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Comparison of Accuracy in Calculation of Absorbed Dose to Patients Following Bone Scan with ^{99m}Tc-Marked Diphosphonates by Two Different Background Correction Methods

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ABSTRACT

To improve the accuracy of the activity quantification and the image quality in scintigraphy, scatter correction is a vital procedure. The aim of this study is to compare the accuracy in calculation of absorbed dose to patients following bone scan with ^{99m}Tc-marked diphosphonates (^{99m}Tc-MDP) by two different methods of background correction in conjugate view method. This study involved 22 patients referring to the Nuclear Medicine Center of Shahid Chamran Hospital, Isfahan, Iran. After the injection of ^{99m}Tc-MDP, whole-body images from patients were acquired at 10, 60, 90, and 180 min. Organ activities were calculated using the conjugate view method by Buijs and conventional background correction. Finally, the absorbed dose was calculated using the Medical Internal Radiation Dosimetry (MIRD) technique. The results of this study showed that the absorbed dose per unit of injected activity (rad/mCi) ± standard deviation for pelvis bone, bladder, and kidneys by Buijs method was 0.19 ± 0.05, 0.08 ± 0.01, and 0.03 ± 0.01 and by conventional method was 0.13 ± 0.04, 0.08 ± 0.01, and 0.024 ± 0.01, respectively. This showed that Buijs background correction method had a high accuracy compared to conventional method for the estimated absorbed dose of bone and kidneys whereas, for the bladder, its accuracy was low.

Key words: *Absorbed dose, background correction, conjugate view method, cumulated activity, MIRD*

INTRODUCTION

Bone scintigraphy is generally recognized as the best method for early detection and diagnosis of cancer of bone or cancers that have spread (metastasized) over the bone and bone lesions.[1,2] Furthermore, this method provides functional information sensitive for subtle changes in bone turnover and perfusion, which assists the clinical management of numerous osseous pathologies.[3] ^{99m}Tc marked diphosphonates (^{99m}Tc-MDP) is essentially maker of both bone perfusion and bone turnover. It is desirable to use the lowest administered activity possible to obtain diagnostically accurate image.[4,5]

Reliable estimates of radiation dose from the use of diagnostic or therapeutic radiopharmaceuticals in nuclear medicine are essential to the evaluation of the risks and benefits of their use.[6-8]

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In nuclear medicine, there are different methods to measure absorbed dose of internally distributed radiopharmaceuticals such as direct measurements by thermoluminescence dosimeter (TLD), extrapolation from animal data, and calculations based on the mathematical biokinetics model.[8-10] Extrapolation of animal data to humans includes inevitable inaccuracy due to large interspecies metabolic differences with regard to the administered radiochemical.

When TLDs are placed on the surface of patients, they show just dose of gamma rays but no other radiation such

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as alpha and beta. Absorbed dose calculations provide a scientific basis for evaluating the biological effects associated with administered radiopharmaceuticals in cancer therapy. Radiation dosimetry supports treatment planning, dose-response analyses, predictions of therapy effectiveness, and complete the patient medical records.[7,10]

The general Medical to estimate Internal Radiation Dose (MIRD) method is used to estimate internal emitter whole organ absorbed dose.[7-10] To estimates the human absorbed dose, the initial step involves activity calculation. In this method, the dose absorbed in the target organs is estimated as a function of activities accumulated in the source organs and it provides a generally correct mathematical estimate dose.

The conjugate view method is the standard and most frequently approached technique used for quantification of organ activities in human studies for dosimetry.[11] It is important to collect sufficient information concerning the activity uptake and to determine the elimination rates in the organs of interest to plan patient-related dosimetric studies in an appropriate manner.[12]

In recent years, several methods have been recommended to acquire information on the temporal change in the radionuclide biodistribution including scintillation camera imaging, discrete probe monitoring, tissue sample counting, and excreta collection.[13] On the other hand, a low count rate can be a problem later, leading to high statistical uncertainties and noisy images.

To improve the accuracy of the activity quantification and the image quality, scatter correction is needed, and various methods have been reported and investigated.[14] One of more reliable methods is subtraction method.[15] This method is applied, because it is a more reliable technique when a region of interest (ROI) is drawn over a source region on an image, some counts from the region will have originated from activity in the subject's body that is outside of the identified source region.

These sources are scattered radiation from other ROIs, background radiation, and due to other sources.[16,17] According to the literature, there are no sufficient data on measurements of dose in critical organ and the effects of scatter radiations and its accurate corrections in bone scanning. For this reasons, activity quantification from these images needs accurate correction for scatter radiations.

The main goal of this study was to compare accuracy in calculation of absorbed dose to patients following bone scan with ^{99m}Tc-MDP by two different methods of background in conjugate view method of Buijs and conventional.

MATERIALS AND METHODS

Study Patients

The study was performed on 22 adults patients (11 men and 11 women with an age average of 38 ± 12 years) referred to the Nuclear Medicine Center at Shahid Chamran Hospital in Isfahan, Iran. Selection criteria included normal kidney functions with no signs and symptoms of bone's trauma history. All patients signed a consent form after receiving the details.

Measurement Procedure

Bone scintigraphy was performed (10, 60, 90, and 180 min) after the intravenous (IV) injection of 22 mCi ^{99m}Tc-MDP using a dual-head gamma camera (Philips, ADAC, forte, Netherlands) equipped with low-energy and high-resolution collimators located in the Nuclear Medicine section of Shahid Chamran Hospital, Isfahan, Iran. A 20% energy window around the photopheak of ^{99m}Tc was used (centered on 140 keV). Images are acquired with the patients lying on their back. The lower thorax-upper abdomen of the patient was imaged in conjugate anterior and posterior views (1 min counts).

ROI was manually drowned around pelvis bone and the bladder and kidneys which they are the critical organs in bone scanning. Then, image was saved using a computer program. A background region was defined for each organ in this smaller ROI and then adjusted to the organ area. The organ activity was calculated using the conjugate view method with the following equations:[5]

$$A = \sqrt{\frac{IA \times IP}{e^{-\mu_e t}}} \times \frac{f}{c}$$

where I_A and I_P are the observed counts in the anterior and posterior projections (counts/time), t is body thickness at the position of the each organ (pelvis, bladder, and kidneys), μ_e is the effective linear attenuation coefficient (0.143/cm for ^{99m}Tc), f is equal to $(\mu_e\ t/2)/\sinh(\mu_e\ t/2)$ and represents a correction for the source region attenuation coefficient (μe) and source thickness (t), and C is system calibration factor (count rate per unit activity) that this factor used in this study was obtained by counting a known activity of ^{99m}Tc for a fixed period of time in air using the same camera setting.

By two different Buijs and conventional background correction methods, counting rate was obtained.

Buijs Method

For obtained corrected counting rate, the counting rate measured in an adjacent ROI was subtracted from the counting rate in organs ROI, in according to the formula reported by Buijs *et al*. equation.[15]

$$I_A = I'_A - I_{BGA} \times F$$

$$I_P = I'_P - I_{BGP} \times F$$

where I_A (I_P) is the background corrected counting rate in the anterior (posterior) organ ROI, I'_A (I'_P (is the measured counting rate in the anterior (posterior) organ ROI, and I_{BGA} (I_{BGP}) is the counting rate in the anterior (posterior) background ROI. F is the fraction of the total background activity I_{BGA} to be subtracted from the measured activity in the source organ ROI, I_A (I_P) and is defined as follows:[15]

$$F = 1 - (t/T)$$

where t is the organ thickness and T is the body thickness (cm) at the source organ.

Conventional Background Subtraction

In this method, the counting rate was measured in an adjacent ROI which subtracted from the counting rate in the organ ROI, using the following formula:[5]

$$I_A = I'_A - I''_A \times S_A$$

$$I_P = I'_P - I''_P \times S_P$$

In this formula, I_A (I_P) and I'_A (I'_P (are defined before. I''_A (I''_P) is the counts per pixel (count/pix) rate in the anterior (posterior) background ROI and S_A (S_P) is the number of pixels in the anterior (posterior) source ROI region.

Absorbed Dose

After the computation of activity, time activity curves for source organs including pelvis bone, bladder, and kidneys were constructed and fitted to exponential disappearance curves to estimate initial organ uptakes and disappearance half-time by MATLAB software. Cumulative activities for each source organ were estimated from the integral of the area under the time-activity curves.

The MIRD Committee Method for determining absorbed dose was used according to the following equation:[12]

$$D_T = \Sigma\tilde{A}_S \times S\,(S \rightarrow T)$$

where D_T is the mean absorbed dose to the target organ (T) from the source region (S), $\tilde{A}_S$ is the integral cumulated activity from the source region estimated for each patient, and S (S → T) is the mean dose per unit of cumulated activity or S factor that defined previously for more than 100 radionuclides and more than 20 source and target regions.

Statistical Analysis

The results acquired by *t*-test (independents samples test) was compared with data of MIRDose. The whole results were described as the mean ± standard deviation (SD), and $P < 0.05$ was considered statistically significant.

RESULTS

Time-activity

Figures 1 and 2 show plots of organ activity for each organ at various times (10, 60, 90, and 180 min) after injection of the ^{99m}Tc-MDP with Buijs and conventional background

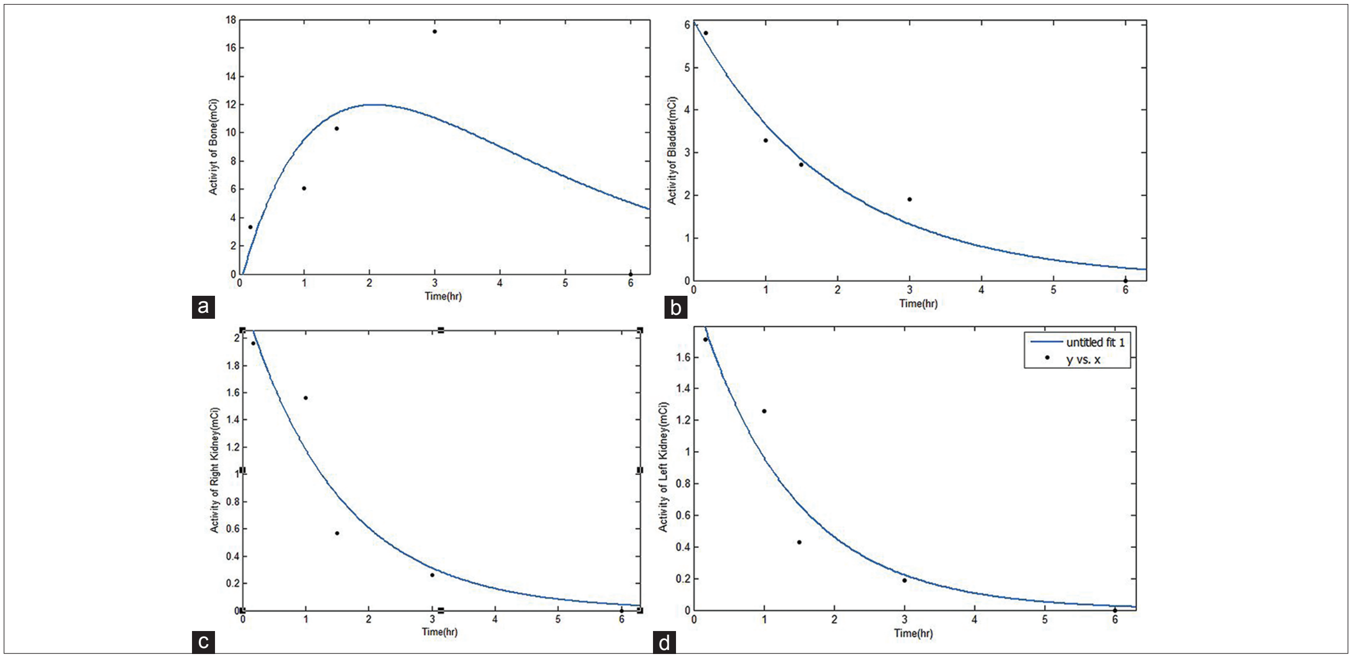

Figure 1: Activity time curves for bone, (a) bladder, (b) right kidney, (c) and left kidney (d) after injection of intravenous ^{99m}Tc-marked diphosphonates in Buijs method

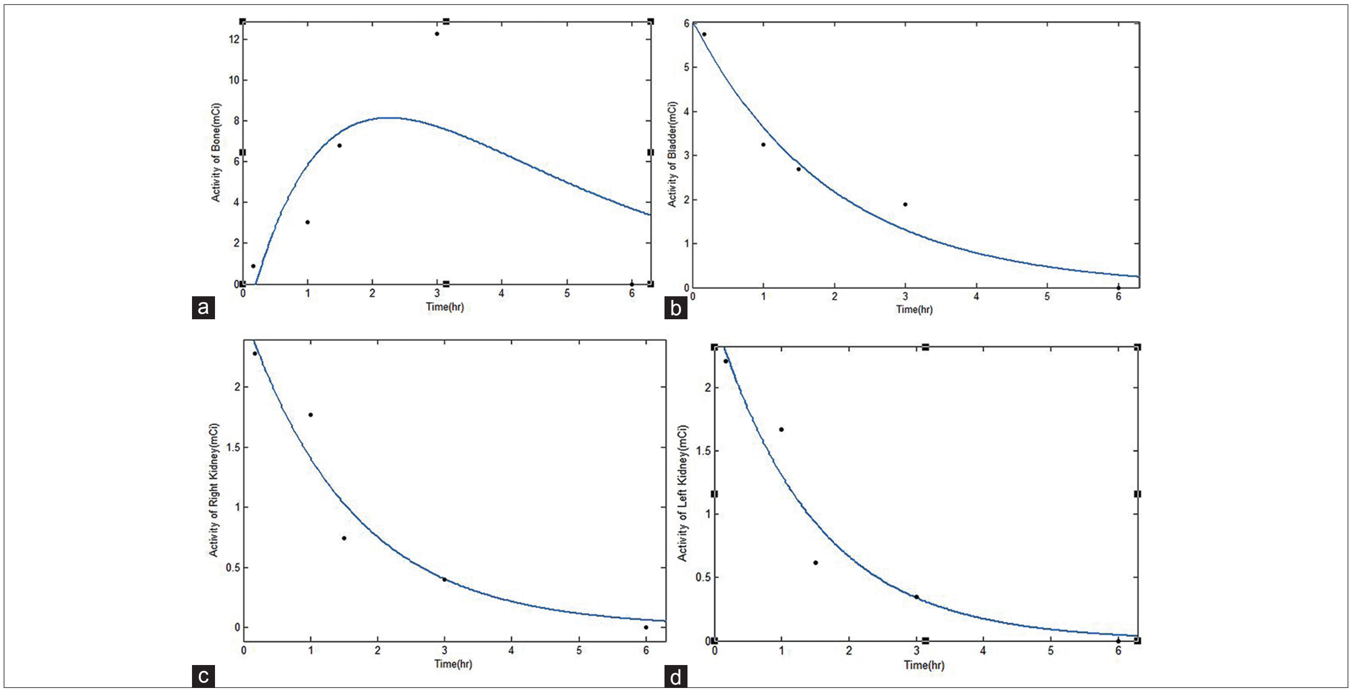

Figure 2: Activity time curves for bone, (a) bladder, (b) right kidney, (c) and left kidney (d) after injection of intravenous ^{99m}Tc-marked diphosphonates in conventional method

correction methods in conjugate view method. In these figures, it is evident that in all organs the activity gradually diminishes over time, except in the bone, where activity increases after the injection.

Organ Absorbed Dose

Table 1 represents the absorbed dose per unit of injected activity (rad/mCi) ± SD for all source organs at 6 h after IV injection by two different background correction methods in conjugate view method. Calculations were made in accordance with MIRD recommendations. This values for pelvis bone, bladder, and kidneys by Buijs method were 0.19 ± 0.05, 0.08 ± 0.01, and 0.03 ± 0.01 and by conventional method, were 0.13 ± 0.04, 0.08 ± 0.01, and 0.024 ± 0.01, respectively.

In bone and kidneys, significant differences were found between the two methods ($P < 0.05$); however, for bladder, there were no obvious differences in absorbed dose between the two methods ($P > 0.05$).

Table 2 shows the difference percentage of absorbed dose with standard value for bone, bladder, and kidneys in Buijs method and conventional method. In addition, Figure 3 shows comparison of between two background correction methods in conjugate view method.

DISCUSSION

The accuracy of absorbed dose in nuclear medicine depends on the methods used for activity quantification measurements and organ dosimetry. The activity quantification based on planar scintillation camera imaging and the corrections for attenuation and scatter rays was investigated. Many studies have noted that factors such as the effective attenuation coefficient, body thickness, device sensitivity, background activity (the most important factor), and overlapping tissue influence the accuracy of activity quantification.[15-20]

The major sources of uncertainty in quantification of an organ or a tumor activity from planar images are the activity present in the tissue surrounding the source. The most common method used for background correction is to subtract the counts in a selected background ROI from the counts in the ROI drown over the organ of interest (representing the sum of activity in the organ and the surrounding background). In the literature, two important methods of Buijs and conventional background correction were applied for the measurement of activity and finally absorbed dose of source and target organs. The conventional method, which is the simplest background correction method, is based on using a ROI appropriately placed adjacent to the organ ROI. The number of counts per pixel in that background ROI is subtracted from the counts per pixel in the organ ROI. The conventional method will overestimate the background as it does not consider the actual organ thickness, but one of the other simplified methods was proposed by Buijs *et al*. in which the organ thickness and body thickness are required. In fact, this method is used to avoid over-subtraction of background activity due to the volume occupied by the organ.

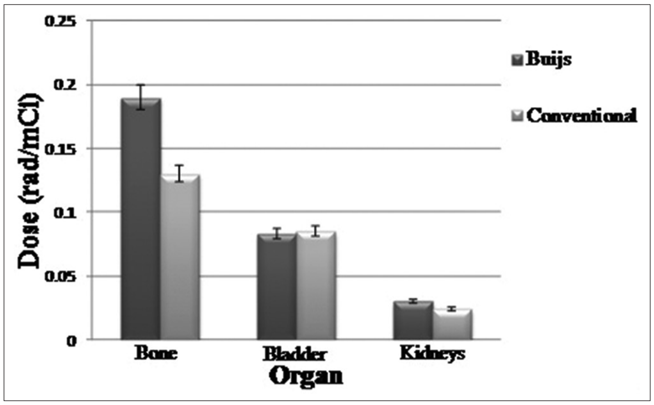

Figure 3: Comparison of absorbed dose per unit of injected activity between two background correction methods

Table 1: Result of absorbed dose per unit of injected activity (rad/mCi)±standard deviation after administration of ^{99m}Tc marked diphosphonates intravenously between two background correction methods (n=22)

Organ	Conventional	Buijs	*P*
Bone	0.13±0.04	0.19±0.05	<0.05
Bladder	0.08±0.01	0.08±0.01	>0.05
Kidneys	0.024±0.01	0.03±0.01	<0.05

Table 2: The percentage difference between the absorbed dose in this study (Buijs and conventional) with medical internal radiation dose software

Organ	Buijs (%)	Conventional (%)
Bone	13	43
Bladder	36	35
Kidneys	3	22

The present study showed that the Buijs background correction method was more accurate than the conventional method on estimated absorbed dose for bone and kidneys, but it did not differ from the bladder [Table 1]. As results in Table 1 represents, the absorbed dose within the bladder is more than kidneys which showing its agreement with the data of MIRDose software.[15] These values for bone, bladder, and kidneys in Buijs method were 13%, 36%, and 3% and also in conventional method were 43%, 35%, and 22%, respectively.

Buijs *et al*.[15] used five different methods of background correction to estimate organ activity, combined with quantitative planar imaging. They showed their method provided more accurate results for the estimation of actual activity in an organ, compared with methods without background subtraction or with conventional background correction.

The need for standardization of methodology led to the development of organ phantoms to facilitate interlaboratory comparisons of organ activity measurements. The important studies by Jönsson[16] revealed widely varying results among different laboratories and led to the general adoption of standardized methods for acquiring data that reduced interlaboratory variability. Concern regarding the safe and effective use of radiation in medicine led to the development of standardized procedures and methods for calibrating the amount of activity administered to patients. Some of the error factors, such as organ thickness and variations in background activity, could be overcome performing phantom measurements to determine which background correction method is the most suitable for the organ of interest.

CONCLUSION

One of the major sources of uncertainty in quantification of organ or tumor activity from planar images is the activity present in the tissue surrounding the source. The most common method used for background correction is to subtract the counts in a selected background ROI from the counts in the ROI drown over the organ of interest (representing the sum of activity in the organ and the surrounding background) which was major goal of the present study.

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Conflicts of Interest

There are no conflicts of interest.

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