Chapter 1

INTRODUCTION

According to World Health Organization, about 10 million new cancer cases are being registered every year. Death due to cancer itself contributes to 12% of the total mortality. Lung and colorectal cancers are the commonest among men and breast and cervical cancers are leading among women.

Cancer of the uterine cervix is the most common cancer that affects women in India. Early detection and proper treatment can control it to some extent. Radiotherapy alone or supplemented with surgery and/or chemotherapy is the widely used treatment strategy followed all over the world.

In late 1895, Wilhelm Conrad Roentgen reported that, while working with a cathode tube, he had observed a new kind of rays. These he denoted as "X-rays", to indicate that their nature was still unknown. Roentgen observed that these rays could pass through the body tissue, part of a hand but were attenuated by bones. The visualization of the inside of the body would prove to have an enormous impact on medicine. Soon after the discovery of X-rays and their amazing ability to pass through flesh, a second application was found for them. It was claimed that X-rays had a specific destructive effect on rapidly dividing tissue cells, especially tumors, compared with their effect on normal tissue. In the early years, for instance, X-ray therapy of cervical cancer was performed by the simultaneous application of two X-ray tubes placed on the abdomen and directed at the cervix, and a third one irradiating the cervix through the vagina. In addition to
X-ray therapy, however, there was a second type of radiation used in the treatment of tumors, namely "radium therapy". Soon after the discovery (26 Dec 1898) of Radium (Ra-226) by Madame Curie, a school of practitioners arose who were interested primarily in the physiological rather than the tumoricidal powers of this new substance which were termed “radioactive”. The treatment policy was called "mild radium therapy" and involved the oral or parenteral administration of microgram quantities of Radium (Ra) and its daughter isotopes often as cures for rheumatic diseases, hypertension and metabolic disorders.

Manufacturers of patent medicines responded to this market by producing a variety of over the counter radioactive preparations including pills, elixirs and salves. One such nostrum was ‘radiothor’ a popular and expensive mixture of Ra-226 and Ra-228 in distilled water. Radiothor was advertised as an effective treatment for over 150 endocrinology diseases, especially lassitude and sexual impotence. Over 400,000 bottles each containing over 2µCi (74kBq) of Ra were apparently marketed and sold worldwide between 1925 and 1930. The death of the Pittsburg multimillionaire sportsman Eben M. Byers, who was an avid Radiothor user by repoisoning in 1932, brought an end to this era and prompted the development of regulatory control for all radiopharmaceuticals.

In the context of the discovery of X-rays and their presumed relation to phosphorescence, Antoine-Henri Becquerel made a study of uranium salts. During one of these experiments, in 3rd March 1896, he discovered a new form of radiation. This discovery was elaborated upon by Marie (Sklodowska-) Curie who used a piezo-electrometer developed by her husband Pierre Curie to study whether this kind of radiation also emanated from other elements. Their personal contribution to the start and early development of clinical applications should not be overlooked. “The Curies
did not limit their support to providing radium sources to medical pioneers but took a deep interest in the horizons of radium therapy. Pierre was one of the first to search for and demonstrate a biological effect of radium radiation. He investigated the radioactivity of the waters of hydrotherapeutic resorts. Marie took care of the measurement of the medical sources personally, convinced that the result of the treatment depends on the precise knowledge of the amount of radium applied.4

Radiotherapy is defined as the treatment of malignant diseases using radiation. More than 70% of human body consists of water and when radiation interacts with the human body, a lot of free radicals (of H and OH) will be produced. These free radicals are very active in producing DNA damage and this eventually ends up in cell death. The aim of radiotherapy is to bring maximum damage to tumor cells with minimum damage to the normal cells. Radiotherapy can be broadly classified into two, viz, teletherapy and brachytherapy. Here the radioactive sources used are in sealed form.

Teletherapy

Treatment of cancer using radiation can be done by keeping the source of radiation at a distance from the target (tumor) and such type of treatment is termed as teletherapy. Two types of teletherapy machines are available. They are teleisotope machines (uses radioisotopes such as Co-60, Cs-137 or Ra-226) and linear accelerators. Linear accelerators are now widely used because it can provide multiple photon and electron energies of various ranges, with a capability of providing field sizes to any desired shape using Multi leaf Collimators (MLCs). Most modern linear accelerators are capable of delivering a very highly conformal radiation to tumor by minimizing dose to the critical structures around. Special techniques such as intensity modulated radiotherapy (IMRT), image guided radiotherapy (IGRT)
etc are available to provide radiation beam intensity profile of any shape. Portal imaging facility and associated dosimetry system provided with linear accelerators facilitates to confirm the accurate delivery of radiation.

Fig. 1.1 A Modern linear accelerator with IGRT facility (Courtesy: M/s Varian)

**Brachytherapy**

Brachytherapy is the treatment where sealed radioactive sources are placed directly inside the tumor or near to it in a definite configuration to deliver a uniform dose to the tumor with a variation of not more than ± 10%. This type of treatment is known in other names as contact therapy, pleziotherapy or mould therapy. It plays an important role in the management of cancers in several sites, including the brain, head and neck, uterine cervix, endometrium, and prostate. Recently there is a growing interest in using brachytherapy for reducing restenosis and treatment of vascular diseases. The advantage of this type of treatment compared to teletherapy is, the rapid fall off of absorbed dose with increasing distance from the sources. High doses (up to 70 Gy) may be safely given to a localized target region over a short time\(^5\). Hence, by giving a superior
localization of dose to the tumor, surrounding critical structures can be effectively avoided from getting higher doses. The dose gradients around an implant and dose heterogeneity within an implant are much higher than those in external beam radiotherapy. The short duration of brachytherapy treatment of the order of 2-7 days to deliver 20-70Gy by removable implants is more convenient for the patients compared to the 5-7 weeks of treatment by external radiation. Radiobiologically this short duration will prevent the proliferation of the tumor cells and the continuous irradiation provides time for reoxygenation of the hypoxic cells allowing time for the radioresistant cells to become radiosensitive. Moreover, this continuous radiation allows redistribution of the tumor cells within the cell cycle, allowing cells in the less sensitive S-phase to move to more radiosensitive M phase. The high dose given at the centre of the tumor will help in eradicating the less sensitive central core hypoxic cells. Brachytherapy is a form of conformal therapy because the dose distribution can be manipulated to match the irregular tumor shape and since the sources are implanted directly into the tumor, the chances of geographical miss due to patient movement are reduced.

Brachytherapy is classified mainly in to four categories based on the surgical approach to the target volume, viz, mould therapy, interstitial brachytherapy, intracavitary and intraluminal brachytherapy. Arranging the radioactive sources in a special configuration following certain rules on a tissue equivalent material can treat the superficial lesions by placing it in contact with the lesion. This type of treatment is called mould treatment. The dose to be delivered is prescribed at the surface. In interstitial implantation the sources are pierced in to the tumor and arranged in single or multiple planes and thereby delivering the prescribed dose at a treating distance. A block of tissue can be treated this way. Certain specially designed applicators are placed inside the natural cavities of human body for delivering the dose. This form of treatment is known as intracavitary brachytherapy. Intraluminal brachytherapy is the temporary placement of a
radioactive source or sources in a linear arrangement inside the lumen. It is often used for tumors that obstruct the opening of a pulmonary bronchus, biliary duct, oesophagus, etc. Catheters placed by endoscopy are afterloaded with radioactive sources to deliver a dose that can relieve the obstruction.

The Curies isolated radium in 1898. Brachytherapy got a boost after the purification of radium by Marie and Pierre Curie and the construction of platinum needles to contain the radium sulphate. Radon gas in glass capillaries were also used in the earlier times as a brachytherapy source.

The wide acceptance of brachytherapy as a mode of curative treatment is due to its conformity of dose (the treatment volume can be made to closely approximate the target volume\(^8\)) and short treatment times involved for both temporary and permanent implants. The tumor region gets a high dose that need not be uniform with in the tumor but the dose delivered should not be less than the tumorocidal dose. A non-uniformity above the tumorocidal dose within in the tumor is acceptable and in that sense brachytherapy can be considered as a conformal type of treatment with very minimal dose to the surrounding normal tissue. There is no irradiation of normal tissue between the patient's surface and the treatment volume as in external beam therapy.\(^8\)

**Ideal brachytherapy source**

The desired characteristics of a brachytherapy source as listed by Walstam\(^9\) are listed below:-

a. It should be insoluble, non-toxic and available in solid form, because these criteria will minimize hazards from any accidental source breakage and eliminate completely the inhalation risk.
b. The radioisotope should not emit any alpha or beta radiation so that the thickness of encapsulation can be reduced and the dosimetry becomes simpler.

c. The specific activity of the source should be high so that miniaturized source with high activity can be produced for use in high dose rate remote after loaders which will increase the patient comfort and reduce treatment time drastically.

d. For avoiding the frequent replacement of sources and for delivering treatment at a constant dose rate, the half life of the source should be sufficiently high for temporary implants while for permanent implants it should be small enough.

e. Those isotopes that would emit energies ranging from 200 to 400 keV are ideal.

f. It should be available at low cost

There are several situations where brachytherapy is the only mode of treatment choice:

- the tumor is localized
- in palliative indications where to improve efficacy and reduce the overall treatment time and morbidity
- in tumors recurrent after external beam radiotherapy (EBRT)
- in postoperative treatment of the tumor bed where the region at higher risk for recurrence

However, brachytherapy is generally not used in the following situations\textsuperscript{10},

- nature of disease is diffuse and extensive
- patients with distant metastases or diffuse disease without local palliative indications
- patients not suitable for anesthesia if it is required
- inaccessible tumors
• patients who are unable to comply with the radiation safety requirements

Radium and Radium substitutes

Brachytherapy started by using Radium-226 source. It is available in different forms such as tubes, needles etc in various ranges of lengths and activities. Radium being the sixth member of uranium series, emits 49 gamma rays during its decay to stable lead with an energy spectrum from 0.184MeV to 2.45MeV (an average energy of 0.83MeV for use in dosimetry). Ra-226 disintegrates with a half-life of 1600 years to Radon-222 and within one month, it will attain secular equilibrium with radon if it is encapsulated. One century after the isolation of radium, it has been abandoned mainly due to radiation protection difficulties.

The disadvantages of radium for recommending its substitutes are: - a) Radium usage involves excessive exposure to the radiotherapists and staff b) Radium sources are not suitable for developing after loading techniques due to its low specific activity (nearly 50MBq/mm³) c) Radium is a very hazardous material and accidental breakage of radium needles can cause considerable internal and external exposure. d) Being a bone seeker with long half-life, the body burden of radium is very low. e) The chance of contamination is very high if it breaks, especially with a gaseous daughter product Rn-222, which would lead to exposure through inhalation. f) Since its gamma energy is very high, radiation protection becomes very difficult when it comes to transportation of source and requirement of heavy rectal shield in applicators used in the treatment of carcinoma of uterine cervix. Table1.1 shows the isotopes used in brachytherapy and their characteristics.
### Table 1.1 Physical Characteristics of Brachytherapy sources

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Exposure rate constant (\text{R-cm}^2\text{mCi}^{-1}\text{hr}^{-1})</th>
<th>Mean Photon energy (MeV)</th>
<th>Half-Life</th>
<th>Half-value layer thickness (mm of Pb)</th>
<th>(F_{\text{muscle}}) (cGy/R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-60</td>
<td>13.07</td>
<td>1.25</td>
<td>5.26 years</td>
<td>10.2</td>
<td>0.962</td>
</tr>
<tr>
<td>Ra-226</td>
<td>8.26*</td>
<td>1.03</td>
<td>1622 years</td>
<td>14.0</td>
<td>0.962</td>
</tr>
<tr>
<td>Cs-137</td>
<td>3.28</td>
<td>0.662</td>
<td>30 years</td>
<td>5.57</td>
<td>0.962</td>
</tr>
<tr>
<td>Ir-192</td>
<td>4.69</td>
<td>0.380</td>
<td>73.83 days</td>
<td>2.5</td>
<td>0.962</td>
</tr>
<tr>
<td>Au-198</td>
<td>2.35</td>
<td>0.412</td>
<td>2.70 days</td>
<td>2.68</td>
<td>0.962</td>
</tr>
<tr>
<td>Yb-169</td>
<td>1.58</td>
<td>0.093</td>
<td>32 days</td>
<td>0.48</td>
<td>0.960</td>
</tr>
<tr>
<td>Am-241</td>
<td>0.12</td>
<td>0.0595</td>
<td>432.2 years</td>
<td>0.126</td>
<td>0.937</td>
</tr>
<tr>
<td>Sm-145</td>
<td>0.78</td>
<td>0.043</td>
<td>340 days</td>
<td>0.060</td>
<td>0.922</td>
</tr>
<tr>
<td>I-125</td>
<td>1.45</td>
<td>0.028</td>
<td>59.6 days</td>
<td>0.025</td>
<td>0.920</td>
</tr>
<tr>
<td>Pd-103</td>
<td>1.48</td>
<td>0.021</td>
<td>17 days</td>
<td>0.004</td>
<td>0.920</td>
</tr>
</tbody>
</table>

(Adopted from: Principles and practice of brachytherapy by Subir Nag, p48)

* The exposure rate constant for all the radionuclides except Radium-226 is for a bare point source with no filtration. For radium, this value is for a source with 0.5mm platinum filtration and it is expressed in units of \(\text{R-cm}^2\text{mg}^{-1}\text{hr}^{-1}\).

+ Exposure in air to dose in muscle conversion factor
Role of brachytherapy in the management of cancer of the uterine cervix.

The two main modalities of radiation treatment of cancer of the uterine cervix are teletherapy and brachytherapy. External irradiation is used to treat the whole pelvis and parametria, including the pelvic lymphnodes, while the central disease (cervix, vagina and medial parametria) is primarily irradiated with intracavitatory brachytherapy.

High energy photons are usually preferred for pelvic treatment because they decrease the dose to peripheral normal tissues (especially bladder and rectum) and provide a more homogeneous dose distribution in the central pelvis. The pelvis can be treated with either two fields from anterior and posterior or for patients with higher thickness usually three to four fields for getting an acceptable homogenous distribution at the tumor area while minimizing the dose to the critical structure such as rectum and bladder.

The superior border of the pelvic portal should be at the L5-S1 interspace to include the lower common iliac nodes. This margin must be extended to the L3-L4 or even L2-L3 interspace if the entire common iliac nodal chain needs to be covered. If there is no vaginal extension, the lower margin of the portal is at the inferior border of the obturator foramen. When there is vaginal involvement, the entire length of the vagina should be treated down to introitus. The lateral margin is 1.5 to 2 cm beyond the lateral margin of the pelvic brim.

For the lateral fields, the anterior border of pubic symphysis and the space between S-2 and S-3 are anterior and posterior limits respectively. Intraoperative measurement\textsuperscript{11}, sagittal MRI scans\textsuperscript{12} and CT scan treatment planning\textsuperscript{13} have revealed inadequate posterior coverage with standard radiotherapy fields. Therefore, the radiotherapy committee of the
Fig. 1.2 Anterior and Right lateral portals used for external beam therapy.
Gynecologic Oncology Group (GOG) has redefined the posterior limit of lateral fields to be behind the sacral hollow to avoid under dosing or missing the tumor.

Patients with documented positive paraaortic metastasis are usually treated with extended fields to encompass the retroperitoneum. The dose of radiation to paraaortic region is limited to 45 to 50 Gy for bringing down bowel complications. Also, if surgical staging is performed, it should be by an extraperitoneal approach. Five year survival rates ranges from 20 to 40% with extended field radiation. Survival rates are higher for patients with microscopic or small paraaortic disease than for patients with massive paraaortic involvement\textsuperscript{14}. Distant metastasis is a predominant pattern of failure in these patients.

Control rates obtained for the treatment of cancer of cervix with external beam and brachytherapy is found to be better than that with external beam alone\textsuperscript{15,16}. Brachytherapy plays a critical role in the successful treatment of cervical cancer. For cancers of cervix, local-regional control correlates with cure and survival. The use of brachytherapy in cervical cancer has significantly increased over time. Komaki et al.\textsuperscript{17} reviewed the patterns of care study results of 1973, 1978, and 1983. For patients with stage III cervical cancer, 61% received brachytherapy in 1973, compared with 77% in 1978, and 88% in 1983 (p<0.001). The 1996 to 1999 survey showed that over 92% of patients treated with curative intent received brachytherapy, of which 16% received high dose rate (HDR) brachytherapy\textsuperscript{18}.
Systems of Brachytherapy

Intracavitary brachytherapy for cervical carcinoma was profoundly impacted by the development of various systems which attempted to combine empiricism with a more scientific and systematic approach\textsuperscript{19}. A dosimetric system refers to a set of rules concerning a specific applicator type, radioactive isotope, and distribution of the sources in the applicator to deliver a dose to the designated treatment region\textsuperscript{20,21}. The aim of all published dosimetric system is simple: to provide a set of guidelines for the brachytherapist which, if followed, enables a prescribed dose to be delivered to the patient as accurately as possible.

Stockholm system

The Stockholm system began with the work of Forsell at the Radiumhemmet in 1910 followed by Heyman in 1914 and was published in 1924. Several modifications followed, including those of Kottmeir. This system delivers the doses in three fractions each lasting for nearly 20-30 hours, separated by one to two weeks. The uterus contained 30-90mg of radium and the vaginal applicators (cylinders or boxes) 60-80 mg, with more radium in the vaginal applicators than the uterus. Total mg-hrs was usually 6500-7100 for the combined vaginal and uterine radium. The vaginal and uterine applicators were not fixed together. The longest possible intrauterine tube was recommended for increasing the dose to the paracervical region and the pelvic lymph nodes. There was limited use of external beam.

The Paris system

The Paris system was developed at the Institute of Radium in Paris in 1919 under Regaud, Lacassagne, and associates and was first described in 1929. It prescribed a fixed number of mg-hrs for a given tumor.
volume on the basis that for any given geometric arrangement of specified sources, dose at any point is directly proportional to the amount of radioactivity in the sources and to the implant duration. Regaud believed that better results were more for low dose rate than delivering high dose of short duration because more cells would be irradiated during mitosis. The rubber intrauterine tube typically contained two 13.33mg radium sources and one 6.6mg radium source, and the two cork intravaginal cylinders (colpostats) each contained 13.33mg of radium. This was usually kept for nearly 120 hours to deliver 7200 to 8000 mg hours, equally divided between the uterus and vagina. There was no connection or specified relationship between the uterine and vaginal sources. The colpostats were typically inserted alone for part of the implant, followed by colpostats and tandem together and completed with tandem alone. For increasing the percentage depth dose, a longer intrauterine applicator was used.

**The Manchester System.**

The Manchester system had its origin from Paris System and was described by Tod and Meredith in 1938 and later modified in 1953 at the Holt Radium Institute, Manchester in 1953. This system was the first to feel the need for introducing the prescription in terms of dose rather than mg-hours. It standardized the treatment with predetermined dose and dose rates directed to fixed points in the pelvis and changed the empiricism followed by other systems. The fixed points A and B were selected on the theory that the dose in the paracervical triangle impacted normal tissue tolerance and not the actual dose to the bladder, rectum or vagina. The paracervical triangle was described as a pyramidal-shaped area with its base resting on the lateral vaginal fornices and its apex curving around with the anteverted uterus. “Point A” was defined as 2cm lateral to the central canal of the uterus and 2cm from the mucous membrane of the lateral fornix in the axis of the uterus. “Point B” was located 5cm from midline at the level of Point A and
was thought to correspond to the obturator lymph nodes (Fig1.3). The dose at Point B depended little on the actual geometric distribution of radium, such as the size of the ovoids and intrauterine tubes, but almost entirely on the amount of radium used. A consistent dose rate was achieved by a set of strict rules, dictating the relationship, position and activity of radium sources in the uterine and vaginal applicators. Three types of ovoids viz, small (2cm dia.), medium (2.5cm dia) and large (3cm dia) and intrauterine tubes of different lengths were used and it was recommended to use the largest possible ovoids and as separated as possible laterally to throw dose to point B. Vaginal packing was used to reduce the bladder and rectal dose to below 80% of point A. It was recommended to treat the entire uterine canal and load the tandem in 2:1, top to bottom. The intrauterine: vaginal radium ratio was suggested to be 1.6:1 (65% of radium in tandem; avoid>50% radium in ovoids) as the vaginal mucosa was felt to be vulnerable to injury if more than 40% of the total dose to Point A was delivered through the vaginal mucosa. Two intracavitary applications of 72 hours with a 4-7 day interval between them were given to deliver a dose of 8000 R at 55.5r/hr to Point A and 3000R to Point B.

Fig1.3. Original definition of Points A and B according to the Manchester system. (From Meredith WJ. Radium dosage: the Manchester system. Edinburgh: Livingstone, 1967, with permission.)
Fletcher (M.D.Anderson) System

The Fletcher system was established in the 1940’s at M.D.Anderson Hospital. A paper describing the development of the Fletcher applicator appeared in 1953. As done in Paris system, mg-hours was adopted for dose prescription based on the fact that for any geometric arrangement of specified sources, the dose at any point is proportional to the amount of activity and the implant duration. Previous systems such as Paris and Stockholm had used mg-hours but there was no theoretical basis on how much radium should be used to control the disease based on their type and stage. The only guiding factor was clinical experience and that too subjective. To control the disease and morbidity effectively, Fletcher was of the opinion that one should know exactly the energy absorbed at various points in the pelvis and various lymph node groups, guide the treatment in such a way that the bladder and rectum should not be overdosed and ensure that the primary disease in the cervix and fornices and immediate extensions into the paracervical triangle are adequately treated. Even before the introduction of computerized planning, Fletcher did direct measurements of dose in the patients and planning in three dimensional technique using orthogonal X-rays and dose finders. Two insertions were delivered in such a way that isodose curve of 3500R of each insertion was taken for dose delivery. Great attention was given to rectum and bladder and if the dose to these organs were within in the tolerance limit (below 7500 gamma R for bladder and 7000 gamma R for rectum) and if the applicator geometry is satisfactory, then the radium was left in place for 72hours, followed by second insertion in 10 days of approximately 72 hours. Individualization to fit the anatomical situation was an essential aspect of this system. It was Fletcher and Durrance who defined a plane called “Lymphatic Trapezoid of Fletcher”
In his 3D approach of dose determination, Fletcher defined a trapezoid with several points such as external iliac nodes, low common iliac nodes, para-aortic lymph nodes and these points are from a plane with in the pelvis. The pelvic wall point of Chassagne was used to find the dose to the lateral parametria and obturator lymph nodes. The dose received at the low common iliac nodes and external iliac nodes would give an idea of the additional external beam contribution required for parametrial and nodal boost fields. With the implant loadings and durations outlined by Fletcher, typical dose rates at point A were found to be approximately 57cGy per hour and vaginal surface dose rates 100cGy per hour. The median doses to point B and to the ICRU-38 (International Commission on Radiation Units and Measurements Reports No.38) rectal and bladder reference points averaged 28%, 59%, and 60% of the point A doses respectively. The median total dose to the bladder and rectum were 68 and 70 Gy. The total dose delivered to the vaginal surface was limited to 120-140 Gy or 1.4-2.0 times the point A dose.

**Washington University System**

This system, established in 1959, is closely related to the M.D. Anderson system with the primary prescription that of mg-hrs, and is also a descendant of the Manchester system. This system also adopted the Manchester concept of point A, vaginal surface dose to avoid the undertreatment of tumor and excessive irradiation of the vagina and the use of largest possible ovoid size as well as the use of tandems loaded to the tip. Loading of the applicators is slightly different with the tandem loaded with 20-10-10 mg-Ra-eq of Cs-137, the large colpostats loaded with 30 mg-Ra-eq, the small with 20mg-Ra-eq and mini-ovoids loaded with 10mg-Ra-eq of Cs-137. These loading give a slightly higher dose rate of 60-70 cGy/hr to point A than the traditional Manchester loadings and increase the ratio of the percentage vaginal surface to point A dose rate to 167%. First intracavitary
treatment is done usually after 20Gy to whole pelvis with midline step wedge followed by a second insertion 2-3 weeks later. In patients with IB disease, 10Gy is given to the whole pelvis, 40Gy to parametria with midline shielding, with intracavitary doses ranging from 6500-7500 mg-Ra-eq-h (60-80Gy to point A and 60 Gy to the pelvic wall). In patients with IIA, IIB, and III disease, higher cumulative doses of 8000-8500mg-Ra-eq-h (70-95 Gy to point A and 70Gy to pelvic wall) are given. If the whole pelvis dose is raised to 40Gy, only 6000mgRa-eq-h is given. The dose to the pelvic lymph nodes ranges from 50-70Gy. Standardized AP-PA fields are typically used during external beam.

ICRU-38 system.

This report\textsuperscript{21} is mainly dealing with the treatment of carcinoma of cervix for which the anatomical region of interest is similar for every patient. This system is aiming at providing recommendations regarding the minimum requirements needed when reporting and the concept of reference volume enclosed by the reference isodose curve rather than a target-dose specification. According to this report, while reporting, the technique description should contain details regarding the sources and the type of applicator used, the total reference air kerma, the volume enclosed by the reference isodose (60Gy), the absorbed dose of organs at risk such as the rectum and bladder, the reference points related to the bony structures and the pelvic reference points etc. As the different isodose surfaces are close to each other, the indication of the reference volume must be supplemented by the indication of the Total Reference Air Kerma, the sum of the products of the reference air kerma rate and the irradiation time of each source.

The absorbed dose level of 60Gy is widely accepted as the reference level for the conventional low dose rate brachytherapy and if it is given in fractions the total of all the fractions should lead to 60Gy. In other
situation of treatment, the contribution from both external beam radiation therapy and brachytherapy is included in the 60Gy isodose. The reference isodose volume, which is approximately the product of the dimensions such as width (dw), height (dh) and thickness (dt) of the pear shaped isodose volume, is measured form the oblique frontal and oblique sagittal planes.

**American Brachytherapy Society System**

The American Brachytherapy Society\textsuperscript{22} (ABS) provides guidelines for using high dose rate brachytherapy in the management of patients with cancer of cervix by taking into consideration the current availability of resources in most institutions (Subir Nag et.al, 2000). The dependence of Manchester defined point A on the ovoid positions results in wider variations in dose to the point A. The variation of point A often occurs in a high-gradient region of isodose distribution. Hence the ABS recommends prescribing dose to a consistent location falling parallel to the tandem called point H. A line is drawn connecting the mid-dwell positions of the ovoids. This line intersects the tandem. The point H is found by moving along the tandem superiorly a distance equal to the sum of ovoidal radius and 2cm, and then laterally 2cm perpendicular to the tandem.

It can be seen that each system has its merits and demerits. As F M Khan points it - “…universal agreement does not exist as to the superiority of any one system. The problem is perhaps with the nature of brachytherapy, no more sophisticated than gourmet cooking…as in cooking, there is a little bit of everything: art, science, technique, and taste.” \textsuperscript{23}
The optimal placement of applicator

The method of placement of the gynecological applicator inside the cavity is utmost important in the success of correct delivery of dose to the tumor. The ABS has put forward some recommendations regarding the selection and placement of the applicators. An applicator should be selected in such a way that it should be able to optimally treat the disease and should easily be placed in an anatomically distorted vagina. The largest diameter that can be accommodated in the fornices without displacement should be inserted. The ovoid should fit snugly against the vaginal fornices. Ideally, the tandem and ovoid should be inserted so that the tandem bisects the ovoids on lateral view. Deviation from this position will end up in anterior or posterior displacement of ovoids and will induce a cold spot on the anterior or posterior lip of the cervix. The tandem should fall midway between the ovoids and parallel to the body axis on anteroposterior view. Too wide ovoid separation may result in under dosage. A deviated tandem, typically toward one side will result in an underdosage to the opposite parametrium. The flange should be at the level of cervix. The ovoids surface should not be dropped down from touching the flange which will result in high dose to bladder. The caudal tandem displacement can lead to a hot spot in the vagina, and thereby high dose to rectum and bladder. There should be adequate packing. The effectiveness of anterior and posterior packing should be identified from lateral view. Jampolis\textsuperscript{24} conducted an analysis on 494 patients and found that nearly 2% of the patients were affected with central failure due to improper placement of the colpostats during brachytherapy. Perez found a correlation of poor insertion technique with increased risk of central failure\textsuperscript{25}.
Afterloading Techniques.

The technique of afterloading involves the placing of non-radioactive needles, tubing, or applicators into the patient prior to the introduction of radioactive sources. The radiographs which are used for dosimetry are usually taken at this stage using non-radioactive markers inserted into the applicators. This helps the radiotherapist and his team to spend more time in keeping the applicators in good geometry, which helps in proper treatment delivery. After confirming the proper position of the applicator within the tumor, the radioactive substance can either be placed manually inside the applicator by the operator (manual afterloading) or can be directed into the applicator by means of a remotely controlled mechanism called remote afterloader (remote afterloading). The implantation technique can either be temporary or permanent. In permanent implants, a radioisotope is implanted into the tumor site, emitting low doses of radiation over the lifetime of its radioactivity. A permanent implant may be advantageous when the target volume is irregular and complex, making temporary catheter placement impractical and avoiding situations that result in potential kinking of the catheters. Moreover, a higher total radiation can be delivered to the target volume. Temporary implants are commonly used in head and neck cancers.

Remote Afterloaders

The introduction of remote afterloaders (RALs) in brachytherapy helped to reduce the radiation exposure to radiation workers associated with the procedure, especially to those who are performing bedside care for these patients. A more consistent treatment can be given using RALs and this improved the treatment results one-step forward than manual after loading techniques. “The high dose rate and pulsed dose rate would not be possible (or would at least be highly inconvenient) without the use of afterloading devices. Also, the modern development of conformal
brachytherapy using stepping or oscillating source positions has been dependent on the availability of computer-controlled, accurate source positioning, which would not be possible without afterloading\textsuperscript{26}. The afterloading concept was introduced by Henschke and minimizes the potential radiation exposure during an implantation procedure\textsuperscript{27-28}. Other advantages of remote after loaders can be summarized as follows\textsuperscript{29}

1. Radiation exposure to staff virtually eliminated.
2. Improved control of isodose distribution.
3. Low probability of misplacing or losing sources.
4. No source preparation work.
5. Source Loading, unloading and recording performed automatically

Basic components of a remote afterloader are a) a radioactive source b) a safe for the source c) a remote operating console d) a source drive/ control mechanism e) a source transfer/ guide tube f) applicators. The planning is done using a treatment planning system and information such as source position, dwell times etc. for a particular accepted plan is transferred to the remote after loader units either manually or using floppy disc or online. This will permit the RAL to sort the sources and then drive the source pneumatically or using cables through the transfer tubes to the preplanned positions with in the applicator.

**Isotopes used in Remote Afterloaders**

The commonly used radioisotopes in RALs are Co-60, Cs-137 and Ir-192. The isotope Co-60 was the first radionuclide used in RAL because of its high specific activity (200Ci/gm). But its reasonably shorter half-life (5.26 years) and high energy (1.17 MeV and 1.33MeV) gamma rays make radiation protection relatively difficult. The gamma energy from Cs-137 (0.66MeV) is less penetrating compared to Co-60 and it has a relatively
longer half-life. But these advantages are overturned by its only one disadvantage of having shorter specific activity (10Ci/gm). Ir-192 is now most often used in all types of RALs. Its half-life is short (73.83 days) compared to the other two isotopes, which is a disadvantage. But the nearly ideal gamma ray energy (0.38MeV) makes radiation protection the simplest. Its relatively higher specific activity (400Ci/gm) makes it possible to make a very small source, which is suitable for all types of brachytherapy treatments.\(^\text{30}\)

**Types of Remote Afterloaders**

ICRU Report 38 mentions the definitions of low, medium, high and pulsed dose rate coming under brachytherapy. The rate of delivery of dose at the point of prescription is termed as the dose rate. Based on the dose rate used in brachytherapy, the remote afterloaders are categorized into four.

They are:

1. Low dose-rate (LDR): Dose rate between 0.4Gy/hr to 2Gy/hr
2. Medium dose-rate (MDR): Dose rate between 2Gy/hr to 12Gy/hr
3. High dose-rate (HDR): Dose rate greater than 12 Gy/hr
4. Pulsed dose rate (PDR): Instantaneous dose rate between 1Gy/hr to 3Gy/hr

**Low Dose Rate / Medium Dose Rate Afterloaders**

If the rate at which the dose is delivered at a particular prescription point in medium (dose rate at or near the point A of the Manchester system\(^\text{26}\)) is very low and if it is at the rate of 0.2cGy to 2Gy per hour, then it falls under low dose rate afterloaders. MINIRAD from Isotopen-Technik, Selectron (LDR/MDR) and Microselectron LDR, both from
Nucletron Engineering BV, Netherlands, Curitron from BEBIG, Germany are some examples of commercially available low dose rate machines. Details of a few commonly used LDR/MDR remote afterloaders are explained below.

a. MINIRAD

In MINIRAD, the source used is Ir-192 or Cs-137 in wire form having an outer diameter of 0.9mm and a length of 120mm or 200mm. Smallest outside diameter of the applicators is 1.6mm. It can be operated in two modes; single patient mode and multiple patient mode. In single patient mode it treats only one patient and the machine can perform treatment interruptions and source retrieval as and when required or if someone enters the treatment room. This feature is not possible in all the patients if one chooses multiple patient mode, wherein several patients are loaded with sources in rapid succession and the unit is disconnected from each patient once the initial source transfer is complete. Hence it only reduces the radiation exposure to radiation workers who insert or remove the source. It has got sixteen channels particularly applicable for LDR interstitial therapy of the breast and prostate.

b. Selectron - LDR/MDR

Selectron –LDR, the most widely used low dose rate machine, possess a maximum of 48 spherical Cs-137 sources each having equal activity ranging from 370MBq to 1.48GBq which are housed in a storage container having a maximum storage capacity of 81.4GBq. It has got 3 or 6 channels and depending on the availability of sources, one can treat one or two patients simultaneously. A source train of maximum 48 positions (equal to 12cm length) can be programmed using microprocessor with any pellet being active or inactive (using non-radioactive spacers made of ferromagnetic material having the same diameter as that of source).
depending on the required dose distribution. The active and inactive pellets are sorted by a magnetic source sorting mechanism as pellets move from the main safe to the intermediate safe, where they are stored immediately prior to treatment. These programmed source trains in different channels are transferred pneumatically to the properly connected applicators (smallest outer diameter is 6mm). Most of the Selectron users opt for sources having still higher activities than used in Selectron-LDR, so that the dose rate delivered to Manchester point A is in the range of medium dose rate, putting it in what might be called the MDR category.

c. Microselectron - LDR

The microselectron-LDR, a low dose rate interstitial unit having fifteen channels (Nucletron Corporation, Columbia, MD) uses either conventional Ir-192 seeds in ribbons, or Cs-137 seeds in a pre-selected configuration. It has got a secondary storage safe. The unit is designed for continuous irradiation and treatment and the sources are retracted into safe each time the room door is opened. The treatment planning can be done using the Nucletron Planning System.

d. Curietron - LDR/MDR

It uses a maximum of four source trains consisting of Cs-137 sources and spacers, inserted in a stainless steel spring with one of the extremities closed. The movement of the source train can be controlled from outside the treatment room.

e. The Buchler GMBH

This system uses cable driven sources which oscillates within the uterine tube, and the required dose distribution is achieved by determining how long the source is maintained in each position.
High Dose Rate Machines

An HDR dose and number of fractionations equivalent to a given dose of LDR can be found by considering the radiobiological behavior of cells at two different dose rates\textsuperscript{31}. Machines working under different dose rate can bring the same effect, with little disadvantages, if used properly and adequately. Many vendors are selling high dose rate remote afterloading machines with different sources and the user has got sufficient choices of the machine based on the clinical and financial judgments. Buchler GmbH & Co. from Germany is marketing afterloading BUCHLER Facts, which is capable of doing interstitial, intracavitary, intraluminal and intraoperative therapy. It has a twelve-channel indexer and can be loaded with either a point source Ir-192 or a linear source Ir-192. Sixty steps are available with incremented steps of 1- to 10-mm for a maximum length of 300-mm.

Curietron Oris (CIS-US), France is another machine meant only for intracavitary high dose rate brachytherapy using source trains of Cs-137 capsules of desired length. Various applicators are available with this system.

Curietron-192 HDR unit is designed for intracavitary and interstitial treatments having twenty treatment channels and in each channel the source can move to a maximum of 64cm using thirty-two steps. The source used is 10Ci Ir-192.

The GammaMed 12i (the latest version of HDR after loader from Isotopen-Technik Dr. Sauerwein GmbH Germany, presently from Varian Med. Sys. Inc.) uses high activity Ir-192 sources. It can manage all the three main modes of brachytherapy with twenty four channels, each channel allowing forty steps of 0.1cm to 1cm increment over 40cm length.
Other earlier versions from this company were Gamma Med II (intracavitary unit, Ir-192 source, activity: 740 GBq,) and model IIi (12 channels, Ir-192 source, activity: 370 GBq)

Omnitron 2000, from Omnitron Corporation, USA is another HDR machine using 12Ci Ir-192 source with 20 channels to drive the source into the applicator. This can also be used to perform the three modes of brachytherapy

The Selectron HDR from Nucletron is designed for intracavitary and intraluminal brachytherapy treatments and contains twenty Co-60 pellets with a total activity of 370GBq. It has three channels.

Another high dose rate machine using Ir-192 source from Nucletron is Microselecton-HDR. A brief description of this particular machine will be presented in chapter IV as the present study uses the details of patients treated in this machine.

BEBIG, Germany also offers its high dose rate machine, BEBIG Multisource HDR, which can accommodate either Ir-192 or Co-60 source. It has an automated calibration system and an independent verification system with an integrated camera.
Fig.1.4 Commercially available modern high dose rate machines. (A) Microselectron HDR (B) GammaMed Plus (C) Curietron Multisource HDR (D) Varisource system
(Courtesy: M/s Nucletron; M/s Varian and M/s BEBIG)
Table 1.2 Some specific features of high dose rate machines (courtesy ESTRO booklet No. 8)

<table>
<thead>
<tr>
<th>Serial No</th>
<th>Manufacturer or Vendor</th>
<th>Varisource 200 Series (Varian Medical Systems Inc., USA)</th>
<th>Microselectron HDR (Nucletron, The Netherlands)</th>
<th>GammaMed 12i (Varian Medical Systems Inc., USA)</th>
<th>GammaMed Plus (Varian Medical Systems Inc., USA)</th>
<th>MultiSource (Bebig, Germany)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>1x44mGy-h⁻¹ @ 1m</td>
<td>1x40mGy-h⁻¹ @ 1m</td>
<td>1x80mGy-h⁻¹ @ 1m</td>
<td>1x60mGy-h⁻¹ @ 1m</td>
<td>1x100mGy-h⁻¹ @ 1m for Ir-192</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.59mm OD 5mm L</td>
<td>1.1mm OD 5mm L</td>
<td>1.1mm OD 5mm L</td>
<td>0.9mm OD 5mm L</td>
<td>1x25mGy-h⁻¹ @ 1m for Co-60</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Embedded in the Nitinol (Nickel-Titanium) source drive wire</td>
<td>Laser welded to drive cable</td>
<td>Welded to steed drive cable using a special weld technique</td>
<td>Laser welded to drive cable</td>
<td>Laser welded to drive cable</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>1,500mm</td>
<td>1,500mm</td>
<td>1,250mm</td>
<td>1,300mm</td>
<td>1,500mm</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>20</td>
<td>18</td>
<td>24</td>
<td>24</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Step-back, 20 steps</td>
<td>Step-forward 48 steps of 2.5mm over 12cm; 5mm over 24cm</td>
<td>Step-back, 60steps 1-10mm step size in 1mm increments</td>
<td>Step-back, 100steps step size as required in 1mm increments</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Stepping source at 48 positions, dwell times to 99% in 0.1s increments</td>
<td>Stepping source and dwell times to 99% in 1s increments</td>
<td>Stepping source and dwell times to 99% in 1s increments</td>
<td>Stepping source and dwell times to 99% in 1s increments</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Backup motor and independent backup drive assembly. Backup battery and additional backup hand crank.</td>
<td>Dual monitors and backup battery; emergency hand crank</td>
<td>Hand crank, backup battery</td>
<td>Backup motor powered by backup battery. Additional backup hand crank</td>
<td>Backup retraction drive system, additional hand crank and backup battery system</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>Separate control unit and treatment planning system</td>
<td>Separate control unit and treatment planning system</td>
<td>Integrated control unit and treatment planning system</td>
<td>Separate control unit and treatment planning system</td>
<td>Separate control unit and treatment planning system</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Yes, different optimization techniques</td>
<td>Yes, 300 optimization points</td>
<td>Yes, 60 optimization points</td>
<td>Yes, different optimization techniques</td>
<td>Yes, different optimization techniques</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>Small source wire allows use of 21G(0.84mm) needles</td>
<td>Memory storage, 99 standard treatments. Database of all treated patients</td>
<td>Memory storage of all planned and treated patients</td>
<td>Fixed length treatment distance and length check eliminate errors due to incorrect treatment length entry</td>
<td>Automated calibration and guide tube verification, database for applicators and patients, Co-60 or Ir-192 source</td>
</tr>
</tbody>
</table>
Pulsed Dose Rate Machines

Pulsed dose rate uses a large number of small fractions in an effort to simulate the radiobiologic advantages of LDR, but with the obvious advantages of stepping source and the radioprotection advantages of remote afterloading as in HDR. The outcome of in vitro experiments, of Brenner and Hall (1991), Mazeron et al (1992) and Armour E et al (1992), as well as of those of Fritz et al (1998), stated that from a radiobiological point of view, even for the largest implants, a source with a dose rate of 1Gy/hour or less using the pulsed dose rate method, should be adequate to be considered to be used as an alternative to the 0.5Ci or smaller linear activity of classical LDR treatments.

Using minimum pulse duration of 10 minutes repeated at every hour with a dose rate as low as possible such as 10Gy per day, comparable results of LDR in terms of local control and late side effects could be achieved using a PDR source with a dose rate of 1Gy/hr.

Microselectron - PDR

The microselectron-PDR is an afterloading brachytherapy delivery system that incorporates a single iridium-192 source, which may be propelled along one of 18 channels, each of which can be attached to a catheter, needle or other applicator or conduit previously placed within a proposed treatment volume. The single stepping source can be programmed to stop at or dwell at a variety of sites at 2.5mm intervals or longer interval along the applicators. This system has been widely used for the treatment of cancer of cervix but its role is slowly taken over by the high dose rate machines
Merits of HDR over other techniques

Low dose rate brachytherapy has been widely used with its proven role in decreasing the local recurrence rate and increasing the survival rate\textsuperscript{37,38}. Though LDR has got unbeatable clinical records, a few disadvantages that lead to the development of High Dose Rate (HDR) brachytherapy are existed. They are the prolonged treatment time involved and the consequent mandatory hospitalization, applicator movement and the patient discomfort due to being in the same position throughout treatment for the success of the treatment, and the possible exposure to the caregivers. Since the dose is delivered at a higher rate, the chances of potential toxicity must be higher than LDR. This concern has initially raised some reluctance in replacing LDR with HDR in United States\textsuperscript{39}. But it has gained wide acceptance all over the world today as its advantages outweigh disadvantages.

The potential late toxicity due to higher dose per fraction in HDR can be reduced by adequate selection of low dose per fraction and more number of fractions. Moreover, the late tissue complications can be minimized by separating these tissues farther away using retractors than in LDR, as the treatment time involved in HDR is very short compared to LDR. The shorter treatment time of the HDR unlike in LDR treatment reduces the discomfort of the patient due to prolonged bed rest. This short duration treatment also helps to avoid the possibility of the movement of the applicator during treatment; more number of patients can be treated in a day by treating them on outpatient basis. For the technical point of view, it has got some other added advantages compared to the LDR. Since the dimension of the HDR source is very small compared to the LDR, the size/diameter of the applicator is very much compact and this reduces the need for dilatation of the cervix; the applicator can easily be inserted and
therefore reduces the need for heavy sedation. Treatment-dose- distribution optimization is possible using HDR stepping source by dwelling at different positions and for different dwell times. This helps to give more conformal radiation to the region of interest\textsuperscript{40}. Another important advantage in HDR is that the total treatment time can be shortened by the appropriate interdigitation of intracavitary radiation (ICR) with an external beam radiotherapy (EBRT) schedule\textsuperscript{41}. There are a lot of studies comparing LDR with HDR in terms of local control, survival, and morbidity\textsuperscript{42-48} which does not show any significant differences between the two, while some others report that HDR is superior in terms of low rate of rectal morbidity. Table 1.3 lists some of the advantages and disadvantages of LDR and HDR in cervical cancers.

**Quality Assurance in Brachytherapy**

It is important to deliver safely, accurately and consistently the correct dose to the desired site within acceptable limits of accuracy without unnecessarily irradiating the patient, public and staff. This can be achieved only when safe work practices are strictly followed according to certain guidelines or protocols. To achieve this, equipment meant for the treatment should be tested for its functions regularly and confidence should be built up on its working and functions. This will ensure the quality of the treatment and the work practices. The variation in dose to tumor site can be either due to the clinical procedures such as the uncertainty in indication of the tumor volume on a localization radiograph or that due to physical procedures such as the determination of source strength, the dosimetric calculations etc. International Commission on Radiation Protection (ICRP) and World Health Organization (WHO) recommend that the uncertainty in dose specification due to these physical procedures should not be greater than 5%. A dose that is administered to the wrong treatment site is considered as misadministration.
## Table 1.3. Advantage and disadvantages of LDR and HDR
(Courtesy: Brachytherapy applications and Techniques. Philip M Devlin, 2006)

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDR</td>
<td>HDR</td>
</tr>
<tr>
<td>• &gt;100 years of data</td>
<td>• Inpatient treatment</td>
</tr>
<tr>
<td>• Standardized doses</td>
<td>• Short administration time</td>
</tr>
<tr>
<td>• Standardized treatment plans</td>
<td>• Standard source strength</td>
</tr>
<tr>
<td>• Standardized treatment time</td>
<td>• Source easily available</td>
</tr>
<tr>
<td>• Maximum two insertions</td>
<td>• Intravenous (IV) conscious sedation feasible</td>
</tr>
<tr>
<td></td>
<td>• Reassessment of tumor size with multiple fractions</td>
</tr>
<tr>
<td></td>
<td>• Dose optimization of normal tissues</td>
</tr>
<tr>
<td></td>
<td>• No staff exposure</td>
</tr>
<tr>
<td></td>
<td>• Applicator stabilized during treatment</td>
</tr>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
A comprehensive quality assurance program is necessary to verify that the devices used for treatment are performing in accordance with the manufacturer’s specifications to deliver the treatment accurately and safely.

Aims and Objectives of the proposed study

The calculation and reporting of dose to the critical organs such as bladder and rectum in the treatment of cancer of cervix using orthogonal films and its correlation with rectal and bladder complications need to be studied further to evaluate the correct reporting of dose. Various methods are available to find out the dose at these critical organs. The variation in dose at these points depends on applicator geometry, amount of packing, immobilization of the applicator and the selection of these points. In a practical situation, the catheter tracking for the reconstruction of the applicator may pose difference in the judgment of the position, due to the poor visibility or overlapping, of the x-ray markers of the ovoids from the lateral radiographs. The selection of rectal and bladder points and the dwell positions to achieve a desired distribution will change from person to person. This study aims to find out the variation, if any, to the bladder and rectal doses when different observers do the treatment planning (inter-observer variation) for the same patients.

Another aspect of the study is to see the variation of the rectal and bladder doses and their percentage variation when it is assumed that a particular patient is being treated in successive sittings with a treatment plan, which is planned for the first sitting.

During applicator insertion for treating cancer of the uterine cervix by remote after loading technique, most of the centers use gauze packing for reducing the rectal and bladder dose by separating them away
from the applicator. The procedure is painful and provides discomfort to the patient especially when the treatment duration is long. Joelsson and Backstrom have shown that the dose on the anterior rectal wall increases by 26% over 24 hours due to maceration of the gauze packing. Though HDR is a short duration procedure the maceration of gauze packing can not be ruled out. The efficacy and adequacy of packing can be understood only during the simulation procedure. If this is found to be inadequate, then for repacking, the patient has to be taken back to the theatre and this will again provide discomfort to the patient, loss of time for the brachytherapy team, simulator procedure time, and at the same time another patient’s chance of getting treatment if the hospitals, such as RCC, Trivandrum, is treating more patients in a day. This serious issue can be avoided if one makes necessary adjustments of the packing at the simulation room itself. This forced us to make a low cost, single use, independently controllable device from naturally available resources for reducing the rectal and bladder dose.

The design of this new device and its production and its clinical evaluation also form a major part of this study. Whether the introduction of this balloon can retain reproducibility in treatment over successive treatments will also be evaluated. The geometrical variation within a fraction and between fractions when the balloon is inflated with different volume will be studied and presented. Attempt will be done to see whether the introduction of the balloon can bring down the inter observer variation in planning.

Outline of the Thesis

The first chapter of this research work describes briefly about brachytherapy, the different systems followed, the different types of remote afterloaders available, and a brief description of aim and objectives of the present study.

A literature survey relevant to the aims and objectives is presented in chapter II.
In chapter III, explanation of the various quality assurance tests done on the important machines involved in the study is presented.

In chapter IV, the materials and methods adopted for fulfilling the thesis are explained. The design criteria adopted and the development of the balloon and its use in clinical situation is explained in this chapter.

Chapter V presents the results obtained from the study and the discussion is presented along with the results.

The conclusion of the thesis is presented in chapter VI along with scope for future work.
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