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Physical Quality Parameters Affect Charged Particles Effectiveness at Lower Doses

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Abstract: Effectiveness of inactivation effect in V79 cells has been investigated. Relative biological effectiveness for charged particles has calculated utilizing initial slopes of V79 survival curves published in literature. Radiation quality parameters such as particle energy, linear energy transfer, linear primary ionization, mean free path and effective charge are determined. As results of this research, meaningful relationships between radiation effectiveness and physical quality parameters which characterize radiation quality are obtained. Radiation mechanism action of charged particles has elucidated in terms of these quality parameters.

Key words: Relative biological effectiveness · Physical parameters · Inactivation effect

INTRODUCTION

Knowledge how ionizing radiation cause damage to biological systems is one of the most important and challenging goals of radiation research [1]. In radiation protection absorbed dose which defined as the amount of energy transferred or absorbed in the medium by charged particle use as physical quality parameter to quantify biological effect which are produced by these particles at high doses. In contrast utilizing this physical quantity i.e. absorbed dose to quantify the biological effects at low dose region is insufficient approach. However, absorbed energy as physical quality parameter is inadequate for determining the effectiveness of inactivation for charged particles. Relative biological effectiveness (RBE) is used to quantify the effectiveness of charged particles of different particles at the same level of damage which produced by different qualities of radiations. Comparison of various qualities of charged particles can be made in terms of their relative effectiveness. In mathematical formation, RBE is given as the ratio of absorbed doses by reference radiation to test radiation. The reference radiation is usually ortho-voltage e.g. 250 kVp x-ray or hard gamma radiation e.g. ^{60}C. Because the essential weaknesses related to RBE as biological quantifier parameter of effectiveness for charged particles at lower doses, a new form has been set for RBE. RBE in its new form is defined as the ratio of initial slope of survival curve of tested radiation to the initial slope of the reference curve of 250 kVp x-ray or ^{60}C gamma ray [2].

The accessibility of huge data has been manifested that RBE is dependent on specific factors such as the absorbed dose, dose rate, effect level (end-point) in addition to radiation quality (radiation type). The applicability to relate RBE with these factors has enabled making RBE as a unified parameter of quantify the effectiveness of any radiation quality and for any biological end-point.

The relation between linear energy transfer (LET) and RBE is well established. Response curve for such correlation indicates that there is an optimum value for RBE which occurs at 100 keV/μm for LET for any radiation quality [3]. This optimum value is independent of end-point and cell type. Although, such convex-shaped curve is not unified for all biological effects (end-points), thus LET is considered as a fundamental parameter of any radiation quality. Its application in explaining effectiveness (i.e. RBE) is restricted [4]. Other physical parameters which don't take into account to determine the effectiveness of ionizing radiation, such as deuterons and tritiums, including particle charge and its velocity. However not much research has been addressed or discussed on such relations, in addition, the effectiveness of utilizing these radiation quality parameters to elucidate cell radiosensitivity.

This paper reviews secondary data published in literature on the inactivation of V79 cells by deuterons and tritiums particles, to better interpret the relationship between RBE and radiation quality parameters. In this research five physical quality

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parameters, i.e. charged particles energy (E), linear primary ionization (I), radiation mean free path (λ) and effective charge (Z_{eff}) were studied.

MATERALS AND METHODS

This research is based on extracted secondary data from published materials [5-8]. RBE is mainly defined using mathematical expression (1).

$$RBE = \frac{D_{x-ray}}{D_{t-rad}} \text{ Producing the same end-point} \ldots\ldots \quad (1)$$

Where $D_{x\text{-ray}}$ and $D_{t\text{-rad}}$ are the absorbed doses of reference and test radiation respectively, producing the same level of biological end-point.

However, for the purpose of this paper RBE is calculated using equation (2). Equation (2) is based on the initial slopes (α) of V79 radiation induced survival curves. In this case RBE is focused on cell inactivation at low dose [9].

$$RBE = \frac{\alpha_\tau}{\alpha_X} \quad (2)$$

Where α_τ and α_x are the initial slopes of the V79 survival curves produced by test radiation and reference x-ray respectively.

Effective Charge (Z_{eff}) of deuteron and tritium particles is calculated using equation (3).

$$Z_{eff} = \left(\frac{E}{84 \times A}\right)^{1.2} \quad (3)$$

Where E and A are the ion energy and the mass number of charged particles respectively.

Physical quality parameter I or linear primary ionization represents the number of ionization events per nanometer of track length of charged particle traversal in the medium, i.e. I gives linear ionization density produced by charged particle interactions in the medium.

However radiation mean free path, (λ) represents the spacing between the lethal events of ionizations occurred from traversing of charged particle through the medium, It would be expected that the most effective λ would represents the distance between the double strand of a DNA.

The physical parameters for every ion studied in this paper are taken from the same experiments. Linear primary ionization and mean free path are interpolated using the standard values of physical parameters Watt [10]. The bio-physical relationships between RBE and the different physical radiation parameters will be assessed on the types of correlations developed between the selected parameters.

RESULTS AND DISSCSSION

Fig. 1(a) and 1(b) indicate an inverse linear relationship between linear energy transfer and particle energy (E) for deuteron and tritium particles. The ionization density which is given by LET for ionizing radiation (^{2}H and ^{3}He) decreases with increase in energy.

For ^{2}H, an LET of 100 keV μ^{-1} is represented by extrapolated energy of 2×10^3 keV. As for ^{3}He, an LET of 100 keV μ^{-1} is expressed by extrapolated energy of 15×10^3 keV. The both responses are represented mathematically as $LET = -8.29\times10^{-3} E + 46.80$ ($R^2 = 0.95$) for ^{2}H particles and $LET = -3.36\times10^{-3} E + 80.19$ ($R^2 = 0.92$) for ^{3}He particles.

Relationships between RBE and particles energy of ^{2}H and ^{3}He are shown in Fig. 2(a) and 2(b) respectively. The RBE peaks for these two particles are 12.5 keV and 11.12×10^3 keV. Applying these values to the regression line in Fig. 1(a) and Fig. 1(b) gave LET value of 44.5 keV μ^{-1} for ^{3}He particles.

The bell-shaped relationship of RBE-LET is verified [11] in Fig. 3(a) and Fig. 3(b) for ^{2}H and ^{3}He particles. The maximum value for ^{2}H and ^{3}He occur at LET$\cong$ 7.03 keV μ^{-1} and LET$\cong$ 44.5 keV μ^{-1} respectively.

Fig. 4(a) and Fig. 4(b) show the relationship between RBE and linear primary ionization (I) for ^{2}H and ^{3}He particles used to irradiate V79 cells *in vitro*. The RBE of these particles decreases dramatically with linear primary ionization (I) to reach the minimum at 1.06 nm^{-1} for ^{2}H and 0.24 nm^{-1} for ^{3}He particles. These values represent the number of ionization events (energy deposition) that are required to produce the double strands breaks (DNAs) of DNA (Deoxyribose Nucleic Acid). The effectiveness of DSBs is reverse above the certain value for ^{2}H particles and the overall trend is showing parabolic response.

The relationship between RBE and mean free path λ which represents the connection between the effectiveness of charged particles through the medium (cell) is plotted in Fig. 5(a) and Fig. 5(b). There is a good correlation between RBE and λ in this range of charged particle energies. The minimum effectiveness of inactivation occurs by ^{2}H and ^{3}He particles at mean free path 10.30 nm and 4.16 nm respectively. After these values the inactivation of effectiveness increases versus increasing in mean free paths for both particles. The maximum values for effectiveness of inactivation for ^{2}H and ^{3}He particles occur at 38.94 nm and 6.53 nm respectively.

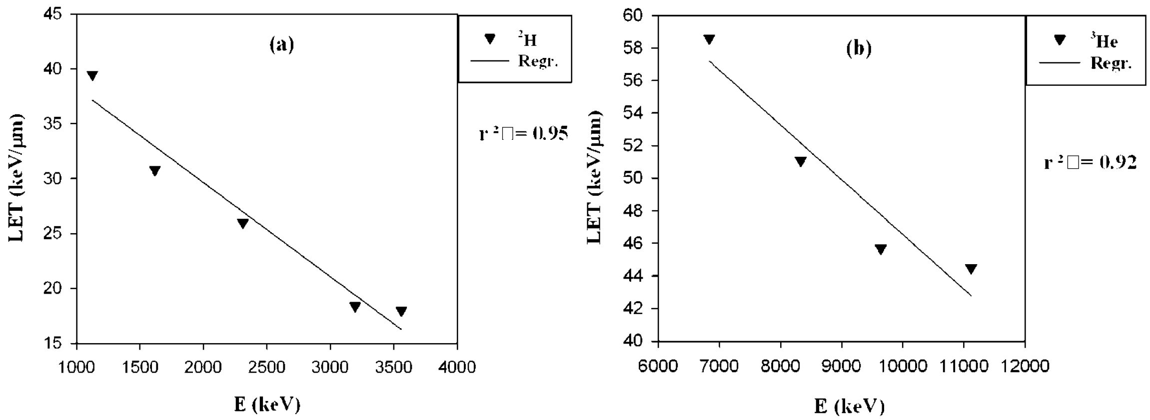

Fig. 1(a,b): (a) Relationship between linear energy transfer (LET) and energy (E) for deuteron particles which are used to irradiate V79 cells *in vitro*.

(b) Relationship between linear energy transfer (LET) and energy (E) for tritium particles which are used to irradiate V79 cells *in vitro*.

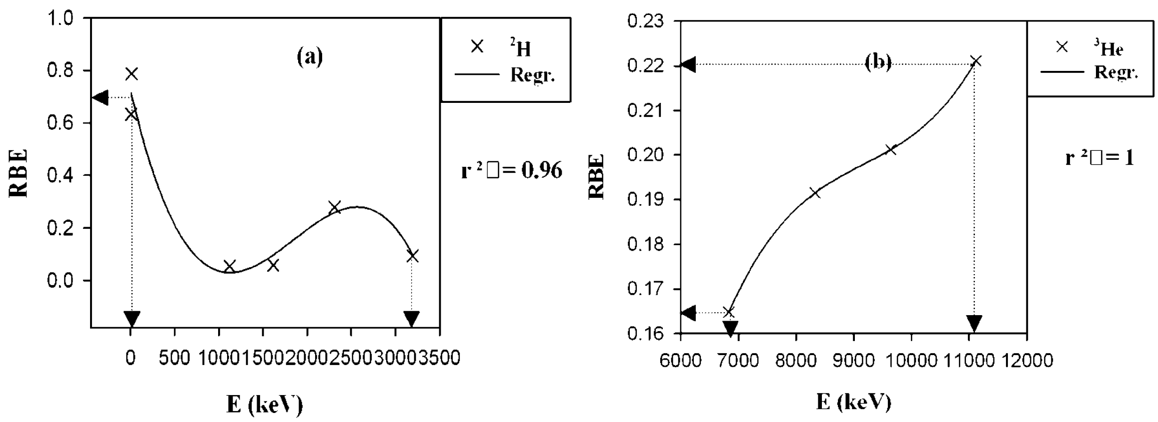

Fig. 2(a,b): (a) Relationship between relative biological effectiveness (RBE) and energy (E) for deuteron particles which are used to irradiate V79 cells *in vitro*.

(b) Relationship between relative biological effectiveness (RBE) and energy (E) for tritium particles which are used to irradiate V79 cells *in vitro*.

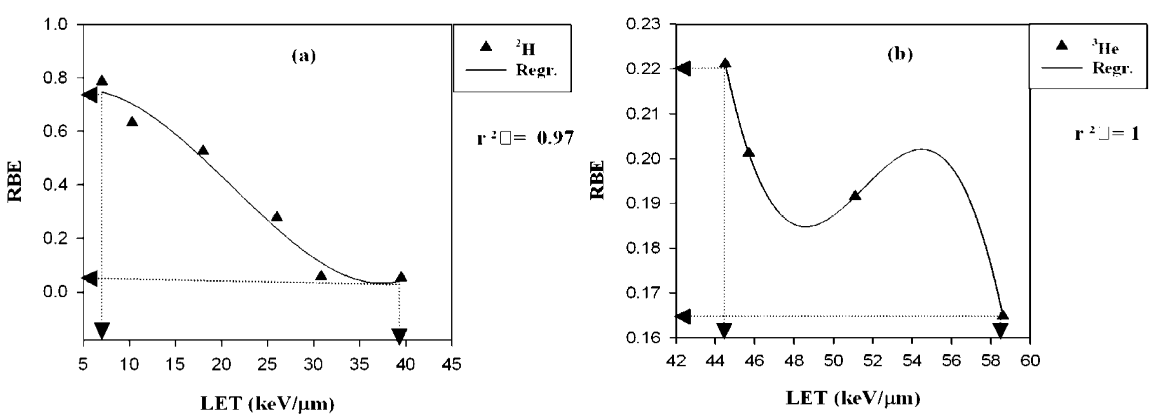

Fig. 3(a,b): (a) Relationship between effectiveness (RBE) and linear energy transfer (LET) for deuteron particles which are used to irradiate V79 cells *in vitro*.

(b) Relationship between effectiveness (RBE) and linear energy transfer (LET) for tritium particles which are used to irradiate V79 cells *in vitro*.

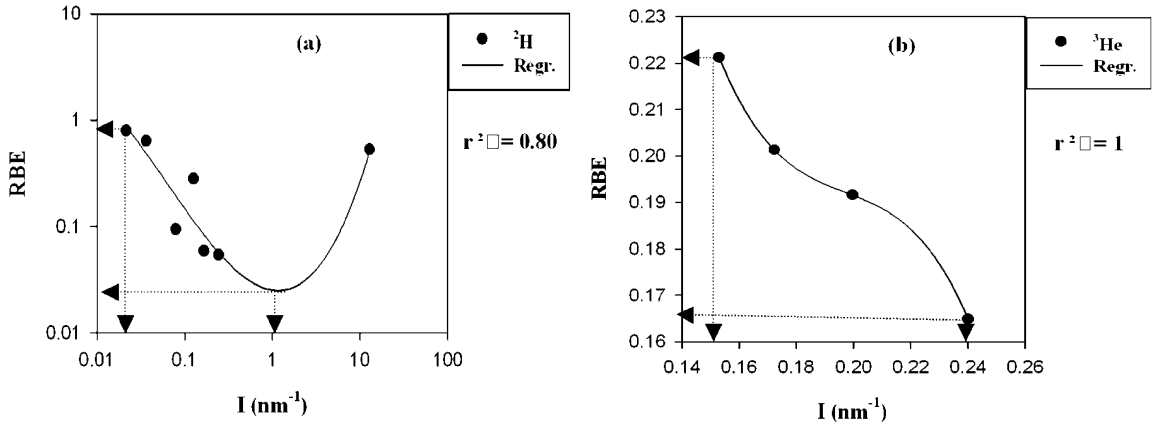

Fig. 4(a,b): (a) Relationship between relative biological effectiveness (RBE) and linear primary ionization (I) for deuteron particles which are used to irradiate V79 cells *in vitro*.

(b) Relationship between relative biological effectiveness (RBE) and linear primary ionization (I) for tritium particles which are used to irradiate V79 cells *in vitro*.

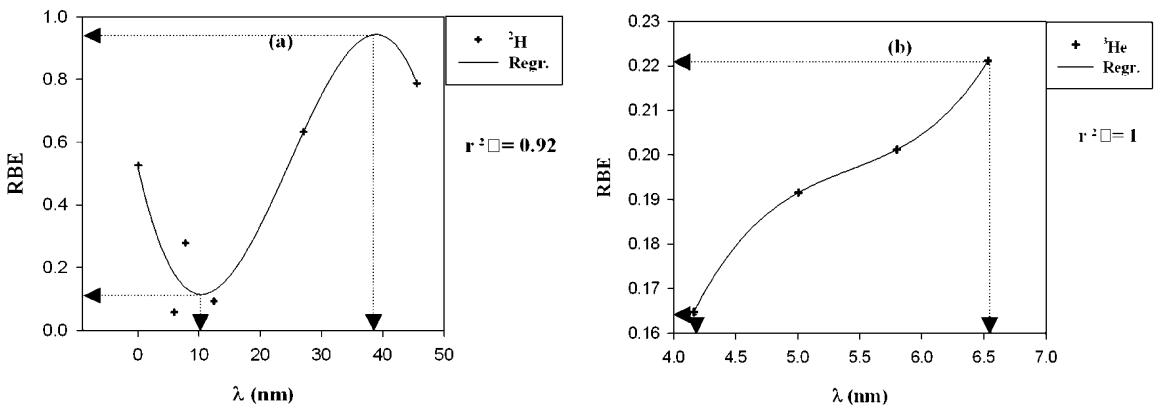

Fig. 5(a,b): (a) Relationship between relative biological effectiveness (RBE) and mean free path (λ) for deuteron particles which are used to irradiate V79 cells *in vitro*.

(b) Relationship between relative biological effectiveness (RBE) and mean free path (λ) for tritium particles which are used to irradiate V79 cells *in vitro*.

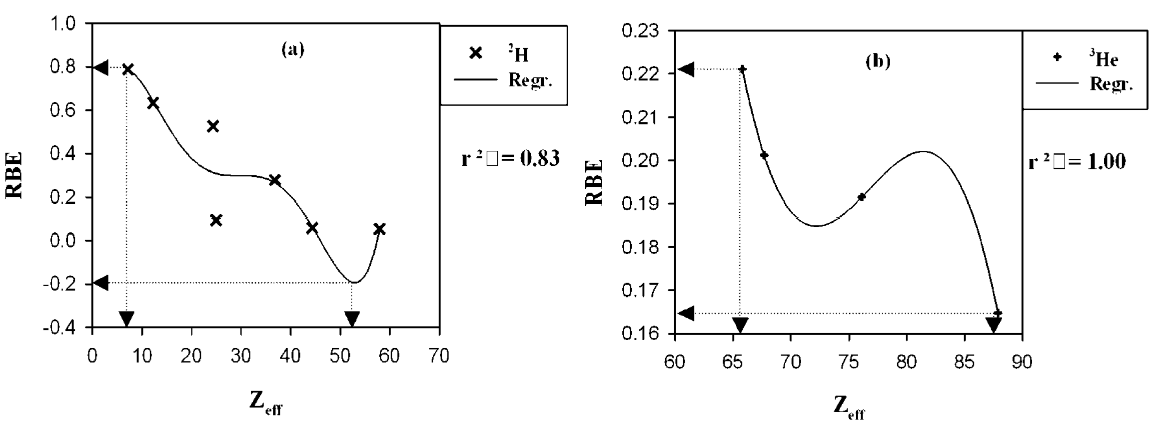

Fig. 6(a,b): (a) Relationship between relative biological effectiveness (RBE) and effective charge (Z_{eff}) for deuteron particles which are used to irradiate V79 cells *in vitro*.

(b) Relationship between relative biological effectiveness (RBE) and effective charge (Z_{eff}) for tritium particles which are used to irradiate V79 cells *in vitro*.

Plots between RBE and Z_{eff} for ^{2}H and ^{3}He particles indicated bell-shaped responses as that showed by RBE-LET relationships [Fig. 3(a) and Fig. 3(b)] respectively. Two different RBE peaks were observed from ^{2}H and ^{3}He particles, Fig. 6(a) and Fig. 6(b), at 10 and 83, these values correspondences for LET values of 7 keV μ^{-1} and 55 keV μ^{-1}.

Representing the relative effectiveness in terms of these physical parameters supplies new unified approach to explain and understand the underlying mechanism of radiation action in mammal cells at lower doses. In addition, the characteristic correlation between effectiveness and quality parameter for peculiar effect enables direct interpretation of cell inactivation mechanism.

CONCLUSION

Relationships between physical quality parameters and radiation effectiveness of inactivation have been investigated in details to interpreter the ionizing radiation effectiveness of inactivation for V79 cells at lower doses.

The amount of energy deposited in biological entities is not appropriate measure to quantify and interpreter the effectiveness of ionizing radiation (charged particles) mechanism especially at lower dose region.

Spacing of energy deposited events in charged particle tracks is very important criterion which should be take into account of explain the effectiveness of inactivation effect produced by charged particles.

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