Calculation of Standardized Uptake Value (SUV) from PET-CT Image by Using In-House Developed MATLAB Software

[1]Muntakim Mahmud Khan, [2]M Mahfuza Khatun , [3]Abdus Sattar Mollah,

[4]Tanima Sharif, [5]Nahid Farzana Mim, [6]Selim Reza

[2]Department of Biomedical Physics & Technology, University of Dhaka, Bangladesh.
[2]Assistant Professor, Department of Genetic Engineering & Biotechnology, Bangabandhu Sheikh Mujibur Rahman Maritime University, Dhaka,
[3]Professor, Department of Nuclear Science & Engineering, Military Institute of Science & Technology (MIST), Dhaka, Bangladesh
[4]Major, Bangladesh Army
[5]Department of Biomedical Engineering, MIST, Dhaka
[6]Senior Scientific Officer, Institute of Nuclear Medicine & Allied Sciences (INMAS), Dhaka, Bangladesh

Correspondence address: M Mahfuza Khatun, Assistant Professor, Department of Genetic Engineering & Biotechnology, BSMRMU, Dhaka, Bangladesh. Email: mahfuza.gebt@bsmrmu.edu.bd.https://www.bsmrmu.edu.bd

ABSTRACT

The Standardized Uptake Value (SUV) is one of the fundamental parameters to determine whether a region may be considered a "tumor" or "malignant" from PET-CT-derived images. When a measured SUV value is around 2.5, it is non-malignant. Again small tumorous areas can also show a maximum SUV of <2.5. The main objective of this study is to develop a computer program based on MATLAB for calculating SUV from PET-CT-derived images. This study also projects the way of calculating SUVs in a facile way. The study was particularly concerned with the 2D PET-CT images which were initially derived from commercial medical image processing software. Unlike the DICOM (Digital Imaging and Communications in Medicine) formatted PET-CT produced image, the study calculated these images in JPG (Joint Photographic Group) format. Each command and instruction of this program produces the selection of a region of interest (ROI) sequentially. The programming code also extracted the recognition of the desired ROI in cancerous cells. In the study, we have loaded 13 different PET-CT image samples in the software as input. These inputs were used to reach the final result by using in-house developed MATLAB code. A correlation (polynomial expression) between the calculated SUV and the acquired SUV value from commercial software had been established in order to reduce the error. It is concluded that the in-house developed MATLAB program can be used for rapid estimation of SUV value within an acceptable error range.

Key words: Standardized Uptake Value (SUV), JPG formatted PET-CT images, MATLAB software, Correction factor, Polynomial expression.

INTRODUCTION

The advancement of detecting and measuring parameters plays supportive roles in the image processing domain. The scope of image processing and analysis employed in medical applications is to enhance the quality of the acquired image and extract quantitative information from medical image data with high accuracy (1). There are several modalities of nuclear medicine image processing. But in this case, specifically, the PET image processing features will be the topic to be focused on. PET, or Positron Emission Tomography images are widely used in many clinical applications, such as tumor detection and brain disorder diagnosis. PET/CT imaging is becoming more popular as a tool for quantifying an individual's response to therapy. The two most significant sources of variation that occur in practice are the amount of injected FDG and the patient's weight. In nuclear medicine (NM) practices, to evaluate the standard FDG (as a radionuclide) uptake value, the activity concentration of FDG and the patient's weight are crucial factors. The standardized uptake value (SUV) is a dimensionless ratio used historically by NM professionals to distinguish between "normal" and "abnormal" levels of uptake (2). It is marked out as the ratio of activity per unit volume of a region of interest (ROI) to the activity per unit whole body volume and is contemplated to be a semi-quantitative parameter. The SUV is then used to determine the malignancy within the ROI. Currently, SUV measurements are not sufficiently standardized between PET/CT scanners (3). SUV parameters of FDG-PET, such as the average SUV (SUVavg), and the ratio of tumor SUVmax to liver SUV (SUVT/L), have predictive significance. Also, SUVR, MSE, SNR, and PSNR of PET images have quantitative

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predictive significance. In this study, an alternative method to determine this SUV from PET-CT-derived images will be established by MATLAB-based programming. Also, correction factors and several polynomial expressions will be implemented to reach as accurate a measurement as possible. It will ensure the alternative extraction of SUV values besides the commercial medical image processing software-derived SUV values. 'imagej' software was also used to show the values of SUV related parameters from the histograms of different images. We aimed to use MATLAB as an alternative way to calculate SUV from the JPEG-formatted images of PET-CT.

The key factor influencing the motivation behind this study is the ever-increasing use of standardized uptake values (SUVs) in clinical FDG-PET/CT oncology imaging, which has a specific role in assessing patient response to cancer therapy. However, in practice, there are several sources of bias and variance introduced in the measurement of FDG uptake in tumors and also in the conversion of the image count data to SUVs. Ideally, the use of SUVs removes the variability introduced by differences in patient size and the amount of FDG injected. Not accounting for all these error sources can lead to potential errors of 50% in SUV calculations (4). SUVs have been used in the delineation of GTVs for esophageal, lung, and tumor cancers. That's why, in this study, the calculation of the SUVs of PET images by MATLAB software-based programming has taken on a major role and will come out as an alternate way of determining SUV values rather than the commercial-based software. Image quality has also been enhanced by reducing the Gaussian noise, which can vary the intensity gradient of the PET-CT-derived images. The correction factor was also implemented, as a scaling factor was needed to reduce the variations from the vendors that provided commercial software for the calculation of SUV. The working process also required software called "imagej" for processing the histograms of the images and extracting quantitative features from them.

METHODS

1. Equation of SUV

The standardized uptake ratio is a simple way to measure the activity in PET imaging. Since, it is used in practice for image analysis with cancer detection. The general idea of the definition of SUV can be described as the ratio of the image-derived concentration C (image) and the whole body concentration of the injected radioactivity C (injected).

SUV = C(image)/ C (injected)

C(image)is also defined as the pixel intensity of images that carry information such as the size of each pixel, color combination, and logical address.

The C (injected) value is nothing but the ratio of the injected radioactivity (also known as "injected dose") and body weight. Thus, we can derive it as,

C (injected) = ID/ BW

Where, ID= Injected dose

   BW= Body weight

Both C(image) and C(injected) parameters are time variants. So the ultimate equation of SUV at time t post-injection,

SUV= C (image) (t) /ID(t)/BW

The physical unit of C (image) is often defined as mCi /mL and the C (injected) is mCi/g. So the unit of SUV we will find is g/ml.

When the SUV can be taken from the reconstructed images, this value is further to be calculated through this given equation:

SUV = (PET image Pixels) / (injected dose in mCi)/ (Body weight in kg) (5).

2. Algorithm for Calculating SUV

The measurement of the SUV is directly dependent on computation analysis, and the values are extracted from the images that are loaded first on any particular software. Some significant software is commercially used for calculating SUV from PET-CT images to detect tumorous or malignant tissues. However, in this study, the operation was carried out by a programming code written in MATLAB and subjected to JPEG-formatted PET-CT images.
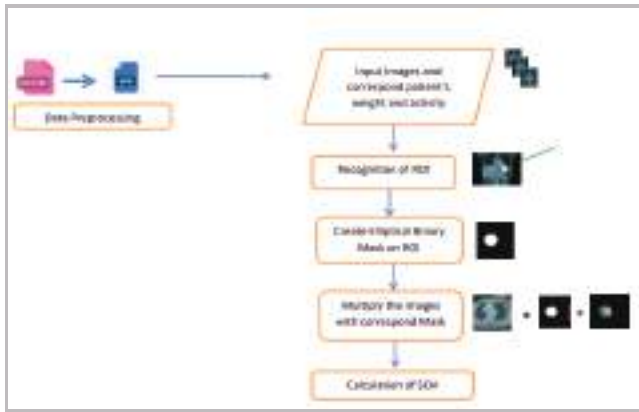
Figure 1: Flow chart diagram of obtaining SUV from MATLAB

3. Preprocessing of Dataset

As it is known, PET-CT provides anatomical and physical features of images, and these modalities are combined after that. Therefore, the PET-CT dataset is reconstructed with different mathematical algorithms to reflect the spatial distribution of the injected radiotracer (6). Those images are either evaluated in a combination of PET and CT modalities or observed individually. The dataset, along with the patient's demographics (for example, the patient's ID, ages, weights, and activity of the injected dose), was collected from the Institute of Nuclear Medicine and Allied Science (INMAS), Dhaka. The PET-CT unit of this institute initially examines the images through commercial-based software called "Syngo®: Siemens." The dataset contains combined images (both anatomical and physical features were recorded) that were previously stored in DICOM format, where the format was further converted into JPG format. The few images were annotated (e.g., mean SUV, min SUV, max SUV, standard deviation), which helped to correlate with the current study.

4. Recognition of ROI in PET-CT Image with Tumor or Cancerous Cells

After loading a previously selected image into MATLAB, this section of code first uses the ellipse () function to select any circular-shaped ROI and then uses the create mask () function to create a binary mask.A region of interest (ROI) is a section of an image that is intended to perform any operation such as filtering, changing the contrast, multiplying with any constant value with an image pixel, and so on.This selection will be useful in medical image analysis to denote the tumor from any image.This region is defined as a binary mask. The binary mask creates an image with the same size as the image we want to process, with pixels that define ROI set to 1 inside it and 0 outside it.

In the FDG-PET scan before the patient's diagnosis, the radioactive tracers are swallowed, inhaled, or injected into the vein. Generally, cancerous or tumor cells have the ability to absorb more glucose than other tissues. Thus, cancer cells absorb more FDG, the PET scanner detects the radiation given off by the FDG, and the scanner is responsible for producing bright color-coded pixels in a certain area of the tumorous cell region during image reconstruction. Moreover, these bright colors have higher pixel intensities than the other pixels. Therefore, normal cells and tumor cells can be easily distinguished, and the physicist can denote the specific area of cancerous or tumorous cells from images (7).
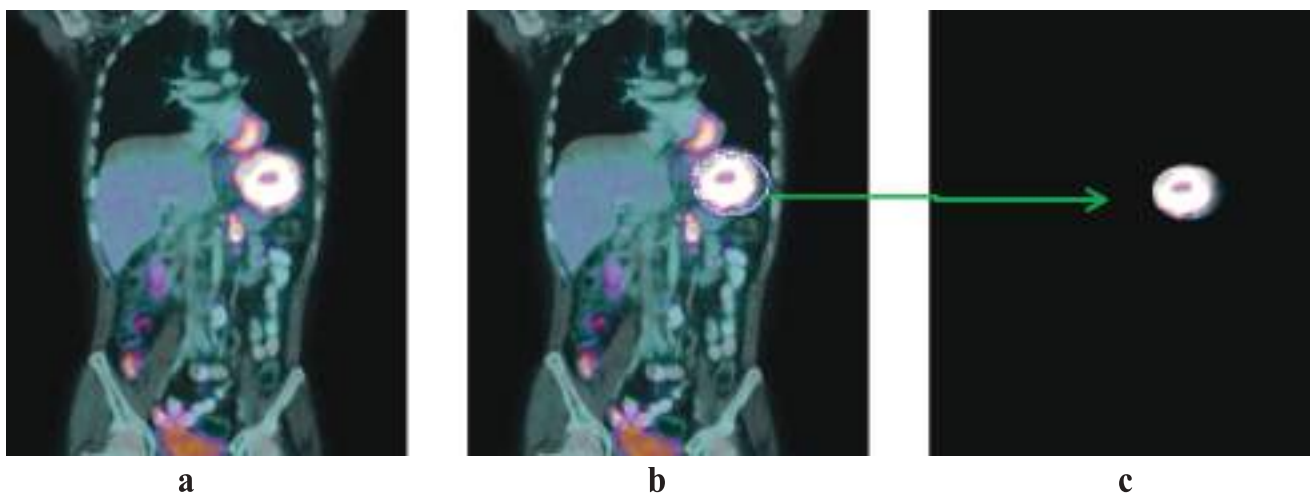

a   b   c

Figure 2: (a) Loaded image from MATLAB of cancer patient. (b) Selected ROI at cancerous portion. (c) Constructed image with created mask & ROI

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5. Correlation between Acquired SUV and Calculated SUV with the Expression of Polynomial Curve Fitting

A non-linear relation between acquired SUV and calculated SUV has been generated by polynomial curve fitting. The operation has been driven by MATLAB software using some particular built-in functions such as polyfit (), polyval (). Since the polynomial equation may have been associated with more than one degree, in this research different equations have been obtained on the basis of taking the degree of orders and determining their coefficients as well. The percentage of error has also been calculated by comparing their performances. Polynomial curve fitting in MATLAB was used in this study.Curve fitting is used to construct a curve or mathematical function. It provides the best fit to the series of data points. It can involve interpolation or smoothing. Each constraint on the graph can be a point of curvature. Angle and curvature can be added at the end of the curve. This phenomenon is called the end condition. Considering the equation for a polynomial curve, it is given as:

$$p(x)=p1xn+p2xn-1+...+pnx+pn+1$$

The nth order degree of the equation has n+1 number of coefficients.

It is also possible to determine the expression of the higher degree of order and estimate the error because we have evaluated the mean percentage of error regarding the degree of polynomial curve fitting up to the sixth term. Klassen et al.(8) came to the conclusion that obtaining the coefficients for the greater degree of polynomial curve fitting is essentially impossible and that the higher degree of polynomial expression can be problematic if the number of samples is limited.

DATA ANALYSIS & RESULTS

1. Evaluation of Patient's demographics

A total of 11 patients were included, and their corresponding body weights (kg) and injected doses (mCi) were recorded as well. Among them, the highest recorded weight was 92 kg, and the injected dose (ID = 8.22 mCi) of that particular patient was the highest as well. Each patient had at least one annotated image where the mean SUV was given on the image. To calculate the mean of SUV by using MATLAB, about 13

images were initially taken (at least one annotated image of each patient and two extra images randomly). For evaluation the correction factors, the number of images was the same as the mean SUV calculation.

2.Data Analysis of Annotated mean SUV with Calculate mean SUV

The major focusing point was to analyze and compare the SUV between the acquired (original) and calculated value. Since the SUV was calculated from 13 images by using MATLAB software, it's important to make a comparison of calculated value of in this study corresponding with the annotated value of the SUV. From the analysis of these images in MATLAB, Table 1 & a graph from Figure 3 of annotated and calculated mean SUV are given below:

Table 1: Quantitative list of Annotated SUV with the correspond values of Calculated SUV
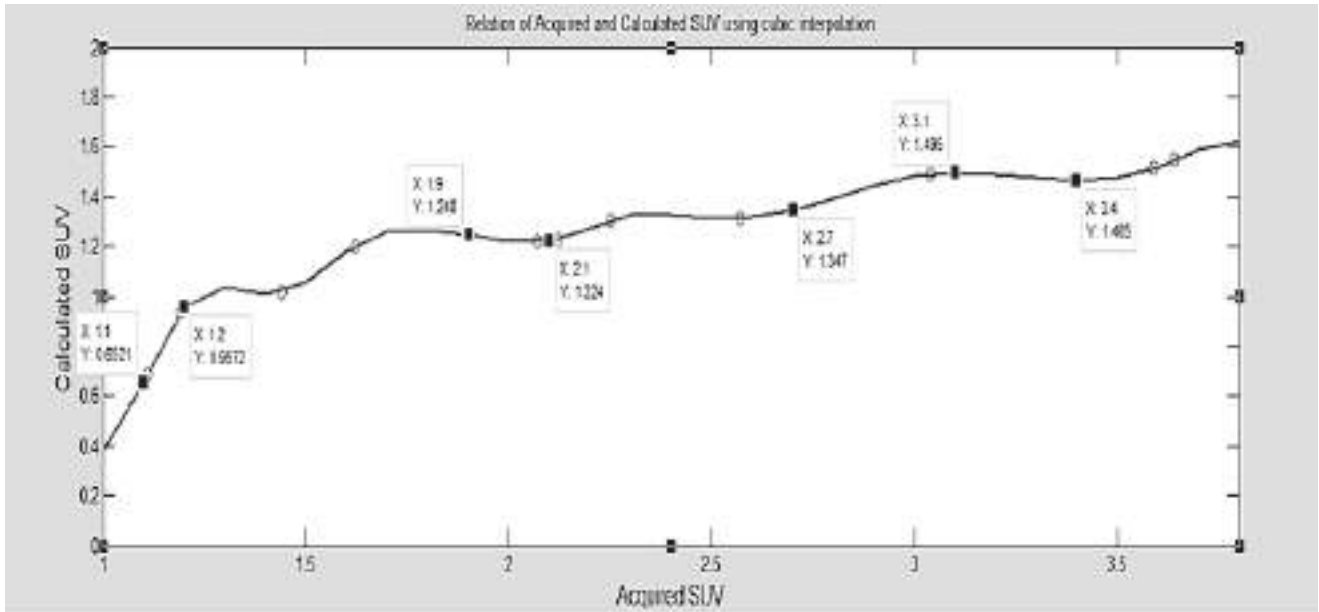
Annotated _SUV		Calculated _SUV	
0.89	2.25	0.589	1.3055
1.11	2.57	0.6874	1.3133
1.19	3.04	0.9361	1.4896
1.44	3.59	1.0145	1.5132
1.62	3.64	1.2023	1.5474
2.07	3.85	1.2186	1.6
2.12		1.23	
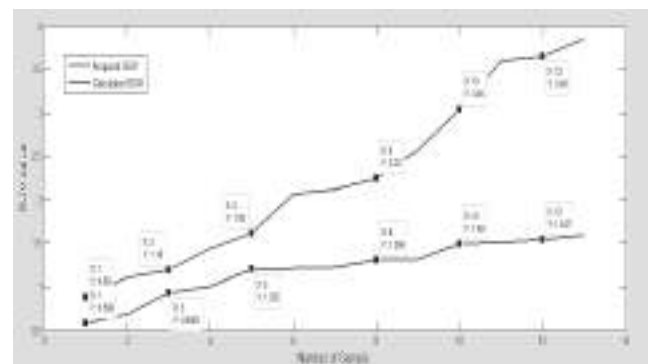
Figure 3: Graphical representation of annotated (acquired) SUV and Calculated SUV. The red curve indicates the acquired SUVs arranged in descending order. The blue curve indicates the calculated SUV values with the response of acquired SUV at the same coordinate along x-axis.

The relationship had been provided with a smooth curve when the polynomial interpolation took place. Paul Nevai, et al. (9) had used spline cubic interpolation to calculate approximate results from the input variables and had given smoothness at the curve. In MATLAB software there is already a built-in function that is generated as a "Spline()" function to interpolate the

proper data and provide a better relation from those variables. Thus, this particular operation was placed to apply spline cubic interpolation.It was clearly distinguished the nonlinear relation between the Annotated SUV values and Calculated SUV values from MATLAB.

Figure 4: Annotated (Acquired) vs Calculated SUV using cubic interpolation

4. Quantitative measurement of polynomial curve fitting

We have examined our result to correlate the calculated SUV with acquired SUV by using polynomial curve fitting. This is one of the most useful analysis tools that we can get the relationship between these response variables. The aim of using this curve fitting is to introduce a polynomial equation for these independent variables (annotated and calculated SUV values) to get the correlation more significantly and obtain the result within the tolerated range.

In our research, we built a code to express the polynomial curve fitting from 2nd degree to 6th degree

Degree of Order	Derived Equation	% of error
2nd	$y= 3.3773\ x^2 -4.5098\ x +2.4764$	6.5%
3rd	$y=0.807\ x^3 +0.6841\ x^2 -1.6730\ x +1.5498$	6.32%
4th	$y= -8.8766\ x^4 + 39.9472\ x^3 - 61.8348\ x^2 + 40.9849\ x -8.8750$	5.34%
5th	$y = 9.8278\ x^5 - 63.2387\ x^4 + 157.2100\ x^3\ -184.7943x^2 + 103.4789x\ -21.1584$	4.973%
6th	$y= -.2510\ x^6 +11.4882\ x^5 -67.705\ x^4 +163.4672\ x^3 -189.5899\ x^2 +105.3830\ x - 21.46$	4.972%

Table 2: Numerical information of polynomial expressions of multiple degree of orders (2nd-6th) for correlating with annotated and calculated SUV

consecutively in order to correlate our calculated SUV with the annotated SUV. The independent variable having existent coefficients is generated from the code. Here the independent variable that is considered as annotated SUV (defined as "x") and the polynomial functions (defined as "y" in Table 2) represent the calculated SUV. However, each degree polynomial function provides optimum curve fitting as well as considerable coefficients. The results from 2nd to 6th degree of polynomial functions and the graphs are given below:
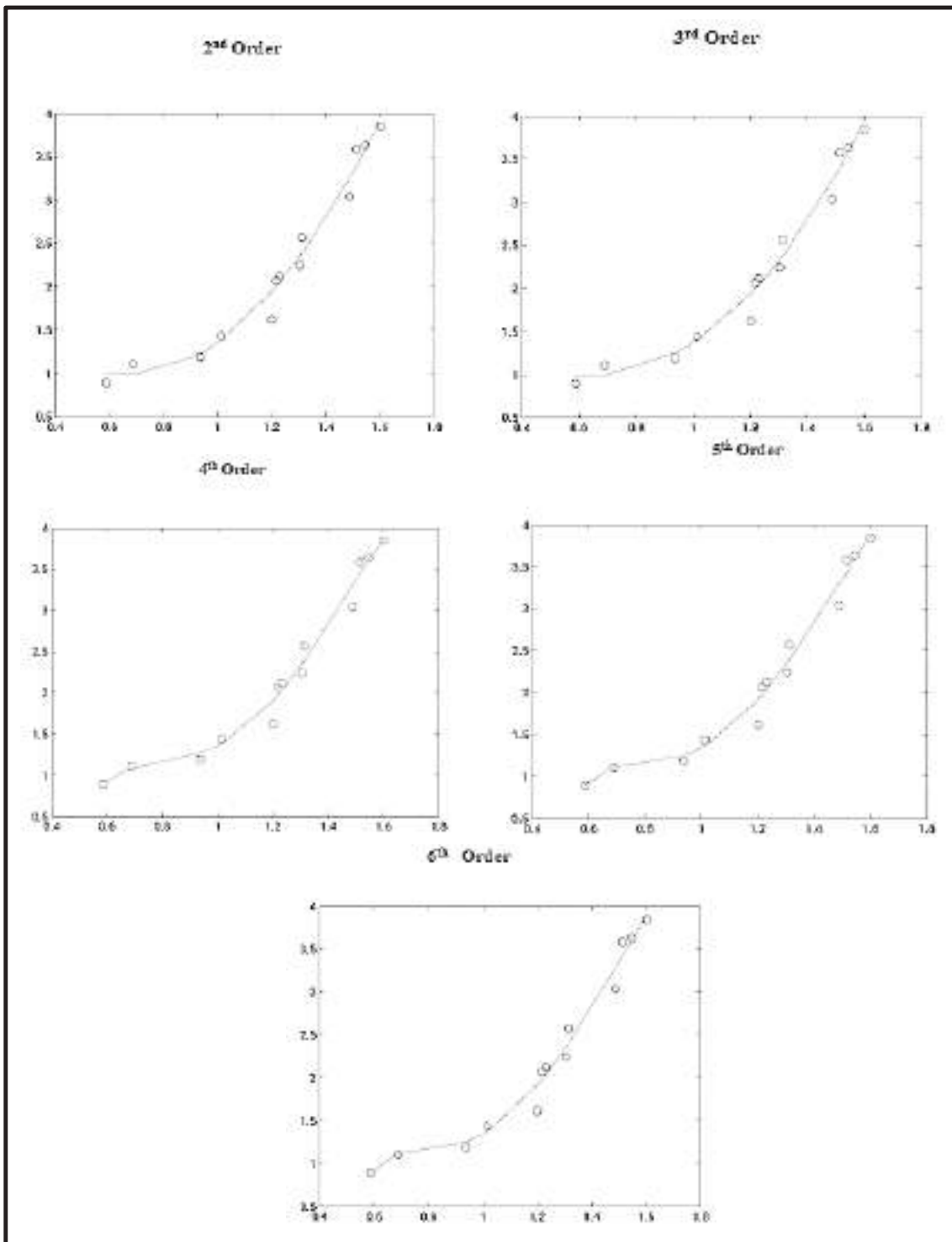
Figure 5: Polynomial expression with different degree of orders of calculated SUV with Annotated SUV. The calculated SUV above the graphs indicates along the X-axis & Annotated SUV indicates along the Y-axis

SUV from PET-CT Image by MATLAB Software

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DISCUSSION

The research work was intended to establish an in-house developed MATLAB program for calculating SUV (Standardized uptake value) and other quantitative information. Here, MATLAB acted as the main assistive tool to find out the relation between the calculated SUV and the acquired SUV. In general, most hospitals use the DICOM format to generate 3d information. The DICOM formatted images are also able to convert in JPG format. It typically shows 2D information from images. Our calculated SUV values are figured out in 2D PET-CT images by selecting the ROI (Region of interest). However, in the selected image for the same ROI, the calculated SUV's are not equal to the acquired SUV's. Therefore, we have obtained the correlation between acquired SUV and calculated SUV through polynomial expressions. The fitted curve can also be represented by multiple degrees of orders. In this study, we have examined 2nd degree of order to 6th degree of order for polynomial curve fitting. By using the 6th degree of polynomial expression, the mean percentage of error has been found as 4.97%. So, it is a more appropriate outcome as justifying correlation of the calculated SUV values which were obtained from this research through using MATLAB compared with the acquired SUV values that had been collected from the hospital as 2D PET-CT images through commercial based software.

CONCLUSION

To summarize, a straightforward and convenient algorithm was built for calculating the Standardize Uptake Value (SUV) by MATLAB. From our research, we were able to accomplish the result with an accepted range of errors using our developed code. The function can be used as an assistive plan of action. Thereby, not only a substantial result is provided by this operation when the main commercial-based software is out of service but many researchers, doctors, oncologists can use the method as a second choice or for further investigations.

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