Determination of effective dose distribution on the target volume of cancer and organ at risk using MCNPX

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Abstract. One method of therapy in cancer is Brachytherapy, which is by implanting radioactive radiation that emits gamma into the target organ. Because brachytherapy will also provide radiation doses to healthy organs around it so before doing therapy it is better to do the simulation first so that the dose received is the maximum target and the dose received by healthy organs in the vicinity (organ at risk) is minimal. The purpose of this study was to determine the distribution of the absorption dose in liver cancer with radiation source γ 103 Pd using MCNPX. In this study the target organ used was liver (liver cancer). Organs at Risk in liver cancer are the right lung, kidney and pancreas. One way to simulate this is to use Monte Carlo N Particles eXtended (MCNPX). In this study used 103 Pd radioactive. the variation in the number of seeds used is from 10 to 70 seeds with an increase of 10. The 103Pd activity used is 2x10^3 Ci. The results of the MCNPX simulation show that the effective dose is directly proportional to the number of seeds used. Effective doses in the liver are 0.101 to 0.699 Sv, in the right lung 0.032 to 0.229 Sv, in the kidney 0.0005 to 0.0039 Sv and in the pancreas 0.0001 to 0.0149 Sv. If in the liver the percentage of effective dose is 100%, then the distribution of effective dose percentage in the right lung is 34.67%, kidney 0.63% and pancreas 1.06%. The percentage of the effective dose distribution is relatively safe because it is still below 75%.

1. Introduction

Treatment of cancer can be done by doing radiation therapy. Radiation therapy can be done externally (teletherapy) and internally (brachytherapy). Teletherapy is radiation therapy by providing radiation without having to hit the object. While brachytherapy is radiation therapy by inserting a radiation source into the body [1]. The American Association of Physicists in Medicine (AAPM) recommends that the dose inaccuracy of brachytherapy is ± 5%[2]. One of the things that is important to note in brachytherapy is the accuracy in administering the dose. The accuracy of dosing is necessary so that patients do not experience receiving excessive or underdosing when the cancer has to be irradiated. Cancer cells are tried to receive the dose as determined and normal cells around the cancer get the lowest possible dose so planning is needed before doing therapy. Planning in determining the dose distribution can be done with a simulation using Monte Carlo. Monte Carlo N Particle (MCNP) is the accurate and reliable technique for calculating the dose and results of radiation therapy [3-7]. MCNP simulation becomes an
effective tool for the dosimetry of low energy photon brachytherapy [8]. The absorption dose simulation using MCNP6 software also produces dose rate data in the direction equation (1)

$$g (r) = 0.9979 + 0.0043r - 0.0002r^2 - 0.0001r^3 + 8e-6r^4 - 1e-7r^5$$  (1)

with a coefficient of determination $R^2=1$. which means that the data is suitable for the order polynomial function 5 in accordance with the recommendations of AAPM TG-43U1 [9]. By producing this radial dose function, the radial dose function value $g (r)$ for various $r$ values can be accurately determined [10]. Some of the previous studies related to this study included MCNP to find a relationship between dose and seed count and dose and activity of radiation sources derived from 103Pd in prostate cancer therapy [4]. In thyroid cancer therapy, the absorbed dose in the thyroid will increase with an increase in 131I activity but the dose absorbed in other organs is smaller than the thyroid and the maximum effective dose of thyroid at 131I activity is 200 mCi but for surrounding organs it is still safe [11]. Research on MCNP for dose calculation in lung cancer therapy using 131Cs resulted in the equation (2)

$$D_s = (0.35 x s + 0.49) A$$  (2)

where $D_s$ is the absorption dose, $A$ is the activity. $s$ is the number of seeds [5]. Previous research on the simulation of 103Pd radiation absorption dose determination in breast brachytherapy using MCNP5 software with the Permanent Breast Seed (PBSI) technique, the value of the dose received by the sternum and left lung was smaller than the dose received by the breast [12]. Some of the organs that have been dosed on brachytherapy that have been simulated using MCNP are prostate [4] [13], lung organ [5], thyroid [11], breast [12] [14]. MCNPX is a development of MCNP which is a code for calculating the continuous energy, generalized, and time-dependent transport of neutrons, photons, and electrons which is a product of the Los Alamos National Laboratory, University of California United States [15].

The purpose of this study was to determine the distribution of the absorption dose in liver cancer with radiation source $\gamma$ 103 Pd using MCNPX. Radioactive 103Pd has an energy of 21 KeV and a half-life of 16.9 days. The choice of radioactive 103Pd due to low-energy $\gamma$ radiation is an effective radiation treatment for internal cancer therapy. Radiation therapy using low energy radioactive means that all radiation energy will be absorbed by the interaction process of photons with matter so that the radiation that passes into healthy tissue is relatively small [16]. The absorption dose of the organ at risk will also be calculated and analyzed whether the dose is received is still within the permitted limits. MCNPX has included several new capabilities especially for transmutation analysis, burn up and delayed particle production. Several tallys (calculation modes) and new methods of variant reduction have also been developed for better data analysis techniques [17].

2. Methods

The procedure for making a liver cancer brachytherapy simulation consists of three stages. namely the manufacture of liver phantom geometry with the 1996 version of the ORNL-MIRD model [5], defining the radiation source and the position of the radiation source and selecting the tally to be calculated. Geometry and material definition of the ORNL-MIRD phantom material are very important in making the brachytherapy simulation. In making geometry, several inputs are needed namely density constituent material, shape and size of surfaces and cells. In the phantom geometry the ORNL-MIRD model is a geometric form of the human body which consists of three main parts namely the head, body and legs [5].

The definition of the radiation source is required for simulating particle travel. In brachytherapy the radiation source is modeled in the form of seeds which are randomly placed in the liver. The definition of the source required as MCNPX input is the type of particles emitted. the energy and abundance of the particles. and the direction of the particle beam. Sources of radiation used in this study are as follows: Nuclide 103Pd in the form of points with 2x10-3 Ci activity, 21 keV energy, 63.9% intensity and has a half-life of 16.9 days [1]. the variation in the number of seeds planted is 10,20,30,40,50,60, and 70.
The input file creation consists of three stages, namely cell cards, surface cards and data cards. The first step is carried out by inputting a cell card containing the specifications for the space between the surfaces, material density, material definition and the name of each cell, followed by inputting the surface card containing the shape and value of the surface area that intersects the coordinate axis. Input data card containing material data, particle source data, tally used and the number of simulated particles. The output of the MCNPX calculation results is stored in a file called metal. Metal contains the deposition per transformation of the simulation execution results. The simulation execution results in metal display the value in MeV / trans units. The output in the form of deposition energy per transformation still has to be processed again to obtain the absorption dose and effective dose through calculations.

The transformation number is the product of the initial radiation activity of a radioactive in Becquerel units with the life span of the radioactive. The transformation number \( U_s \) can be calculated using equation (3)\[18\].

\[
U_s = A_0 \tau
\]  

where \( A_0 \) the initial radioactive activity. \( \tau \) is the radioactive life span. To calculate the absorbed dose, namely the energy \( E \) absorbed by the mass unit \( m \) equation (4) is used.

\[
D = \frac{E}{m}
\]  

The total absorption dose in the organ \( (D\tau) \) can be calculated if the transformation number has been determined. so that it can be written in equation (5)\[18\].

\[
D\tau = \frac{E}{m} \times U_s
\]  

By multiplying by the tissue / organ weight factor \( W_T \) and radiation weight factor \( W_r \), the effective dose \( (E\tau) \) unit Sv is obtained, as in equation (6) \[19\].

\[
E\tau = W_r \times W_T \times D\tau
\]

In Figure 1 there is the organ cell number on the ORNL-MIRD phantom, the density and volume of each organ can be seen in table 1.

Figure 1. The liver and surrounding organs \[20\]
Table 1. Density and volume of each organ from the ORNL-MIRD Phantom Model [18]

| No cell | Name of Organ  | Volume (liter) | Density (kg/liter) |
|---------|----------------|----------------|-------------------|
| 2200    | Liver          | 1.830          | 1.040             |
| 2300    | Right lung     | 1.810          | 0.296             |
| 2100    | Kidney         | 0.288          | 1.040             |
| 1500    | Bile           | 0.0637         | 1.040             |
| 2500    | Pancreas       | 0.0907         | 1.040             |

The pancreas organ is not visible in Figure 1 because it looks at the XZ coordinate, while Figure 1 is located on the YZ axis. This study makes the geometry of the liver at the Cartesian coordinate position (-6.98; 0; 35.32) just below the right lung.

3. Result and discussion

The first step, calculating the distribution of the absorbed dose in the liver and surrounding organs, namely the kidneys, right lung and pancreas. The results of the absorption dose calculation are presented in Table 2.

Table 2. Distribution of absorbed dose

| Jumlah seed | absorbed dose Liver (Gy) (%) | absorbed dose right lung (Gy) (%) | absorbed dose kidney (Gy) (%) | absorbed dose Pancreas (Gy) (%) |
|-------------|------------------------------|----------------------------------|------------------------------|-------------------------------|
| 10          | 2.53                         | 100                              | 0.26                         | 10.4                          |
| 20          | 5.09                         | 100                              | 0.49                         | 9.78                          |
| 30          | 7.49                         | 100                              | 0.87                         | 11.6                          |
| 40          | 9.87                         | 100                              | 1.37                         | 13.9                          |
| 50          | 12.41                        | 100                              | 1.54                         | 12.4                          |
| 60          | 14.90                        | 100                              | 1.77                         | 11.8                          |
| 70          | 17.46                        | 100                              | 1.91                         | 10.9                          |
| Average     | 100                          | 11.56                            | 0.21±0.02                    | 0.36±0.26                     |

The percentage of the absorbed dose received by the right lung is 11.56%, kidney is 0.21% and pancreas is 0.36% relative to the liver so that the percentage of the dose in the liver is 100%. The amount of this percentage is smaller than the allowable amount of 75% [21]. These results are also consistent with several studies that have been conducted, that organs at risk receive an absorption dose that is still below the permissible threshold [4][5][11][20].

Each organ has its own tissue weight factor so that the effect of radiation that occurs in these organs is different. Even though the absorption dose received by these organs is the same. The effect of the tissue weight factor on the dose received by the tissue is called the effective dose. Apart from being influenced by the tissue / organ weight factor, the effective dose is also influenced by the radiation weight factor. So to calculate the effective dose, can use equation (6). The tissue / organ weight factor value for lung, kidney and pancreas is 0.12 while the tissue / organ weight factor for liver is 0.04 [22]. By looking at the weight value of the tissue, then with the same absorption dose in the four organs, the liver will have an effective dose of one-third of the effective dose for the lungs, kidneys or pancreas. The results of the calculation of the effective dose and the percentage of the effective dose for each
number of seeds can be seen in table 3. The graph of the relationship between the number of seeds and the effective dose can be seen in Figure 3.

Table 3 Distribution of effective dose and percentage of dosage

| Number of seeds | effective dose liver (Sv) | % | effective dose right lung (Sv) | % | effective dose kidney (Sv) | % | effective dose Pancreas Sv | % |
|-----------------|--------------------------|---|-------------------------------|---|--------------------------|---|---------------------------|---|
| 10              | 0.101                    | 100| 0.032                        | 31.21| 0.0005                  | 0.55| 0.0001                    | 0.09|
| 20              | 0.204                    | 100| 0.059                        | 29.32| 0.0013                  | 0.68| 0.0006                    | 0.28|
| 30              | 0.299                    | 100| 0.105                        | 34.91| 0.0021                  | 0.71| 0.0025                    | 0.83|
| 40              | 0.395                    | 100| 0.164                        | 41.66| 0.0027                  | 0.69| 0.0032                    | 0.82|
| 50              | 0.497                    | 100| 0.185                        | 37.29| 0.0032                  | 0.64| 0.0075                    | 1.50|
| 60              | 0.596                    | 100| 0.212                        | 35.53| 0.0034                  | 0.58| 0.0108                    | 1.81|
| 70              | 0.699                    | 100| 0.229                        | 32.79| 0.0039                  | 0.56| 0.0149                    | 2.13|
| average         | 0.63                       | 100| 0.63±0.07                  | 34.67±4.10| 0.63±0.07     | 1.06±0.77| 1.06±0.77                  | 2.13|

Table 3 shows the average percentage of effective dose relative to the liver as follows: the effective dose in the right lung is 34.67%. in the kidney 0.63% and in the pancreas 1.06%.

From Figure 2 it can be seen that the effective dose increases with increasing the number of seeds used. The effective dose for all organs has the same trend, which is directly proportional to the number of seeds used. This is because by increasing the number of seeds, the energy from the radiation source increases, so the absorption dose increases. Increasing the absorbed dose will also increase the effective dose.

These results are in accordance with several studies conducted, among others, [10],[20] that increasing the number of seeds will increase the absorption dose. If the absorbed dose is increased, the effective dose will also be increased for the same organ. Based on the results of the calculation of the effective dose, it can be analyzed that the contribution of scattering to the liver greatly affects the value of the effective dose received by the surrounding organs. Nevertheless, percentage of effective dose received by organs around the liver (organs at risk), like the right lung, kidney and the pancreas is still at safe limits, that is below 75%.
4. Conclusion
The calculation of the effective dose from the brachytherapy modeling results using MCNPX shows that if the percentage of the effective dose in the liver is 100% (0.101 - 0.699 Sv). Then the percentage of effective dose distribution in the right lung was 34.67% (0.032 - 0.229 Sv), kidney 0.63% (0.0005 - 0.0039 Sv) and pancreas 1.06% (0.0001 - 0.0149 Sv) with safe criteria because it is below 75%. Seeing the results of this study, the Brahytherapy method is safe to do because it fits its purpose, that the largest dose in the target organ and the dose in the surrounding organs is relatively small.

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