Distribution of Brachytherapy Doses for Cervical Cancer using Vaginal Cylinder and Ovoid Applicators

R Arif Wibowo¹, Bambang Haris², Cindy Anindya Putri Winarya¹, Khusnul Ain³

1. Physics Department, Faculty of Science and Technology, Airlangga University, Surabaya, Indonesia, email: r-arif-w@fst.unair.ac.id
2. Regional General Hospital of dr. Soetomo, Surabaya, Indonesia
3. Biomedical Engineering, Faculty of Science and Technology, Airlangga University, Surabaya, Indonesia

ABSTRACT. Brachytherapy is a method for the treatment of cancer, especially cervical cancer. Intracavitary brachytherapy is done by inserting an applicator into the patient's body. Various types of applicators can be used. This study aims to determine the difference in the distribution of doses between vaginal cylinder and ovoid applicators in brachytherapy cervical cancer. There are 16 radiation dose data at point A right and left. The initial dose is given to patients in the ranges from 6 - 8.5 Gy. Calculation of radiation doses are based on AAPM TG-43 by using the Brachytherapy Planning program and done at point A right and left. The radiation point A dose with both applicators were analyzed using independent t-test. The average dose using an ovoid applicator is 2.596 Gy for point A right and 2.630 Gy for point A left, while with the vaginal cylinder applicator is 1.565 Gy at point A right and 1.564 Gy at point A left. There is a significant difference in the dose received by HR-CTV in terms of point A left by using both types of applicator (sig. = 0.007) and from point A right by using each applicator (sig. = 0.001) with α = 0.05. Ovoid applicators provide a more homogeneous dose in terms of the radiation dose at point A so that it becomes an applicator that is more effective in intracavitary brachytherapy of cervical cancer.

1. Introduction

Cancer is a cell that grows and spreads uncontrollably. Cancer can affect all parts of the human body, so that it becomes one of the main causes of death in the world population. There are many cases of cancer that occur in the world, especially in women, namely breast cancer, vaginal cancer, and cervical cancer. Based on estimates of the number of cancer patients in Indonesia, Central Java and East Java Province are the provinces with the highest cancer estimates, which are about 68,638 and 61,230 people respectively. Cervical cancer is a cancer with the highest prevalence in Indonesia, which is equal to 0.8 /100 or an estimated absolute number of 98,692 people [8].

Some of the usual treatments for cervical cancer therapy are surgery, chemotherapy, and radiotherapy. Surgery can kill the impact of cancer cells in only limited areas. While chemotherapy is the use of drugs that are distributed throughout the body, it also has an adverse effect that affects healthy cells around cancer cells [1].

Radiotherapy is classified into two types, namely external and internal radiotherapy or brachytherapy. External radiotherapy uses the source of photons in the machine and directs the photon beam to the patient. This one is also called teleterapi [5].

Internal radiation or brachytherapy utilizes radionuclide sources that have been wrapped in capsule and inserted directly in the target volume or near it. The source in brachytherapy is covered to
accommodate radioactivity, give source hardness, and absorb $\alpha$ radiation generated from source decay. The source of radionuclides that are inserted in the body can be temporary or permanent, with the techniques used commonly i.e. interstitial and intracavitary. Intracavitary treatment is always temporary and relatively short in time [7].

Based on the dosage, brachytherapy is classified as Low Dose Rate (LDR), Medium Dose Rate (MDR), and High Dose Rate (HDR). Brachytherapy LDR and HDR are more commonly used than MDR. LDR has a dose 0.4 to 2 Gy / hour and HDR has a dose more than 12 Gy / hour. The advantages of using HDR brachytherapy include good immobilization that can be carried out on an outpatient basis, good comfort for patients, good accuracy of source position and applicator, independent care with source optimization, and radiation protection for radiotherapists [4].

The most common depiction of dose distribution is using two-dimensional (2-D) dose distribution. The depiction also shows the isodose rate line, desired target, and source location. Calculation of 3-D provides an analysis of dose distribution by considering coverages of the target volume and doses for normal tissue. The calculated dose values were used in the surface depiction of isodosis and DVH [7].

The dosage on the target (HR-CTV) can be reviewed from point $A$. According to the recommendations of the American Brachytherapy Society (ABS) point A is defined as a coordinate point $(2,2)$ cm or $(-2,2)$ cm from the source $(0,0)$ [6].

Previous research on dose evaluation was conducted by Reduan Abdullah, et. al. (2015) [10] regarding to the evaluation of Organ at Risk (OAR) dose based on a two-dimensional treatment plan for intracavitary brachytherapy corresponding to cervical cancer [10]. There was also an evaluation of Organ at Risk (OAR) dose of cervical cancer using Dose Volume Histogram (DVH) in brachytherapy by R. Arif Wibowo, et.al. [9]. From these previous studies can be seen that evaluation of a better dose is by using DVH. Accordingly to see the dose distribution on the applicator can be started from reviewing the dose value on DVH, namely D100, D90, and D50 which are dose at the ratio of the total volume of 100%, 90% and 50%. Intracavitary applicator determination in Brachytherapy HDR is very important in therapy with different dosage applicator distribution. In terms of application, the vaginal cylinder and ovoid applicator are used for cervical cancer that has not reached the uterus. However, it is necessary to distinguish the dose distribution from the two applicators to determine the effectiveness of each applicator.

2. Materials and Methods

2.1. Preparation.

In the process of brachytherapy must be ensured that all components in therapy are calibrated and ready for use. The patient must be declared ready.

2.2. Installation of Applicator.

Before brachytherapy is carried out, the patient is anesthetized locally. The purpose of anesthesia is to reduce pain during the installation of the applicator. The purpose of anesthesia is to reduce pain during the installation of the applicator. The applicator function is to irradiate tumors in the cervix. The applicators that will be used in this study are the ovoid and vaginal cylinder.

2.3. Process of CT-Scan.

Scanning is performed after the applicator is attached. Patients will be observed with a CT-scan to get images displayed in 3D using Digitally Radiography Reconstruction (DRR). The obtained results are distributed to the Brakiterapi HDR room for the continuation of the Treatment Planning System (TPS) process through the Digital Imaging and Communications in Medicine (DICOM) program. The definition of the target is determined by a doctor through a contour process, in this process each organ will be colored in a different color.
2.4. Implementation of TPS.

After obtaining data from the CT scan room, TPS will be carried out in the HDR brachytherapy room. TPS is a dose calculation process for the patient's cervix. In the TPS process, a Brachytherapy Planning program is used that can calculate the dose using images from the patient's CT scan and dose distribution from DVH.

2.5. Determination of Dose Distribution.

To determine the dose distribution of each applicator, a right and left A points were observed in the patients on the scanning results. This process can define the target dose specifications. The dose distribution of $D_{100}$ and $D_{90}$ were calculated on DVH based on the American Association of Physicist in Medicine (AAPM) TG-43 using a computer program in the brachytherapy HDR control room for the geometry of each applicator. This is intended to find out how the doses of the applicators is distributed to cervical cancer. Theoretically, the dose distribution according to AAPM TG-43 can be explained by the equation [7]:

$$
\hat{D}(r, \theta) = S_K \Lambda G(r, \theta) g(r) F(r, \theta),
$$

where

- $\hat{D}(r, \theta)$: the dose rate at point P,
- $r$: the distance of position vector of point P from source,
- $\theta$: the angle between the position vector of point P to the axis of the source,
- $S_K$: intensity of kerma of source’s air (μGy.m².h⁻¹),
- $\Lambda$: dose rate constant in water,
- $G(r, \theta)$: geometric functions,
- $g(r)$: radial dose function,
- $F(r, \theta)$: anisotropic function.

2.6. Data analysis.

Statistical analysis performed for the distribution of doses at point A is the normal test. The difference in radiation dose from both applicators was tested by Independent T-test using an application program of the IBM SPSS Statistics 21. From the Independent T-test can be seen that there is or no difference in radiation dose at point A.

3. Result and Discussion.

This study involved 16 patients diagnosed with cervical cancer with stage I - IIB and aged 50 to 68 years. Eight female patients were treated using an ovoid applicator, while the rest used a vaginal cylinder applicator. The dose of radiation prescribed in each patient has a range between 6 - 8.5 Gy. Figure 1 (a) shows the doses distribution using a vaginal cylinder applicator in the Brachyvision Treatment Planning System, while a distribution using an ovoid applicator is shown in Figure 1 (b).

![Figure 1](image_url)
Tables 1 and 2 show that the prescribed dose given to patients is not the same in each applicator. This dose does not depend on any factor so it cannot be compared between patients with one another. The radiation dose at right and left A points also does not depend on the age of the patient.

### Table 1. Prescribed and Radiation doses using an ovoid applicator

| Age (year) | Prescribed Dose (Gy) | Radiation dosage with ovoid applicator at point A (Gy) | right | left |
|------------|----------------------|----------------------------------------------------------|-------|------|
| 50         | 6.00                 |                                                          | 2.591 | 2.891|
| 50         | 8.50                 |                                                          | 2.839 | 2.765|
| 55         | 7.00                 |                                                          | 2.123 | 2.382|
| 55         | 7.50                 |                                                          | 3.457 | 3.633|
| 55         | 8.50                 |                                                          | 2.090 | 1.720|
| 55         | 8.50                 |                                                          | 2.460 | 2.630|
| 58         | 8.00                 |                                                          | 2.030 | 1.880|
| 58         | 8.50                 |                                                          | 3.174 | 3.845|
| Average    |                      |                                                          | 2.596 | 2.718|

### Table 2. Prescribed and Radiation doses using an vaginal cylinder applicator

| Age (year) | Prescribed Dose (Gy) | Radiation dosage with vaginal cylinder applicator at point A (Gy) | right | left |
|------------|----------------------|------------------------------------------------------------------|-------|------|
| 50         | 8.50                 |                                                                  | 1.455 | 1.526|
| 51         | 7.00                 |                                                                  | 1.233 | 1.189|
| 56         | 7.00                 |                                                                  | 1.224 | 1.314|
| 57         | 7.00                 |                                                                  | 1.832 | 1.879|
| 60         | 8.50                 |                                                                  | 1.738 | 1.892|
| 60         | 7.00                 |                                                                  | 1.605 | 1.577|
| 60         | 7.00                 |                                                                  | 1.321 | 1.263|
| 68         | 7.00                 |                                                                  | 2.109 | 1.868|
| Average    |                      |                                                                  | 1.565 | 1.564|

The average dose received at the right A point for the ovoid and vaginal cylinder applicator respectively are 2.596 ± 0.569 Gy and 1.565 ± 0.317 Gy. While the average dose received by patients at the left A point for both the ovoid and vaginal cylinder applicator are 2.178 ± 0.805 Gy and 1.564 ± 0.292 Gy respectively. Statistical tests using the independent $t$-test showed that there were significant differences in doses at both right and left points between the two types of applicator (with significance values of sig. = 0.001 and sig. = 0.007 respectively).

The dose distribution of each applicator can be determined from the dose at a certain volume indicated by Dose Volume Histogram (DVH). The dose is taken at $D_{90}$ because according to EMBRACE the $D_{90}$ is the dose assigned and reported for HR-CTV of cervical cancer [3]. Then the dosage is seen at $D_{100}$ and $D_{50}$ to determine the dose distribution of each applicator. Table 3 shows a certain volume dose of the ovoid applicator while table 4 is a dose at a certain volume using a vaginal cylinder applicator. The dose distribution in both applicators according to $t$-tests is that there is no significant difference (sig. = 0.951) with $p = 0.05$. 

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### Table 3. Specific volume doses using ovoid applicators

| No. | Doses at Volume using Ovoid Applicator (Gy) | \(D_{100}\) | \(D_{90}\) | \(D_{50}\) |
|-----|-------------------------------------------|-----------|-----------|-----------|
| 1.  |                                           | 3.970     | 6.612     | 11.020    |
| 2.  |                                           | 3.452     | 7.365     | 11.518    |
| 3.  |                                           | 4.817     | 7.404     | 11.948    |
| 4.  |                                           | 5.072     | 8.533     | 14.891    |
| 5.  |                                           | 4.544     | 7.626     | 15.033    |
| 6.  |                                           | 3.334     | 7.643     | 14.975    |
| 7.  |                                           | 4.377     | 7.643     | 14.975    |
| 8.  |                                           | 6.730     | 11.264    | 25.346    |
| **Average** |                                        | 4.537     | 8.011     | 14.963    |

### Table 4. Specific volume doses using vaginal cylinder applicators

| No. | Doses at Volume using Ovoid Vaginal Cylinder Applicator (Gy) | \(D_{100}\) | \(D_{90}\) | \(D_{50}\) |
|-----|-------------------------------------------------------------|-----------|-----------|-----------|
| 1   |                                                             | 3.941     | 7.376     | 13.088    |
| 2   |                                                             | 5.829     | 8.854     | 14.335    |
| 3   |                                                             | 6.017     | 9.148     | 15.088    |
| 4   |                                                             | 6.759     | 8.697     | 13.105    |
| 5   |                                                             | 6.057     | 9.604     | 13.873    |
| 6   |                                                             | 6.790     | 9.118     | 13.733    |
| 7   |                                                             | 5.713     | 8.456     | 14.192    |
| 8   |                                                             | 6.097     | 8.486     | 14.943    |
| **Average** |                                                        | 5.900     | 8.717     | 14.045    |

According to the European Study on MRI-guided Brachytherapy in Locally Advanced Cervical Cancer (EMBRACE) in 2008, the effectiveness of applicators in brachytherapy of cervical cancer can be determined from the dose received by HR-CTV and OAR [3]. The dose received by HR-CTV must be more than 6 Gy per fraction and the dose of \(D_{2cc}\) received by OAR must be less than 70 - 75 Gy overall plus EBRT in the rectum, less than 75 Gy in the sigmoid and less than 90 Gy for the bladder.

The results are in accordance with the first EMBRACE criteria i.e. the dose received by the target (HR-CTV) is more than 6 Gy per fraction. Both applicators according to the criteria as an applicator are effective in the treatment of cervical cancer based on the EMBRACE statement. According to Ka-BAPETEN No. 21 of 2002 the effective therapy can provide a large dose of cancer targets and a minimum in surrounding healthy tissue (OAR) [2]. At Point A, the ovoid applicator matches the first criterion because it gives a larger dose. But in both types of applicator, point A is not a target and also not as a reference point for reviewing the dose, thus the dose is taken from the Dose Volume Histogram (DVH). Based on DVH, \(D_{90}\) is the point of determining and reporting doses received by patients who have been internationally recognized. At this point the vaginal cylinder applicator matches the BAPETEN criteria in the first effectiveness criteria because it gives a larger dose to the target cancer (HR-CTV) which is stated through \(D_{90}\).

### 4. Conclusion
1. The average dose received at the right A point for the ovoid and vaginal cylinder applicator respectively are 2.596 ± 0.569 Gy and 1.565 ± 0.317 Gy. While the average dose received by patients at the left A point for both the ovoid and vaginal cylinder applicator are 2.178 ± 0.805 Gy and 1.564 ± 0.292 Gy respectively.

2. There is a significant difference in doses at right and left of A points between the two types of applicators (with significance values of sig. = 0.001 and sig. = 0.007 respectively). According to the test there is no significant difference of dose distribution in both applicators (sig. = 0.951) with p = 0.05.

3. According to the first criteria of EMBRACE, the ovoid and vaginal cylinder applicator were effective. But according to BAPETEN, the vaginal cylinder applicator is more effective in brachytherapy of cervical cancer.

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