Comparison of Dose Volume Histogram (DVH) of Simulated Object Calculated by Analytically and Treatment Planning System (TPS): Preliminary Study

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Abstract. TPS is the key to the success of external radiotherapy medication, which directly affects the quality of treatment planning and accuracy of dose calculation within the plan. The output of TPS’s plan result is in form of DVH curve. DVH is the reference for dose dispersion on the target or healthy organ. Within this research, DVH result from the TPS and DVH result from analytical calculation were compared. The DVH comparison was started by creating a simulation object in form of virtual phantom using Matlab program in various geometrical shapes, which were sphere, cube, and cylinder. The planning on simulation object was conducted using TPS Eclipse. From the result of the plan using TPS Eclipse and analytical measurement, it can be concluded that the highest value difference was on the sphere object simulation. While for the D_{\text{max}} and D_{\text{min}} value comparison, the highest difference was in D_{\text{min}} with the highest discrepancy. This was caused by the voxel size on each measurement. Besides, the dose value of interpolation and voxel determination on the surface of the geometrical simulation object also affected the value of analytical measurement, so it resulted in the higher value compared to the calculation result on each TPS.

1. Introduction
Cancer is a disease that is caused by uncontrolled cell growth and changes into abnormal cell that spreads out to the body tissues and damages the other body tissues [1]. Cancer medication is performed by using several modalities, such as through chemotherapy, radiotherapy, and surgery. Almost 50\% of cancer medication uses radiotherapy which requires individualistic planning in its implementation [2][3]. Radiotherapy planning is a radiotherapy simulation which uses TPS software and intended for the optimization of administrating high dose on the tumor and the lowest dose as possible on the healthy tissues around it [4].

One of the results of TPS is in form of DVH (Dose Volume Histogram) curve which shows the correlation between the dose on tumor target and the protected healthy organs around the tumor (organ at risk), and volume. DVH curve is used to determine the prescription dose by radiation oncology doctor.
By doing so, TPS calculation precision on the tissue volume will greatly affect the success of the radiotherapy [5]. DVH has become a standard tool to evaluate radiation therapy planning and functioned as the groundwork for several general biological models. In terms of DVH accuracy, TPS system does not have any standard and general process running during commissioning with certain aspects [6]. With the non-existence of this certain manual, DVH calculation through clinical software can be considered as unequal to the reality notwithstanding it has been universally used to evaluate and to approve treatment planning. Therefore, there should be DVH verification to examine the accuracy on DVH curve.

A research on the difference of DVH value was also conducted by Nelms, et al which compared TPS Eclipse and PlanIQ (v2.1) using analytical calculation on Matlab. This research obtained comparison values which were not quite different, either between TPS and Matlab or PlanIQ and Matlab [6]. Another research that has been done by Min, et al used 35 treatment planning from different patients and targets. This research used super-sampling calculation and all treatment planning were processed on the TPS and MIM Maestro v6.1 software (MIM Software Inc., Cleveland, OH). The result of the research showed that the difference between DVH value obtained from TPS and MIM software was relatively small. Most significant differences showed up on small organs such as eyes lens, eyeball, and optical nerves of less than 10cc volume [7]. Meanwhile, in this research study, the used simulation objects that have various geometrical shapes, such as sphere, cylinder, and cube, and the TPS Eclipse was used to generate the DVH curves that would be compared to the results of the Matlab calculation.

In this research, an initial study was conducted to determine the calculation precision on the volume of tissues which were exposed to radiation based on the analytical calculation using Matlab program. The objects of the research were simulation objects in form of virtual phantom in geometrical shapes of sphere, cylinder, and cube, therefore the structures’ edges could be well determined by the TPS. The development of simulation objects and DVH calculation were conducted using Matlab R2014a program. DVH calculation on Matlab was based on the analytical calculation, thus it could be compared with the TPS’ DVH result. In order to obtain the DVH curve, simulation objects of the same size were used, for both TPS and Matlab. The dose administration simulation was performed using Eclipse TPS for X-6 MV ray by using single beam. Then the DVH from analytical calculation result from Matlab was compared with the TPS calculation result. The comparison results were expected to be used as the reference in verifying DVH curve for each TPS used in the radiotherapy planning.

2. Experimental method
2.1 Designing virtual phantom

![Figure 1](image1.png)

**Figure 1.** The object’s 3D display from the simulation using Matlab program (a) sphere, (b) cube, (c) cylinder
This research was started by creating simulation objects in form of virtual phantoms by using Matlab R2014a program. Three virtual phantom shapes were selected: sphere, cube, and cylinder. The sphere’s diameter, cube’s side, and cylinder’s circular diameter or height were all 5 cm, then obtained the volume of sphere is 62.6 cm$^3$, cube is 130.7 cm$^3$, and cylinder is 102.7 cm$^3$.

2.2 The making of DICOM format

The making of DICOM format was conducted by adding identification data on the 3D image of simulation objects that were produced by Matlab program based on the hospital database. As an example, every patient has to have their personal data, such as name, hospital ID, and date of birth. Therefore, with the addition of several data of the hospital, the simulation objects’ image can be converted into DICOM format and then becomes recognizable by the TPS.

There are several DICOM format differences with the existing image format. First, a DICOM file consist of a header which stores the information of patient’s name, scan type, image dimension, and so on for medical image. Meanwhile the existing format stores image file within a file (*.img) and header data in another file (*.hdr). The second difference is that DICOM standard image can be compressed to reduce the image size. The first 794 byte in DICOM is sued as the header. The size varies based on the amount of stored information. DICOM also needs 128 byte as the preamble which will be followed by characters ‘D’, ‘I’, ‘C’, ‘M’; and the information from the header will be organized in group [8].

It should be noticed that DICOM format image is only marked with number and point (e.g. ‘CT.1.2.246.352.71.3.496497982.502596.20110816120811.dcm’). Several parts of the file name may reflect the slice sequence, and DICOM file name usually does not represent a certain content or parameter and it even does not contain DCM existence. It means that in order to arrange and reconstruct the data serially or to learn it, the content has to be checked and organized based on several references.

The DICOM data of simulation objects of sphere, cylinder, and cube were input to Eclipse TPS, then the planning was run and produced DVH curve. Figure 2 displays one of the slices of sphere simulation object from the DICOM format that had been completed with the hospital database. The left part shows the file name that represents the number of slice, the middle part is a sphere image that was designed using Matlab program, and the right part is the hospital database.

![Figure 2. The display of an object slice of simulation object with DICOM format which was opened using MicroDicom software (a) sphere, (b) cube, (c) cylinder](image)

2.3 DVH calculation on TPS

By considering simulation objects as the target in radiation exposing, DVH calculation was conducted using Eclipse TPS. TPS calculated the dose and produced DVH through planning. Planning was performed on the simulation objects under the conditions of using 100 cm SAD, 6 MV photon energy, the field size was in accordance with the target (simulation object) size, algorithm used on TPS was AAA algorithm, 2 Gy dose on maximum point, and $0^\circ$ gantry angle.
Figure 3. The display of planning result on Eclipse TPS for cylinder simulation object. (a) transverse direction planning, (b) 3-dimention view planning, (c) coronal direction planning, (d) sagittal direction planning

2.4 DVH Calculation using Matlab Program
DVH Calculation via Matlab Program used analytical calculation and dose distribution that was provided by the TPS calculation. This dose distribution was then processed on the Matlab software along with the volume analytical calculation to obtain the DVH curve.

The formula for DVH cumulative analytical calculation, \( V(D) \), was derived from the simple 3D geometrical object. With one-way dose change, \( D(x) \), \( dV \) dose, can be written as the result of an area, \( A \), and length, \( dx \), \( dV = Adx \). The derivative of \( x \) towards the dose, \( D \), can be obtained and substituted for the equation of volume, \( dV = A(dx/dD)dD \). Area, \( A \), can become a function of \( x \), in this case the substitution of \( x = x(D) \) was required [6].

\[
V(D) = A(x(D)) \frac{dx}{dD} dD
\]  
(1)

DVH function is the integral of Equation (1) with appropriate edge.

\[
V(D) = \int_{D_{\text{max}}}^{D_{\text{max}}} A(x(D)) \frac{dx}{dD} dD
\]  
(2)

Volume on Equation (2) can be integrated into \( x \), with appropriate edge, then can be substituted into,

\[
V(D) = \int_{x(D)}^{x(D_{\text{max}})} A(x)dx
\]  
(3)

Curve for analytical DVH was modified to calculate the structure extension on TPS.

3. Discussion
DVH from the result of Matlab and TPS for various simulation objects can be seen on Figure 4 and Table 1 and 2. The comparison DVH of was conducted by observing the maximum dose (\( D_{\text{max}} \)), minimum dose (\( D_{\text{min}} \)), \( D_{98} \), \( D_{90} \), \( D_{80} \), \( D_{50} \) and \( D_{5} \) values on the main axis. \( D_{\text{max}}, D_{\text{min}}, D_{98}, D_{90}, D_{80}, \) \( D_{50}, D_{20}, D_{5} \) were taken as the reference and compared directly on the table. On the sphere simulation object, the highest dose of value difference between the result of TPS planning and the result of MatLab was on volume 98% with discrepancy 5.65%, while on volume 50% had the least discrepancy of 2.17%. For cube simulation object, the highest difference value was on volume 98% with discrepancy 1.85% and the least difference was on volume 5% with discrepancy of 0.97%. For cylindrical simulation object, the highest dose value was also on volume 98% with discrepancy 5.45%, and volume 80% was the least discrepancy of 1.28%. From the simulation object virtual phantoms, the highest value
difference was on sphere object simulation with the dose value difference 0.05 Gy on volume 98% and discrepancy 5.56%. While the smallest value difference was on the cube object simulation on volume 5% with the value difference 0.02Gy and discrepancy 0.97%.

Table 1. The dose result from the calculations of TPS and analytic (Matlab) for sphere, cube, and cylinder simulation objects

| Shape     | Volume (%) | Dose (Gy) | $|\Delta|$(Gy) | Discrepancy (%) |
|-----------|------------|-----------|---------------|-----------------|
| Sphere    |            | TPS       | MatLab        |                 |
|           | 98         | 0.90      | 0.95          | 0.05            | 5.56            |
|           | 90         | 1.50      | 1.57          | 0.07            | 4.67            |
|           | 80         | 1.65      | 1.72          | 0.07            | 4.24            |
|           | 50         | 1.84      | 1.88          | 0.04            | 2.17            |
|           | 20         | 1.99      | 2.05          | 0.06            | 3.07            |
|           | 5          | 2.08      | 2.14          | 0.06            | 2.88            |
| Cube      | 98         | 0.54      | 0.55          | 0.01            | 1.85            |
|           | 90         | 1.01      | 1.02          | 0.01            | 0.99            |
|           | 80         | 1.5       | 1.52          | 0.02            | 1.33            |
|           | 50         | 1.84      | 1.86          | 0.02            | 1.09            |
|           | 20         | 2.02      | 2.04          | 0.02            | 0.99            |
|           | 5          | 2.06      | 2.08          | 0.02            | 0.97            |
| Cylinder  | 98         | 0.55      | 0.58          | 0.03            | 5.45            |
|           | 90         | 1.17      | 1.19          | 0.02            | 1.71            |
|           | 80         | 1.56      | 1.58          | 0.02            | 1.28            |
|           | 50         | 1.84      | 1.87          | 0.03            | 1.63            |
|           | 20         | 2.00      | 2.03          | 0.13            | 1.50            |
|           | 5          | 2.10      | 2.13          | 0.03            | 1.43            |

Table 2. The value of Dmean, Dmin, and Dmax from the calculation result using TPS and Matlab for sphere, cube, and cylinder simulation objects

| Shape     | Point of Observation | Dose (Gy) | $|\Delta|$(Gy) | Discrepancy (%) |
|-----------|----------------------|-----------|---------------|-----------------|
| Sphere    | $D_{\text{min}}$     | 0.43      | 0.5           | 0.07            | 16.28           |
|           | $D_{\text{max}}$     | 2.1       | 2.15          | 0.05            | 2.38            |
| Cube      | $D_{\text{min}}$     | 0.25      | 0.27          | 0.02            | 8               |
|           | $D_{\text{max}}$     | 2.1       | 2.12          | 0.02            | 0.95            |
| Cylinder  | $D_{\text{min}}$     | 0.24      | 0.27          | 0.03            | 12.5            |
|           | $D_{\text{max}}$     | 2.11      | 2.14          | 0.03            | 1.42            |
(a)

(b)
Figure 4. DVH curve for (a) sphere, (b) cube and (c) cylinder simulation objects. \( D_{\text{min}} \) is the first dose of the DVH curve down under 100\%, 98\% is the dose at volume 98\%, 90\% is the dose at volume 90\%, 80\% is the dose at volume 80\%, 50\% is the dose at volume 50\%, 20\% is the dose at volume 20\%, 5\% is the dose at volume 5\%, \( D_{\text{max}} \) is the maximum dose.

Besides the comparison of value difference for each different volume, it can be concluded the comparison between \( D_{\text{max}} \) and \( D_{\text{min}} \) which was received on each simulation object as shown on Table 2. From the value of \( D_{\text{min}} \) from the result of calculation between TPS and analytic for all structure and beams variation, all structure exceeded 3\%. While for \( D_{\text{max}} \) on all object simulation had discrepancy <3\%. \( D_{\text{min}} \) described the first dose where the cumulative DVH curve went down under 100\%, while \( D_{\text{max}} \) was the last dose shown by the curve. If the curve only had a little gradient on \( D_{\text{min}} \), the volume mistake, in definition, would be very little, but if the curve had a big gradient on \( D_{\text{min}} \), the value difference would be big as well.

The observed discrepancy varied, some data was on the range <3\%, but there were data that exceeded the discrepancy value 3\%. This was because all dose value was on the surface that was decided by the contour coordinate and not limited on voxel dose in volume (which by the definition would be on surface). Every possible mistake was from numerical effect: voxel size, voxel lattice alignment vs the location of lattice dose, dose interpolation, and voxel surface determination inside or outside the structure. The performance difference had to be related with the difference of voxelation structure and dose interpolation between both systems.

This research is an initial study which will be continued by varying the beam’s number and geometry. It is expected to obtain a program which can be used as a tool to compare the DVH calculation from various TPS.

4. Conclusion
This research successfully created simulation object virtual phantom using program MatLab with geometrical variations: sphere, cube, and cylinder with difference volumes. From the planning using
TPS Eclipse and analytical measurement result, the highest value was on sphere simulation object. While the value comparison $D_{\text{max}}$ and $D_{\text{min}}$, the highest difference was on $D_{\text{min}}$ for all simulation objects. There was not the same value on this planning for all simulation objects. From the different geometrical simulation object, the DVH error was different as well. This was caused by the size of voxel on each measurement. Besides that, the interpolation of dose value on geometrical structure’s surface also affected the result of analytical measurement in resulting bigger value compared to the calculation result on TPS.

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