Dose Assessment of the Rectum during Brachytherapy of the Cervix Using Gafchromic Films

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ABSTRACT

Internal radiation therapy, refers to as brachytherapy, involve putting a source of radiation with high photon in or near a cancerous tissues. The type of brachytherapy used most often to treat cervical cancer is known as intracavitary brachytherapy. Unfortunately however, the radiation source placed in the cervix irradiate the normal tissues of rectum and other nearby organs during intracavitary brachytherapy of the cervix treatment. This high doses received by parts of the rectum is a concern for clinicians and the general public. The aim of this study is to assess the dose delivered to the rectum using Gafchromic films and compare it with the optimized dose calculated by the Brachy Prowess 4.60 Treatment Planning System (TPS) reports for empirical validation and system verification. Fletcher suite applicators were used to perform thirty (30) different clinical insertions on the constructed cervix phantom and results evaluated. The mean difference between the doses calculated by the TPS and the doses measured by the Gafchromic film for the rectum at the distance of 0.5cm from the edges of the film was 23.1% (range -42.42 to +40.41). At a distance of 1.5cm for the rectum the mean was 22.5% (range -49.45 to +46.48). The TPS calculated maximum dose was typically higher than the measured maximum dose. However, in some cases, the measured doses were found to be higher than the doses calculated by the TPS. This is due to positional inaccuracies of the sources during treatment planning. It is recommended that in vivo dosimetry should be performed in addition to computation.

Keywords : Brachy Prowess, Rectum, Intracavitary, Optimised Dose, Gafchromic

I. INTRODUCTION

The rationale for successful radiotherapy for patients with carcinoma of the cervix is to deliver high radiation dose to the cervix and paracervical region with steep dose gradients anteriorly and posteriorly to keep rectum within the low dose region. The most frequent clinical complications of intracavitary radiation treatments of cervical cancer result from a high dose delivered to the portions of the rectum that are in close proximity to the sources. In order to keep the dose to these critical structure as low as possible; assessments of the dose to these organs is very crucial. Therefore it is expedient that the effective doses and organ specific dose of each patient be known to estimate risk of healthy organs in order to institute measures to protect patients undergoing treatment and also to serve as a guide and awareness to oncologist, medical physicist, nurses radiographers and all medical staffs in charge of patients. In Intracavitary Brachytherapy of the cervix, clinical complications do results from high doses received by parts of the rectum. However, the most developing countries are yet to factor in regular comprehensive clinical assessment of dose during treatment of the cervix. Currently, very few research works has been carried out to empirically validate the optimized dose calculated by the Brachy Prowess 4.5 Treatment planning system (Plan dose) to the actual dose received

by this organ in the treatment of cervical cancer, which is of much concern to many national and international bodies who are always emphasizing on patient protection, hence the need to know the exact dose received by these critical organs.

It will also serve as a guide and awareness to Oncologists, Medical physicists, Nurses Radiographers and other related professionals to help optimize patient doses.

As a results it is important to assess the absorbed dose to the rectum and compare it with the optimized dose calculated by the Brachy Prowess 4.60 Treatment Planning System (TPS) reports for empirical validation and system verification.

The development of IMRT has given computers more responsibility for the delivery of radiation, including field placement and weighting. It is seldom possible to measure dose distribution directly in patients treated directly with radiation. Data on dose distribution are almost entirely derived from measurements in phantoms-tissue equivalent materials, usually large enough in volume to provide full scatter conditions for the given beam of the human body. These objects are more readily available and provide more consistent results than the use of a living subject or cadaver, and likewise avoid subjecting a living subject to direct risk. Placing detectors within the human body can lead to medical complications hence the need for phantoms. Again, direct measurement of rectal dose has been attempted using miniature ionization chambers or scintillation detector dose rate meters. However, these rigid systems give unacceptable variability in the results and correlate poorly with calculated values.

In vivo dosimetry provides an extra 'check' to ensure that systematic errors have not been acquired during the treatment planning process. If an inconsistency is found, the plan can be corrected before the patient begins to suffer irreversible problems from the error.

In vivo dose measurements can be divided into entrance dose measurements, exit dose measurements and intracavitary dose measurements. Entrance dose measurements serve to check the output and performance of the treatment apparatus as well as the accuracy of the patient set-up; Exit dose measurements serve in addition to check the dose calculation algorithm

and to determine the influence of the shape, size and density variations of the body of the patient on the dose calculation procedure; Sometimes it is also possible to determine the intracavitary dose in readily accessible body cavities such as the oral cavity, oesophagus, vagina, bladder and rectum. The most frequent clinical complications of intracavitary radiation treatments of cervical cancer result from a high dose delivered to the portions of the rectum that are in close proximity to the sources. Applicator placement with respect to the location of the rectum is therefore very important, in order to keep the dose to the rectum as low as possible. In many instances surgical cotton gauze is used to displace the sensitive structures away from the applicators.

II. OBJECTIVES

The objective of this study is to assess the absorbed dose to the rectum and compare it with the optimized dose calculated by the Brachy Prowess 4.60 Treatment Planning System (TPS) reports for empirical validation and system verification.

III. LITERATURE

In a group of 38 patients with carcinoma of the uterine cervix, a work carried out by. radiation doses were measured by thermoluminescent dosimeters (TLDs) placed in catheters introduced into the urinary bladder and rectum during a 24 h uterovaginal application of 226Ra.(Rasovská O, Ott O, Strnad V, Tacev Tte al) The values of radiation doses registered by the TLDs were compared to those calculated from roentgenograms made after 24 h. To calculate the radiation doses, Brachy 9.3-C of the planning unit Evados (Siemens, FRG) program was used. Using nonparametric comparison tests, no statistically significant differences were found between the values of radiation doses registered by TLDs and those calculated after 24 h of uterovaginal application of 226Ra. Only in the oral part of the rectum, at a distance of 10 cm and above from the anal orifice, there were differences between doses measured by TLDs and those calculated from roentgenograms made after 24hrs of brachytherapy. These differences were caused by the movement of the flexible catheters carrying the TLDs. (Neoplasma. 1990; 37(2):205-11)

In vivo dose measurements not only serve to check the dose delivery to the target volume but are also applied to assess dose to organs at risk (e.g. the eye lens, gonads and lung during TBI) or in situations which the dose is difficult to predict (e.g. non-standard SSD or using bolus).If entrance dose alone measurement alone are applied, the entrance dose alone has to be converted to the corresponding target dose. Various methods are available to obtain the midline dose from entrance and exit dose values. These methods give generally good results for homogenous situations but in the presence of inhomogeneities considerable deviations can occur.

Radiochromic film is a new type of film in radiotherapy used for in vivo dosimetry. The most commonly used is the Gafchromic film. It is a colourless film with a nearly tissue equivalent composition (9.0% hydrogen, 60.6% carbon, 11.2% nitrogen and 19.2% oxygen) that develops a blue colour upon radiation exposure. Radiochromic films contain a special dye that is polymerized upon exposure to radiation. The polymer absorbs light, and the transmission of light through the film can be measured with a suitable densitometer. Radiochromic film is self-developing, requiring neither developer nor fixer. Since radiochromic film is grainless, it has a high resolution and can be used in dose gradient regions for dosimetry. Conventional detectors such as thermoluminescent dosimeters and ionization chambers are inappropriate dosimeters at small distances from a brachytherapy source due to their relatively large size. Silver halide x-ray films have been used as radiation dosimeters, but the development process can affect the resultant optical density. The temperature and chemical composition of the processor affects the optical density, thereby influencing the dose reading. Some of the problems experienced with conventional radiation dosimeters are resolved by using radiochromic type films. The major advantage of this type of detector over other detectors is the possibility to obtain complete dose distributions with high spatial resolution (Dempsey et al, 2000). This is particularly important with respect to the dose at field and block edges, at tissue interfaces, in small fields (Yamauchi et al, 2004) and IMRT fields. The present possibilities offered by radiochromic films are essentially due to the improvement of the homogeneity and sensitivity of commercial emulsions (Meigooni et al, 1996; Butson et al, 1998-b; Devic et al, 2004; Chui-Tsao et al, 2004).

Radiochromic films such as Gafchromic HD-810 and MD-55 contain only carbon, hydrogen, nitrogen, and oxygen and have approximately 25% lower response to kV than MV radiation. Gafchromic EBT2 contains minor amounts of sulphur, chlorine, potassium, and bromine. In designing EBT2, trace components with moderate Z values are added to boost photoelectric absorption of keV photons.

IV. BRACHYTHERAPY

Sources used in brachytherapy are low air kerma rate sources that require chambers of sufficient volume (about 250 cm3 or more) for adequate sensitivity. Well type chambers or re-entrant chambers are ideally suited for calibration and standardization of brachytherapy sources. Figure 2.3 shows a schematic diagram of a well type chamber. Well type chambers should be designed to accommodate sources of the typical sizes and shapes that are in clinical use in brachytherapy and are usually calibrated in terms of the reference air kerma rate.
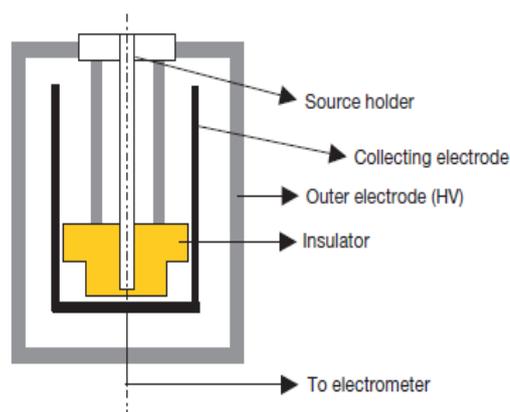

Figure 1. Basic design of a brachytherapy well type chamber

Gafchromic Films

Gafchromic EBT dosimetry film has been developed specifically to address the needs of the medical physicist and dosimetrist working in the radiotherapy environment. In common with previous Gafchromic films, EBT film is self-developing, but it also incorporates numerous improvements in ISP's radiochromic film technology. Some of these improved features include:

✓ Dose range 1cGy - 800cGy; EBT film is ten times more sensitive than its previous generation Gafchromic HS film and MD-55

- ✓ Energy independent from the keV range into the MeV range
- ✓ Uniformity better than 1.5%
- ✓ Larger with two different formats; 8"x10" and 14"x17"
- ✓ Faster and lower post-exposure density growth
- ✓ Will withstand temperatures up to 70ºC

1) 2.7.2. Configuration and Structure of Gafchromic EBT

Gafchromic EBT is made by laminating two coatings. The coatings are manufactured to a single specification. The EBT laminate is identified by its batch number. At all steps of the manufacturing process the intermediates and components are identified by their batch numbers. The configuration of Gafchromic EBT film is shown in Figure 2.8.
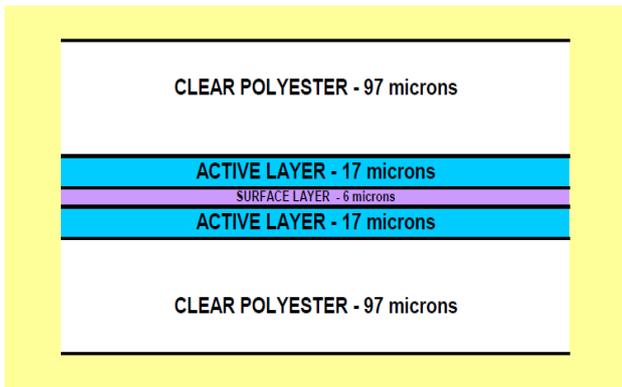

| CLEAR POLYESTER - 97 microns |
| ACTIVE LAYER - 17 microns |
| SURFACE LAYER - 6 microns |
| ACTIVE LAYER - 17 microns |
| CLEAR POLYESTER - 97 microns |

Figure 2 : Configuration of Gafchromic EBT Dosimetry Film

2) 2.7.3. Gafchromic EBT Dosimetry Film Characteristics

This high sensitivity radiochromic film has been designed for the measurement of absorbed dose of high-energy photons used in IMRT in the 1cGy to 800cGy dose range. The response to photons has been found to be energy-independent in the MeV range and measurements at energies down to about 30keV reveal that the sensitivity changes by less than 10%.

V. MATERIALS

Locally fabricated cervix phantom from Perspex (PMMA) sheets, tape measure, Gafchromic films, PTW plastic water phantom (type 267), Colbalt-60 teletherapy machine, Low Dose Rate (LDR) Brachytherapy machine with Cesium-137 source, C-arm

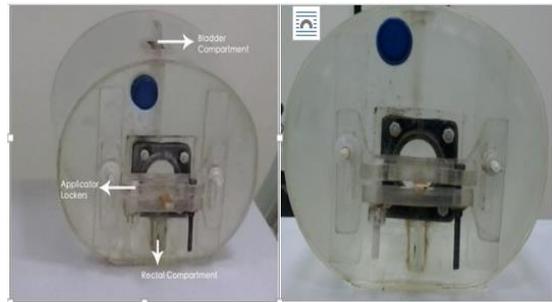x-ray unit, Fletcher Suite of Applicators, Prowess 4.60 Treatment Planning System (TPS) and Densitometer.
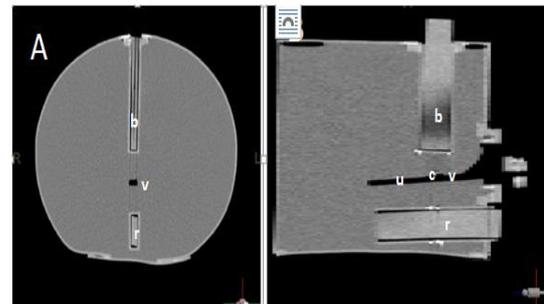

Figure 3 : Cervix Phantom

Figure 4 : CT images of constructed phantom

Figure 5 : Fletcher Suite Applicators

Figure 6 : C-arm x-ray unit

Figure 7: Gafchromic Films

Figure 8 : Co-60 Teletherapy

Figure 9: C-Arm X-Ray

Figure 10: Experimental Setup

VI. METHODOLOGY

Typical clinical implants (or insertions) for cervical intracavitary brachytherapy were performed on the fabricated cervix phantom with the Fletcher suite of applicator. Procedures and protocol in use at the oncology centre were adhered to during the implementation of the implants.

In inserting the applicators into the host, the volume of water in the phantom was halved to reduce pressure on the latex rubber tube forming the vagina walls. After the insertion and the applicators held in place, the phantom was refilled. The filling was done such that the phantom was devoid of air bubbles, the air bubbles detected were allowed to migrate to the opposite end of the phantom with the vagina orifice. Imaging were done for the phantom with the applicators in place with the C-arm x-ray machine. For each implant two radiographs orthogonal to each other were taken for treatment planning to determine dose rates to prescription points. The dose prescription points were as follows; for implants including a tandem the prescription point was point A. For ovoids only the prescription points were to the surface of the ovoids and depth of 0.5 cm from the surface of the ovoids. These prescription points are currently in use by the oncology centre Thirty (30) different applicator configurations that are often used in clinical applications were implemented on the phantom. For each applicator configuration implemented on the phantom, strips of Gafchromic films from the same lot# that was calibrated were cut to the required size, such that they fitted perfectly into the compartments of the phantom mimicking the bladder and the rectum. The films were then sandwiched between the Perspex slabs of the respective compartment, and then the films and slabs inserted into their corresponding compartments. Films were cut to size of 17×3.6cm for the rectum. Prior to the insertion of the films it was ensured that each compartment was dried to prevent discoloration of the film particularly at the edges. The placements of the films inside the phantom were done after the imaging process.

The applicators were connected to catheters in use for the applicators, and the catheters connected to their respective channels on the AMRA brachytherapy machine (see figure 8). The ovoids were connected to channels V1 and V5. For an implant with uterine tube or tandem, the channel to use was selected based on the
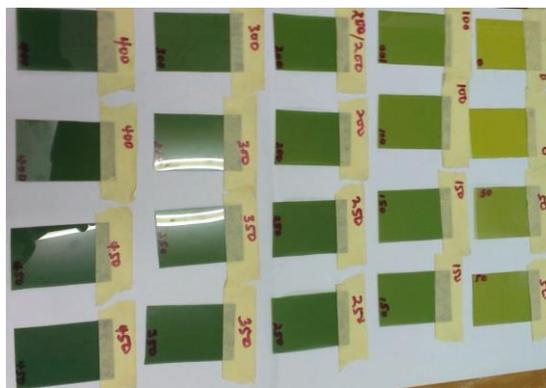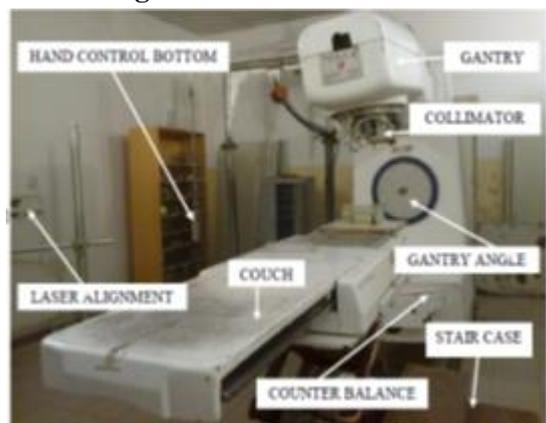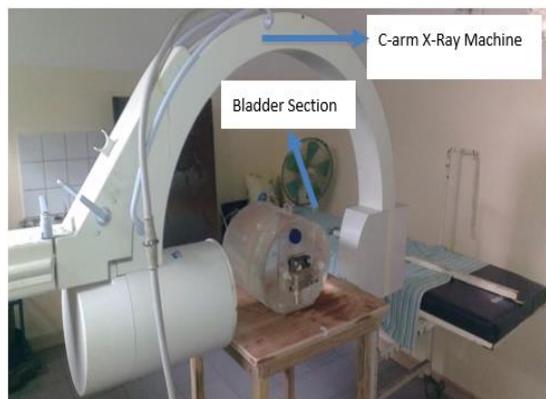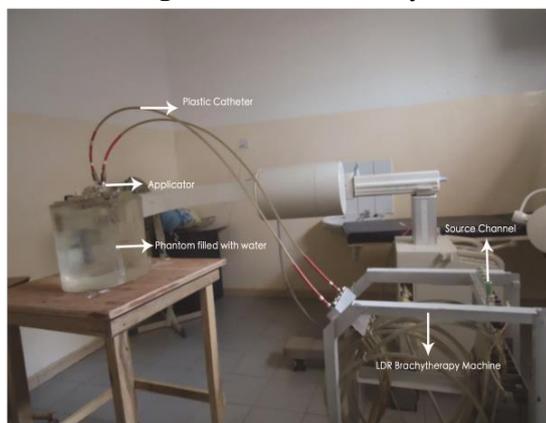
length of the tandem which had protruded beyond the midpoint of the ovoid viewed on the lateral radiograph of the implant and also taking magnification into consideration. Channel U2 was chosen for the smallest length; U3 for medium length; and U4 for the longest length. After connecting the catheters to their respective channels, the selected channels were engaged and treatment initiated with the manual afterloading mechanism of the brachytherapy machine. Time at the start and end of each treatment were then noted. The exposure time for the films or the treatment time ranges from a day to two.

Procedures for the identification of source positions on the orthogonal radiographs and the digitization of these positions into the treatment planning systems in use at the oncology centre were strictly followed during the treatment planning of the brachytherapy implants carried on the phantom. The special radio-opaque marks placed within the phantom were used to identify calculation points on the films, which were also digitized for dose rates to be determined for those points. The points were 0.5 cm and 1.5 cm from the edges of the films towards the applicators for the rectum.

These points were in line with the marks placed within the phantom. The edges of the films were easily identifiable on the radiographs due to the way the compartments for both the bladder and the rectum were designed. These points were therefore identified on the exposed Gafchromic films, and the same densitometer which was used in the film calibration was used to read optical densities of films at the identified points. The readings of the films were done 24hours after exposure. The optical densities obtained were converted to doses using the calibration equation obtained from the sensitometric curve. The dose rates calculated with the TPS for the points were also converted to doses by multiplying the dose rates with the treatment time.

The doses calculated with the TPS were compared with the measured ones with the densitometer, and the percentage errors determined as:

$$\% \, error = \frac{TPS \, dose - Film \, Dose}{TPS \, dose} X100$$

Figure 11 : Experimental set-up showing plastic catheters connected from the phantom to the LDR-Brachytherapy machine with Gafchromic films inserted into the rectal and bladder compartments of the phantom.

VII. RESULTS

Calibration Curve

In figure 10, a plot of dose as a function of optical density is depicted for the Gafchromic film. Above the curve presented are the correlation equation and the correction coefficient, R^2. From the curve, it shows that there is a linear correlation between the absorbed dose and the optical density of the latent image obtained on the film after irradiation. With reference to the value of the correction coefficient, $R^2 = 0.9964$, which is very close to unity; it signifies that the correlation equation can be use to predict or determine absorbed dose of a film from its optical density. The correlation equation is given by;

$$y = 1062.8x - 10.405$$

where y and x are absorbed dose and optical density of irradiated film respectively.

Table 5.0 of Appendix C depicts the variables needed for the calibration that is the temperature, pressure and the optical densities measured. Table 6 depicts the parameters of the calibration protocol used (TRS 398) as described earlier in chapter two. The electrometer readings which give the charges are shown in table 7. The scaling factor which enabled dose readings in plastic (Dw (plastic)) to be converted to dose readings in water (Dw) have also been depicted in table 8.
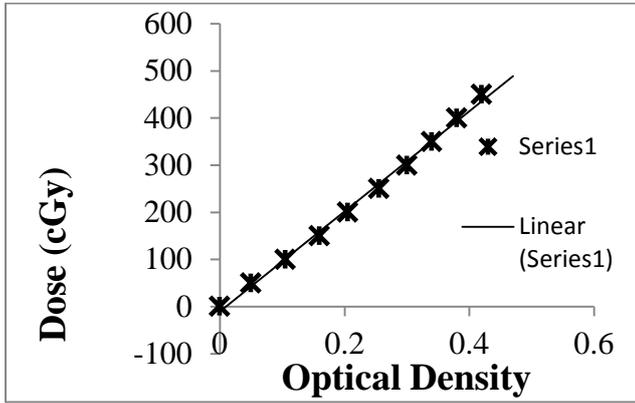
Figure 12 : Calibration Curve

Film Readings

Table 4 depicts the optical densities measured by the Gafchromic films after the films were inserted into the rectal compartment of the constructed phantom and was left some number of hours. These optical densities were applied to the calibration equation gives the doses measured by the film.

Dose to prescription points

The dose prescribed to point A which represents the location where the uterine vessels cross the ureter has been depicted. It is believed that the tolerance of these structures is the main limiting factor in the irradiation of the uterine cervix. Dose prescribed to the surface of the ovoid and dose to a depth of 0.5cm from the surface of the ovoid have also been depicted in table 2. This is done in-accordance with the ICRU Cervical Intracavitary dose reporting Recommendations.

Rectum Dose

The doses calculated by the TPS and the film were outlined their respective distances. The doses calculated by the TPS were then compared to the doses measured by the Gafchromic film. Deviations in the measured dose with the TPS are expressed as a percentage difference of the dose measured by the TPS.
Table: 1 Summary of Results

Comparison of dose calculated by the TPS with dose measured by the film at 0.5 cm and 1.5 cm from the edge of the film for the rectum.

	Rectum			
	Distance from edge of film (cm)			
	0.5		1.5	
Insertions	Diff (cGy)	% Diff	Diff (cGy)	%Diff
Mean	47.92	23.143	27.04	22.45
MIN	-66.54	-42.42	-52.42	-49.45
MAX	250.65	40.41	111.63	46.48

VIII.   DISCUSSIONS

The main objective of this research was to assess the absorbed dose to the rectum using Gafchromic films and compare it with the calculated dose by the treatment planning system (TPS) for system verification. Thirty insertions were carried out on the phantom and evaluated.

The mean difference between calculated dose and measured dose for the rectum at a distance of 0.5cm from the edges of the film was 23.1% (range -42.42 to +40.41). At a distance of 1.5cm for the rectum the mean was 22.5% (range -49.45 to +46.48). The study showed that the TPS calculated maximum dose was typically higher than the measured maximum dose.

However, in some cases, the measured doses were found to be higher than the doses calculated by the TPS. These deviations are due to positional inaccuracy of the sources. The imaging technique used at the centre cannot locate the exact position of the sources. This is because the c-arm x-ray facility used is automated making the technique variables fixed, preventing the x-ray energy from being altered, making it difficult to take the required radiographs in order to locate the positional accuracy of the sources. During treatment planning the sources are assumed to be in the centre of the applicators which is not necessarily the case. Since the doses were measured at distances of 0.5cm and 1.5cm respectively, once the assumed positions of the sources are not accurate, one will definitely encounter deviations in the dose measurement, because a slight deviation in distance will mean a higher or lower deviation in dose. Again, during imaging, dummy needles must be used to view the dwell places and the exact positions of the sources but the kind of applicators used at the centre makes it difficult to do so. Modern plastic applicators make visualization of sources easier in order to determine their exact positions.

The highest dose deviation determined for the rectum with a mean difference of 22.45 at a distance of 1.5cm from the edges of the film. Shielding provided in the applicators is another factor responsible for this dose variation. The tungsten shield provided in the Fletcher suite applicators to reduce dose to the rectum has been a major contributing factor to the dose deviation in this study. It is evident from the data obtained that the shields reduce dose drastically. In fact dose perturbation due to applicator shielding especially could be dramatic with differences as high as 50%. Many researchers, like J.F. Williamson (1990) have performed Monte Carlo calculations around a single Fletcher Suite Delclos (FSD) ovoid and evaluated dose reductions as large as 50% due to the shielding provided in these applicators. Meli JA et al have also reported that Gynaecology applicators with bladder and rectal shields achieve dose reductions as large as 25% at some locations; their dose reduction characteristics are well documented. Faiz M. Khan and Roger A. Potish reported (1998) that attenuation from Cs-137 sources in intrauterine tubes (tandems) alone measures as much as 5% dose deviation depending on the angle but this is a commonly neglected effect. Interestingly, the mathematical algorithm used by the TPS at the NCRNM failed to account for the shielding provided in these applicators as shown section 2.13.1 of chapter two. This deviation however shows that the centre is working within the acceptable limit.

Another reason for dose variation in this study has to do with the source strength. There is an incorporation of deviation and manufactures quoted value.

The exact source strength for the Cesium-137 in use is not known. It is the manufactures' quoted value that is being used for the treatment planning and this has some level of deviation.

There was no calibration done to determine the exact source strength. The NCRNM did not have the ionization chamber needed for the calibration. It was in 2009, that the IAEA gave the NCRNM a well type ionization chamber designed for High Dose Rate (HDR) which of-course could not be used for the calibration of the LDR due to the discrepancies in the length of the well. So the centre is still using the manufacturer's quoted value which has an uncertainty of 2.5%. This is highly responsible for the dose variation encountered in this study.

Some researchers found out that the mean deviation from the manufacturer's value could be as high as 2.47 for each source. The LDR brachytherapy machine has five channels. In all clinical insertions, a maximum of three channels were used. This implies that dose deviation resulting from this unknown source strength is 7.41%. Jacek G. Wierzbicki and Richard Meyer (1991) performed a routine verification of the strength of Cs-137 brachytherapy source and found out that the uncertainty of the source strength was 2%. Cs-137 brachytherapy sources usually have vendor supplied calibrations that should be verified by the user. In addition to this, routine calibration of brachytherapy sources should be done annually. It is important that in quality control the different sources from different batches should not be confused based upon the original vendor-specified source strength supplied at the time of original purchase.

Another factor that contributed to dose reduction was the applicator shift in the elapsed time between the imaging and the treatment stage. This is because in Intracavitary brachytherapy a slight shift in positions of the applicators results in significant deviation of dose. These dose deviations evaluated are within the acceptable limit of brachytherapy practices.

IX. CONCLUSIONS

Dose to the rectum was assessed in intracavitary brachytherapy of the cervix by the irradiation of the cervix phantom constructed. Thirty (30) clinical insertions were carried out and the highest mean dose difference between calculated and measured dose was determined as 23.1% for the rectum. These variations in dose are within the acceptable limit. Ideally, in intracavitary brachytherapy of the cervix, where Fletcher suite applicators are used, dose variations as large as 25% are expected. In fact dose perturbations generally in brachytherapy do go as high as 50%. In order to achieve accurate patient dosimetry, the ovoid shields must be included in the dose model (algorithm). Dose assessments to the rectum during clinical irradiation showed that the variations between the TPS dose and measured dose were within the acceptable limit, so the intracavitary brachytherapy practises at the NCRNM is safe.

X. RECOMMENDATIONS

In vivo dosimetry should be performed in addition to treatment planning computation. In vivo dosimetry is a reliable solution to compare the planned and actual delivered dose to organs at risk.

It is recommended that the Regulatory Authorities monitor periodically, the dosimetry effectiveness, and conduct regular checks on the facilities at the NCRNM to ensure that fundamental requirements are met for patient protection.

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