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Photon Dose Distribution Analysis Using Three-Dimensional Conformal Radiation Therapy (3DCRT) And Intensity Modulated Radiotherapy (IMRT) Techniques In Cervical Cancer Cases Based On Histogram Volume Dose Curve (DVH)

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ABSTRACT

Radiotherapy is one of the effective treatment methods for cervical cancer, although it is faced with great challenges in delivering an accurate dose of radiation. The purpose of this study was to compare the effectiveness of two cervical cancer treatment techniques, namely Three-Dimensional Conformal Radiation Therapy (3DCRT) and Intensity Modulated Radiotherapy (IMRT) in terms of conformity, homogeneity, and protection of Organs at Risk (OAR). The study used primary data from DVH 3DCRT and IMRT techniques collected from 15 cervical cancer patients. Conformity index (CI) and homogeneity (HI) were evaluated, and dose at OAR was assessed according to QUANTEC rules. The results showed the average CI value for the 3DCRT technique was $(96,7 \pm 1,5) \times 10^{-2}$, while for IMRT it was $(98,8 \pm 0,8) \times 10^{-2}$. In addition, the average HI score for the 3DCRT technique was $(9,6 \pm 1,5) \times 10^{-2}$, and for IMRT it was $(6,8 \pm 1,9) \times 10^{-2}$. In the 3DCRT technique, V_{50} for the rectum ranges from 0 – 57%, V_{65} for the bladder is 0%, and V_{50} for the left and right femoral heads ranges from 0 – 15.92% and 0 – 10.86%. While in the IMRT technique, V_{50} for the rectum ranges from 0 – 40,56%, V_{65} for bladder is 0%, and V_{50} for the left and right femoral heads ranges from 0 – 0,3% and 0 – 1,05%. The results of this study showed that the IMRT technique was better and more effective in treating cervical cancer than the 3DCRT technique. The IMRT technique has a higher CI value, indicating a better level of conformity, as well as a lower HI value, signifying a higher level of homogeneity. In addition, the IMRT technique is also able to provide better OAR protection.

Keywords : Cervical Cancer, 3DCRT, IMRT, Conformity Index, Homogeneity Index

I. INTRODUCTION

Cervical cancer is a cancer that attacks the cervix or cervix caused by the *Human Papillomavirus*, this cancer ranks fourth most often found in the world [1], with an estimated 604,000 new cases and 342,000 deaths worldwide in 2020 [2]. *The Global Cancer Observatory* (Globocan) in 2018 has analyzed data from 185 countries which shows that Indonesia is one of the largest contributors to cervical cancer cases in Southeast Asia with a total of around 24 per 100,000 women each year [1]. With these statistics it is certainly important to find an effective method of prevention, examination and treatment for cervical cancer. The method currently being developed in Indonesia for the treatment of cervical cancer is radiotherapy with *Linac aircraft* modality.

External radiotherapy with *Linear Accelerator* (Linac) modality is a very effective treatment for early and advanced cervical cancer [3]. The ionizing radiation properties emitted by radiotherapy aircraft can ionize and result in cancer cell death directly by inducing DNA double-stranded break [4]. Although external radiotherapy plays an important role in cancer treatment due to its working principle and effectiveness, it also has great challenges in delivering radiation doses accurately with minimal toxicity [5], so the selection of the right technique becomes very important in radiotherapy. *Three Dimensional Conformal Radiation Therapy (3DCRT) and* Intensity Modulated Radiotherapy *(IMRT) techniques* are advanced radiotherapy techniques that have been developed in recent decades to increase the degree of suitability of the target area as well as radiation dose, and to reduce toxicity to normal organs [5].

The Three Dimensional Conformal Radiation Therapy (3DCRT) technique is one of the planning techniques in external radiotherapy developed in the late 1990s as the treatment of choice for cancer with better targeted coverage of radiation dose distribution and significantly reduced toxicity in normal organs compared to 2D-CRT [5]. The development of the 3DCRT technique is the *Intensity Modulated Radiotherapy* (IMRT) technique which refers to 3-dimensional imaging data. IMRT allows for radiation doses to correspond more precisely to the 3-dimensional shape of the tumor by modulating or controlling the intensity of the radiation beam at several small volumes [5].

The thing that needs to be prepared before doing radiotherapy treatment is to make a planning system. *Treatment Planning System* (TPS) is a therapy planning system using radiation with output in the form of a radiation dose distribution curve on the target or commonly called the *Dose Volume Histogram* (DVH) so that the dose can be known in *Gross Tumor Volume (GTV), Clinical Target Volume (*CTV), *Planning Target Volume* (PTV) and also *Organs at Risk* (OAR) [6]. The level of conformity of the irradiation plan can be measured by *the Conformity Index* (CI) which shows the ratio of the target volume exposed to the reference dose to the PTV volume. CI values close to 1 are more *conformal* [7]. Then for uniformity of dose distribution can be calculated with the *Homogeneity Index* (HI) which shows the difference between the dose close to the maximum and almost the minimum normalized with the *median* dose. HI values close to zero indicate a more *homogeneous* dose distribution in PTV [7].

In this study, as many as 15 samples of *CT-Simulator* image data that have been contoured by Radiation Oncology Doctors and TPS data using the 3DCRT technique in cervical cancer with 6 MV linac aircraft and with the same dose will be collected for *re-planning* by researchers assisted by medical physicists using the IMRT technique. The dose values obtained on the OAR, *Conformity Index* and *Homogeneity Index* of both techniques will be analyzed to find out which technique has a better dose distribution.

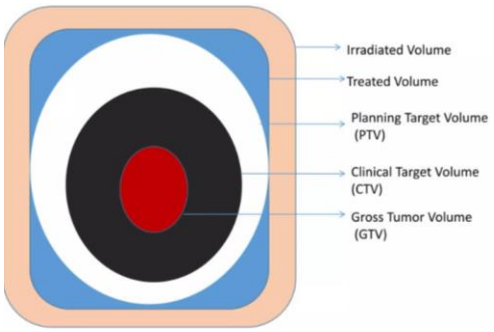
II. THEORETICAL BASIS

Radiotherapy

Radiotherapy is one of the many ways that have been proven effective in cancer treatment, namely by

giving patients a certain dose of ionizing radiation that can ionize and result in cancer cell death directly by inducing DNA double-stranded break [8]. Radiotherapy is divided into two types, first the radiation source is outside the patient's body commonly known as *External Beam Radiotherapy* (EBRT), then there is the radiation source placed in the patient's body known as *Brachytherapy* [8].

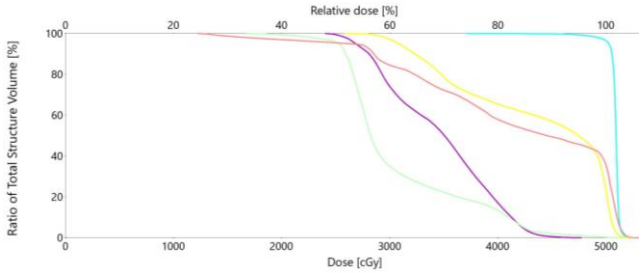
Some things that need to be prepared before doing radiotherapy treatment, is to make a *Treatment Planning System* (TPS). TPS is a computer system used to plan radiotherapy treatment both doses, fractions performed, direction of irradiation angle, and number of irradiation fields. The output of TPS is a curve that gives an idea of radiation dose in *Gross Tumor Volume (GTV) which* is the volume of tumor that can still be seen or palpable, *Clinical Target Volume (CTV) which includes GTV and microscopic dispersal* areas, Planning Target Volume (*PTV) or areas planned to be the target of irradiation, and also* Organs at Risk *(OAR) around cancer [6].*



Gambar 1. Target Volume (ICRU, 1993)

Dose Volume Histogram **(DVH)**

Dose Volume Histogram (DVH) is a curve that describes the distribution of doses to targets or organs in the *Treatment Planning System.* DVH can be used as a benchmark for the success or failure of a *plan* carried out based on dose optimization at the target irradiation (PTV) and limitations on at-risk organs (OAR). DVH can clearly display the level of conformity and homogeneity of doses on a target so that it can be used as an evaluation material, but DVH cannot clearly display the position of *hot spots* or doses that are below the threshold [6]. Here is an example of DVH.



Gambar 2. *Dose Volume Histogram*

Three-Dimensional Conformal Radiation Therapy **(3DCRT)**

3DCRT is a radiotherapy planning and delivery process that refers to three-dimensional imaging data (CT Simulator) and the shape of the irradiation field is adjusted and as close as possible to the target volume to maximize the dose received by the tumor and minimize the dose received by surrounding healthy tissue [9]. The 3DCRT technique usually uses a smaller number of fields so that the irradiation time is shorter than the IMRT technique, then the MLC is static and the beam management is still manual so as to produce a uniform dose for each field.

Intensity Modulated Radiotherapy **(IMRT)**

IMRT is a method of radiotherapy with high precision. Unlike the 3DCRT technique which can provide a uniform intensity to the target, IMRT provides a non-uniform intensity. In the IMRT technique, the influence of non-uniform energy in a complex target is achieved by several beams, in this case the dynamic MLC forms a new irradiation field during therapy. IMRT uses a large number of monitoring units compared to 3DCRT because it involves many beams, achieving accurate beam intensity at each point in the tumor tissue [7].

Conformity Index

The degree of plan conformity is measured by the conformity index (CI) which is the ratio of the volume of tissues receiving at least 95% of the specified dose divided by the volume of PTV. CI values close to 1 are more conformal [7].

$$CI = \frac{V_{95\%}}{V_{PTV}} \qquad (1)$$

where CI *is the Conformity Index*, $V_{95\%}$ is the volume of tissue receiving at least 95% of the dose and VPTV is the volume of PTV.

Homogeneity Index

The homogeneity index (HI) is the difference between the near-maximum and near-minimum doses normalized with the median dose, in other words, the homogeneity index indicates the degree of dose uniformity. A close HI value of zero indicates a more homogeneous dose distribution in PTV [7].

$$HI = \frac{D_{2\%} - D_{98\%}}{D_{50\%}} \qquad (2)$$

where HI is the homogeneity index, $D_{2\%}$ is the dose at 2% tissue volume, $D_{98\%}$ is the dose at 98% tissue volume, and $D_{50\%}$ is the dose at 50% tissue volume.

III. RESEARCH METHODS

The research was conducted for 6 months at the Radiation Oncology Installation of Indriati Solo Baru Hospital, Sukoharjo, Central Java for data collection and at the Department of Physics, Faculty of Science and Mathematics, Diponegoro University for data processing. The data used in this study is primary data. Primary data were obtained from medical records of cervical cancer patients undergoing treatment at the radiotherapy facility of Indriati Hospital Solo Baru. Data collection was carried out by sampling as many as 15 patients treated with the 3DCRT technique which would then be made a comparison plan using the IMRT technique. *External Beam Planning with the 3DCRT technique was made by* medical physicists using 4 irradiation fields from directions 0, 90, 180 and 270 with a total dose of 50 Gy in 25 times the fraction, while the IMRT technique was made by researchers using the same dose, amount and direction of irradiation *field as the* 3DCRT technique.

The output of the plan is the DVH curve in which dose values can be found in OAR, as well as V95, D2%, D50%, and D98% in PTV. To calculate CI and HI respectively can use the formulas (1) and (2), after which the average value is calculated using the following formula

$$\overline{CI} = \frac{CI_1 + CI_2 + CI_3 + \cdots + CI_{15}}{15} \qquad (3)$$

$$\overline{HI} = \frac{HI_1 + HI_2 + HI_3 + \cdots + HI_{15}}{15} \qquad (4)$$

It is this average calculation that will then be analyzed and compared to find out which technique has a better dose distribution.

IV. RESULT AND DISSCUSSION

Dose limitations in OAR are regulated in QUANTEC, where for cervical cancer there are several OARs as in table 1.

Tabel 1. OAR in cervical cancer

OAR	Dose	Volume
Rectum	5000 cGy	< 50%
Bladder	6500 cGy	< 50%
Femoral Head	5000 cGy	< 5%

Then obtained the dose value on OAR in each patient using the 3DCRT and IMRT Techniques as follows.

Tabel 2. OAR dosage using 3DCRT

Patient	Rectum (%)	Bladder (%)	Femoral Head L (%)	Femoral Head R (%)
1.	0	0	0	0
2.	7,20	0	0,86	0
3.	0,21	0	0,80	1,85
4.	26,57	0	15,92	1,64
5.	36,30	0	0	0
6.	52,75	0	0,38	1,41
7.	32,67	0	0	0
8.	13,84	0	0,03	0
9.	16,29	0	7,67	7,42
10.	1,30	0	0	0
11.	11,39	0	1,59	0
12.	4,79	0	0,44	0,32
13.	30,18	0	0	0
14.	57,85	0	10,71	10,86
15.	47,97	0	0	0

Tabel 3. OAR dosage using IMRT

Patient	Rectum (%)	Bladder (%)	Femoral Head L (%)	Femoral Head R (%)
1.	0	0	0	0
2.	17,45	0	0	0
3.	1,59	0	0	0
4.	35,45	0	0	0,31
5.	3,38	0	0	0
6.	6,23	0	0	0,18
7.	9,86	0	0	0
8.	2,06	0	0	0
9.	0	0	0	0
10.	1,84	0	0	0
11.	0,41	0	0,30	0
12.	1,79	0	0	0
13.	40,26	0	0	0
14.	0,12	0	0	1,05
15.	1,66	0	0	0

Based on the analysis that has been done and presented in table 3 it can be concluded that the IMRT technique can protect OAR better than the 3DCRT technique, this is evidenced by the fulfillment of all dose limitations in all *organs at risk* and the average dose value smaller than 15 patients.

CI Value 3DCRT and IMRT Techniques

A comparative graph of *the Conformity Index* (CI) of 3DCRT and IMRT techniques is presented in figure 3.

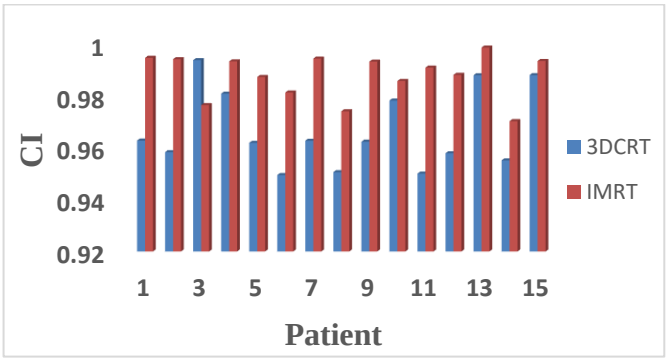


Figure 3. Comparison graph of CI 3DCRT and IMRT Techniques

From the comparison graph of CI techniques 3DCRT and IMRT it can be seen that the IMRT technique has a higher CI value and is close to one for almost all patients, so it can be concluded that the IMRT technique has a higher average CI value than IMRT technique. The mean CI value for the 3DCRT technique was (96.8 ± 1.5) x 10^{-2} and for the IMRT technique was (98.8 ± 0.86) x 10^{-2}

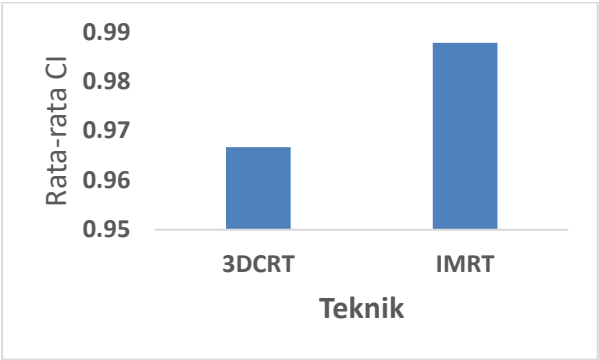


Figure 4. Average Of CI 3DCRT and IMRT Techniques

HI Value 3DCRT and IMRT Techniques

A comparative graph of *the Homogeneity Index* (HI) of 3DCRT and IMRT techniques is presented in figure 5.

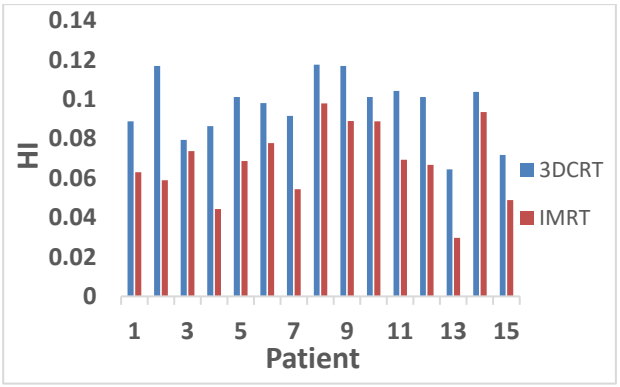


Figure 5. Comparison chart of HI 3DCRT and IMRT Techniques

Based on figure 5, it can be seen that the IMRT technique has a lower HI value than the 3DCRT technique for each patient, marked with a lower graph. So that the average HI of the IMRT technique is lower than the 3DCRT technique. The average HI value for the 3DCRT technique was (9.6 ± 1.6) x 10^{-2} and for the IMRT technique was (6.8 ± 1.9) x 10^{-2}.

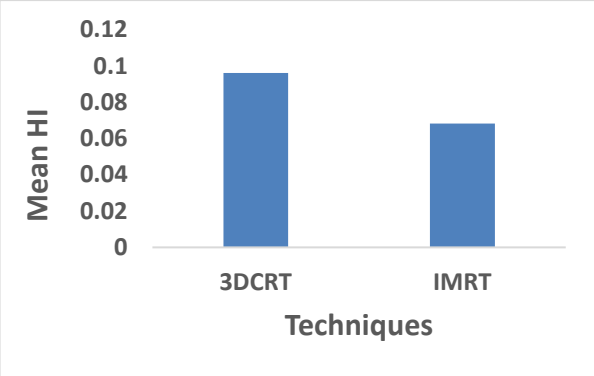


Figure 6. Average HI of 3DCRT and IMRT Techniques

Comparative Analysis of Conformity Index of 3DCRT and IMRT Techniques

The 3DCRT technique has a CI value ranging from 0.9495 to 0.9939 with an average value of 0.9667, while for the IMRT technique it ranges from 0.9703 to 0.9987 with an average value of 0.9878. Overall, the CI values of both techniques meet the standards set out in ICRU reports 62 and 83 so that both irradiation techniques are considered to be usable in radiotherapy planning cervical cancer cases. However, the average CI value of the IMRT technique is greater and close to the ideal value for CI which is 1, so the IMRT technique is considered more conformal than the 3DCRT technique.

Comparative Analysis of Hormogeneity Index of 3DCRT and IMRT Techniques

The 3DCRT technique has an HI value ranging from 0.064 to 0.118 with an average value of 0.0962, while for the IMRT technique it ranges from 0.03 to 0.098 with an average value of 0.068. Overall, the IR scores of both techniques have met the standards set out in ICRU reports 62 and 83 so that both irradiation techniques are considered to be used in radiotherapy planning, especially cervical cancer cases. However, the average value of the IR of the IMRT technique is smaller and close to the ideal value for HI which is 0, so the IMRT technique of dose distribution is considered more uniform than the 3DCRT technique.

V. CONCLUSION

In the 3DCRT technique, the *volume of the rectum* exposed to a dose of 5000 cGy ranges from 0-57% with an average volume of 22.61%, for the bladder *there is no volume exposed to a dose of 6500* cGy so that the average volume is 0%, for the left femoral head the volume exposed to the dose of 5000 cGy ranges from 0-15.92% with an average volume of 2.56%, finally for the femoral head Right volume exposed dose 5000 cGy ranges from 0-10.86% with average volume of 1.57%. Then in the IMRT technique, the volume of the *rectum exposed to a dose of 5000 cGy ranges from 0-40.56% with an average volume of 8.14%, for the* bladder there is no volume exposed to the dose of 6500 cGy so that the average volume is 0%, for the left femoral head the volume exposed to the dose of *5000 cGy ranges from 0-0.3% with an average volume of 0.02%, finally* for the femoral head Right volume exposed dose 5000 cGy ranges from 0-1.05% with average volume 0.10%.

The 3DCRT technique has CI $(96.8 \pm 1.5) \times 10^{-2}$ and HI $(9.6 \pm 1.6) \times 10^{-2}$, while the IMRT technique has CI $(98.8 \pm 0.86) \times 10^{-2}$, and HI $(6.8 \pm 1.9) \times 10^{-2}$. So it can be concluded that the IMRT Technique has a more *conformal* and *homogeneous* dose distribution than the 3DCRT Technique.

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