Dose estimation ($D_{\text{org}}$) in lenses, thyroid and ovaries in intracavitary brachytherapy treatments (LDR).


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Abstract. About 80 intracavitary brachytherapy implants are carried out every year in the Radiotherapy Oncology Department of Ntra Sra. Candelaria University Hospital. The implants were performed with a low dose-rate remote afterloading system (Curietron) using the Delouche technique. A total of 30 implants were analysed, in 20 of them two vaginal sources were used, in the rest two vaginal and uterine sources of variable length depending on target volume size were used. In this work the average dose ($D_{\text{org}}$) received in interest organs as both lens, thyroid and ovaries have been estimated using the thermoluminescence dosimeters (TLD) type GR-200. Five TLD pairs were put in the proximity of interest organs studied on the patient. The values of measured doses were analysed depending on the total dose of treatment (T.D.) given in the target volume (T.D. = 20-50 Gy) and the reference isodose volume.

The results in lens and thyroid presents a proportional increase of $D_{\text{org}}$ depending on the treatment total dose. In implants with two vaginal sources, the $D_{\text{org}}$ in lens and thyroid oscilate between 3.7 mGy and 4.4 mGy respectively for T.D.=20 Gy, and 7.1 mGy and 8.9 mGy for T.D.=50 Gy. The implants with two vaginal and uterine sources show a substantial increase in the $D_{\text{org}}$ in all organs. The doses in ovaries depending strongly of the reference air kerma rate used in uterine source, oscilated between $R=773$ mGy, $L=980$ mGy using reference air kerma rate of $24.46 \, \mu$Gy h$^{-1}$m$^{-2}$ and $R=1206$mGy, $L=1354$mGy using uterine source of $32.21 \, \mu$Gy h$^{-1}$m$^{-2}$

The average exposure rate estimated in both ovaries depending on the reference isodose volume. The implants with two vaginal and uterine sources with a 50% increase in reference volume implies a 35% higher exposure rate, with results between 25.1 – 34 mGy h$^{-1}$.

1. Introduction

Since the beginning of this century, the placement of radioactive isotopes within or next to tumours volumes, are radiation therapy procedures known as brachytherapy, has been in routine clinical use in radiation therapy$^{(1)}$. In the treatments of tissue at significant depths from the patient surface, an inherent disadvantage of external radiation therapy is the compulsory irradiation of the tissue located between the site of disease and the entry surface of the beam. The placement of a radiation source adjacent to deep-seated target, such as a gynecologic structure, provides large dose delivery to the proximal target and decreasing dose to structures beyong the treatment region, it is due to the rapid decrease in intensity as a function of distance from the source. Often used in conjunction with external beam teletherapy is a mechanism for boosting the total dose to the target while limiting the dose to near healthy organs as bladder, rectum and small intestine$^{(2)}$.

The intracavitary brachytherapy with $^{137}$Cs sources, has been in broad clinical use for decades in the treatment of gynecologic cancers. The position sources in the implants results in a pear-shaped volume of irradiation. This shape usually results from the cross-irradiation produced by at least three sources: a superior median source in the uterine cavity oriented along its long axis, and two sources located in the upper vagina, one on either side of the cervix$^{(3)}$. This geometry reveals significant variation in the dimensions of the irradiation volume depending on the implantation technique and the reference isodose chosen. Several implantation techniques has been developed as the Fletcher-Suit, or Delouche afterloading applicators.

Protection of the patient in radiation therapy requires, uniquely, not the avoidance of radiation exposure or even the avoidance of risk of severe damage to some tissues. Once the choice of the appropriate radiation treatment is made, it involves the production of the minimum of treatment-related complications. The latter involves making unwanted radiation doses as low as reasonably achievable
(ALARA), according to the system of dose limitation recommended (ICRP). In intracavitary brachytherapy the applicators to hold radioactive sources will be appropriate placement for both the treatment plan desired and the anatomical characteristics of the patient\(^{(4)}\).

The aim of this work, from the viewpoint of the radiological protection of the patient treated with intracavitary brachytherapy, is to estimate the dose levels received in different critical organs \((D_{\text{org}})\) as the lenses, thyroid and ovaries depending on the reference isodose volume chosen and the total dose \((T.D.)\) given of treatment in the target volume \((T.D. = 20-50\ \text{Gy})\).

2. Material and Methods

The intracavitary brachytherapy is a very appropriate treatment in a large majority of gynecologic tumours: cervix, uterine corpus and vaginal. Most tumours gynecologic in advanced stages are treated by means of hysterectomy, it followed of adjunct treatment with external irradiation and intracavitary brachytherapy\(^{(3)}\), the total dose given with intracavitary irradiation was between 20-30Gy. The intracavitary irradiation is currently employed as only treatment for early stages disease, in this cases the total dose given were 50-60Gy.

In the Ntra Sra Candelaria Hospital, the intracavitary brachytherapy implants applied in the gynecological cancers treatment are performed by means of a low dose-rate remote afterloading system (Curietron). In all the implants analysed the Delouche applicators were used, these applicators consists of a disposable flexible polythene tubes provided in sterilized packets\(^{(3)}\). The system is composed of two vaginal ovoids or an intrauterine tandem and two vaginal ovoids. The ability to establish a stable dose rate to a given anatomic structure is critical in brachytherapy if an accurate dose is to be administered. This requires the radioactive material used in the implant to be fixed relative to each other and to the regional anatomy. The Delouche applicators are stabilized centrally by a pyramidal rigid plastic block. To cope with individual variations in patient anatomy, different combinations of uterine source length and spacings between the vaginal ovoids (20-40 mm) are used.

In total 30 intracavitary implants were analysed, in 20 of them two vaginal sources with a reference air kerma rate of 7.27 \(\mu\text{Gy h}^{-1}\text{m}^2\) and 1.59 cm long were used. The rest of implants were performed with these vaginal sources plus one uterine source adapted to the target volume size. The uterine sources were used with minimal and maximum reference air kerma rate of 19 \(\mu\text{Gy h}^{-1}\text{m}^2\) and 32.21 \(\mu\text{Gy h}^{-1}\text{m}^2\) and variable length between 4-6.87 cm respectively.

The thermoluminiscence dosimeters (TLD) type GR-200(LiF:Mg,Cu,P) were used in the measurement of different organs doses during the intracavitary brachytherapy implants, this is the most convenient dosimetry system\(^{(5)}\), the TLD offers an ideal method in view of its sensitivity and the ease of manipulation\(^{(6)}\). These dosimeters presents a lineal response with a dose absorbed in a range between \(10^{-7}\ \text{y} 12\ \text{Gy}\) and they are nearly 30 higher than the Magnesium and Titanium impurities dosimeters. In the 30 Kev – 3 Mev range the energy dependence is less than 20 %. Another important characteristics is the simple glow curve which only has 6 peaks and has no changes when the dosimeters are irradiated with neutrons.

The thermal treatment is an essential procedure for the reusability of these type of dosimeters, because they are thermal treatment sensitive, if the pre.-irradiation annealing is above 245 °C it has been proved that the glow curve change as there is a sensitivity loss of the dosimeters. Some works recommend, if the residual signal is between an acceptable range, annealing times as short as possible. In this work we used the following thermal treatment:

Pre Irradiation Annealing : 240 °C for 10 minutes. In order to erase the high temperature peaks and avoid its interference with the dosimeter readings.
Pre-Reading after irradiation: 135 °C for 5 minutes. With this treatment we erase the less stables low temperature peaks and reduce the dosimeter fading.

Reading: 50ºC preHeating during 0 sec. 275 º C during 26.7 sec wiht a Heat Rate of 15ºC/sec. curve reading. This reading acts as a dosimeter annealing.

We followed the recommended procedure of the reader manufacturer to calculate the calibration factor for each dosimeter. The dosimeters were annealed and after irradiated with a uniform dose of 10 cGy on a Cobalt-60 unit at 0.5 cm depth, this Cobalt-60 unit was calibrated before the irradiation of the dosimeters, after the irradiation the pre-reading and reading cycles were used. Using the reader software the calibration factors for each dosimeter were obtained. These factors applies only for this thermal treatment, another thermal treatment represents a new calibration of the dosimeters.

In 30 patients treated with intracavitary brachytherapy implants were performed estimates of organs doses in different interest regions of the patient, as: both lenses, thyroid and both ovaries. Six TLD pairs were used by patient, each pair was packed in polythene bags 5 mm x 5 mm, the bags heat-sealed were attached with adhesive tape on the surface of the patient near of interest organs where doses were to be measured for two hours exposition, one pair TLD was located outside treatment room as control dosimeters. After each exposure, the doses in the TLD group were read on a Harshaw TLD 2000 reader. Once time read the dosimeters, were calculated the average reading of each dosimeters pair to estimate the organ dose given in whole treatment.

Computer assisted dosimetric analysis in every implants were carried out by available program development in our Department following the recommendations established by the ICRU Report 38 for dose specification in intracavitary irradiation(7), its displays multidimensional isodose maps which permit the establishment of relatively uncomplicated rules for dose specification adapted to Delouche implantation technique. In order to obtain the distribution around an implant, the reconstruction of the source localizations in space must be known. The orthogonal reconstruction method used was the radiografic method. Two-plane radiographs of the implant are taken in a lateral (LT) and antero-posterior (AP) orientation. Either a radiotherapy simulator is used and a localization box with cross-wires on the faces of the box is placed over the patient.

3. Results and Discussion

The maximum and minimum doses results measured on different interest organs while intracavitary brachytherapy implants with two vaginal sources are shown in Table I, also are presented the average doses ($D_{org}$) calculated on these points in all patients.

<table>
<thead>
<tr>
<th>Organs Measured</th>
<th>20Gy</th>
<th>25Gy</th>
<th>30Gy</th>
<th>50Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lens (mGy)</td>
<td>3.7 (1.5-5.6)</td>
<td>4 (1.9-7.1)</td>
<td>6.3 (4.1-8.5)</td>
<td>7.1 (3.8-9.8)</td>
</tr>
<tr>
<td>Thyroid (mGy)</td>
<td>4.4 (1.7-6)</td>
<td>4.9 (3-7.7)</td>
<td>7 (6.2-8.9)</td>
<td>8.9 (6.5-11.9)</td>
</tr>
<tr>
<td>Right Ovarie (mGy)</td>
<td>370 (135-487)</td>
<td>404 (204-700)</td>
<td>419 (414-424)</td>
<td>421 (199-819)</td>
</tr>
<tr>
<td>Left Ovarie (mGy)</td>
<td>394 (270-537)</td>
<td>471 (275-800)</td>
<td>530 (403-657)</td>
<td>573 (300-1122)</td>
</tr>
</tbody>
</table>

Table I. Results of average doses $D_{org}$ (minimum-maximum doses) measured in interest organs.

The dose in lens was measured on both eyes, in general, the results obtained were very similar, maximum differences of 1-2 mGy appears in some implants with three sources, the results in lenses have been calculated from averaged doses in both lenses. The average doses ($D_{org}$) calculated oscilate
between: 3.7 mGy (T.D.=20 Gy) and 7.1 mGy (T.D.=50 Gy). The results show a proportional increase of $D_{\text{org}}$ depending on the treatment total dose. The minimum dose measured was 1.5 mGy (T.D.=20 Gy) and maximum dose 9.8 mGy (T.D.=50 Gy).

In thyroid the doses measured were higher, the minimum dose measured was 1.7 mGy (T.D.=20 Gy) and maximum dose 11.9 mGy (T.D.=50 Gy), the average doses ($D_{\text{org}}$) calculated oscilate between: 4.4 mGy (T.D.=20 Gy) and 8.9 mGy (T.D.=50 Gy), the $D_{\text{org}}$ increase nearly twice when the dose given change between 20 – 50Gy.

The average doses obtained in both ovaries (right (R) and left (L)) are highest, the $D_{\text{org}}$ varies between: R=370 mGy, L=394 mGy (T.D.=20 Gy) and R=421 mGy, L=573 mGy (T.D.=50 Gy). The dose in ovaries were estimated from measured in points on the patient surface where the ovaries are located. The minimum dose measured was R=135 mGy, L=270 (T.D.=20 Gy) and maximum dose R=819 mGy, L=1122 (T.D.=50 Gy).

<table>
<thead>
<tr>
<th>Total Dose of Treatment (Two vaginal and uterine sources)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organs Measured</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>Lens (mGy)</td>
</tr>
<tr>
<td>Thyroid (mGy)</td>
</tr>
<tr>
<td>Right Ovarie (mGy)</td>
</tr>
<tr>
<td>Left Ovarie (mGy)</td>
</tr>
</tbody>
</table>

Table II. Results of average doses $D_{\text{org}}$ (minimum-maximum dose) measured in interest organs.

In general, the implants with two vaginal and uterine sources present a substantial increase of the doses measured in all organs, the values are shown in the Table II. The average doses ($D_{\text{org}}$) calculated in lens oscilate between: 9.1 mGy (T.D.=30 Gy) and 30 mGy (T.D.= 45 Gy), while in thyroid the average dose is increased between 11.2 – 43 mGy. The results shows that an increase of 1.5 times in the total dose given implies doses in lens three times higher and four times higher doses in thyroid. The measured dose in both ovaries depending substantially of the reference air kerm a rate\(^8\), used, between 19 $\mu$Gyh\(^{-1}\)m\(^2\) and 32.21 $\mu$Gyh\(^{-1}\)m\(^2\) in the uterine source, the measured dose in both ovaries oscilated between R=773 mGy, L=980mGy using an uterine source with reference air kerm a rate of 24.46 $\mu$Gyh\(^{-1}\)m\(^2\) and R=1206mGy, L=1354mGy using an uterine source of 32.21 $\mu$Gyh\(^{-1}\)m\(^2\).

In intracavitary therapy for gynecological cancers, due to the steep dose gradient in the vicinity of the sources, i.e. throughout the target volume, the specification of the target absorbed dose in terms of the absorbed dose at specific points implies significant uncertainties. Therefore, a different approach was considered to be necessary, the specification of a reference volume\(^9\) is recommended in the ICRU 38. The volume to be reported is the tissue encompassed by the reference isodose surface, it is described by the maximum three orthogonal dimensions, height, width and thickness of the isodose surface where the dose is prescribed in three planes\(^10\).

Several variable parameters influence in the dimensions of the reference isodose volumes including: spacing between vaginal sources, angle between the long axes of the vaginal sources and the uterine tandem and legth of respective sources\(^3\). Isodose reference volumes calculated for all patients are shown in Table III, the means volumes vary between 36 – 51 cm\(^3\) for implants with two vaginal sources and greater pear-shaped volumes between 123 – 185 cm\(^3\) for implants with two vaginal and uterine sources.
Reference Isodose Volume

<table>
<thead>
<tr>
<th>Organs Measured</th>
<th>Two vaginal sources</th>
<th>Two vaginal and uterine sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>36cm³</td>
<td>43cm³</td>
</tr>
<tr>
<td>Right Ovarie (mGy h⁻¹)</td>
<td>3</td>
<td>6.8</td>
</tr>
<tr>
<td>Left Ovarie (mGy h⁻¹)</td>
<td>3.4</td>
<td>6.2</td>
</tr>
</tbody>
</table>

Table III. Exposure rate estimated in ovaries in both implants types versus reference

The average exposure rate estimated in both ovaries depending on the reference isodose volume is shown in the Table III. In the implants with two vaginal sources a 42% increase in reference isodose volume implies three times higher exposure rate, with results between 3.4 – 10.1 mGyh⁻¹. Nevertheless, the implants with two vaginal and uterine sources present an slower increase, a 50% increase in reference volume implies a 35% higher exposure rate, with results between 25.1 – 34 mGyh⁻¹. The intracavitary implants with two vaginal sources presents smaller reference isodose volumes and therefore much lower exposure rate in ovaries region.

The exposure rate measured in lenses and thyroid depending on exposure rate in the implant axes for both types of analysed intracavitary implants (total dose of 25 and 30Gy respectively), the results are presented in Table IV. The implants with two vaginal sources shows a stronger increase of the exposure rate measured of 2.5 and 2 times in lenses and thyroid, for variations in the axis exposure rate from 50cGyh⁻¹ to 140cGy h⁻¹. The implants with two vaginal and uterine sources shows a slower increase, about a 40% in lenses and thyroid, for variations in the axis exposure rate from 200cGyh⁻¹ to 600cGy h⁻¹.

Table IV. Exposure rate measure and calculated in lens and thyroid versus exposure rate in implant axis.

<table>
<thead>
<tr>
<th>Organs Measured</th>
<th>50 cGy h⁻¹</th>
<th>100 cGy h⁻¹</th>
<th>140cGy h⁻¹</th>
<th>200cGy h⁻¹</th>
<th>600cGy h⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lens (µGy h⁻¹)</td>
<td>32 10</td>
<td>60 20</td>
<td>80 28</td>
<td>210 40</td>
<td>300 120</td>
</tr>
<tr>
<td>Thyroid (µGy h⁻¹)</td>
<td>56 13.5</td>
<td>90 27</td>
<td>104 39</td>
<td>340 54</td>
<td>470 162</td>
</tr>
</tbody>
</table>

M.= Exposure rate measured with TLD; C. = Exposure rate theoretical from inverse square distance

On the other hand, in order to estimate the exposure rate theoretical in lenses and thyroid received by a standard woman due to brachytherapy intracavitary treatment from the values of exposure rate in implant axis. The standard woman were considered with the following distances: implant axis – patient surface=10 cm, patient surface – thyroid measure point=60 cm and patient surface – lenses measure point=70 cm. It is well known that the intensity of a radiation beam emitted from point source...
is inversely related to the square of the distance from the source\(^2\), a grossly simplified assumption that the implant may be considered a point allows an estimate of the exposure rate to be made from inverse square considerations (ISD) using the established distances, from these assumptions and considering the values of exposure rate in the implant axes and a standard woman with the before distances, the exposure rate will reduce by a factor of \(2 \times 10^{-4}\) in lens and \(2.7 \times 10^{-4}\) in thyroid. The exposure rate measured with TLD and calculated (ISD) in lenses and thyroid for both types of analysed intracavitary implants are shown in the Table IV, the results presents a high underestimation of exposure rate calculated respect to measured, the results shows a measured-calculated ratio between 2-4 for both intracavitary implants types.

4. Conclusions

A total of 30 brachytherapy intracavitary implants have been analysed, in 20 of them two vaginal sources were used, the results of average doses (\(D_{\text{org}}\)) in lens and thyroid are presented, with values of 3.7 mGy and 4.4 mGy respectively for 20 Gy of total dose given and 7.1 mGy and 8.9 mGy respectively for a treatment total dose of 50 Gy. The results in lens and thyroid show a proportional increase of \(D_{\text{org}}\) depending on the treatment total dose. The measured doses in both ovaries are highest, the minimum measured dose was R=135 mGy, L=270 (T.D.=20 Gy) and maximum dose R=819 mGy, L=1122 (T.D.=50 Gy).

In the rest of implants two vaginal and uterine sources were used, the results shows doses values higher in all organs. The results shows that an increase of 1.5 times in the total dose given implies doses in lens three times higher and four times higher doses in thyroid. The measured dose in both ovaries depending substantially of the reference air kerma rate used in the uterine source, the maximum dose in ovaries were R=1206 mGy, L=1354 mGy using an uterine source of 32.21 \(\mu\)Gyh\(^{-1}\)m\(^{-2}\).

The isodose reference volumes were calculated for all patients. The implants with two vaginal sources presents smaller reference isodose volumes and therefore much lower exposure rate in ovaries region. The exposure rate in ovaries show results three times higher for a 42\% increase in reference isodose volume. Nevertheless, the implants with two vaginal and uterine sources present an slower increase, with results between 25.1 – 34 mGyh\(^{-1}\).

The dependence of exposure rate measured in lenses and thyroid versus the exposure rate in the implant axes for both implants types were analysed. The implants with two vaginal sources shows a stronger increase of the exposure rate, however the implants with two vaginal and uterine sources shows a slower increase of the exposure rate.

The analysis of the results shows that the average dose (\(D_{\text{org}}\)) calculated in the lenses and thyroid is determined by the total dose given in the treatment, on the other hand, the direct application of inverse square distance law for to calculate of received dose in lens and thyroid isn’t applicable in this type of studies, because the results of calculated doses underestimates respect to the values measured doses. Hovewer, the dose given in the ovaries strongly depends on the isodose reference volumes.

5. References


