, 3, and 4, respectively. During treatment, only one channel of the "U" must be selected and used depending upon the measured length of the tandem protruded.

It has been found clinically that if the measured length (L) of the protruded tandem is ≤ 4 cm, that is, L < 4 cm, then channel 2 must be used. Furthermore, if the measured length of the protruded tandem is between 4 and 5 cm, that is, 4 cm < L < 5 cm, then channel 3 must be used. Again, if the measured length of the protruded tandem is >5 cm, that is, L > 5 cm, then channel 4 must be used.

Source localization

A very important function in brachytherapy is to obtain the correct geometric localization of the applicator in order to treat the target volume adequately. The dose distributions are totally dependent on the inverse square law effect assuming the source to be a point source. As a result, proper positioning of the radiation sources is very important during treatment of gynecological malignancies.

In this study, source localization was determined from the three-dimensional (3D) co-ordinates and orientation of each source relative to the patient anatomy. It was accomplished by at least two orthogonal radiographs X-ray films.

The 3D source locations were input into the treatment planning computer, with the co-ordinate system being orthogonal to the x-, y- and z-axis. Localization began by entering source co-ordinates on the projected image into the computer by means of the digitization process. A single point

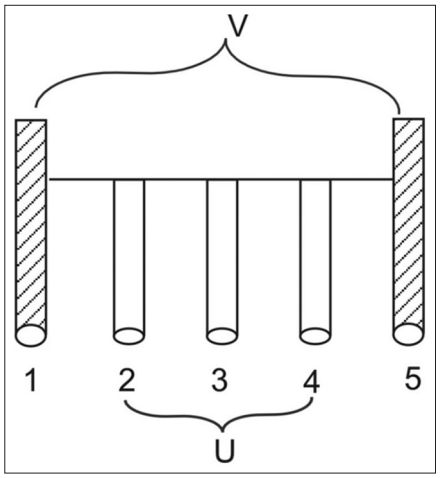

Figure 2: A schematic diagram of AMRA-Curietron showing the arrangement of channels for intracavitary brachytherapy

in space (3D) results in two co-ordinates in each projection image (two-dimensional). The origin of the 3D co-ordinate system was taken as a reference point and was chosen as a point near the center of the applicator and as a point that can easily be identified on both projection images. Using an isocentrically mounted simulator unit, the isocenter-point was placed in the center of the applicator and designated as the point of origin. The central axis passes through this isocentric point, and is indicated by a cross hair, which can easily be identified on a projected image. This cross hair in the two projected images (anterior and lateral) was then used for origins in the projected images. After all the sources have been identified, the co-ordinates of each end of a linear source on each projection image are sequentially entered into the TPS. The orthogonal projection images provide the greatest accuracy because digitization errors translate to the smallest source co-ordinate errors. With all techniques, digitizing accuracy improves with increasing magnification.

For a patient's tumor to be irradiated, the applicator was placed close to or inside the planned tumor volume (PTV). The projection images to visualize the position of the source catheters inside the patient and their locations were documented. During this process, dummy or nonradioactive source replicas may be used to simulate the actual source placement inside the source applicators. Projection images of the sources in place are critical for determining the dosimetry of the application. In order to aid dose calculations, precise localization of the sources in three spatial dimensions (3D) were used[11] and two orthogonal radiographic images were taken. The dose rate distributions in relation to the tumor volume and critical structures were calculated using the TPS at the facility. Once the dose rate distributions and the treatment time have been accurately determined, the patient was ready for loading the sources for treatment.

Computer dose calculation

For dose rate distributions surrounding an ICBT implant, a computer calculation in multiple planes or a volume (3D) and display facilities are necessary. It is, therefore, necessary to reconstruct the source positions during digitization. The computer calculations of dose rate distributions consist of summing up the dose contributed by each source at the grid points arranged in the 3D lattice. Points having the same dose rate were connected by an isodose curve or surface. The dose rate distributions were then viewed in various planes within the implant.

Dose to the planned tumor volume

For PTV, the coverage and the homogeneity of the dose rate distributions are the main factors relating to tumor control and late reacting normal tissue damage inside the PTV (e.g. necrosis). A conformity index (CI) is always used as an optimization procedure, and CI is defined according to the ICRU as the quotient of the treated volume and the volume of the PTV.[12] The significance of CI is that it determines whether the treated tumor volume has been totally encompassed by the PTV. For ideal situations, CI = 1 indicating that there should be zero dose outside the PTV, that is no dose should be deposited to the critical structures. If impossible, then efforts should be made such that doses do not exceed the specified organ or normal tissue tolerance level.

In this work, the source arrangements were carefully selected for both the lateral and anterial-posterial radiographs taken. These radiographs were forwarded to the dosimetrist or physicist for treatment planning. The diameters of both the ovoid and tandem used were 2.0 cm and 0.6 cm, respectively. Based on these diameter values, magnifications were calculated for both the tandem and the ovoids using orthogonal radiographs and the sources are loaded onto the ovoids and tandems using the radiographic magnification factors.

In clinical practice, radiation therapy is based on dose computations that reports absorbed dose to water.

Treatment time

Once the point(s) or isodose for prescribing the dose to the tumor and the desired dose rates distributions are known, the treatment time can be calculated. The treatment time is calculated by dividing the prescribed dose to point A by the dose rate at the same reference prescription point.

This treatment time is valid for the actual strength of the source(s) at a particular moment in time, usually when the dose calculations are performed. When the source decay is very small during an irradiation, it can be assumed that the dose administered at a given point increases linearly with time. This is the case when the irradiation time is much shorter than the half-life of the radionuclide used. In practice, this is true for radioactive sources like cesium-137. However, it is necessary to correct the source activity for decay at least once a year since the half-life of the brachytherapy source is very long.

In clinical practice, the time of implant *t* is very short (only some few days) for such LDR brachytherapy source like caesium-137 which lasts only for some few days in comparison with the half-life of the caesium-137 source.

RESULTS AND DISCUSSIONS

The study shows how ICBT has been used to treat various tumor stages ranging from stages I-IV. The advantage of this method compared with normal radiotherapy is that ICBT

could be used when the tumor is well-defined and localized. During treatment the brachytherapy sources are inserted into the tumor volume whereas in normal radiotherapy the sources are outside the patient.

Tables 1-4 show the calculated the implant time of the caesium-137 radioactive source for different source arrangements or channels used in clinical practice at the brachytherapy center. Also provided, are the prescribed doses to the reference point and the calculated dose rate to the same point. The source arrangements in the channels are (1-2-5), (1-3-5), (1-4-5), and (1-5), respectively.

Figure 3 shows the calculated average dose rates to the reference point, the bladder, and the rectum plotted for the various source arrangements or channels. The corresponding average treatment time is also shown in Figure 4. It would be observed from Tables 1 and 4 and Figure 3 generally that the dose rates to the rectum and the bladder are much lower compared to that of the dose to the reference point. This is mainly due to the anatomical positions of these critical organs relative to the various source arrangements. The lowest values of the dose rates were recorded for the source arrangements in D (1-5) and the highest values for A (1-4-5).

In Figure 4, the highest average treatment time was recorded for the source arrangement C (1-3-5) and the lowest for B (1-2-5). The source arrangements in A (1-4-5) and C (1-3-5) represent advance stages of the tumors where tandems are used in addition to ovoids and the measured lengths of the protruded tandems are >4 cm. The arrangements of the sources depend upon the stage of the tumor in the cervix. Tumors which spread to the uterine tube should always have tandem insertions in addition to ovoids. The measured length of the protruded tandem also depends on the tumor stage and the channel to be used during the treatment planning process. If there is no spread of tumors into the uterine tube, then no tandem is required.

It is observed that the calculated dose rate to both bladder and rectum was found to be less than the dose rate to the reference point in all cases. The time of implant of the radioactive source in ICBT treatment depends mainly on these two parameters namely, the prescribed dose to the

Table 1: Calculated time of implant for the source arrangement of (1-2-5)

Patientsss Identification number	Prescribed dose to point A (cGy)	Calculated dose rate to point A (cGy/hr)	Calculated dose rate to bladder (cGy/hr)	Calculated dose rate to rectum (cGy/hr)	Treatment time (hr)
B1	2500	58.10	46.00	41.60	43.30
B2	2500	45.25	26.00	18.00	55.25
B3	2500	43.45	18.90	35.90	57.54
B4	2500	44.00	35.50	23.50	56.82
B5	3000	48.65	24.50	15.50	61.67

Table 2: Calculated time of implant for the source arrangement of (1-3-5)

Patient Identification number	Prescribed dose to reference point A (cGy)	Calculated dose rate to reference point A (cGy/hr)	Calculated dose rate to bladder (cGy/hr)	Calculated dose rate to rectum (cGy/hr)	Treatment time (hr)
C1	3000	53.80	46.90	19.10	55.76
C2	2500	45.25	26.00	18.00	55.25
C3	3000	52.80	18.40	23.70	56.82
C4	3000	46.65	14.80	29.10	64.31
C5	3500	57.90	38.30	29.00	60.45
C6	3000	50.80	28.30	21.50	59.06
C7	3000	40.25	19.40	25.40	74.53

Table 3: Calculated time of implant for the source arrangement of (1-5)

Patient Identification number	Prescribed dose to point A (cGy)	Calculated dose rate to point A (cGy/hr)	Calculated dose rate to bladder (cGy/hr)	Calculated dose rate to rectum (cGy/hr)	Treatment time (hr)
D1	2500	52.70	24.00	14.10	47.44
D2	3000	88.65	14.10	19.30	33.84
D3	3000	77.70	27.20	24.20	38.61
D4	3500	95.05	20.90	22.50	36.82
D5	2500	45.55	11.80	14.90	54.88
D6	3000	44.15	30.00	31.00	67.95
D7	3500	88.65	19.30	14.10	39.48
D8	2500	53.25	16.00	18.60	46.95
D9	3500	61.85	22.80	26.30	56.59
D10	3000	48.05	16.20	20.10	62.43
D11	3000	42.25	25.5	21.20	71.00

Table 4: Calculated time of implant for the source arrangement of (1-4-5)

Patient Identification number	Prescribed dose to point A (cGy)	Calculated dose rate to point A (cGy/hr)	Calculated dose rate to bladder (cGy/hr)	Calculated dose rate to rectum (cGy/hr)	Treatment time (hr)
A1	3000	70.05	55.40	49.60	42.83
A2	3000	65.70	53.00	49.70	45.66
A3	3500	55.05	43.40	40.20	63.58
A4	2500	55.65	47.10	38.70	44.92
A5	3000	51.15	41.40	24.50	58.65
A6	3000	51.80	28.10	32.70	57.92
A7	2500	55.10	28.40	30.70	45.37
A8	3000	50.70	30.40	26.60	59.17
A9	3500	62.20	49.20	27.00	56.27
A10	3500	54.60	44.30	28.50	64.10
A11	3000	47.60	18.20	17.80	63.02
A12	3500	54.00	31.80	26.80	64.81
A13	3000	50.70	25.60	14.20	59.10
A14	3500	55.20	28.40	24.90	63.41
A15	3000	51.85	36.00	20.60	57.86
A16	3500	53.25	37.20	28.50	65.72
A17	3000	50.85	43.20	32.80	59.00
A18	3000	54.95	32.80	32.70	54.60
A19	3500	66.55	35.80	29.70	52.59
A20	3000	55.35	30.80	24.00	54.20
A21	3000	52.50	25.60	31.30	57.14
A22	3000	53.85	34.30	28.70	55.71
A23	2500	54.60	35.30	22.60	45.79
A24	3000	42.00	37.60	34.30	71.43
A25	3500	54.05	34.00	27.50	64.75
A26	3000	51.55	32.40	39.10	58.20
A27	3000	49.55	22.00	33.70	60.55
A28	3000	53.80	26.60	34.20	55.76
A29	3000	53.20	26.40	35.80	56.91
A30	3500	55.25	20.50	25.90	63.35
A31	3500	51.05	18.70	23.20	68.56
A32	3000	56.70	31.40	27.80	52.91

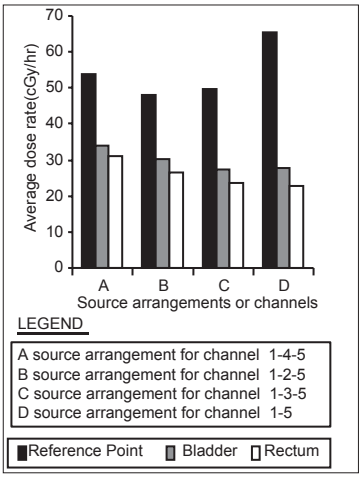

Figure 3: Average dose rate to reference point and critical organs for various source arrangements

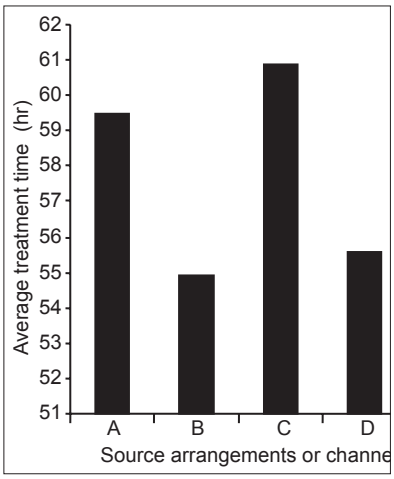

Figure 4: Average treatment time for various source arrangements

reference point and the calculated dose rate to the same point. In clinical practice, time of interruption should always be taken into account during ICBT treatment.

CONCLUSION

The treatment time of caesium-137 LDR radioactive source for ICBT treatment has been determined using the Manchester system. The results show that the implant time depends on the dose prescribed to a reference point, which is usually set up by the oncologist at the oncology center and the dose rate to the same point, which is also determined by the dosimetrists using the TPS. The implant time for advanced stages of the tumors was found to be much higher as depicted by the source arrangements A (1-4-5) and C (1-3-5) as shown in Figure 4, respectively.

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