

A new Standard Uptake Values (SUV) Calculation based on Pixel Intensity Values

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Abstract— Positron Emission Tomography (PET) is one of the major cancer imaging tools for both diagnosis and staging. The prognostic significant parameter for PET scan is Standard Uptake Values (SUV). The SUV can be used as a tool to supplement the visual interpretation for physician. However the SUV can not be calculated without the vendor's application software. In order to calculate the SUV without the vendor's application software, a new standard uptake values (SUV) calculation scheme based on image intensity has been introduced. This new scheme is tested by using 108 slices of DICOM files obtained from 11 patients (8 men, 3 women). The comparative study between this scheme and the GE Xeleris workstation has been done and the results showed that the correlation between the two systems is statistically significant with a 99% confidence interval. The average percentage of accuracy is 85% for the report at a 95% confidence interval. So this scheme can be used as an alternative tool to calculate the SUV and it can be installed in any computers.

Keywords—Positron Emission Tomography combined Computed tomography (PET/CT), Standardized Uptake Value (SUV), The Digital Imaging and Communications in Medicine (DICOM)

I. INTRODUCTION

PET/CT was launched to market in early 2001. It has been popular since then. Now PET/CT has been became one of the main imaging tool for both diagnosis and staging in cancer. PET/CT can also be used in radiation treatment planning (RTP) because of the ability to demonstrate the physiological data of the tumor cell. PET/CT is classified as medical device that measures radioactive traces injected into the body.

PET is a non-invasive diagnostic tool that provides tomographic images and quantitative parameters of the blood perfusion, cell viability, proliferation and / or metabolic activity of tissues. These images result from the use of different substances of biological interest (glucose, amino acids, and hormones) labeled with positron emitting radionuclides.

PET radiopharmaceuticals are used for diagnostic. They are used for imaging of metabolic pathway in the body. F18-FDG is a widely used technique in clinical practice today.

FDG could be used as tracer for diagnosis of cancer because FDG is an analog of glucose that the living cell will be taken up in the first stage of glucose pathway. The taking of FDG by cell depends on an increased of glycolytic activity in neoplastic cell which is a cancer cell.

The simplest semi-quantitative approach is to estimate the concentration of tracer in a given region from PET images by using an ROI analysis. The semi-quantitative measure of local FDG uptake has been developed and utilized in differentiating benign from malignant lesion since malignant lesions in general having greater uptake. SUV (Standardized Uptake Value) is the value that often used in PET scan.

Standardized Uptake Value (SUV) is universally used in routine clinical practice. It is used as a parameter of the semi-quantitative in FDG - PET analysis. The SUV provides a determination of activity in a defined region of interest (ROI) normalized to the patient's body weight and administered dose. Being a ratio, it is unit less and is calculated by

$$SUV_{bw} = \frac{\text{Measure Activity in Region of interest (ROI)}_{(mCi/ml)}}{\frac{\text{Injected Dose}_{(mCi)}}{\text{Body Weight}_{(g)}}} \dots(1)$$

SUV is affected by several factors. It has a strong positive correlation with weight if it is calculated in body weight term. The time of measurement is also effected, the earlier imaging provides low results, and conversely delayed scans provide high SUV. Also the other factors such as dose extravasations, attenuation parameters, reconstruction parameters, partial volume effect and plasma glucose level in patient blood affect the value of SUV.

The cut-off value for malignant lesion is 2.5 and it has largely been proven to be an oversimplification. SUV is the one of many criteria used for interpretation, including visual uptake, lesion size relative to uptake, and also clinical history. Some routine clinical purpose, visual analysis of PET images is sufficient for clinical interpretation. SUV does provide an objective parameter for image analysis and is useful for research purpose. For patients with cancer, it is important to report SUV of chosen index lesions.

Either SUV_{maximum} or SUV_{mean} in a region of interest (ROI) can be used. Nevertheless physician prefers to report the case by the Maximum SUV. Because the maximum SUV is least affect by partial volume effect, [2] so in this research we calculate the SUV_{max} which is obtained from the Maximum Pixel Value in the image slice.

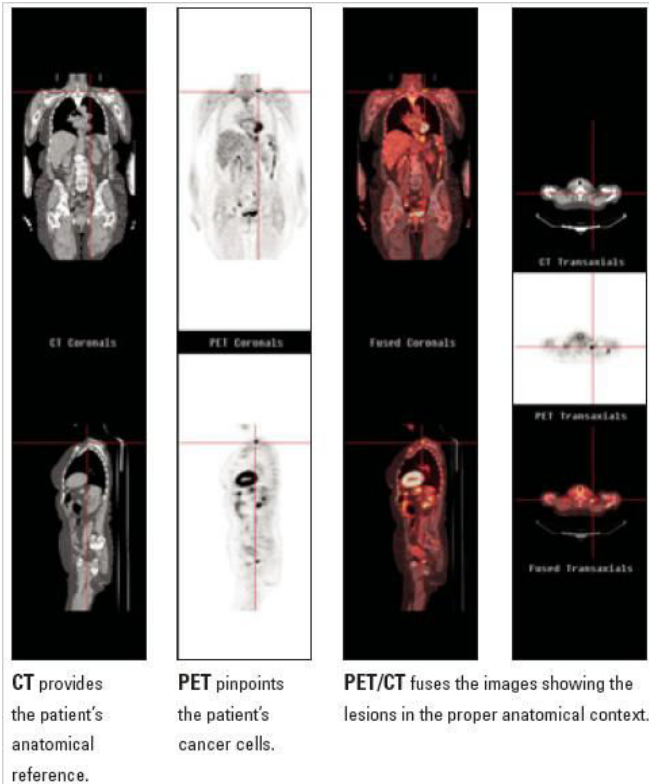


Fig 1. the example of all image planes from PET/CT : coronal plane(above), sagittal plane(below), transaxial plane(right) (<http://www.westcoastradiology.net/images/pic-pet-ct-1.jpg>)

To calculate the SUV, ROI was drawn on the image that appears on the screen by the reader (physician). The computer then calculates the average density or maximum density in that ROI, then the decay of uptake in the period and counting efficiency were corrected. The pixel intensity value in the ROI area finally was converted to the activity per gram of tissue, assuming tissue density is equal to 1 g/cc. [1-2]

The body weight (kg) and injected dose ($\mu\text{Ci(Bq)}$) were together used, the SUV is calculated for the ROI using Eq. 1. All process above needs a specific application program.

Each manufacture (vendor) in the market has their own application which supports only the files from their equipment. Moreover the workstation of application is mostly installed nearby the equipment or in the hospital area. The limitation of data accessible is the main motivation in this research. We eradicate limitation by created the application program for calculate the SUV using MATLAB which is a widely used in science and engineering.

In this research, DICOM (Digital imaging and communications in medicine) [3-4] file is used as the sample source. DICOM is not just an image or file formats. DICOM file is a file format developed by the DICOM Standards Committee whose members are partly members of NEMA. The strength of DICOM files is the exchangeability between two entities that are capable of receiving image and patient data. DICOM also enables the integration of scanners, servers, workstations, printers, and network hardware from multiple manufacturers into a picture archiving and communication

system (PACS). It covers all of the data transfer, storage and display protocol created and designed to cover all aspects of digital photography, medical simplified.

Picture Archiving and Communication System (PACS) is an electronic system dedicated to medical image management. It enables the following image cycle: production on imaging devices, archiving, transfer via network and consultation, processing and softcopy reading on stations. It is a standard for file formats and inter-system communication used in hospitals and clinical labs for storing radiology images (Xrays, MRIs, CTs, PET/CT, etc).

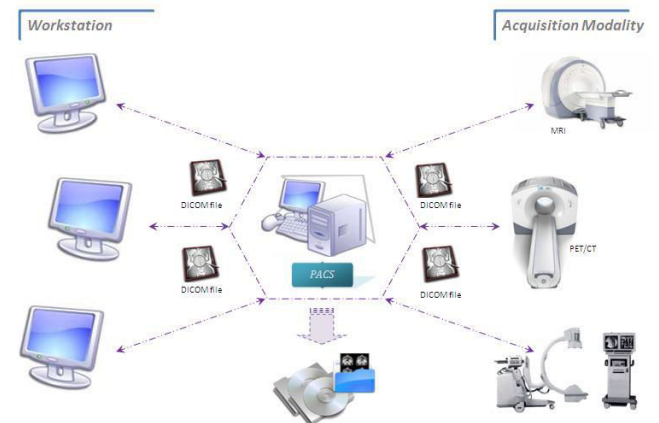


Fig 2. The work flow diagram of PACS and DICOM in the system.

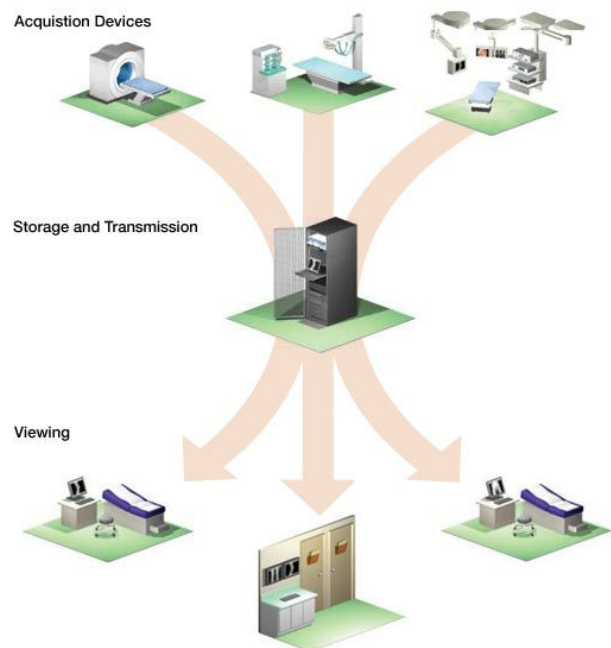


Fig.3. Major Picture Archiving and Communication System (PACS) components. Image acquisition devices (modalities) store

A DICOM file is easily divided into two main parts which are the DICOM image and the metadata (header). The SUV calculation scheme is created based on the data from both part.

Preamble	First 127 bytes contain blank area called preamble. This is a comment area.
Prefix	DICM is the prefix that identifies that this file is a DICOM image file. Strictly speaking, all the DICOM files must possess this preamble & prefix.
DATA ELEMENTS (Tag, VR, VL, Values)	A Data Element.
DATA ELEMENTS (Tag, VR, VL, Values)	It is the Data elements all the way down...
Pixel Data	And then comes the pixel data. Pixel data is nothing but the image. The image's pixel values are stored here. This pixel data array is followed by the a unique tag '7FE0 0010', which tells you that it is Pixel data values.

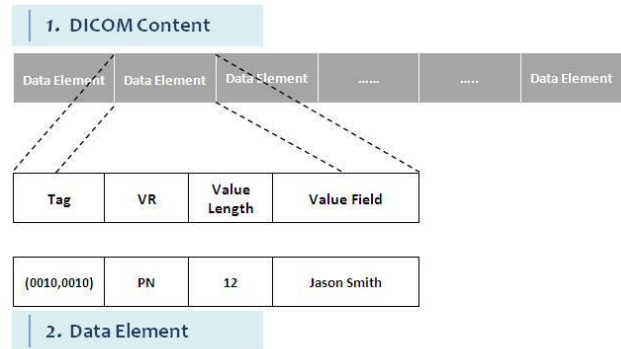


Fig 4. The data elements consisting of TAG, VR, Value Length and Value field.

A DICOM file contains binary *attribute* or data elements. Each element consists of

1. A tag, in the format of group, element (XXXX,XXXX) that identifies the element.

- A Group No. Tells you about an entity.
- An Element No. Identifies the exact information in the group

For Example, In the tag (0010,0020): Group No. is 0010 and Element No. is 0020. The Group no. 0010 tells you that the information is about PATIENT and the Element No. 0020 tells you that the information is about the PATIENT NAME.

Some Groups: (Group numbers are in Hexadecimal)

- Group 2: Contains File Meta information
- Group 8: General series info.
- Group 10: Patient info.
- Group 20: General Study info.
- Group 28: Image info.

Etc.

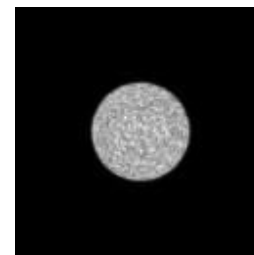
2. A Value Representation (VR) that describes the data type and format of the attribute's value. It is an optional field.

3. A value length (VL) that defines the length of the attribute's value.

4. A value field containing the attribute's data.

Each data element must be read in order to march through the file and find the data of interest.

The current DICOM standard specifies that the file contains the string "DICM" starting at byte position 128.



(a)

Field	Value	Min	Max
PixelDataGroupLength	32780	32780	32780
ImageIndex	83	83	83
DeadTimeFactor	1.0365	1.0365	1.0365
ScatterFractionFactor	0.2066	0.2066	0.2066
DoseCalibrationFactor	1213	1213	1213
DecayFactor	1.0291	1.0291	1.0291
SliceSensitivityFactor	1	1	1
SecondaryCountsAccumulated	0	0	0
PrimaryPromptsCountsAccumulated	0	0	0
FrameReferenceTime	183000	183000	183000
CoincidenceWindowWidth	0	0	0
TransverseMesh	2	2	2
AxialMesh	[1;2]	1	2
ScatterCorrectionMethod	'Model Based'		
DetectorLinesOfResponseUsed	'0'		
ReconstructionMethod	'3D IR'		
DecayCorrection	'START'		
AttenuationCorrectionMethod	'measured, 0.096000 cm-1.'		
RandomsCorrectionMethod	'SING'		
CountsSource	'EMISSION'		
Units	'BQML'		
SeriesType	'STATIC IMAGE'		
PatientGantryRelationshipCodeSequence	<1x1 struct>		
DataSetOrientationInformationCodeSequence	<1x1 struct>		

Fig. 5. The DICOM file is reviewed by MATLAB (a.) Image part (b.) Header (Metadata) part.

For more practicable, the performance of the scheme was tested by comparing to the well-known application from GE healthcare (Xeleris workstation).

This paper will present the SUV calculation scheme that was created from DICOM files by using MATLAB [5-6] and the performance test of the SUV scheme by comparison of the SUV from the scheme to the SUV obtained from the Xeleris workstation. For more practicable, the tests were based on patient files.

II. METHOD

Since the similar study is not much prevalent. So we have to start doing the research by PILOT STUDY. The purpose of pilot study is for studying the characteristic of DICOM file type that would be used in the research. The Pilot study has done by scanning phantom instead of patients. Then the obtained files could be used for study further.

In the pilot study, we used DICOM files from Phantom scan (PILOT STUDY). It must be prepared, and we use the WCC phantom or well Counter Correction Phantom and do the scan according to the Phantom preparing for Quarterly QC.

The algorithm of the SUV calculation scheme

- a) Extract pixel intensity value from PET image.
Define the region of interest (ROI) in the image and then extract the pixel intensity value in that ROI. The maximum of the value is used for SUV_{max} calculation.
- b) Convert the obtained pixel intensity value from ROI to the activity concentration in Becquerel.
The pixel intensity value represents the accumulation of activity in the region, the conversion needs the parameter from the metadata part which is containing all information of the scan.
The attributed tags in this part include Rescale Slope, Rescale Intercept, dose calibration and Units. (Only Rescale slope is individual in each slice). [7-8]

$$\text{Activity Conc. in ROI}_{(Bq/ml)} = \text{Pixel Value} \times \text{Image Scale Factor} \times \text{dose calibration} \dots\dots(2)$$

$$\text{Image Scale Factor} = \text{Rescale Slope} \dots\dots(3)$$

- c) Together all other related attributed tag for calculate SUV within a file slice.
Full fill the SUV calculation formula (1) by the actual activity and body weight which are obtained from these attributed tag i.e. Total Dose (0018,1074), Series Date (0008,0021), Series Time (0008,0031), Radiopharmaceutical Start Time (0018,1072), Radiopharmaceutical Half Life (0018,1075) and Patient Weight (0010,1010)
- d) Calculate as a volume term by integral SUV from many slices.
In practical, SUV calculation is analyzed in the Volume of Interest (VOI). So In this study , We defined the volume of interest (VOI) and then summarized the SUV in every slice in the volume. The ROI of SUV from each slice is all same position and size.

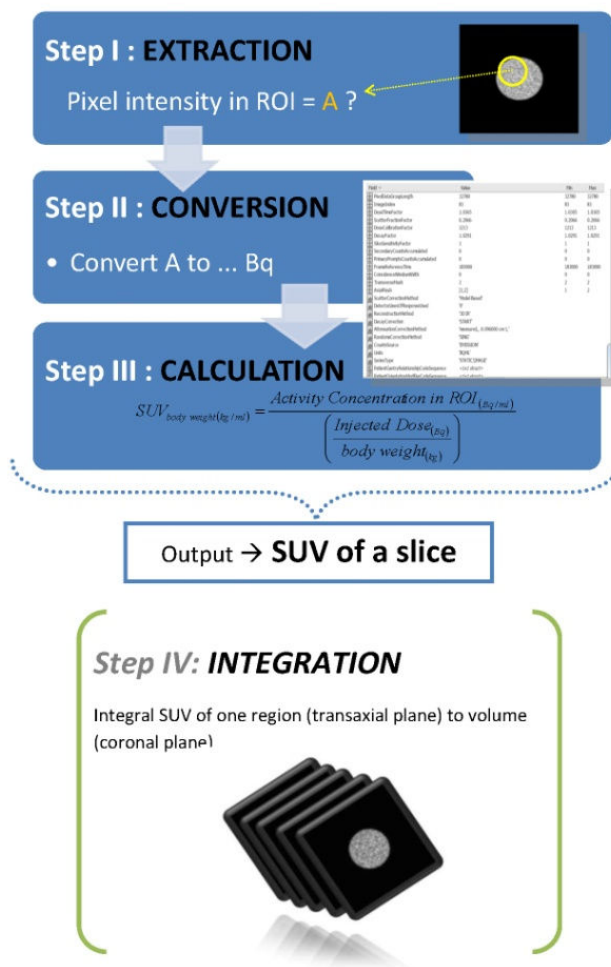


Fig 6 SUV calculation algorithm of MATLAB scheme

For more practicable the SUV calculation Scheme testing is needed. This research uses the same sample to compare SUV from two methods. This SUV calculation Scheme is operated on the PC with the installed MATLAB. In order to evaluate the performance of the scheme, it is compared to the SUV that obtained from the Well-known application software from GE healthcare (Xeleris workstation).

The scheme will be tested by inputting the PET DICOM file. The first aspect in this comparison is that both systems need to proceed in the same file. After a study of GE healthcare DICOM file by doing the PILOT STUDY, we found that GE healthcare has stored the DICOM file by arranged inversely. The first file (Slice No.1) on Xeleris is the last DICOM file (Slice No.277) on MATLAB.

Both Xeleris and MATLAB (the SUV calculation scheme) allow the interpretation of ROI analysis. The circular ROIs were drawn surrounding the region of FDG uptake (lesion). In each patient is consisted of many of file slices according to each lesion on each patient. The SUV in the defined region was recorded by the Xeleris® workstation and MATLAB.

The main SUV calculation scheme was created as an application that can calculate the SUV by drawing

immediately on the DICOM files that you want to know. Both systems are needed to analyze on the same file, and also matched region of interest (ROI). The ROI within slice was drawn in the same location and size. So another application is needed to be created to compare them both. It was run by calling the file as ROIs model (include position and shape) for the next DICOM file to compare.

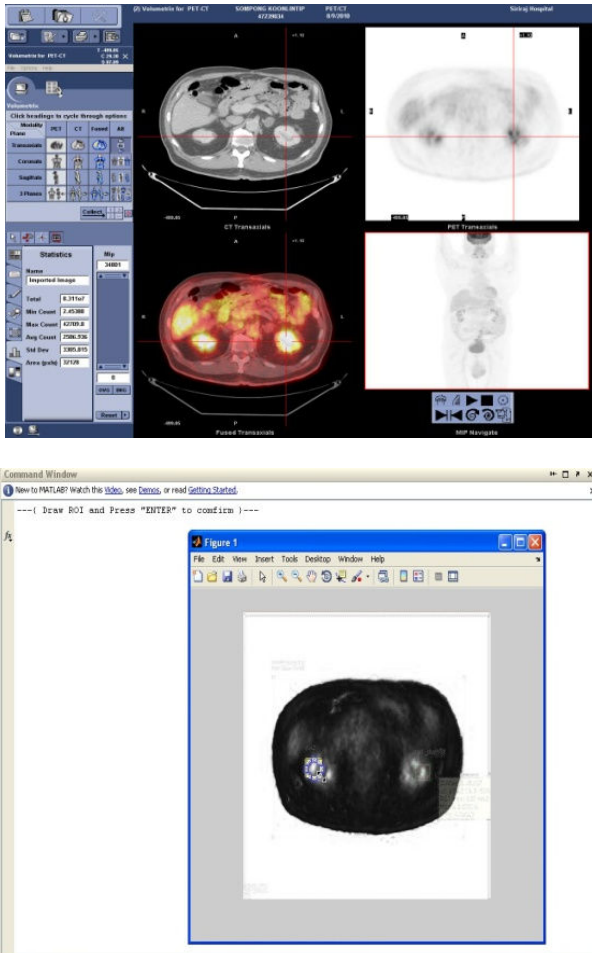


Fig 7 Analysis screen of (a) Xeleris Workstation (b) MATLAB scheme

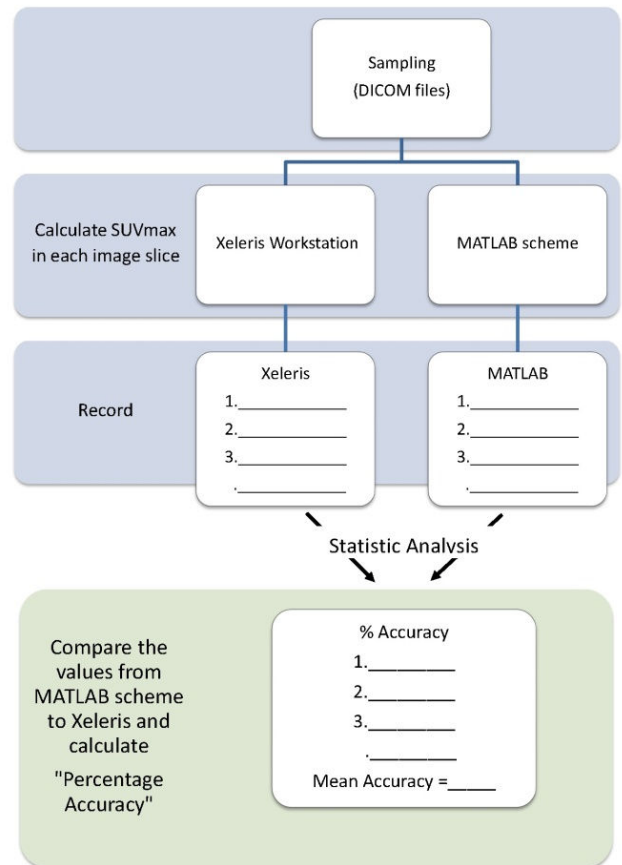


Fig 8 procedure of data sampling and analysis

The statistical analysis was tested by using SPSS version 11.5 and Microsoft excel. The correlation between two variables reflects the degree to which the variables are related. The most common measure of correlation is Pearson's Correlation. Pearson's correlation reflects the degree of linear relationship between two variables. It is used when both variables are at least at interval level and data parametric.

The SUV from new MATLAB scheme was compared to the Xeleris workstation. It was performed with 108 file slices from 11 patients. The correlation of both systems was analyzed with Pearson's correlation technique. The accuracy of new scheme was tested by calculating the relative error between both system and distribution of these result were tested.

III. RESULTS

The SUVs from the new scheme which was created by MATLAB were directly compared with the well known PET/CT application, Xeleris Workstation. It was performed the comparison by using 108 slices of DICOM files that were obtained from 11 patients (8 men, 3 women). Those files were randomly sampled by computer. They were taken through F18-

FDG PET/CT scanning at Siriraj Imaging Center during January to October 2010.

The SUV from Xeleris Workstation and MATLAB were compared by the Pearson correlation Test. The result showed high correlation coefficient of 0.974 indicating a close correlation of results from Xeleris workstation and MATLAB. R^2 is 0.9487, we can say that about 99% of comparable capability to predict the SUV_{MATLAB} from $SUV_{Xeleris}$, 1% remain for other factors plus randomness

Table 1 The correlation of maximum SUV between 2 systems. *Correlations*

		Xeleris	MATLAB
Xeleris	Pearson	1	.974(**)
	Correlation		
	Sig. (2-tailed)		
	N		
MATLAB	Pearson	.974(**)	1
	Correlation		
	Sig. (2-tailed)		
	N		

** Correlation is significant at the 0.01 level (2-tailed).

Table 2 Statistical an analysis of accuracy of SUVs obtained from MATLAB scheme.

N	Mean	%		Std.
		Accuracy	SD	Mean
108	85.203	6.732	0.647	
95%Confidence Interval for Mean	Lower Bound	83.919		
	Upper Bound	86.488		
	- Minimum	75.16		
	- Maximum	99.96		

From table 1, the average of percentage accuracy is 85% and for the report at 95% confidence interval, the result ranged from 83.91% to 86.48%.

The performance of MATLAB scheme was tested by comparing the obtained SUV_{max} to the Xeleris Workstation.

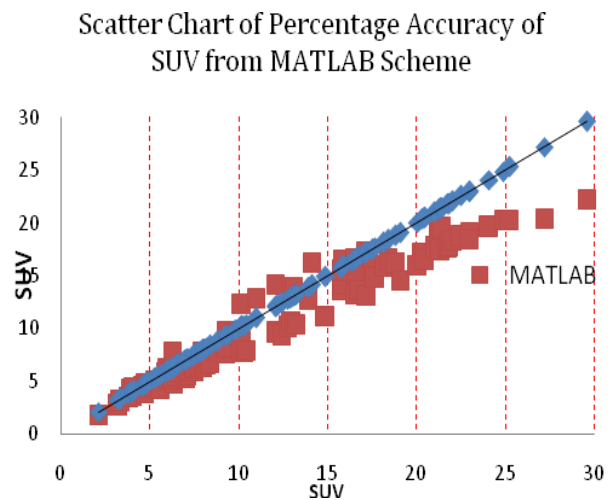
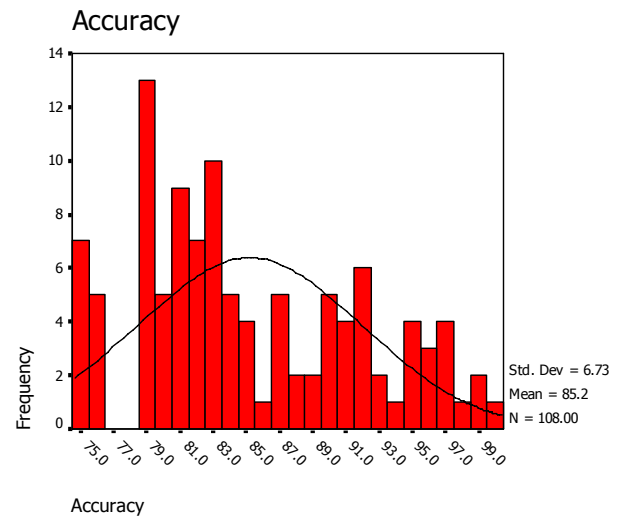


Fig.9 Histogram and Chart of the percentage accuracy from MATLAB and Xeleris workstation.

The percentage accuracy of MATLAB is normally distributed significantly with a 95% confidence interval.

Table 3 The percentage accuracy of SUV arranges by range.

Range	N	\bar{X}	SD
$X_a < 5$	14	90.82	4.71
$5 < X_b < 10$	38	85.52	6.42
$10 < X_c < 15$	20	82.50	6.19
$15 < X_d < 20$	17	87.83	7.84
$X_e > 20$	19	81.84	4.21

The chart in Fig.9 shows the percentage accuracy of SUV sorted by range from 0-30.

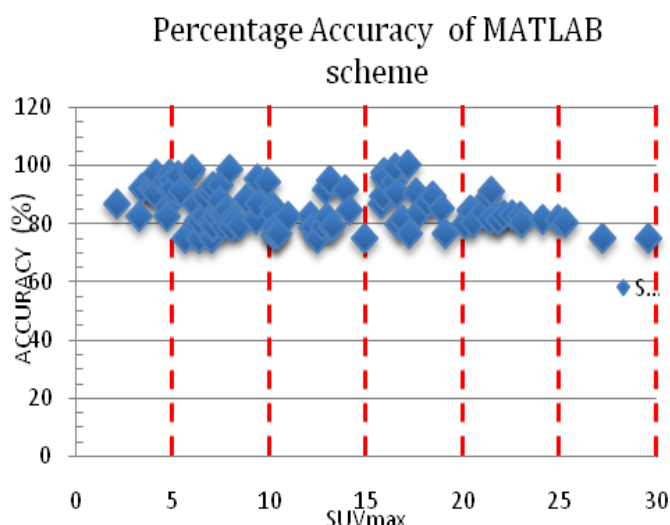


Fig.10 Scatter gram of percentage accuracy from the MATLAB scheme.

From the percentage accuracy of SUV from MATLAB scheme arranged by range (table 3), the result shows high accuracy in the lower range (at SUV < 5). The accuracy of estimate is expressed by confident interval with specific confidence level. At 95% confident interval, the accuracy of SUV from the MATLAB scheme is 85%.

IV. DISCUSSION

The calculation scheme is different in data type, so the conversion is mainly needed in every step. A lower SUV compared to the Xeleris workstation in all study may possibly because of the data lost in conversion step. Since the MATLAB scheme is defined in term of the amount of SUV value, we found that the small value of SUV gives high accuracy compared to the large value. It means that the MATLAB scheme is high effective for using with the small SUV.

The data viewing, analysis and interpretation in a PET / CT scanning are often done by software that is installed within the workstation area or where the PACS is accessible. Besides, the application software is generally from the same manufacturer of the scanner. These are the problem and reason that is leading to this research.

The sample source of this research is DICOM files. These are archived from PET/CT Discovery STE (DSTE) scanner [9]. In the comparative study, it was tested by comparing with the Xeleris workstation. Both DSTE and Xeleris workstation are manufactured by GE healthcare and routinely operated in Siriraj Imaging Center.

The SUV scheme in this research was created by DICOM file based on the attribute of GE's vendor. Each vendor implements DICOM in its own dialect. Even though, the SUV calculation is based on the fundamental formula, but different vendor's DICOM impose slightly different method. So, this SUV scheme was supported only for GE's DICOM.

However, it can be simply completed more ultimately in a future.

This scheme was created by using MATLAB language. MATLAB is a technical computing language which is a widely used tool in science and engineering community. It allows creation of user interfaces. Therefore, the scheme can be developed to be the convenient and easy-to-use application program with an uncomplicatedly approach. Moreover, instead of MATLAB, the scheme can also be written in any other programming language.

V. CONCLUSION

This research presented the SUV calculation in a new technique. The study was divided into 2 main sections. The first section is about the creation of SUV calculation scheme and the second section is about the scheme testing. However, for more understanding, the pilot study was done firstly.

The agreeable results above were represented in order to reassure that the scheme of SUV calculation provided the correct SUV value. It can be interchangeably used for PET/CT analysis and interpretation instead of the application from any well-known vendor.

Generally, Vendor's DICOM is not always useable by another vendor's products. The application software is built up for using with its own scanner. That is a weakness of the application software in today's market. So the new scheme was created to eliminate that limitation.

In an ideal scheme, it should be able to read all every vendor's DICOM. But in this research DICOM files from PET/CT DISCOVERY STE (DSTE) were used. It is a scanner of GE healthcare's vendor. DSTE is an only PET/CT scanner which is used in Siriraj Imaging Center.

The SUV from the scheme which was created by MATLAB could be used interchangeably with PET/CT Xeleris® workstation. It can also be used for interpretation of PET/CT image without losing the capacity to accurately measure the SUV.

The new scheme is a stand-alone application, running on PC with MATLAB installing. Therefore, the new scheme allows for more simple interpretation of SUV. Physician can access, interpret and analyze data without other software.

The interchangeability of this scheme offers user to the convenient and approachability of data. The benefit of this scheme is that it can be adopted as a PET/CT analysis tool to medical imaging system. It allows a reduction in the number of computer for the practice. Moreover, it allows direct comparison with prior study without consideration of modality and its archive procedure, which is beneficial in a multi-vendor surrounding.

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