Original Article

Comparison of the protection performance in a composite shield and a lead standard shield in terms of biological effects in nuclear medicine

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ABSTRACT

Introduction: In the nuclear medicine departments, staff exposure to radiation is inevitable during patient positioning and radiopharmaceutical preparation. There is controversy regarding the use of usual lead aprons with respect to penetrating gamma rays used in nuclear medicine departments as well as production of characteristic lead x-ray from aprons.

Methods: This research compares the shielding properties of poly vinyl alcohol reinforced by lead acetate, with lead shield based on biological damage to blood cells from the Technetium-99m source. All computations have been carried out by using the WinXcom program. In addition, the alkaline comet assay has been used to estimate DNA damage at the single cell level. Statistical comparisons were analyzed by using the T-test.

Results: Calculated value of μ_m is 0.7616 (cm^2/ g), HVL is 7.4 mm and density is 1.224 g/cm^3. A significant difference in reducing the amount of DNA damage by 0.5mm sheet of lead was not found.

Conclusion: Considering the effects of distance and time on lead acetate composite, results showed that increasing the distance has a significant impact on harm reduction. Even at a distance of 100 cm from the source at all exposure times, the damage is much reduced, compared to the groups with and without a lead shield.

Key words: Composite; Lead; Protection; Nuclear medicine

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INTRODUCTION

Nuclear medicine has grown quickly in recent years, and with the invention of gamma cameras, PET & SPECT, the use of radioisotopes in the diagnosis and treatment of disease has become inevitable [1]. Ionizing radiation is presented as a factor that has always produced deleterious biological effects, which can cause serious and incurable damage in people who somehow deal with radiation [2]. Although the deleterious effects of exposure usually require relatively high doses, molecular biological studies have shown that the risk of malignancy and cancer for ionizing radiation is a simple function of the dose of radiation, and the threshold is lacking. Hence, the hypothesis that low-dose radiation entails no risk of cancer has no basis [3, 4].

The frequency of chromosomal damage in radiation workers has been reported by various researches even in those who have had lower exposure than the limit for most of the general population [4, 5]. Studies performed by the International Commission for the Assessment of Radiation Protection (ICRP) show that the risk of fatal cancer in low dose for radiation staffs aged between 24 and 62 years is 4 percent [6]. According to the radiosensitivity deoxyribonucleic acid (DNA), this molecule is a key target in the beam body [7]. The review of DNA damage in people who have been exposed to beams is very important. Another reason for genetic studies is the physical limitations of instruments for workers exposed to radiation [8].

In nuclear medicine, Technetium is used as the gamma emitter in most cases [9]. Personnel of the nuclear medicine departments involved in patient positioning, personnel engaged in the preparation of radioactive materials, and patients who have had radioactive material prescribed to them—in the form of the dose of the external exposure received [10, 11]. Reduction of external exposure is possible by minimizing the exposure time, maintaining a distance from the radiation sources, and using aprons [12, 13]. High-density materials such as lead absorb gamma rays effectively [14, 15].

Nowadays, aprons made of lead are being used at some of the nuclear medicine centers, and claims have been made that excellent results have been obtained [16-18]. However, there are studies rejecting the use of lead aprons at nuclear medicine centers [19]. It has been observed by the authors that lead aprons are infrequently worn in Nuclear Medicine departments [20]. Historically, shielding has rarely been used while positioning patients as it is impractical and the time involved may be long. The weight of 0.5 mm lead-equivalent apron can be about 9 kg. Constant loading on the spine and standing may result in back pains [21]. Another reason for the limited use of lead aprons may be related to the common misconception among nuclear medicine technician (NMTs) that their use may actually increase their dose by converting higher energy photons, commonly employed in nuclear medicine, to lower energy photons, which are more readily absorbed in the tissues of the body. For patients injected with 140 keV 99mTc, a high ratio of photons will pass through the patient without interacting with their body and Compton scattering is the main interaction. This interaction leads to the production of lower energy radiations (scatter photons). Some of these radiations will be absorbed to the patient while others escape or undergo further interactions. These lower energy escaping photons may result in a higher percentage of photons being absorbed when incident on the NMT. The placement of high atomic number material between the staffs and patient will therefore absorb a high proportion of these photons. Lead, with an atomic number of 82 and K and L-edges of 88 and 13–16 keV (in order), is an effective photoelectric absorber [13]. However, the large gap between absorption edges compromises its shielding effectiveness between 50 and 88 keV [16].

This is a complex issue, however; while there will be a shift to lower energies, there will also be an accompanying reduction in the amount of radiation incident on the wearer, thereby increasing overall protection [20]. The third reason is the lack of sufficient flexibility and the presence of cracks when bent lead is used in certain cases, such as in gloves, and these play a key role in reducing their efficiency [22].

Because of these issues, in recent times researchers have paid much attention towards the construction of polymer composites suitable for using against ionizing radiation, such as gamma rays [18]. Polymers have properties such as flexibility, lightness and high resistance to chemicals [23]. Therefore, in this study, we will prepare a composite shield, against 140 keV gamma radiations, and compare its protection effects with lead.

METHODS

Theatrical calculations

Calculations of mass attenuation coefficient

The mass attenuation coefficients (μm) were calculated for lead acetate – PVA polymer samples, using a computer program WINXCOM. This program was used to calculate the total mass attenuation coefficient for elements, compounds and mixtures at photon energies varying from from1 keV to 100 GeV. Using the values of mass attenuation coefficient, the values of HVL is given by [13]:

$$\mu_m = \Sigma\, w_i(\mu_m)_i \qquad (1)$$

$$HVL = 0.693/\mu \qquad (2)$$

Calculations of density of composite

The density (ρ) of an object is defined as the ratio of its mass to its volume. The density test was performed according to the testing procedure of the ASTM D 1505 method.

Calculations of heaviness

Lead was assumed standard and normalized 100%. With reference to lead, the % of heaviness of the other conventional shielding materials along with lead acetate-PVA samples were evaluated by using the following formula [20]:

$$\%\ \text{of heaviness} = \frac{\text{Density of given material}}{\text{Density of lead}} \times 100$$

Composite development

PVA (molecular weight 44 g/mol) was taken from LG Chemical Company and Lead acetate powder which was obtained from Sigma-Aldrich Company.

At first, the PVA powder was dissolved in the distilled water to make a 50 wt% aqueous solution by heating at 60 ºC for 1 h under stirring. After that, the composites of lead acetate were produced in the ratios of 50% (in weight) by adding lead acetate in the form of solid crystal to PVA solutions and heating at 70 ºC for 2 h under stirring. The composites were prepared by solution casting of PVA/ $(CH_3COO)_2Pb$ solutions on to a to 15×15×2 cm open glass molds. In order to remove residual solvent, the molds were left drying at room temperature (25ºC) for 7 days [20].

Participant preparation

The aim was to compare the effectiveness of 0.5-mm lead (2HVLs) and 14.8-mm composite (equivalent to 0.5 mm Pb) in shielding from Technetium-99m gamma rays.

The activity in the air has been equal to 30 mCi. The source used in liquid form and the volume was 2 ml. The source was put in order to simulate the situation in terms of the exposure of patient and staff members who have been working with radiopharmaceuticals. With a constant source position compared to blood samples, we tested the biological damage before and after the exchange of the gamma-ray protective apron types as follows:

(a) Without 0.5-mm lead aprons

(b) With 0.5-mm lead aprons

(c) Exchanging 0.5-mm lead—with 14.8-mm PVA (0.5 mm Pb equivalent)

Irradiation

In this study, biological damage to blood cells were estimated at various distances (5,25,50 and 100 cm) from the source, with and without a 0.5-mm lead shield and 14.8-mm PVA**.**The time of exposure was 15,30,45 and 60 minutes.

Sample preparation for Comet assay

The comet assay (single-cell gel electrophoresis) is a sensitive and simple technique for evaluating (DNA) strand breaks in individual cells. It was first developed by Östling & Johansson in 1984 and later modified by Singh et al. in 1988. It has since increased as a standard technique for measurement of DNA damage/repair, bio monitoring and genotoxicity testing. The resulting image that is obtained resembles a "comet" with a discrete head and tail. The head is composed of complete DNA, while the tail consists of damaged (single-strand or double-strand breaks) or broken pieces of DNA.

In this study, volunteers were healthy unexposed. The ages of group ranged from 24 to 62 years. All subjects who agreed to participate in the study were in good health and had completed a detailed questionnaire including items concerning their occupational exposure and potential hazards such as recent vaccinations, viral diseases, smoking, drug consumption and radio diagnostic examinations. People with confounding factors for DNA damage were excluded.

Of each of the samples, 5ml of heparinized peripheral blood were studied. In sterile conditions, blood samples in micro-tubes were distributed. Micro-tubes after irradiation with technetium in defined distances and times, were transferred to the CO_2 incubator at 37 ºC for one hour in order to repair DNA damages resulting from gamma radiation. Slides were prepared in duplicate. Normal 0.5% agarose in phosphate buffered saline (PBS) was layered onto a precleaned.

On microscope slide, cells were mixed with 75 µL of 0.5% low melting point agarose in PBS and the mixture added to the slide. After solidification of the agarose, a top layer of 75 µL low melting point agarose was added. Once the top layer had solidified, the slide gently immersed in cold lysing solution (2.5 M NaCl, 100 mM EDTA, 1% N lauryl sarcosine, 10 mM Tris-HCl, pH 10, to which 1% Triton X-100 and 10% DMSO had been added fresh). The slides were left at 4°C for at least 1 hour. After that, the slides were placed close to each other in a horizontal gel electrophoresis tank near the anode. The tank was filled with fresh electrophoresis buffer (300 mM NaOH, 1 mM EDTA, pH 13) to a level of 0.25 cm above the slides, which were then left to soak for 40 minutes in the alkali. Electrophoresis was carried out for 20 minutes at 19 V and 300 mA. After electrophoresis, the slides were gently removed from the tank and neutralizing buffer (0.4 M Tris-HCl, pH 7.5) was added drop-wise to the slides three times, allowing the slides to sit for 5 minutes each time. The

DNA was stained with 50 µL of ethidium bromide (40 mg/mL). A clean coverslip was then placed over the slide and analysed.

Comets form as the broken ends of a negatively charged DNA molecule become free to migrate in the electric field towards the anode. The assay presents direct determination of the extent of DNA damage in an individual cell. The extent of DNA damage can be assessed from the length of DNA migration, which is resulted by subtracting the diameter of the nucleus from the total length of the image. So, is also possible to determine the degree of damage by grading the cells as undamaged, intermediate (at low damage levels and tailed (with increasing numbers of breaks, DNA pieces migrate freely from the nucleus forming comet images). A minimum of 100 cells were analysed in duplicate for each sample and the slides were scored blind by two independent investigators.

Statistical analysis

Statistical comparisons within the grade of DNA damage in controls and exposed cells were analysed, using the T-test. Significance between groups was evaluated by using two-way analyses of variance (ANOVA Program).

RESULTS

Outcome from this study can be divided into two sections:

1. Compare the physical parameters of composite with lead shield
2. Correlation between biological measurements with exposure time and distance from the source

The values of density, half-value layer, heaviness and attenuation coefficient in composite and lead shields are noted in Table 1, using WinXcom modeling for comparison.

Table 1: The values of density, half-value layer, heaviness and attenuation coefficient in composite and lead shielding

	50% PVA+ 50 % lead acetate	Lead
HVL (Theorical) (mm)	7.4	0.25
% of heaviness	10.7	100
ρ (g/cm^3)	1.224	11.34
µ (cm^{-1})	0.932	27.102
μ_m (cm^2/ g) (WinXcom)	0.7616	0.0239

Table 2 details grade of DNA damage in lymphocytes with 14.8-mm PVA (2HVLs) at various distances from the source and different times of exposure.

The main results are summarized in Table 3, showing the results of DNA damage in lymphocytes with and without a 0.5-mm lead shield.

Table 2: The mean grade of DNA damage in lymphocytes with 14.8-mm PVA at various distances from the source, and different times of exposure.

Time (min)	Distance (cm)			
	5	25	50	100
15	263.5416	293.5047	162.8571	85.2941
30	304.9504	273.0430	183.9416	91.6666
45	306.9606	132.3232	129.4573	72.0930
60	305.3191	199.3055	145.1612	184.2985

As indicated in this table, the densities of lead and lead acetate –PVA shields were 11.34 and 1.224 g/cm^3, respectively. The WinXcom simulation calculations for HVL of lead and lead acetate –PVA shields at 140 keV were 0.25 and 7.4 mm, respectively. Despite the high HVL of composite compared to lead, it was much lighter. With lead at 100% heavier than other shielding materials, lead acetate - PVA is only 16.8% of lead. These results prove that the polymer composite exhibits lightness when compared to conventional radiation shielding materials such as lead.

Using the Kolmogorov–Smirnov test (test K–S), it was found that distribution of DNA damage Variable is normal.

Table 3 shows significant difference in DNA damage between both groups—with and without a lead shield— at distance of 5,25 and 50 cm at irradiation time of 45, 60 and 30 minutes, respectively. Significant difference was noticed in DNA damage between without lead shield and control group (94.607) in 50 cm at 30 min, 5 and 25cm at 45min and 25, 100 cm at 60 minutes. Significant difference in DNA damage between with lead shield and control group (94.607) was observed in 5 and 25 cm at 30 min, 25 and 100 cm at 45 min and 25 cm at 60 minutes.

Comparing groups without lead shield, with polyvinyl Alcohol was shown with a significant difference in 5 and 25cm 15min and 5.25, 100 cm at 45 minutes. Comparing groups with lead shield, with polyvinyl Alcohol be shown a significant in 5.25 and 50 cm at 30 minutes.

DISCUSSION

The authors noted a general lack of published research investigating the biological effects when used lead and composite as a protective aprons in nuclear medicine. Only a few reports are available regarding the comparison of physical measurements of lead and lead-free shields.

The present work includes synthesis of lead acetate-PVA composite for gamma irradiation shielding purpose, which has more advantages than that of lead by good flexibility and less fragility. This may be molded into different shapes, thus making them useful fillers in empty spaces like ducts, trenches and penetrations. Also, this composite is much lighter and does not lead to poisoning.

Table 3: The mean grade of DNA damage in lymphocytes with and without 0.5-mm lead at various distances from the source, and different times of exposure.

Time (Min)	Distance (cm)											
	5			25			50			100		
	With lead	Without Lead	Sig	With lead	Without Lead	Sig	With lead	Without Lead	Sig	With lead	Without Lead	Sig
15	141.7493	126.7231€	NS	80.303	92.5747€	NS	92.624	128.594	NS	135.034	97.5355	NS
30	78.4305§€	108.4169	NS	125.773§€	106.0755	NS	92.673€	118.0143§	P<0.006	103.515	87.0190	NS
45	145.27	188.6415§€	P<0.042	164.495§	168.1425§€	NS	177.017	194.6125	NS	160.900§	129.2985€	NS
60	195.796	163.2680	NS	240.795§	191.2295§	P<0.025	195.036	235.3570	NS	212.268	227.192§	NS

§: Compared with the control group (94.607) is significant. € : Comparing groups with and without lead shield, with polyvinyl alcohol be shown a significant.

In this study, the mean damage to blood cells ranged from 78.4305 to 240.795 with a lead shield, 87.0190 to 235.3570 without a lead shield and 72.093 to 306.9606 with composite shield. The values in Table 3 indicate that DNA damage in both groups -with and without a lead shield- is greater compared to the control group. However, a significant difference in reducing the amount of DNA damage by 0.5mm sheet of lead was not found, and lead does not offer greater protection against radiation.

However, the average damage shows no significant decrease with increasing distance from the source before and after use of lead in this study. But with changing time, damage is effectively caused, and the damage increases with increased exposure time.

Our results were not close to those of Bayram [9]. Their study used a Geiger-Muller detector to measure dose rates to technologists at various distances from patients (0.25, 0.50, 1, and 2 m with and without a lead shield). The measured deep-dose equivalent to technologists was within the range of 0.13 to 0.43 μSv when using a lead shield and 0.21 to 1.01 μSv without a lead shield. This study showed that a 2-mm lead shield reduced the external dose to technologists, markedly. Furthermore, it was found that the external dose rates can diminish as distance from the patient increases.

The reasons for the difference results between two studies can be:

1. In Bayram study, thickness of the lead is four times (8 HVLs Pb equivalent) bigger that the one used in our study, which can cause more protection.
2. Our work focused on the measurements of biological damage and increase damage of DNA by converting higher energy photons, commonly employed in Nuclear Medicine, to lower energy photons which are more readily absorbed in the tissues of the body.

In another study by Warne-Forward, dose measurements with TLDs in an anthropomorphic phantom were observed by the presence of different shielding materials from a 99mTc source.

The lead apron reduced the photo peak by 73% and the Roland apron reduced it by 58%. The Roland material was seen to be more efficient (15%) in reducing the lower energy photons (95 keV) than the lead apron. This is to be expected once the energy of photons decreases below the k-edge for lead (88 keV). The situation is reversed above 95 keV, with the lead apron being 35% more efficient at absorbing photons whose energy is above 95 keV.

Considering effects of distance and time on lead acetate composite, showed that increasing the distance has a significant impact on harm reduction. Even at a distance of 100 cm from the source at all exposure times, the damage is much reduced, compared to the groups with and without a lead shield. It also seems that this polymer is better at long distances. With increasing duration of exposure, there was no significant increase in the rate of cell damage. This result suggests that the range of K-edges associated with different materials used in composite apron construction are less effective than lead in absorbing photons in the range of energies encountered in our study.

In another experimental study by K. Ghazi Khanlou Sani [24], three point sources (^{99m}Tc, ^{201}Tl and ^{131}I) were used in low volumes (0.1cc). The sources were first fixed in the air (the activity of 300 μCi) and then in the water filled with skull phantom (the activity of 1 mCi). As the source was fixed at certain distance (3m), count rating was done by gamma camera with and without a lead apron with thickness of 0.5 mmPb. Results from the measurements showed that count rates were reduced about 83.7%, 83.2%, and 53.7% for 201Tl, 99mTc, and 131I, respectively, and that 0.5 mm lead aprons decrease count rate significantly. Furthermore, this effect is found to be significant for low energy radioisotopes.

The difference in results between two studies can have two reasons:

1. In our study, blood cells are exposed to a much higher activity (30mCi) and more volume of radioactive (2cc) compared to the previous study. This would highly increase the amount of cell

damage and, therefore, reduce the protective properties of lead shield.

2. In our study, the distances from the source is much less than those in the previous study, which can exacerbate the effects of radiation.

In another study, P. Hejazi measured the superficial and deep dose equivalent of chest, gonads and fingers before and after a lead plastic with 0.35mm Pb thickness with TLD for a month. The mean superficial and deep dose equivalent of chest and gonads were equal, but the superficial dose equivalent of fingers from radiopharmaceutical main locality of exposure was more P<0.005). Making use of apron caused reducing the superficial dose equivalent but did not have any effect on the deep dose equivalent because of the high energy of photon that is used in nuclear medicine. Comparison of these results with our research shows thin lead shield (1-2 HVL) does not show effective protection in reduction of radiation dose and biological damage. This is due to high energy of photon that is used in nuclear medicine leading to many biological damages.

CONCLUSION

Correct making use of apron with 0.5mmpb thickness was not reduced exposure because of high energy of photon that use in nuclear medicine.

A combination of Poly Vinyl Alcohol (50%) and lead acetate (50%) in a polymer matrix can be considered as an light and elastic substitute for conventional lead shields for gamma rays of energy 0.140 MeV but protective effects of that is not better than lead. Survey of protective instrumentation was recommended for radiopharmaceutical main locality of exposure in departments of nuclear medicine. Also, to the best of the knowledge of the authors, these data are the first of these kind estimated for a biological damage of gamma ray with new composite.

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