Standardized Uptake Values of 99mTc-MDP in Normal Vertebrae Assessed Using Quantitative SPECT/CT for Differentiation Diagnosis of Benign and Malignant Bone Lesions

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Research Article

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Abstract

**Background:** Quantitative bone SPECT/CT is useful for disease follow up and inter-patient comparison. For bone metastatic malignant lesions, spine is the most commonly invaded site. However, Quantitative studies with large samples size investigating all the segments of normal cervical, thoracic and lumbar vertebrae are seldom reported. This study was to evaluate the quantitative tomography of normal vertebrae using $^{99m}$Tc-MDP with SPECT/CT to investigate the feasibility of standardized uptake value (SUV) for differential diagnosis of benign and malignant bone lesions.

**Methods:** A retrospective study was carried out involving 221 patients (116 males and 105 female) who underwent SPECT/CT scan using $^{99m}$Tc-MDP. The maximum SUV (SUV$_{\text{max}}$), mean SUV (SUV$_{\text{mean}}$) and CT values (Hounsfield Unit, HU) of 2416 normal vertebrae bodies, 157 benign bone lesions and 118 malignant bone metastasis foci were obtained. The correlations between SUV$_{\text{max}}$ and CT values, age, height, weight of normal vertebrae were analyzed. Statistical analysis was performed with data of normal, benign and malignant groups corresponding to same sites and gender.

**Results:** The SUV$_{\text{max}}$ and SUV$_{\text{mean}}$ of vertebrae in males were markedly higher than those in females (P<0.0009). The SUV$_{\text{max}}$ of each vertebral segment showed a strong negative correlation with CT values in both males and females ($r=-0.89$ and -0.92, respectively; P<0.0009). The SUV$_{\text{max}}$ of vertebrae also showed significant correlation with weight and height in males ($r=0.4$, P<0.0009; $r=0.28$, P=0.005), and significant correlation with weight in females ($r=0.32$, P=0.009). The SUV$_{\text{max}}$ of normal group, benign bone lesion group and malignant bone metastasis foci group showed statistical differences in both males and females.

**Conclusion:** Our study evaluated SUV$_{\text{max}}$ and SUV$_{\text{mean}}$ of normal vertebrae, benign bone lesion and malignant bone metastasis foci with a large sample population. Preliminary results proved the potential value of SUV$_{\text{max}}$ in differentiation benign and malignant bone lesions. The results may provide a quantitative reference for clinical diagnosis and the evaluation of therapeutic response in vertebral lesions.

**Background**

Radionuclide bone imaging is the most frequently used imaging technology in nuclear medicine, accounting for about 60.3% in hybrid single photon emission computed tomography/computed tomography (SPECT/CT) examination per year in China [1]. Up to now, the differentiation between lesions and normal bone tissue was mainly based on visual diagnosis, while quantitative analysis has not been well applied in clinic. Quantitative positron emission tomography (PET) bone imaging based on fluorine-18-sodium fluoride ($^{18}$F-NaF) is considered to have potential clinical value. However, $^{18}$F-NaF PET/CT is quite expensive with limited availability [2]. The development of SPECT/CT technology has enabled quantitative assessments of bone imaging using Technetium-99m methylene diphosphonate ($^{99m}$Tc-MDP), a prevailing used SPECT tracer for bone imaging. Compared to $^{18}$F-NaF, $^{99m}$Tc-MDP was more frequently used for the bone imaging in clinic [3]. Beck et al [4] conducted a longitudinal follow-up of 52 bone metastases in 19 patients using SPECT/CT with visual analysis and quantitative analysis. They found that there was a high agreement among the observers in quantitative analysis, while visual analysis was 42% inconsistent with quantitative analysis. Arvola et al [5] proved that SUV obtained from SPECT images of bone metastases of breast and prostate cancer were significantly correlated with SUV obtained from PET images. These findings indicated the feasibility of SPECT quantification using SUV in clinic.
Bone tissue uptake of $^{99m}$Tc-MDP is proportional to blood flow and osteoblastic activity [6]. Hence, bones at different sites can have different normal SUVs. Bone metastasis is a common complication of cancer, and the third most common site of metastasis after lung and liver [7]. For bone metastatic malignant lesions, spine is the most commonly invaded site [8]. Therefore, establishing the SUV range of normal vertebrae is of great value in clinical practice. Kaneta et al. [9] performed a quantitative study of SPECT/CT in 29 patients and measured the MDP of normal vertebrae with different SUVs. The results demonstrated that $SUV_{\text{max}}$ had the lowest variance coefficient, indicating $SUV_{\text{max}}$ was a suitable quantitative indicator in bone imaging.

To our best knowledge, present quantitative studies [9–11] only conducted with small sample sizes evaluated SUV of SPECT imaging of partial normal vertebrae (mostly are lumbar vertebrae). Quantitative studies with large samples size investigating all the segments of normal cervical, thoracic and lumbar vertebrae are seldom reported. The aim of this study was to obtain the $SUV_{\text{max}}$ and $SUV_{\text{mean}}$ in normal vertebrae using $^{99m}$Tc-MDP-SPECT/CT and to investigate the clinical value of quantitative SPECT/CT in differentiation of benign bone lesions and malignant vertebral metastasis.

**Methods**

**Patients**

Retrospective analysis was performed on patients who underwent SPECT/CT scan in Shanghai East Hospital from August 2016 to October 2019, and all patients or family members signed informed consent for examination. This retrospective study was approved by institutional review board of Shanghai East Hospital. The following are the patients’ inclusion criteria: no history of primary bone tumor; no history of vertebral fractures; no history of renal insufficiency; no history of hormone, endocrine therapy, chemotherapy and other treatments affecting bone metabolism; access to the information of patients’ height, weight, measured injection activity (full needle and empty needle) and time of tracer injection, activity measurement and SPECT/CT acquisition.

**SPECT/CT acquisition**

All subjects were injected with 19-22 MBq/kg $^{99m}$Tc-MDP. Whole-body planar imaging and tomographic imaging were performed at 3 hours post injection, which took approximately 40 minutes. Patients were scanned on SPECT/CT (Siemens Symbia Intevo, Erlangen, Germany), a low energy high resolution collimator with a single probe rotation 30 projections over 180° with 20s acquisition time per view, 256×256 matrix, pixel size 2.4×2.4 mm$^2$, 2.4 mm thickness. Low-dose CT scan was performed at 130kV and 10 valid mAs. CT data was reconstructed using a smooth attenuation-correction kernel B31s with 3mm slice thickness and a sharp bone kernel B50s with 5mm slice thickness. SPECT reconstruction was performed based on the B31s CT attenuation map of ordered subsets conjugate gradient enhanced (OSCG) with 2 subsets and 28 iterations without post-smoothing, which generate SPECT data allowing SUV based on body weight ($SUV_{\text{bw}}$) quantification and measurement of $SUV_{\text{max}}$ and $SUV_{\text{mean}}$ using xSPECT reconstruction algorithm (xSPECT/CT, Siemens Symbia Intevo).

**Image analysis**

Two experienced nuclear medicine physicians interpreted the $^{99m}$Tc-MDP planar and SPECT/CT images independently. Discordant results reached consensus with joint reading. Normal vertebrae, benign bone lesion and malignant bone metastasis foci were categorized based on the image interpretation results with follow-up or other
diagnostic imaging inspect such as CT or MRI. Volume of interest (VOI, Siemens 3D Isocontour) were drew on sagittal position. For normal vertebrae, both cortical bone and trabecular bone were included within VOIs and $SUV_{\text{max}}$, $SUV_{\text{mean}}$ and CT values were recorded. For lesions, elliptical VOIs were drew over the hottest area and $SUV_{\text{max}}$ were obtained. (Fig. 1 showed the representative coronal, sagittal, and transversal images with VOIs of normal vertebrae and bone lesions.

**Statistical analysis**

Shapiro-wilk normality test was used to analyze the data distribution. Data were expressed as mean±standard deviation. Data of male and female groups were tested by independent sample T test. Pearson correlation analysis was performed between $SUV_{\text{max}}$ and CT value, height, weight, age. Statistical analysis was performed using SPSS 23.0 statistical software. $SUV_{\text{max}}$ of normal vertebrae, benign lesion and malignant bone metastasis foci were compared corresponding to same site and sex. P<0.05 was considered statistically significant.

**Results**

**Patient data**

A total of 221 patients were included in this study. The collected data and statistical analysis of male and female patients were listed in Table 1. The detailed inclusion number, CT value, $SUV_{\text{max}}$ and $SUV_{\text{mean}}$ of normal vertebrae in male and female patients were shown in Additional file 1&2, respectively.
Table 1
Patient Demographics

| Parameters                  | Male (n = 116) |          | Female (n = 105) |          |
|-----------------------------|----------------|----------|------------------|----------|
|                             | range | mean  | SD    | range | mean  | SD    |
| Age (years)                 | 28–89 | 66.3  | 10.8  | 29–89 | 62.8  | ±11.5 |
| Weight (Kg)                 | 35–85 | 62.8  | 11    | 37–90 | 58.5  | 10.2  |
| Height (cm)                 | 150–181| 168.4 | 6.3   | 145–173| 148.9 | 5.4   |

| Parameters                  | mean  | SD    | CoV   |
|-----------------------------|-------|-------|-------|
| Normal vertebrae (n = 2416) |       |       |       |
| CT values (HU)              | 224.9 | 100   | 0.44  |
| SUVmax                      | 7.87  | 1.57  | 0.19  |
| SUVmean                     | 4.97  | 1.02  | 0.2   |
| Benign bone lesion (n = 157)|       |       |       |
| Thoracic SUVmax (n = 51)    | 10.24 | 1.50  | 0.15  |
| Lumbar SUVmax (n = 106)     | 14.10 | 4.58  | 0.32  |
| Malignant bone metastasis foci (n = 118) |       |       |       |
| Thoracic SUVmax (n = 56)    | 20.37 | 12.18 | 0.60  |
| Lumbar SUVmax (n = 62)      | 27.04 | 13.91 | 0.51  |

Comparison of SUV data of normal vertebrae between male and female patients

SUV\text{max} and SUV\text{mean} of each normal vertebra were compared between male and female patients using Paired t-test (Fig.2). Significant statistical differences were observed in SUV\text{max} of almost all the vertebrae (91.6%) except C1 and L4 vertebrae. And for SUV\text{mean}, more than half of the vertebrae (62.5%) showed significant differences between male and female patients, among which no lumbar vertebra was found with significant differences between two groups. The specific P values of each vertebral segment were listed in Additional file 3. Table 2 demonstrated that the SUV\text{max} of normal cervical, thoracic, lumbar vertebrae in male patients were significantly higher than that in female (P<0.0009). SUV\text{max} of each vertebral region (cervical, thoracic, lumbar vertebrae) also showed significant differences in male patients (Additional file 4). In the meanwhile, CT values did not show significant differences between male and female patients (Fig.3).
Table 2
SUVmax of normal cervical, thoracic, lumbar vertebrae in male and female patients

| Vertebrae | SUVmax (range, mean ± SD) | T-test |
|-----------|---------------------------|--------|
|           | Male                      | Female | P       |
| CERVICAL  | 3.29–12.69, 7.66 ± 1.74   | 2.47–10.89, 6.85 ± 1.64 | <0.0009 |
| THORACIC  | 4.08–12.61, 8.01 ± 1.52   | 2.50–11.69, 7.01 ± 1.68 | <0.0009 |
| LUMBAR    | 3.91–11.83, 7.75 ± 1.46   | 3.19–11.27, 7.04 ± 1.47 | <0.0009 |

Correlation Analysis Of Data From Normal Group

Correlations between SUVmax of normal vertebrae and CT value (HU), age, weight, height were analyzed separately (Table 3). A strong negative correlation was found between SUVmax and CT value in both male (r=-0.89; P < 0.0009) and female (r=-0.91; P < 0.0009) groups. For male patients, correlations of vertebral SUVmax with height and weight were found to be positive (r = 0.28, P = 0.005; r = 0.4, P < 0.0009), while no significant correlation was observed between vertebral SUVmax and age. For female patients, vertebral SUVmax had no significant correlation with age and height but had a positive correlation with body weight (r = 0.32, P = 0.009).

Table 3
Correlations between SUVmax and CT values of normal vertebrae, age, height, weight in male and female group

|            | Male         | Female        |
|------------|--------------|---------------|
|            | r  | P       | r  | P       |
| CT value   | -0.89 | <0.0009* | -0.92 | <0.0009* |
| Age        | -0.45 | 0.656   | 0.23  | 0.069   |
| Height     | 0.28  | 0.005*  | 0.22  | 0.075   |
| Weight     | 0.4   | <0.0009* | 0.32  | 0.009*  |

r represents the correlation coefficient of Pearson correlation analysis, P represents the significance, *P < 0.05.

Comparison of SUVmax in normal vertebrae, benign bone lesion and malignant bone metastasis foci

SUVmax of thoracic and lumbar vertebrae in benign and malignant groups were listed in Table 1. As shown in Fig.4, when comparing SUVmax of normal, benign and malignant groups, statistical differences were shown in each vertebral region of both male and female patients.

Discussion

In this study, we assessed the SUV of 99mTc-MDP in normal vertebrae, benign bone lesion and malignant bone metastasis foci using quantitative SPECT/CT in 221 patients. For normal vertebrae, we evaluated the SUVmax, SUVmean and CT value (HU) of all the 24 vertebral segments in male and female patients. It showed that SUVmax in male patients were markedly higher than those in females. In addition, we found that SUVmax of three vertebral
regions in male patients also showed statistically differences. When comparing $SUV_{\text{max}}$ in different vertebral regions between male and female patients, $SUV_{\text{max}}$ were proved to be significantly different between male and female patients in cervical, thoracic and lumber vertebrae. This reminds us that to establish a quantitative diagnostic reference for differentiating vertebral lesions, lesions should be categorized based on gender and vertebral regions to compare the $SUV_{\text{max}}$. We summarized the range, mean and standardized deviation value of $SUV_{\text{max}}$ in cervical, thoracic, and lumbar vertebrae of male and female patients respectively in Table 2 as a normal reference.

Cachovan et al. [10] used SPECT/CT bone quantification to obtain the mean $SUV_{\text{max}}$ of Tc-99m diphosphono-sponge propanedi-carboxylic acid ($^{99m}\text{Tc-DPD}$) of L3-5 vertebral trabecular bone in 50 females (mean ± SD = 5.91 ± 1.54). In our study, the mean $SUV_{\text{max}}$ of lumbar in female participants was 7.04 ± 1.47, which was slightly higher than the value obtained by Cachovan et al. The small different results may due to the different tracer kinetics. Furthermore, in our study, the VOI contained the cortical bone with high bone salt metabolism which could lead to the increased $SUV_{\text{max}}$. The $SUV_{\text{max}}$ of normal vertebra in our study was similar to the previously reported studies which also included bone cortex in their VOIs [11–17]. It is well known that bone lesions including tumors, inflammation and other diseases often ended up with cortical hyperplasia [17, 18]. Therefore, we suggest the inclusion of cortical bone within the VOI for quantitative analysis.

Besides, we analyzed the correlation between $SUV_{\text{max}}$ of normal vertebrae and CT values (HU), age, height, weight in male and female patients. It comes out that $SUV_{\text{max}}$ of normal vertebrae showed a strong negative correlation with CT values in both men and women. The $SUV_{\text{max}}$ of vertebrae also showed significant correlation with weight and height in male patients, and significant correlation with weight in female patients.

Hounsfield Unit (HU) is a commonly used measurement index in CT images that indicates the X-ray attenuation degree in tissue (also known as bone density). Bone mineral density (BMD) obtained through dual X-ray absorptiometry (DEXA) is the gold standard for the measurement of BMD in clinic [19]. There is still controversy about the relationship between HU and SUV. Previous studies demonstrated a significant positive correlation between HU and BMD [10, 11] [20–23], which was opposite to our findings. To figure out the reason leading to this controversial result, we found that previous studies only analyzed relationship in the lumbar vertebral region. As shown in Fig. 3, HU showed a decreasing trend from cervical to lumbar vertebra. In the meanwhile, $SUV_{\text{max}}$ didn’t show clear changing trend. $SUV_{\text{max}}$ of $^{99m}\text{Tc-MDP}$ in bone is often associated with blood supply and osteoblastic activity [6]. The blood supply of the lumbar artery from the abdominal aorta is richer than that from the vertebral artery [21] and increased pressure of lumbar leads to richer blood supply [9], which could lead to the increased calcium loss in elderly. Hence BMD of lumbar vertebra was lower than the cervical vertebra resulting in a lower HU value. Besides, the age of the subjects, imaging parameters and reconstruction algorithm in different experiments may also lead to different results. Our results were consistent with some other studies [22, 23]. Israel et al. [22] found that the $^{99m}\text{Tc-MDP}$ uptake in bone cortex of osteoporotic women was higher than that of non-osteoporotic women, suggesting that the bone loss in osteoporosis patients may increase bone conversion, leading to the increase of the bone cortex uptake of $^{99m}\text{Tc-MDP}$. Fogelman et al [23] performed SPECT on young women after ovariectomy and found a negative correlation between MDP distribution and BMD. As Table 1 showed, the mean age in our study was 66.3 of male and 62.8 of female. With an increasing possibility of calcium loss, the negative correlation between $SUV_{\text{max}}$ and CT value was observed. It suggests, using hybrid imaging of SPECT/CT, combining $SUV_{\text{max}}$ and CT value (HU) could be used as a potential biological indicator for the evaluation of
osteoporosis, and establishing the SUV\textsubscript{max} and HU of normal vertebral bodies should be taken into consideration. But the mechanism underlying this correlation still need further investigation.

The relationship of SUV and height and weight also showed opposite results with previous studies [7, 9, 11]. It has been reported that SUV\textsubscript{max} of vertebra was independent with height. Maybe the limited sample size in previous studies lead to the controversial results. With a large sample size, our results showed that SUV\textsubscript{max} was positively correlated with the height, weight in men and positively correlated with the weight in women which further validated the hypothesis proposed by Kaneta et al. [9] that the increased pressure leads to more blood supply, thus resulting in the increasing of SUV\textsubscript{max}. In our study, the SUV\textsubscript{max} and SUV\textsubscript{mean} were significantly higher in men than those in women. This might also due to the height of women in our study was generally lower than men. Since the number of patients in each age group was not evenly distributed by height, we did not find a correlation between SUV\textsubscript{max} and age.

With the established reference of SUV\textsubscript{max} in normal vertebrae, SUV\textsubscript{max} of bone lesions were compared with normal reference to verify the differentiating diagnostic value of quantitative SPECT/CT in bone scanning. Our results demonstrated that SUV\textsubscript{max} of normal vertebrae, benign bone lesion and malignant bone metastasis foci were significantly different from each other in thoracic and lumbar regions of male and female patients. The results were consistent with previous studies [15, 16], which verified the differentiating diagnostic value of SUV\textsubscript{max} in bone lesions using SPECT/CT. Different from previous studies, based on our findings in normal vertebrae, data comparison was performed on lesions in different gender and vertebral region groups. Hence, we suggest quantitative diagnose of bone lesions using SPECT/CT should take gender and vertebral regions into consideration. These results also remind us that quantitative SPECT/CT may be of great value in therapy monitoring.

Our study has some limitations. Firstly, although age distribution was wide, the uneven distribution of research object number of each age group could make it hard to reflect the SUV\textsubscript{max} of all ages. Secondly, the SUV\textsubscript{max} acquired in our study was based on body weight. Since the $^{99m}$Tc-MDP uptake mainly exists in bone, the standardization of bone volume can improve the accuracy of quantification [24]. This indicated that bone volume should be included in future studies. In addition, the quantitative accuracy of bone imaging is also affected by the reconstruction parameters. Previous studies have shown that quantitative values increase with higher number of iterations [25]. Therefore, in future studies, we will further stratify experimental subjects according to age, height and BMI. We will further optimize reconstruction parameters such as increasing the number of iterations to obtain more accurate bone quantitative standard values. Although CT value (HU) was evaluated in normal vertebrae, we didn't investigate the diagnostic value of combination of SUV\textsubscript{max} and HU in differentiating bone lesions. This is a promising topic in quantitative SPECT/CT, we will explore its potential diagnostic value in the future.

**Conclusion**

In this study, SUV\textsubscript{max} and SUV\textsubscript{mean} of normal vertebrae were evaluated. SUV\textsubscript{max} of male patients was significantly higher than female patients in different vertebral regions. Quantitative SPECT/CT using $^{99m}$Tc-MDP was demonstrated to have the diagnostic value in differentiation bone lesions of vertebrae. SUV\textsubscript{max} comparison should be performed considering different gender and vertebral region.

**List Of Abbreviations**
Declarations

Ethics approval and consent to participate: Ethical approval was waived by the local Ethics Committee of Shanghai East Hospital in view of the retrospective nature of the study and all the procedures being performed were part of the imaging examination. All methods were carried out in accordance with relevant guidelines and regulations. Informed consent was obtained from all participants.

Consent for publication: Not applicable.

Availability of data and materials: All data generated or analysed during this study are included in this published article [and its supplementary information files].

Competing interests: The authors declare that they have no competing interests.

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Authors’ contributions: NQ participated in its design and coordination, draft the manuscript, also contributed to image diagnosis and statistical analysis; QYM contributed to study designation, data collection and data sorting; ZYW and HQC contributed to data collection; YS contributed to image diagnosis; JZ provided critical review and substantially revised the manuscript. All authors read and approved the final manuscript.
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