Validation of in-house algorithm for SPECT-CT 3D segmentation and high-accuracy cancer internal dosimetry protocol

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Abstract. Tumour volume measurement requires physicist to perform manual delineation for every slice of 2D image produced by SPECT-CT to obtain the total number of pixel of abnormal activities. The total number of pixel is multiplied with spatial resolution of each pixel and thickness between each slice. Physicist delineate abnormal activities of tumour subjectively which lead to inconsistent accuracy of the measured volume. Manual delineation process requires high consumption of time and effort. This work is aimed to verify and validate an in-house developed algorithm that capable of numerically quantify the tumour volume. The results were compared with the actual and manually calculated volume of Phantom Body, scanned with SPECT-CT apparatus. The algorithm verification is performed by comparing the algorithm structure and preliminary results with previous works. The data for validation were obtained by conducting experiment with NEMA-IEC body phantom and Iodine-131. The algorithm structure and outcome were comparable with previous works with slight modification. The algorithm measured volume is 26.9579 cm³ which is only 1.6% error as compared to the actual tumour volume of 26.521 cm³. The algorithm is expected to be used for actual patient data in the near future once sufficient verification and validation procedures are achieved.

1. Introduction
Cancer is one of the biggest death cause of Malaysian. According to Deputy Health Minister Malaysia, 100000 Malaysians diagnose with cancer every year [1]. Unhealthy lifestyle such as smoking, unhealthy diet increase risk of Malaysian suffers from cancer. Malaysia has acquired with high technology and devices in medical which improve the health level of Malaysian and medical fee in Malaysia is affordable for most of the Malaysian. However, mortality rate of cancer patient in Malaysia is relatively high which is 61% [2]. According to Malaysia Health Minister, Datuk Seri Dr Dzulkefly Ahmad, most of the cancer cases of Malaysian are detected at late stage due to Malaysian low health awareness and medical check-up constancy [3]. The report also insisted that the patients
missed the treatment in early stage had been the main cause of decreasing survival rate among cancer patients.

The manual process of delineation of 2D image produced by CT scan or SPECT-CT are time consuming and requires skilled workers [4][5]. Physicists are required to circle the abnormal activities from 2D image to identify the location of the tumour and the size of tumour. The overall process for manual delineation are time consuming, training for skilled workers required effort and time. Besides that, potential error occurs due to contrast of the 2D imaging has low distinguish between normal and cancer cells which lead to physicist include or exclude the abnormal activities pixel during manual delineation. This scenario led to inaccuracy of the internal dosimetry procedure. Besides that, diagnosis results for patient took longer time to process and caused patients to miss the best treatment time.

The aims of this work are to validate result of algorithm measured volume of tumour with NEMA-IEC phantom and to compare the result of algorithms calculated for NEMA-IEC phantom and manual delineation results.

This research enables physicist to implement personalised radionuclide treatment for patients. Based on the volume of interest, the accurate amount of radiopharmaceutical calculated for the specific patient. The suitable amount of radiopharmaceutical injected to patient which minimise the harm to patient and achieve cancer treatment with highest efficiency without lack of dosage or overdose.

2. Literature Review

2.1. Targeted radionuclide therapy

Targeted radionuclide therapy used radiopharmaceutical which capable to localise the position of the tumour and released radiation energy through decay to kill cancer cell. However, targeted radionuclide therapy is inefficient due to fixed dosage of dosimetry for every patient which create two scenarios. First, lack of dosage of radiopharmaceutical to kill larger volume of cancer cell. Second, overdose of radiopharmaceutical lead to healthy cell nearby cancer cell affected. This indicated that dosage of radiopharmaceutical are crucial to perform high accuracy therapy. Targeted radionuclide therapy efficiency and survival rate increased with individualised targeted radionuclide therapy [6]. Individualised targeted radionuclide therapy with the data of volume of tumour are able to calculate dosimetry for each patient.

2.2. Internal dosimetry

Internal dosimetry deals with the absorption dosage rate of radiation energy emitted by radionuclide in targeted organ [7]. Internal dosimetry is crucial in both diagnosis and therapy process to maximise the efficiency for both process. For diagnosis process, dosage of radionuclide is essential to maximise quality of nuclear medicine imaging and minimise the effect of radionuclide to patients. For therapy process, dosage of radionuclide is crucial to maximise absorbed dose for tumour and minimise the toxicities to surrounding normal cells [7]. The formula of calculate the dosage absorb rate is defined as below:

\[
\dot{D} = \frac{k \sum_s A_s \sum_i n_i E_i \phi_i (T \leftarrow S)}{m_T}
\]  

(2.1)

The formula can be simplified as below:

\[
\dot{D} = \frac{\varepsilon}{m}
\]  

(2.2)
where $\varepsilon$ is the activity and energy radiation from radionuclide sources absorbed by targeted tumour and $m$ is the mass of tumour. Each patient has different size of organ and different size of tumour which lead to the dosage required by each patient is vary based on their situation. From Equation 1, mass of tumour is the parameter to determine dosage needed. Mass of tumour obtained through nuclear imaging for better accuracy of dosage calculation.

2.3. Review on comparable algorithms
Visualisation of 3D image based on planar image is interested by physicist as the information in planar image is limited compare to 3D image. Research with regards to 3D image reconstruction using planar image of image modality is conducted. Various type of methods of 3D reconstruction algorithms is used.

3D image simplified the workload and reduced time consumption to calculate the volume of tumour compare to manual delineation. Measurement of volume for tumour have been research by researcher to perform high accuracy of result. Method for measurement of volume consist of various method used in algorithms. The researches data is tabulated as shown in Table 1 and Table 2.

| Study                  | Modalities | Data            | Radionuclide | 3D reconstruction method and process                                      |
|------------------------|------------|-----------------|--------------|--------------------------------------------------------------------------|
| Synesthesia et al.,    | SPECT      | Stress and rest | Tc-99m       | • Isosurface                                                             |
| 2014                   |            |                 |              | • Extract DICOM image                                                    |
|                        |            | myocardium     |              | • Determine isocontour surface for isovalue                              |
|                        |            | DICOM image    |              | • extract pixel value from DICOM data                                   |
| Kyriacou, Christofides,| SPECT      | Kidney image   | Tc-99m       | • Isosurface                                                             |
| & Pattichis, 2016      |            |                 |              | • Used Otsu threshold to determine optimal isovalue                      |
|                        |            |                 |              | • extract pixel value from DICOM data                                   |
| Tory et al., 2005      | SPECT      | 4D kidney      |              | • Isosurface                                                             |
|                        |            | SPECT data     |              | • Isovalue value determine by user                                      |
|                        |            |                 |              | • Direct volume rendering                                               |
|                        |            |                 |              | • High intensity region is highlighted                                  |

2.4. Measurement of volume
Method to measure volume of tumour is an interested topic for researcher to find a quantitative method with high accuracy. Accuracy of volume of tumour enable physicist to perform more accurate diagnosis and treatment. The data used for initial experiment in imaging are mostly Phantom. Phantom is an object that used for imaging in validation of imaging machine. Phantom data from imaging is used to analyse, evaluate the performance of machine. Phantom used to represent as the body of patient send to imaging. There are many type and shape of phantom even phantom that can mimic lung, liver of human. Each phantom type help in physicist for research and validation.

From Table 2, there are two main method used in measure volume of interest which is used of 3D image to obtain pixel value and used of planar image to obtain pixel value. The pre-process for used of 3D image to measure volume is similar to 3D reconstruction which discussed in section 2.6.1. The maximum pixel value for threshold is determined using grey-level histogram in region of interest. The threshold level is either fixed or change based on the user to determine the suitable pixel value in calculation for volume of tumour. If the pixel value overestimated, the volume of the tumour in calculation is smaller than the exact size and vice versa. Thus, pixel value range threshold for tumour calculation must be correct to ensure that the accurate calculation of affected area is achieved. The number of pixel with pixel value within the threshold level is calculated. Volume of phantom is obtained by multiply total number of pixel value with pixel area and slice thickness.
### Table 2. Measurement of volume study.

| Study                                      | Modalities | Data                        | Reconstruct 3D image | Process for measurement of volume | Formula                                                                 |
|--------------------------------------------|------------|-----------------------------|----------------------|-----------------------------------|------------------------------------------------------------------------|
| Erdi, Wessels, Loew, & Erdi, 1995          | SPECT      | 6 Lucite sphere             | Yes                  | Find highest counts for pixel based on grey-level in ROI            | Total number of pixel x pixel area x slice thickness                   |
| Zingerman, Golan, & Moalem, 2009           | SPECT-CT   | Cube and sphere phantom     | No                   | Attenuation correction for SPECT and CT data                       | Overlapping pixel are used for VOI boundary                            |
| Mortelmans, Pamel, Maegdenbergh, Roo, & Suetens, 1986 | SPECT      | Cylinder phantom with 20cm diameter | No                   | Fixed threshold and grey level histogram determine pixel value      | Total number of pixel counted x voxel size                             |
| Synefia et al., 2014                       | SPECT      | Stress and rest myocardium  | Yes                  | Determine isocontour surface for threshold value                    |                                                                        |

In order to obtain planar image, the result of SPECT and CT is attenuated to merge both data. The merged planar image is drawn with Full Width Half Maximum (FWHM) intensity profile across the phantom for each row and column. Every slices are drawn with FWHM intensity profile. FWHM profile is drawn column by column and row by row for all slices. The profile for each row and slice and analyse individually on the original slices. The overlapping pixel is used as border of volume of interest. Figure 1 shows the FWHM intensity profile across a row of sphere phantom.

![FWHM intensity profile across a row of sphere phantom](image)

**Figure 1.** FWHM intensity profile across a row of sphere phantom [8].
3. Methodology
Actual Phantom volume for each diameter of sphere is recorded. The Phantom then referred to nuclear imaging, SPECT-CT machine to produce SPECT and CT DICOM data. The DICOM data used as input for 3D reconstruction algorithms to produce 3D image. Measurement of volume algorithm is used to measure pixel value of reconstructed phantom in 3D structure. Volume of phantom is calculated pixel size multiplied spatial resolution of one pixel and thickness between each slice. The volume of phantom calculated by algorithms is compared with the actual volume of the sphere. The result is validated as the result of algorithms is matched with actual volume. If the result of algorithm has high percentage of error, reconstruction of 3D image process is repeated to ensure the image of phantom reconstructed is correct.

The pixel value obtained from the experiment is measured manually by experienced physician. The pixel value is multiplied with spatial resolution of SPECT to calculate the diameter of the phantom sphere. The diameter is used in formula of volume of sphere. The calculated volume of phantom is compare with the result of volume of phantom calculated by using algorithms. Minimum pixel value and maximum pixel value is set. Minimum pixel value is 395 which is calculated based on phantom sphere experiment. Specific sphere phantom image is reconstructed by using isosurface volume rendering. Phantom image is reconstructed in 3D image and allows physicist to rotate the image for more accurate diagnosis. The pixel size of the specific phantom is calculated by summation of pixel value in between maximum and minimum value pixel value. Volume of phantom is calculated by multiplying spatial resolution, thickness of slices and pixel size.

![Figure 2. Algorithms flowchart for measurement for volume.](image)

4. Results and discussion
To validate the result of algorithms measured volume, Table 3 shows result of comparison between algorithms calculated volume with actual volume of phantom and manual measured volume of phantom. The actual phantom volume result for 37mm sphere is 26.5218 cm³. The error between algorithms measured volume and actual volume is 1.6%. Manual measurement of volume using pixel
value obtain is 27.3913 cm$^3$. Compare with the actual algorithms measured volume of phantom, the error is 1.58%. Error of manual calculated volume compare to actual volume is 3.28%.

Based on the result, the algorithms measured volume result is validated with small error of deviation. The algorithms calculated volume have smaller error to the manual calculated volume. This shows that algorithms calculated volume can reduce the error in measurement of volume. The result obtained is a numeric result which imply the algorithms calculated volume for the result is correct for future set of data as the result in the research study is correct. Hence, the validation of algorithms is achieved.

Table 3. Error of volume of phantom compare with algorithms calculate and actual calculated.

| Method of Measurement | Volume (cm$^3$) | Error of volume compare with algorithms measured | Error of volume compare with actual volume |
|-----------------------|-----------------|-------------------------------------------------|------------------------------------------|
| Algorithms measured   | 26.9579         | -                                               | 1.6%                                     |
| Actual volume         | 26.5218         | 1.6%                                            | -                                        |
| Manual calculate      | 27.3913         | 1.58%                                           | 3.28%                                    |

5. Conclusion

The combination of 3D reconstruction and measurement of volume algorithms are able to reduce the time consumption in diagnosis process. The location of the 3D image is based on the CT topographic image provided location of phantom. The numerical measurement of volume through the algorithm is validated with the actual phantom volume. The error between algorithms measured volume and actual phantom volume is less than 2%. Algorithms measured volume is compared with the manual delineation and calculation based on the planar image. The error percentage is 1.6%. The objective of the research is achieved.

6. References

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**Acknowledgments**

This research is supported by the Fundamental Research Grant Scheme (FRGS), Grant No: FRGS/1/2019 Vot K200 by Ministry of Education, Malaysia.