Standardized Uptake Values of FDG: Body Surface Area Correction is Preferable to Body Weight Correction

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Standardized uptake values (SUVs) are widely used to measure ^{18}F-fluorodeoxyglucose (FDG) uptake in various tumors. It has been reported that normalization of FDG uptake for patient body weight (SUV$_{bw}$) overestimates FDG uptake in heavy patients, as their fraction of body fat (with low FDG uptake) is often increased. The objective of this study was to determine if "normalization of FDG uptake for the body surface area" (SUV$_{bsa}$) is independent of the patient's body size and is more reliable than SUV$_{bw}$. **Methods:** FDG-PET images were acquired on 44 patients (body weight range: 45–115 kg) with cancer. SUV$_{bw}$ [(mCi/g of tissue)/(mCi injected/patient body weight in g)] and SUV$_{bsa}$ [(mCi/g of tissue)/(mCi injected/patient BSA in m^2)] were determined for the liver. Since most observers are accustomed to using the SUV$_{bw}$, the two values were compared by setting the mean SUV$_{bsa}$ equal to that of SUV$_{bw}$. **Results:** SUV$_{bw}$ and SUV$_{bsa}$ were 3.42 ± 0.85 (mean ± s.d.) and 3.42 ± 0.60, respectively. The standard deviation of the SUV$_{bsa}$ was smaller than that of SUV$_{bw}$. More importantly, there was a strong positive correlation between SUV$_{bw}$ and, not only body weight (r = 0.75) but also BSA (r = 0.68), whereas only a weak correlation between SUV$_{bsa}$ and body weight (r = 0.41) or BSA (r = 0.38) was found with a near flat regression line. **Conclusion:** SUV$_{bw}$ overestimates FDG uptake in large patients. SUV$_{bsa}$ appears preferable to SUV$_{bw}$, since it is minimally affected by the body size.

Key Words: fluorine-18-fluorodeoxyglucose; standardized uptake values; body fat

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P ositron emission tomography (PET) using ^{18}F-fluorodeoxyglucose (FDG) has been successfully employed to image glucose utilization in various tumors (*1–15*). PET-FDG imaging has been used clinically to grade the degree of malignancy of tumors, differentiating recurrent tumor from scar or radiation necrosis, predicting patient survival and tumor staging. It has been reported that the degree of FDG uptake in tumors correlates well with its degree of malignancy. In assessing glucose utilization in tumors, some investigators have made an attempt to measure the absolute glucose metabolic rate (*1–5*). The feasibility of such quantitative measurements has been challenged in malignant gliomas (*6–9*). This is mainly due to the variability of the parameters used to calculate metabolic rates.

To assess metabolic activity of various tumors, nonkinetic quantification of relative tumor uptake has been accomplished by comparing tumor to normal tissue or, more commonly, normalizing tumor uptake to injected dose per body weight (*10–15*). The latter is widely used by many investigators and commonly referred to as standardized uptake value (SUV) or differential uptake ratio (DUR) of FDG.

It has been reported that SUV generated by normalization of FDG uptake to patient body weight (SUV$_{bw}$) overestimates FDG uptake in heavy patients, as their fraction of body fat (with low FDG uptake) is often increased (*16*). The objective of this study was to determine if normalization of FDG uptake for the body surface area (SUV$_{bsa}$) is less dependent on the patient's body size than SUV$_{bw}$.

MATERIALS AND METHODS

Patient Population

Forty-four patients (21 males and 23 females) who had PET-FDG studies for suspected or proven abdominopelvic malignancies were randomly selected for this study. The type of tumors in this population included colorectal (n = 28), ovarian (n = 14), renal (n = 1) and lymphoma (n = 1). The patients ranged in age from 30 to 89 yr with the mean ± standard deviation of 61.5 ± 14.9 yr. Body weight ranged from 45 to 115 kg (mean = 79.4 ± 19.5 kg). PET-FDG studies were performed 60–90 min following intravenous injection of FDG.

PET-FDG Imaging

PET-FDG imaging was performed on a Siemens ECAT (Siemens Medical Systems, Inc., Hoffman Estates, IL) scanner. The scanner produces fifteen 8-mm thick slices and has a reconstructed in-plane resolution of approximately 7 mm, an intrinsic

resolution of 5 mm in the x- and y-axes and 7 mm in the z-axis, and a 12-cm longitudinal field of view.

Following at least 4 hr of fasting, patients were carefully positioned in the scanner and the entire abdominopelvic region was imaged. All subjects required two to three separate acquisitions. Transmission scans were acquired prior to the administration of FDG, and the data generated were used to correct for attenuation encountered on emission scans. They were acquired for 10-15 min for a minimum of 10 million counts per direct plane and a total of 220 million counts for the entire data set. The transmission scans were acquired utilizing a ^{68}Ge ring source. Following the completion of the transmission scan, 10 mCi of ^{18}F-FDG were administered intravenously. Emission scans were performed at least 60 min following the administration of the radiopharmaceutical. Several skin marks were used to ensure that an identical field of view was used for both the emission and transmission scans. The urinary bladder was continuously drained by a Foley catheter to minimize accumulation of FDG activity.

Image Analysis

Image reconstruction was performed on the Microvax II computer system (Digital Equipment, Marlboro, MA), and image processing was performed on the SUN 4/110 workstation (SUN Microsystems, Mountain View, CA). A Hann filter was used with a cut-off frequency of 0.5 for reconstruction. Transaxially reconstructed images were bilinearly interpolated and reoriented into transaxial, coronal and sagittal planes.

Transaxial images were used for the computation of SUVs in all patients. These calculations were based on the ratio of activity found in the tissue to the injected dose to the patient and to the subject's body weight or body surface area. FDG uptake was corrected for radiotracer decay. Regions of interest (ROIs) consisting of 12 pixels (0.8 cm^2) were carefully drawn in the upper right lobe of the liver. Although some patients had biopsy-proven metastases, special care was taken to place ROIs in normal parenchyma. Focal areas of intense FDG uptake which were considered to represent tumor sites in the liver were not included in these ROIs. For this purpose, CT scans were also used. For the purpose of quantitative analysis, SUV_{bw} and SUV_{bsa} were calculated as noted below:

$$SUV_{bw} = \frac{\text{Mean PET counts/pixel/sec} \times \text{calibration factor}}{\text{injected FDG dose (mCi)/body weight (kg)}},$$

and

$$SUV_{bsa} = \frac{\text{Mean PET counts/pixel/sec} \times \text{calibration factor}}{\text{injected FDG dose (mCi)/body surface area (m}^2)},$$

where calibration factor = (mCi/ml)/(counts/pixel/sec). The BSA was calculated using the following formula:

$$BSA \text{ (m}^2) = (\text{weight in kg})^{0.425} \times (\text{height in cm})^{0.725} \times 0.007184.$$

RESULTS

SUV_{bw} for the liver ranged from 1.8 to 5.24 (mean ± s.d. = 3.42 ± 0.85). SUV_{bsa} for the liver ranged from 0.056 to 0.111 with a mean of 0.083. Since most investigators are accustomed to using the SUV_{bw}, the mean SUV_{bsa} was normalized to the mean SUV_{bw} for direct comparison of the values acquired with these two different approaches. In other words, each of the 44 SUV_{bsa} values were multiplied
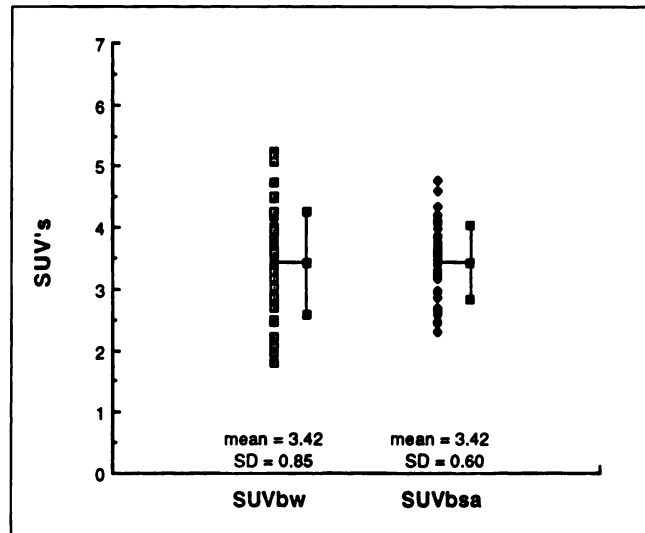

FIGURE 1. Comparison of the range, mean and standard deviation of the liver SUV_{bw} and SUV_{bsa}.

by 3.42 (the mean SUV_{bw}), and then divided by 0.083 (the mean SUV_{bsa}). This corrected SUV_{bsa} for the liver ranged from 2.30 to 4.59 with a mean ± standard deviation of 3.42 ± 0.60 (Fig. 1).

A linear regression analysis was performed for correlating the liver SUV_{bw} and SUV_{bsa}, with the body weight and body surface area, and following results were obtained (Fig. 2):

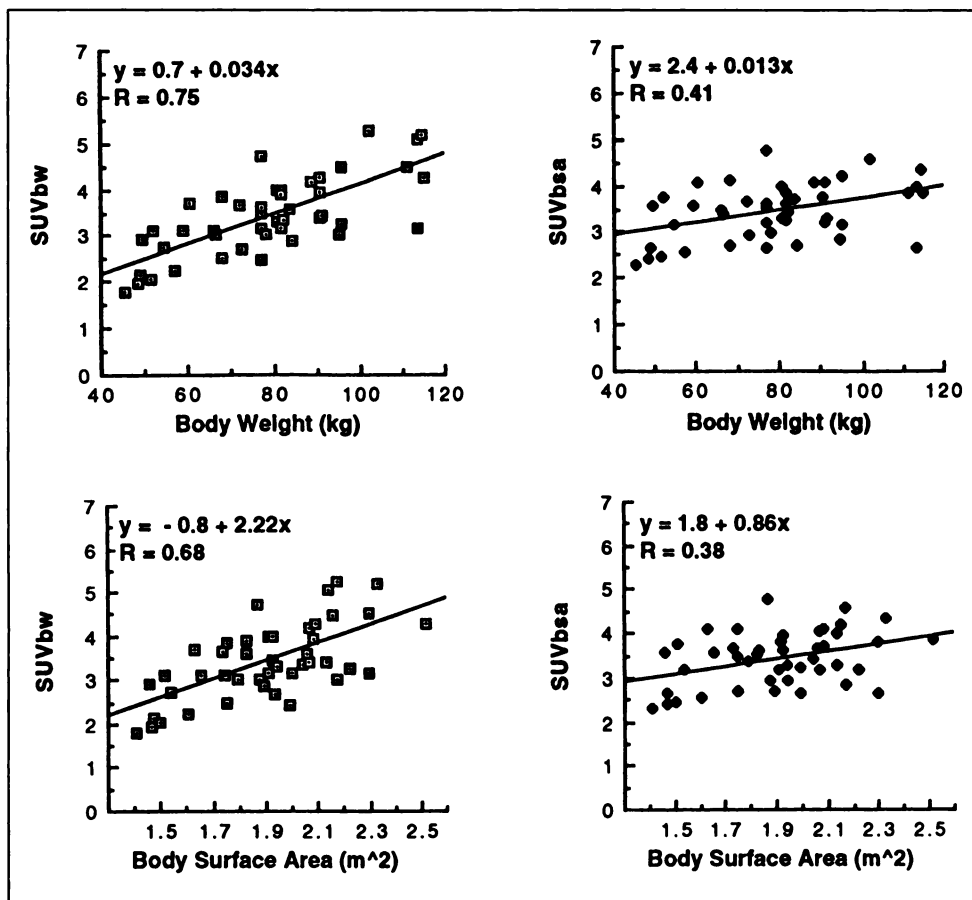$$SUV_{bw} = 0.7 + 0.034 \times \text{(body weight in kg)}$$

$$r = 0.75,$$

$$SUV_{bsa} = 2.4 + 0.013 \times \text{(body weight in kg)}$$

$$r = 0.41,$$

$$SUV_{bw} = -0.8 + 2.22$$

$$\times \text{(body surface area in m}^2) \quad r = 0.68,$$

$$SUV_{bsa} = 1.8 + 0.86 \times \text{(body surface area in m}^2)$$

$$r = 0.38.$$

DISCUSSION

Quantification of the absolute glucose metabolic rate (mg/100g/min) utilizing kinetic modeling would appear optimal to characterize tumor activity, and will further enhance our understanding of tumor metabolism and tumor biology (5,17). It is not feasible, however, to determine this value because of the complexity of parameters required to make such measurements. For example, the lumped constant used to calculate metabolic rates is not currently known for tumor tissues. By contrast, some investigators have shown that visual assessment alone may be satisfactory for grading the malignancy of tumors and predicting the survival, as has been done in patients with gliomas (6-9).

FIGURE 2. Linear regression analysis for correlating the liver SUV_{bw} and SUV_{bsa} with the body weight and body surface area.

In 1941, Kenney et al. described the differential absorption ratio as mCi found per kg tissue/mCi administered per kg body weight to express tissue concentration of radioactive phosphorus (18). This formula has been used to assess relative FDG uptake in various noncentral nervous system tumors as a compromise between the kinetic method and the visual assessment (11–15). It is widely used clinically to determine the degree of malignancy of tumors, to differentiate recurrent tumor from scar or postradiation change, for staging and to assess the response after therapy. This simplified quantitation has also been shown to be as useful as the measurements of kinetic rate constants of glucose in the evaluation of malignant lymphoma (4). Therefore, it appears that SUV (or DUR), as a relative indicator of tumor metabolic activity, may be used to answer some clinically relevant questions, although these values would be most reliably utilized for comparing serial studies performed on the same patient.

Zasadny and Wahl reported that SUV_{bw} is dependent on body weight and these values in some tissues (blood, liver and spleen) in heavier patients are as much as two times higher than those of lighter patients (16). An ideal approach to measure relative FDG uptake would require knowing the volume of distribution for FDG, to which regional values can be normalized. This is not achievable for routine clinical use.

Our data indicate that normalization of FDG uptake by the body surface area produces values that are not as dependent on a patient's body size as is SUV_{bw}. The range of the SUV_{bsa} for the liver (2.30–4.59) was narrower than that of SUV_{bw} (1.80–5.24) with a standard deviation of 0.60 and 0.85, respectively (Fig. 1). More importantly, there was a strong positive correlation between SUV_{bw} and body weight (r = 0.75) as well as body surface area (r = 0.68), whereas only a weak correlation between SUV_{bsa} and body weight (r = 0.41) or body surface area (r = 0.38) was found with a near flat regression line. The slopes of the regression lines of SUV_{bw} (0.034 with body weight and 2.22 with body surface area) were 2.6 times steeper than that of SUV_{bsa} (0.013 with body weight and 0.86 with body surface area). As an example, an increase of 50 kg in body weight may result in an increase of 1.7 SUV_{bw} versus 0.65 SUV_{bsa} for the liver, and an increase of 0.5 m^2 in body surface area may result in an increase of 1.11 SUV_{bw} versus 0.43 SUV_{bsa}.

Alternatively, SUV_{bsa} in heavy (100 kg) patients was only approximately 20% higher than that in light (50 kg) patients, while SUV_{bw} in heavy patients was approximately 70% higher than that in light patients. This implies that lesions with a low-to-intermediate degree of FDG uptake may be associated with a relatively high SUV_{bw} in heavy patients and lesions with an intermediate-to-high degree of FDG uptake may be associated with a relatively low SUV_{bw} in light patients. This could result in errors in

diagnosing recurrent tumors, in grading tumors, or in predicting patient outcome in various clinical situations. It appears that using the SUV_{bsa} will reduce the overlap between benign and malignant lesions.

The range of the liver SUVs in our study could have erroneously become wider than the real normal values for a few reasons. First, some of our study subjects were patients with metastatic disease. Although special care was taken to draw ROIs in normal hepatic parenchyma, it is possible that occult metastatic lesions could have inadvertently been included. It is also possible that some patients could have had an undiagnosed abnormal liver function. Lastly, the FDG-PET studies were performed 60–90 min following the intravenous injection of FDG. The liver FDG activity could vary depending on the time interval between injection and acquisition. Therefore, the range of liver SUVs could have potentially been reduced if all the studies were performed at exactly the same time after the injection. Nevertheless, our study was primarily concerned with a comparison of the SUVs calculated from the two approaches, using the same ROIs, drawn on the same image in the same subject instead of determining SUV for the normal liver. These potential issues should not affect a comparison of the two approaches.

In conclusion, SUV generated by normalization of FDG uptake to patient body weight overestimates FDG uptake in larger patients. SUV_{bsa} appears preferable to SUV_{bw}, since it is not as affected by body size. This may also turn out to be true with most diffusible tracers for which measurement of relative uptake value is intended, as the fatty tissues have not only low FDG uptake but also small fluid space when compared to other soft tissues.

ACKNOWLEDGMENT

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