Original Article

Spreadsheet program for estimating recovery coefficient to get partial volume corrected standardized uptake value in clinical positron emission tomography-computed tomography studies

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ABSTRACT

Purpose: To develop a spreadsheet program for estimation of recovery coefficient (RC) to get partial volume corrected (PVC) standardized uptake value (SUV) in clinical positron emission tomography-computed tomography (PET-CT) studies. **Materials and Methods:** For formulation of this program we used data from a phantom study conducted at our center in which a phantom with a sphere assembly (seven spheres-different diameters) was filled with 18F-Fluorodeoxyglucose solution to get a sphere/background ratio of 8:1, 10:1 and 12:1. PET-CT images were acquired. RC was then calculated from processed PET-CT images. We plotted graph of RC versus lesion-size at different sphere/background ratio using MS Excel function. There was logarithmic increase in RC with increase in lesion size. We fitted the data with a logarithmic equation and found optimum fit (least-square fit).We then validated this program with clinical data using 42 lung nodules in five patients. **Results**: The program estimates the value of RC and object to background ratio in PET-CT for the input lesion-size and displays graph with trendline. When the user enters SUV and background activity measured in clinical PET-CT, it provides the value of RC and PVC SUV. It also validates the data entry and displays appropriate message. It is consistent, reproducible, accurate and provides output for wide range of lesion-sizes (71% of lesions evaluated); however, program does not give output for lesion-size < 9 mm. **Conclusion:** The present spreadsheet program is a useful and easy tool for calculating PVC SUV of clinical PET-CT lesions.

Keywords: Partial volume correction, positron emission tomography-computed tomography, spreadsheet program, standardized uptake value

INTRODUCTION

Standardized uptake value (SUV) is the most widely used semi-quantitative parameter used in positron emission tomography-computed tomography (PET-CT). It is used for categorizing malignant versus benign lesions, and a max SUV of 2.5 or greater is usually consistent with malignancy.[1,2] SUV is also being employed for response monitoring and prognostication of wide array of tumors.[3-12]

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However, assessment of SUV is erroneous in small lesions. For such lesions, if the characterization of a lesion is based on a SUV cut-off (suppose $SUV_{max} > 2.5$), the results can be radically altered. The lesions smaller than twice or thrice of full width half maximum (FWHM) of PET scanner cannot display its true structural (true size) and functional properties (true counts) because of "partial volume effect" (PVE).[13] Therefore, small-sized lesions on PET-CT should be corrected for the error introduced by PVE. This correction can be achieved by applying a particular factor called the recovery coefficient (RC).[14-19]

We had previously carried out a phantom study at our institute to evaluate the PVE introduced in spheres of a phantom and the RC values to be applied for partial volume corrected (PVC) of those spheres.[20] Based on a that study, we had generated a "Look Up Table" for seven different size of lesion only, namely 11, 13, 13.5, 14.4, 15, 18.3 and 19.3 mm having object to background ratio in the PET scan ranging from 2.70 to 19.60, as was seen

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in the phantom. In routine clinical practice, however, we can encounter lesions of variable sizes and a wide range of lesion to background ratios. Hence, there was a need for a program that can provide the value of RC for all lesion sizes having all possible value of object to background ratios on routine clinical PET-CT. We have developed such a spreadsheet program, based on our experimental data.

MATERIALS AND METHODS

Phantom study

The phantom images were acquired using a dedicated PET-CT scanner (Biograph 2, Siemens Medical Solutions, Erlangen, Germany). The phantom was fabricated locally using tissue equivalent material. It consisted of two parts: A hollow cylinder having diameter 18.5 cm and length 20 cm, and multiple spheres. The sphere assembly contained seven spheres of varying diameter ranging from 11 mm to 19.3 mm (i.e., 11, 13, 13.5, 14.4, 15, 18.3 and 19.3 mm). The phantom was filled with water containing 18F-Fluorodeoxyglucose (FDG) to make the sphere versus background activity concentration (μC_i/ml) ratio 8:1. A circular region of interest (ROI) of size as estimated by CT was drawn on PET images of hot spheres. The maximum activity concentration (μC_i/ml) for the hot sphere was noted in all the slices where the image of that sphere was seen on PET-CT. Slice containing maximum activity concentration was determined for each sphere. For measuring the background activity concentration, 12 different circular regions with same area were defined. The processes of drawing region of interest ROIs were repeated on two transverse slices above and two transverse slices below the maximum intensity pixel. Mean activity concentration was recorded for each region and then the average for all 60 regions was calculated.

The value of RC for each sphere size was calculated by the formula:

$$RC = \frac{\text{Measured maximum activity } (\mu C_i) - \text{Background activity } (\mu C_i)}{\text{Known activity } (\mu C_i) - \text{Background activity } (\mu C_i)}$$

The same experiment was repeated at sphere/background activity ratios of 10:1 and 12:1.

Spreadsheet program

This program was created in Microsoft Excel spreadsheet program (Microsoft Office, Microsoft Corp., New Jersey, USA) using the personal computer having Pentium (R) 4 CPU 3.00 GHz, 2.99 GHz, and 504 MB of RAM. We plotted graph of RC versus lesion-size (diameter of sphere in mm) with sphere to background activity ratio at the time of acquisition (namely, 8:1, 10:1 and 12:1). As size of lesion increased, there was an increase in the value of RC and this increase was logarithmic. A logarithmic data fit was performed which provided the following three equations involving RC and lesion-size (diameter of sphere):

$$y = 1.3964 \text{ Ln } (x) - 2.9862 \quad \text{for 8:1} \tag{1}$$

$$y = 0.9455 \text{ Ln } (x) - 1.9905 \quad \text{for 10:1} \tag{2}$$

$$y = 0.3128 \text{ Ln } (x) - 0.7305 \quad \text{for 12:1} \tag{3}$$

Where y = RC and x = lesion-size (diameter of sphere in mm).

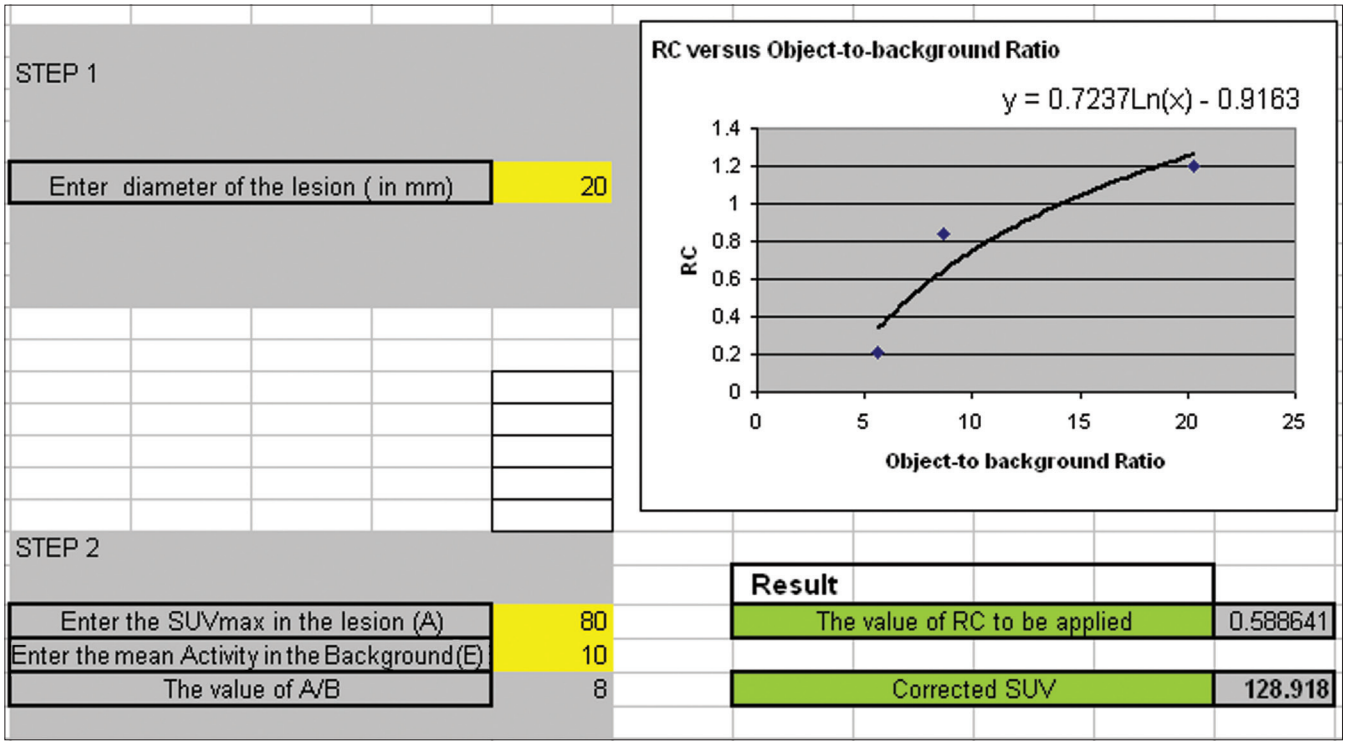

Figure 1: Graphical user interface of the spreadsheet program

Similarly, we again plotted three separate graphs of measured object to background ratio in the PET scan (max pixel in hot sphere: Average background pixel) versus lesion-size (diameter of sphere), and logarithmic data fit were performed. The following three different equations were available for object to background ratios of 8:1, 10:1, and 12:1:

$$y = 24.44 \text{ Ln } (x) - 52.918 \quad \text{for 8:1} \tag{4}$$

$$y = 5.6762 \text{ Ln } (x) - 8.3223 \quad \text{for 10:1} \tag{5}$$

$$y = 6.4 \text{ Ln } (x) - 13.536 \quad \text{for 12:1} \tag{6}$$

Where y = measured object to background ratio on PET and x = lesion-size (diameter of sphere in mm).

We used these three equations (Equations 4, 5 and 6) to estimate the value of measured object to background ratio in the PET scan for a given lesion size when spheres would have been filled with 8:1, 10:1 and 12:1 sphere/background activity ratio at the time of acquisition.

Using equations 1-6, we made the program to generate on-line the value of RC and estimated value of object to background ratio on PET images for a given lesion size when spheres would have been filled with 8:1, 10:1 and 12:1 sphere/background activity ratio at the time of acquisition. The program also generates an on-line a graph, performs logarithmic fit and displays a logarithmic trendline equation for the generated data points.

The program requires the maximum SUV value of the lesion and background as input data from the user. As soon as user enters this data, the program calculates the value of the RC to be applied for the entered lesion-size, based on the logarithmic trendline equation between RC and estimated value of object to background ratio in the PET scan and calculates the corrected SUV using Equation 7:

$$\text{PV corrected activity} = \frac{\text{Measured activity} - \text{background activity}}{\text{RC}} + \text{background activity} \tag{7}$$

Table 1: Finding of positron emission tomography-computed tomography of the 42 pulmonary nodules used for validation of the spreadsheet program

Lesion size (mm)	SUV	SUV/background ratio	RC	Corrected SUV
5.02	1.60	2.36	NA	NA
7.41	1.10	1.36	NA	NA
8.80	0.94	1.19	0.024	−9.19
7.08	1.85	2.27	NA	NA
6.35	0.85	1.13	NA	NA
6.56	0.92	1.10	NA	NA
6.21	0.75	1.08	NA	NA
9.26	1.03	1.34	0.073	9.09
8.19	1.44	1.68	NA	NA
13.93	1.57	1.70	−0.21	−2.15
7.41	1.54	1.33	NA	NA
9.21	1.29	1.23	0.045	6.42
14.40	1.31	1.38	−0.34	−0.96
12.5	5.48	7.60	0.48	10.53
11.41	1.73	1.98	0.017	49.02
8.84	4.80	3.49	0.062	56.60
18.97	11.25	13.54	0.95	11.79
16.57	26.62	19.76	1.12	23.81
9.27	2.43	1.28	0.04	13.04
8.33	2.14	1.05	NA	NA
10.17	2.88	1.45	0.023	39.47
9.73	5.97	3.78	0.17	26.75
14.99	1.87	1.16	0.48	1.06
10.67	2.75	1.53	−0.002	−328.38
9.54	2.30	1.06	0.020	8.33
10.34	4.02	1.89	0.065	31.05
10.16	4.15	2.20	0.10	24.43
10.48	1.88	1.14	−0.05	−2.92
8.41	5.60	2.96	NA	NA
14.67	1.66	2.11	−0.144	−5.28
9.49	6.66	5.79	0.198	28.99
8.70	1.81	1.64	NA	NA
8.70	2.97	2.59	NA	NA
19.90	13.90	14.35	1.00	13.77
17.80	3.92	4.69	0.23	14.12
20.5	7.92	7.87	0.57	12.97
13.09	11.10	12.53	0.72	15.05
23.31	3.24	2.70	−0.293	−5.74
11.54	1.52	1.51	−0.07	−5.60
21.59	17.42	12.94	0.94	18.34
27.66	18.67	14.83	1.14	16.49
16.57	2.05	2.02	−0.263	−2.91

SUV: Standardized uptake value, RC: Recover coefficient, NA: Not applicable

Clinical validation

Test cases were generated to test this program so that boundary condition for it can be defined in which this program can successfully estimate the value of RC and corrected SUV after partial volume correction. Data of five patients with 42 pulmonary nodules was used for this purpose. The SUV_{max} of these nodules and the background was measured on PET. The size was measured on CT. The RC and the PVC SUV of these nodules was calculated using the spreadsheet program.

RESULTS

Graphical User Interface of the program is shown in Figure 1. Data entry has to be completed in two steps. In the first step, the program requires the user to input the lesion-size in mm. Based on the data entered, the program estimates the value of RC and object to background ratio in the PET scan, generates a graph, displays equation for the trendline [see in the upper right end of Figure 1]. In the 2nd step, user is also required to enter the value of SUV of the lesion and background for which the PVE corrected SUV is desired. As soon as the user completes the entry of data, the program displays both the RC to applied and corrected SUV value on result areas [lower right hand side of the Figure 1]. The program gives consistent and reliable result. It is stable and reproducible. It provides appropriate and clear message when the calculation of RC is not possible with this program. In order to validate this program, data of all 42 lesions-their sizes and their SUV to background ratio were fed as input parameter to the

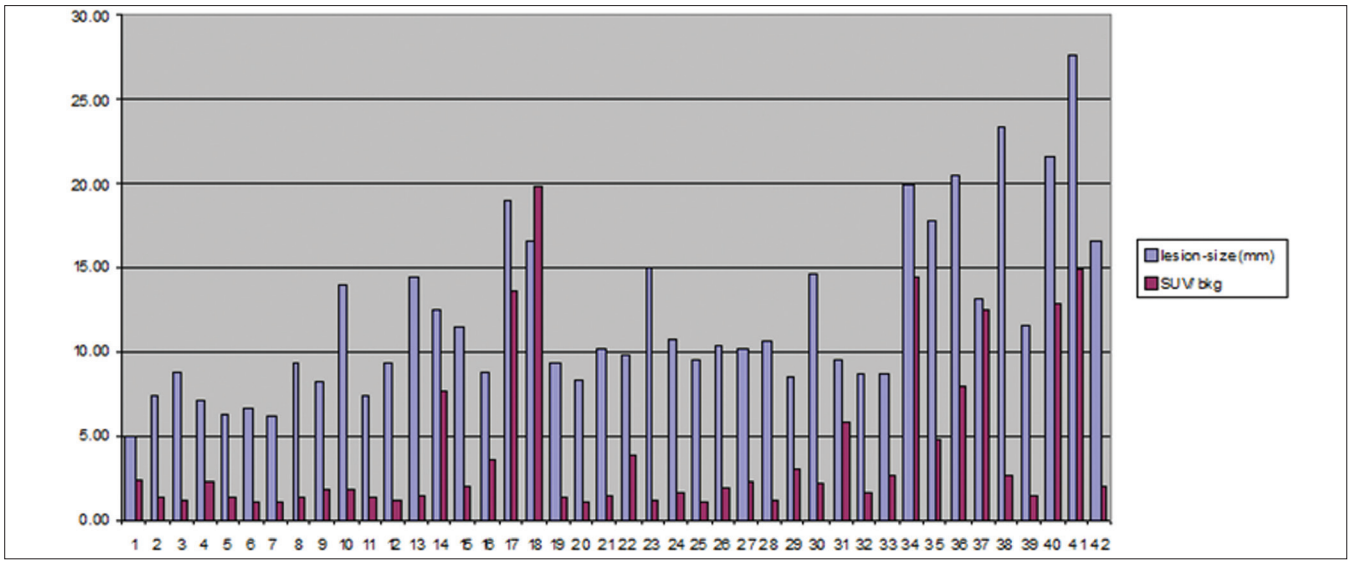

Figure 2: Bar chart displaying the lesion-size (mm) and their standardized uptake value to background ratio of the 42 pulmonary lesions selected for the validation of the spreadsheet program

program in order to calculate the RC and PVC SUV value. Result has been given in Table 1; Figure 2. The lesion-size varied from 5.03 mm to 27.67 mm and SUV to background ratio varied from 1.05 to 19.76. For some lesion-sizes, the generated array of RC and estimated object-to-background ratio was such that it was not possible to calculate the trendline equation (i. e. not possible to fit the data). For the selected 42 lesion-sizes for validation, by using the previous "look up table" generated from phantom study, we were able to estimate the value of RC and PVC SUV for 10 lesion only (24% lesions). However, with the present spreadsheet program we estimated RC and PVC SUV value for 30 lesions (71% lesions).

It can be seen from the Table 1 that this program could not estimate the value of RC and PVC SUV for the lesion-size less than 9 mm (total 10 cases out of 42). It has estimated the value of RC more than 1 for the two lesions of lesion-sizes 16.57 mm and 27.66 mm, which are greater than 16 mm. However, at a same lesion-size of 16.57 mm we have also obtained negative value of RC (–0.263) and corrected SUV value (–2.91). For some lesion-sizes, the generated array of RC and estimated object-to-background ratio was such that it was not possible to calculate the trendline equation (it was not possible to fit the data). In such cases, the program displays the error message "some trendlines cannot be calculated from data containing negative or zero value" [Figure 3].

For lesion-size less than 18 mm, there is a PVE. Based on data fit, however in some cases, the estimated RC value was negative. If we use this value for PVC SUV value then it will be less than measured SUV value without any correction applied. This is erroneous and not acceptable. Hence, user must reject such values.

DISCUSSION

There was a need for a program that can provide the value of RC for all lesion sizes having all possible value of object to background ratio in PET-CT, encountered in the routine clinical practice. We developed such a spreadsheet program based on our experimental data. The program requires Microsoft Excel 2003 to execute. The program is robust and very useful, time saving, and eliminates manual calculation error, which might be introduced in the process of calculation of PVC SUV.

Recently, some studies[21,22] in the literature have generated "look up table" for RC and partial volume correction based upon phantom study. These were similar to our phantom study but with difference in the lesion-size and object-to-background ratio. Furthermore, our study was hot sphere in hot background model while most of the studies employed hot sphere in cold background model. By using the "look up tables" obtained from the phantom studies only those clinical lesions whose size matches the value of the lesion size and the measured object-to-background ratio with that of the study can be corrected for PVE. Our spreadsheet program is entirely different from a simple "look up table"; here we were finding the RC for a given range of lesion-size (11-19.3 mm) in the various condition of object-to-background ratio including the object-to-background ratio not available in simple look table.

However, this program has certain limitations. As RC depends on various factors that can affect the RC and influence the magnitude of PVEs in most cases, therefore, this program can give accurate results only if certain conditions are met. Our program could not estimate the value of RC and PVC SUV for the lesion-size less than 9 mm (total 10 cases out of 42), because the generated data was so dispersed that it was not possible to fit the data for logarithmic relationship between RC and estimated value of object to background ratio. It has estimated the value of RC more than 1 for the two lesions of lesion-sizes (16.57 mm and 27.66 mm, which are greater than 16 mm). However, at a same lesion-size of 16.57 mm we have also obtained negative value

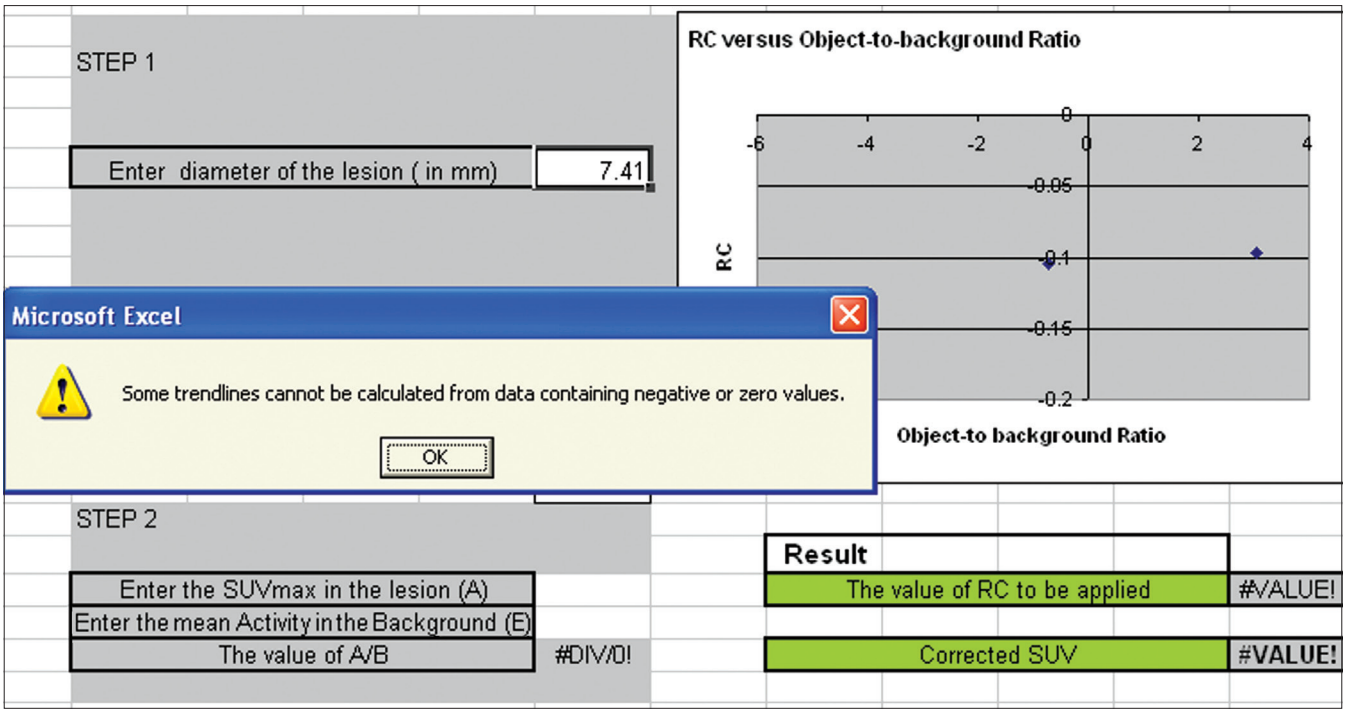

Figure 3: Error message generated in the spreadsheet program when it is not possible to estimate recovery coefficient and partial volume corrected standardized uptake value

of RC (–0.263) and corrected SUV value (–2.91). Serial No. 18 has SUV/Background ratio 19.76 while Serial No. 42 has SUV/Background ratio 2.02, and both have same lesion-size as 16.57. This difference is obviously due to SUV/Background ratio and based on our experimental data it is correct because for same lesion size we had the less value as object-to-background ratio in the experimental data increases that is from 8:1 to 12:1, the value of RC and measured value of object-to-background ratio in PET scan decreases. Therefore, for 19.7 SUV to background ratio the value of RC will be more in comparison to SUV to background ratio of 2.02.

Since this spreadsheet program is based on the data collected in our previous study,[20] any user, who has similar experimental conditions, can use this program. In brief, the following conditions need to be satisfied:

- The FWHM of the PET system should be 6 mm.
- Geometry of lesion should be spherical.
- The maximum pixel value within a ROI should be taken to calculate the value of RCs.

CONCLUSION

We have presented a spreadsheet program which can provide PVC SUV of clinical lesions with ease and accuracy. This can be used for most but not all lesions seen in clinical PET-CT imaging.

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