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Defining Gross Tumor Volume using Positron Emission Tomography/Computed Tomography Phantom Studies

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Abstract Tumor volume and standard uptake value (SUV) calculated from positron emission tomography/computed tomography (PET/CT) images differ from their real values. Besides errors introduced by scintillation materials, photomultiplier tubes, and image reconstruction algorithms, measurements are affected by patients' prostheses, body movements, and body shape. To address these problems, we calculated tumor volume and SUV using the standard phantom (PET Phantom-NEMA IEC/2001) and obtained calibration constants. We found that while tumor volume increases with increasing SUV and tumor diameter, it also increases with increasing SUV and decreasing tumor diameter. Conversely, tumor volume decreases with decreasing SUV and tumor diameter and with decreasing SUV and increasing diameter. These results suggest that a correction factor should be applied to SUV and tumor volume obtained from PET/CT images.

I. Introduction

While imaging modalities to diagnose cancer, such as computed tomography (CT) and magnetic resonance imaging (MRI), provide information on tumor size, positron emission tomography (PET)/CT exploits the fact that cancer cells metabolize glucose faster than normal cells. Because PET/CT provides functional and biochemical images as well as anatomical images, it has become an increasingly popular imaging tool worldwide. The standard uptake value (SUV) shows the uptake ratio of radioactive isotope in normal and tumor tissues, considering that the injected isotope [fluorine-18 fluorodeoxyglucose (^{18}F-FDG)] is distributed evenly throughout the body, and is widely used as a semi quantitative index in PET/CT analysis. However, SUV values can be too small or too large according to the type of crystal scintillator used to measure radioactivity, limitations of system components such as multiplier phototubes, type of image reconstruction program, presence of prostheses, occurrence of movements, and patient body type. If a large quantity of radioactive isotope is delivered during PET/CT, the signal to noise ratio is enhanced and the SUV is more accurate. However, the radioactive isotope dosage should be maintained as low as possible to avoid damage to patients' normal tissues. The use of PET/CT in domestic medical centers is increasing, and there is a need to compare images obtained from different medical centers and establish a method that determines the presence of tumors on ^{18}F-FDG PET imaging and their gross tumor volume (GTV) in order to increase the cure rate while minimizing the side effects of radioactive treatment. Researchers need to establish where cancer cells are concentrated and growing. High radiation doses can then be administered only to the tumor, while the adjacent normal tissues receive minimal doses. If small tumors appear on PET/CT images, the SUV and tumor size are recognized as small but the extent cannot be identified, which then becomes dependent on the clinician's experience and skill.

In the present paper, we established the relationship between tumor volume on PET/CT images and SUV and calculated a correlation factor that allows accurate GTV and SUV estimates from PET/CT images.

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II. Methods and Materials

A. Standardized Uptake Value (SUV)

PET/CT SUV is a semi-quantitative index that measures the difference between the radiation uptake by tumors and the mean uptake. It assumes that radionuclides injected into the body are distributed evenly throughout the body. SUV is calculated as follows.

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$$\text{SUV} = \frac{\text{tracer activity in the tissue per unit mass}}{\text{amount of injected radioactivity per unit body mass}}$$

B. Data Acquisition

^{18}F-FDG was prepared with a radioactivity of approximately 74 MBq and was radiated onto spheres of different diameters (10 mm, 13 mm, 17 mm, 22 mm, 28 mm, and 37 mm), such that the ratio of sphere to background radiation exposure was twice, 4 times, 6 times, 8 times, 10 times, and 12 times

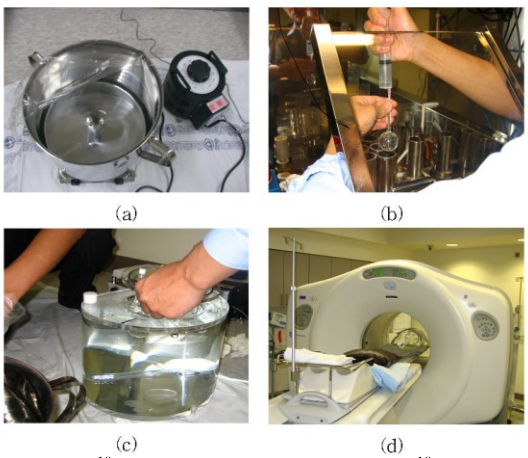
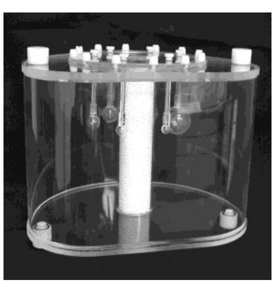


Fig. 1. (a) Mix ^{18}F-FDG in distilled water (b) Inject ^{18}F-FDG into the tumor phantom (c) PET Phantom-NEMA IEC/2001 (d) Acquire a PET/CT image

Table 1. The NEMA/IEC 2001 PET phantom consists of a body phantom, a lung insert, and an insert for six spheres of various sizes

Photograph	Specifications
 	Dimensions: 9.5" × 12" × 9.5" (24.1 × 30.5 × 24.1 cm) Interior length of phantom: 180 mm Inner diameter of spheres (six): 10 mm, 13 mm, 17 mm, 22 mm, 28 mm, and 37 mm Distance from sphere plane to inside wall: 70 mm Volume of empty D-shaped cylinder: 9.7 L Cylindrical insert dimensions: Outer diameter, 51 mm × 180 mm Shipping Weight, 11. l b (4.9 kg)

. Data were acquired and analyzed using Discovery STe (General Electric Healthcare, Milwaukee, MI, USA). A bed image was acquired using the NEMA/IEC 2001 PET body phantom and the standard intake coefficient was calculated. The phantom was prepared by removing the internal structure from the NEMA PET Phantom^{TM} (NU2-2001), a widely used quality control checker in PET/CT analyses (Table1). The experimental steps are photographed in Figure 1.

III. Results

Figure 2 shows the three-dimensional reconstructed PET/CT fusion image obtained by changing the concentration of radioactive matter entering the phantom circle.

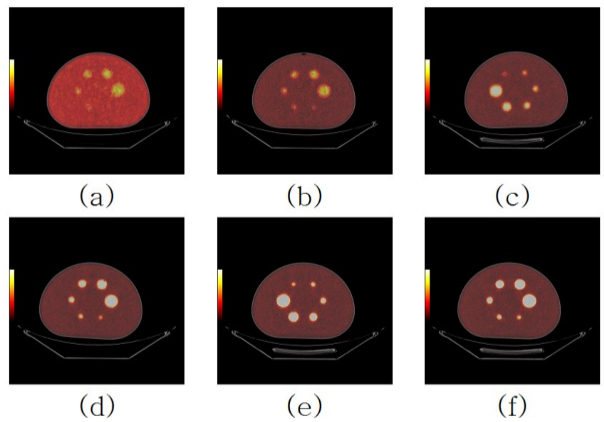


Fig. 2. PET/CT fusion image of spheres injected with radioactivity (a) SUV 2, (b) SUV 4, (c) SUV 6, (d) SUV 8, (e) SUV 10, (f) SUV 12 Numbers indicate the ratio of sphere to background radiation.

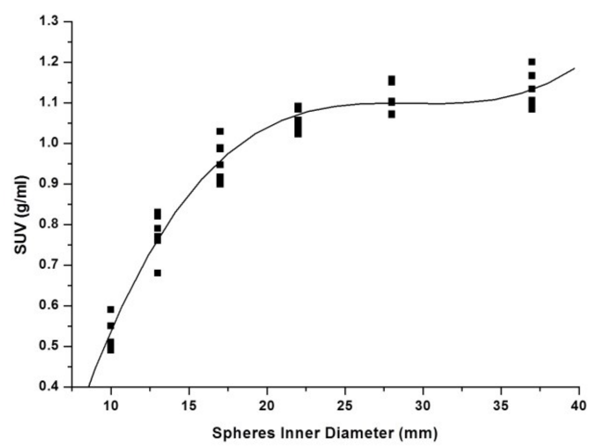


Fig. 3. Relationship between SUV and phantom sphere diameter

The relationship between SUV and spherical diameter is shown in Figure 3. Within the range of 10–37 mm in the phantom, when tumor size and SUV value are small, the expressed SUV is small. The standard intake coefficient in PET/CT can be expressed as $Y = A + B_1 \times X + B_2 \times X^2 + B_3 \times X^3$, where A= −0.882, B_1 = 0.204, B_2 = −0.007, B_3 = 0.0001 (R^2, 0.965; P > 0.0001).

Figure 4 shows the relationship between the spherical diameter and SUV correction factor. Within the range of 10–37 mm in the phantom, the uptake correction for SUV is expressed as $y_0 + A_1 \times e^{(-X/t_1)}$, where y_0 = 0.902, A_1 = 18.248, t_1 = 3.419(Chi^2, 0.005; R^2, 0.96427).

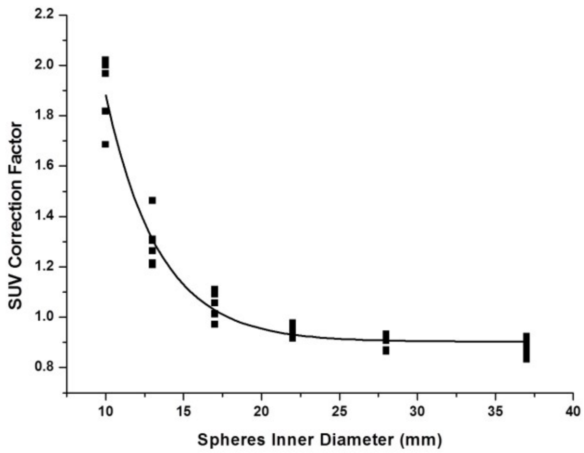


Fig. 4. Relationship between spherical diameter and correction factor for standard intake co-efficient

The true volumes of the imaged spheres are 0.52, 1.15, 2.57, 5.57, 11.49, and 26.52 cm^3. Figure 5 plots the volumes obtained from the respective SUVs (2, 4, 6, 8, 10, and 12) as a function of true volume. Clearly, the measured volumes are affected by both SUV and true volume).

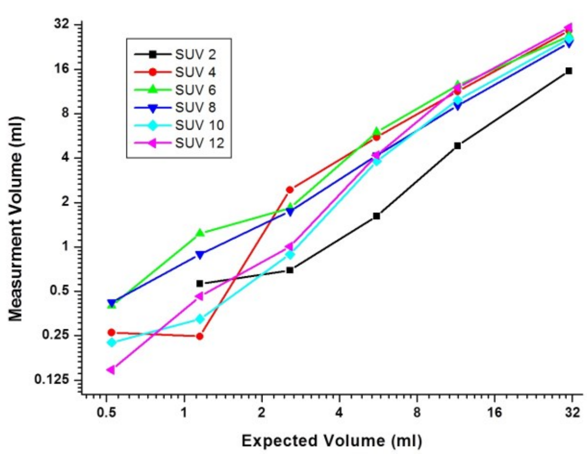


Fig. 5. Relationship between volume obtained by SUV and true volume of spheres

The SUV correction factor as a function of volume is plotted in Fig. 6. Within the range 10-37 mm, the volume correction for SUV is $y_0 + A_1 \times e^{(-X/t_1)}$, where y_0= 1.046, A_1=2.235, t_1=5.428, (Chi^2 0.479, R^2 0.704).

IV. Discussion And Conclusions

To quantitatively evaluate volume estimates by the PET/CT system, we measured SUV of PET/CT using a phantom and calculated a correction factor. We found that small and large phantom tumors yield small and large SUVs, respectively.

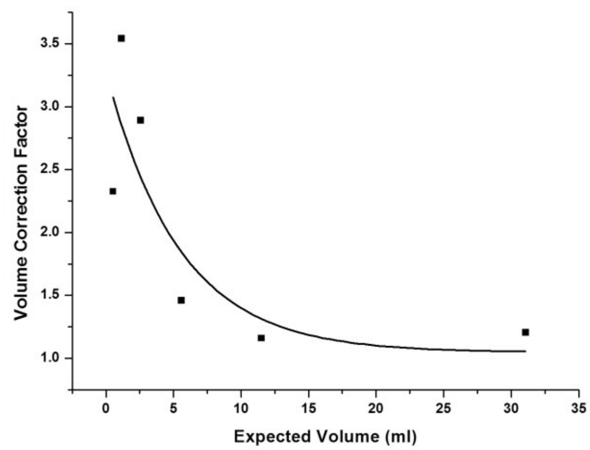


Fig. 6. Relationship between tumor volume and required correction factor according to the size of the spheres

As SUV and tumor diameter increase, the tumor volume increases as expected. However, tumor volume also increases with increasing SUV and decreasing tumor diameter. Conversely, tumor volume decreases when both SUV and diameter decrease as well as when SUV decreases and diameter increases. Therefore, a correction factor is required when estimating SUV and tumor size from PET/CT images.

In this study, PET/CT images were obtained while the phantom was stationary. In patients, intestinal movement will influence the determination of target volume. In addition, because of the relatively long time required for PET/CT imaging, images are obtained in shallow and free breathing status, which can inflate tumor volume and decrease the standard intake coefficient derived from the PET/CT images. Accordingly, patient movements should be considered in future phantom studies.

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