RESEARCH ARTICLE

Fabrication of a cell irradiation technique by alpha-particles using allyl diglycol carbonate (ADC) detector and micro-capillary tubes

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Abstract

Objective: To study the impact of micro-alpha irradiation collimator with a specific design to irradiate specific normal or up-normal cells using capillary tubes and nuclear track detector type CR-39.

Method: The in vitro experimental study was conducted at radiobiology Lab, of the Physics department, Salahaddin University, Erbil, Iraq from February to April 2022. Several alpha irradiation collimators were calibrated using allyl diglycol carbonate to fabricate a suitable blood cell irradiation technique. Time of irradiation and alpha particle energy were calibrated. Healthy blood samples of Albino rats and cancer blood samples were used to assess the applicability of the fabricated cell irradiation technique. The Rats were divided into intervention and control groups. Data was analysed using SPSS software version 28.

Results: Of the 15 healthy, male Albino rats having a mean weight of 230±12g each, there were 12(80%) in the intervention group and 3(20%) in the control group. Microcapillary tubes with suitable diameters had high stability for deposition of a sufficient density of alpha particles on the surface of allyl diglycol carbonate and blood samples. The optimum time of irradiation that had a significant ($p<0.05$) effect was 20 sec corresponding to alpha energy 4.5MeV.

Conclusion: Low irradiation time had significant impact of alpha particles on the average percentage of lymphocyte and neutrophil cells.

Key Words: Neutrophils, Neoplasms, Radiobiology, Carbonates, Lymphocytes

(JPMA 74: S402 (Supple-8); 2024) **DOI: https://doi.org/10.47391/JPMA-BAGH-16-91**

Introduction

Alpha particles have sufficient effect on radiobiology radiation due to low energy transfer.[1] Alpha particles on their own can damage the exposed cells, such as blast cells of leukaemia blood samples.[2] Cell alpha irradiation (nanometre dimensions) technique is a direct method of radiation biology and radiation oncology.[1] The irradiation dose depends on the time of exposure and the radiation activity of alpha sources.[3] Alpha particles are widely used in radiation oncology. Alpha particles, be they from natural or man-made sources, are dangerous only when they are inhaled, ingested, or absorbed through a wound.[4-6] Radon along with its progenies is considered one of the main sources of human lung cancer due to deposition of produced alpha particles from decay of radon and its progenies (^{218}Po, ^{210}Po).[7]

The calibration of the irradiation collimator in radio oncology is critical to get a sufficient dose for specific cancer cells and avoiding damages to healthy cells.[4,5,8,9] Accumulation of alpha particles with different energies and time of irradiation have been used to reduce the blast cells for in vitro irradiation.[10] Irradiations of cells by alpha particles have been done in different aspects of radiation biology in the past.[3,4,11,12]

Some studies[3,4,10,13] showed that the outcome of radiotherapy was not acceptable due to a cross-section of exposed cells and the time of irradiation. Therefore, a cell irradiation technique with short duration of irradiation is necessary in radiobiology and radiotherapy. A study,[5] fabricated an irradiation collimator from organic materials {nuclear track detectors (NTDs)} for radio-oncology cases, but the fabrication was not acceptable for living cells in view of the negative effects on healthy cells.One study[10] proved that the irradiation of cells with limited alpha concentration can be significantly effective, but it was not significant for healthy cells due to the scattering of alpha particles, and long duration of irradiation.

Previous studies,[2,3] did not include the impact of alpha particles on healthy cells during radiotherapy, and did not control the area of exposure while using fabricated irradiation techniques. Also, and they failed to explain how alpha particles affect cell morphology. The current study was planned to study the impact of micro-alpha irradiation collimator with a specific design to irradiate specific normal or up-normal cells using capillary tubes and NTD type CR-39.

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Materials and Methods

Erbil, also called Hawler, is the capital and most populated city in the Kurdistan Region of Iraq. The city belonging to the Erbil Governorate is predominantly Kurdish and has minorities of local Turkmen and Assyrians, as well as Arabs. Turkmens are Erbil's Kurdish Sunni Muslims and majority speak the Sōrānī Kurdish dialect. Other ethnic groups in the city include the Turkmen and Arabs. Other religious groups include Shīʿite Muslims, Assyrian and Chaldean Catholic Christians, Yazīdīs, and Kākā. The area of Erbil is about 115 km^2 and population is 1.5 million regarding statistics of 2020.[14]

The in vitro experimental study was conducted at the radiobiology Lab, of the Physics department, Salahaddin University, Erbil, Iraq from February to April 2022. Several alpha irradiation collimators were calibrated using nuclear track detector type CR-39 (CR-39NTDs) (CR-39NTD is a $C_{12}H_{18}O_7$ polymer with a density of 1.31 g/cm^3 and thickness of 700 mm, it is produced by INTERCAST EUROPE SRL, 43100 PARMA, ITALY) to fabricate a suitable blood cell irradiation technique. Time of irradiation and alpha particle energy were calibrated. Healthy blood samples of Albino rats and cancer blood samples from male leukaemia patients were used to assess the applicability of the fabricated cell irradiation technique.

The irradiation collimators were fabricated using injection needles and micro-capillary tubes with the same diameter (0.5mm). The basic of the design depended on the range-restricted energy of alpha particles in air. The following equation was used to determine the source and detector distance:[15]

$$E_\alpha(X) = E_\alpha(0)\left(1-\frac{X}{R}\right)^{\frac{2}{3}}$$

where Eα (X) was the residual energy of alpha particle (MeV); Eα (0) was the initial energy of alpha particle 5.49 MeV, and R was the alpha particle range in the air (4.08cm).

Density of the alpha particle accumulation on the surface of the detector depended on the time of irradiation, so the time of irradiation was changeable from 5 sec to 60 sec (Figure 1A) for alpha energy 4.5MeV.

Density of the accumulated alpha particles on the surface of the detector was calculated after chemical etching process with 6 normalities of the chemical solutions of NaOH {6N (NaOH)} at 70°C (5, 15). An optical microscopy (Olympus company,UK with high magnification of 600X) equipped with Charge –coupled device (CCD) camera was used to calculate the alpha particle density for each irradiation.

In vitro blood cell irradiation procedures of blood samples of the rats were carried out in the Haematology Laboratory of Biology Department, Salahaddin University. The mice were divided into intervention and control groups. A mixture of xylazine 5mg/kg and ketamine hydrochloride 35mg/kg was used to anaesthetise the animals[16]. Blood samples were withdrawn from cardiac puncture into 5mL tubes with ethylenediaminetetraacetic acid (EDTA). Blood samples of the intervention group were irradiated by alpha particles (E-alpha 4.5MeV) for several time durations of irradiation (Figure 1B). Haematology analysers were used to measure white blood cell (WBC), red blood cell (RBC) and platelet (PLT) counts. The fabricated alpha irradiation collimator was used for irradiation of the leukaemia blood samples collected at the Nanakaly Hospital for Blood Diseases, Erbil, from March to April 2023. Leukaemia blood samples contained blast cells. The 20 samples were taken from males aged 25-64 years with body mass index between 24-30 kg/m^2, All cases were non-smokers. The 6ml samples were classified into controls and cases. In the control group, blast cells percentages were calculated without irradiation, while in the cases group, the blast cells were calculated after irradiation.

Procedures were done for both groups under the same laboratory conditions, and calculations were done using a Binocular compound microscope (Its magnification about 1000x) equipped with a CCD camera. The data was analysed using SPSS software version 28. $P<0.05$ was considered significant.

Results

Of the 15 healthy, male Albino mice having a mean weight of 230±12g each, there were 12(80%) in the intervention group and 3(20%) in the control group. Impact of time duration of irradiation was significant on the density of the accumulated alpha particles for both medical needle and micro-capillarity tube irradiation collimators, indicating that the type of material did not affect the density of alpha particles, and, thus, capillarity tubes were selected for blood irradiation in vitro (Figure 2).

The fabricated irradiation collimator was applied during irradiation of the blood samples of mice with alpha particle via accumulation of 18.84±6.61 alpha per cm^2 for 20 sec on the surface of the sample. The dose of alpha particles did not affect complete blood count (CBC) parameters (Table)

Table-1: Effects of the low dose of alpha particles at t=20 sec on complete blood count (CBC) components of healthy mice.

Blood parameters	Control (Before irradiation) B.I Average ±SDV	Case (After irradiation) A. I	Ratio (A.I/B. I)	Statistical status ($p<0.05$)
RBCs(10^{12}/l)	7.27±0.66	7.30±0.71	1.004	Non-significant
HGB(g/dl)	11.32±1.21	11.41±1.01	1.007	Non-significant
HTC (%)	34.18±3.33	34.22±2.95	1.001	Non-significant
MCV (fl)	51.33±2.13	51.88±1.77	1.010	Non-significant
MCH (pg.)	20.22±1.22	20.47±1.5	1.012	Non-significant
MCHC(g/dl)	35.55±2.44	36.11±1.66	1.015	Non-significant
WBCs (10^9/L)	4.11±1.07	4.00±0.92	0. 97	Non-significant
LYM (10^9/L)	3.55±0.87	3.41±1.01	0.96	Non-significant
LYM%	68.72±3.33	69.01±2.8	1.004	Non-significant

RBC: Red blood cell, HGB: Haemoglobin, HTC: Haematocrit, MCV: Mean corpuscular volume, MCH: Mean corpuscular haemoglobin, MCHC: Mean corpuscular haemoglobin concentration, WBC: White blood cell, LYM: Lymphocyte.

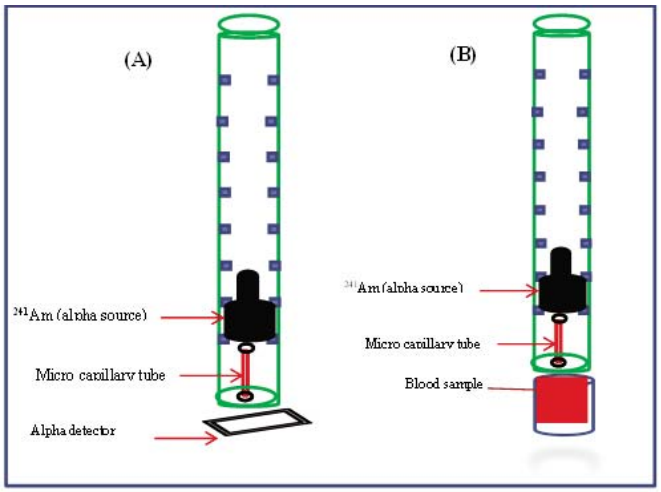

Figure-1: Setup process of the irradiation of nuclear track detectors NTDs (A), and blood samples (B).

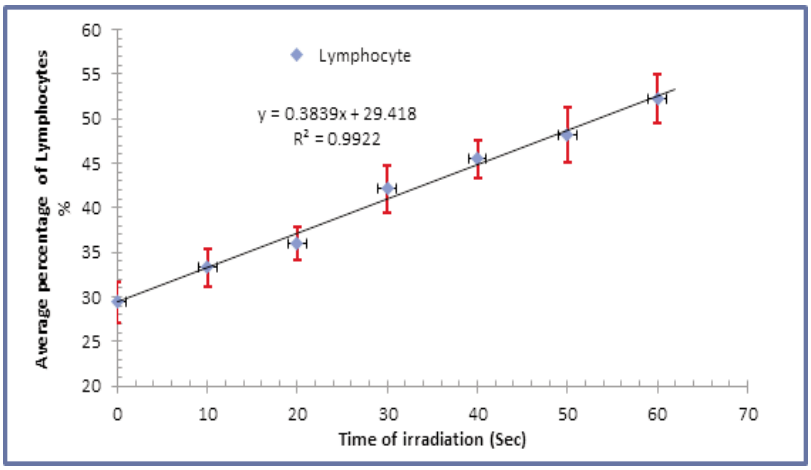

Figure-2: Variation in the average percentage of lymphocytes.

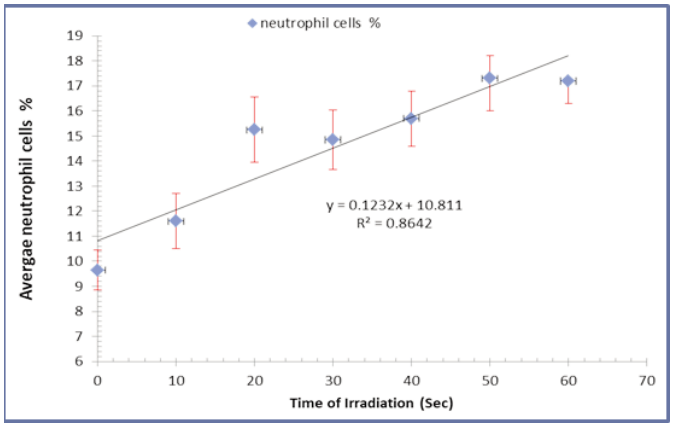

Figure-3: Neutrophil cells with time of irradiation of alpha particles.

The fabricated irradiation technique was used to irradiate leukaemia blood samples. Highly significant impact of alpha particles (E = 4.5MeV) was noted on lymphocyte and neutrophil with the time duration of irradiation (Figure 2-3).

Discussion

The density of the accumulated alpha particles on the surface of the detector for both irradiation tubes increased with increasing duration of irradiation, which was in agreement with earlier studies.[1,4]

The time of 20 seconds was considered appropriate to irradiate the cell samples because the density of alpha particle was more stable at a low dose.Healthy blood cells were less radiosensitive than cancer blood samples, indicating that a low dose could easily affect cancer cells. The finding was in agreement with previous studies.[10,17,19]

Highly significant impact of alpha particles for various time duration of irradiation was found on lymphocyte and neutrophil cells. This was due to radio-sensitivity of these cells.[2]

Conclusion

Optimum time of irradiation was identified as 20 seconds for alpha energy of 4.5MeV. Type of tubes had no effect on the accumulated density of alphas. The fabricated irradiation technique was found to be useful in irradiating leukaemia blood samples.

Acknowledgements: We are grateful to all staff members associated with radiobiology and biological laboratories as well as the animal house at Biology Department for facilitating the study.

Disclaimer: None.

Conflict of Interest: None.

Source of Funding: None.

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