

RELATIVE BIOLOGIC EFFECTIVENESS AND OXYGEN
ENHANCEMENT RATIO AT VARIOUS DEPTHS OF A
910-MeV HELIUM ION BEAM

by

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The 910 MeV helium ion beam from the 184-inch synchrocyclotron at Berkeley has long been used mainly for pituitary irradiations. When the narrow Bragg peak is broadened by using a variable absorber in the beam, it is possible to use this beam for other radiotherapeutic applications. In such cases, the dose contribution from the high LET components at the broadened Bragg peak region is small. However, the experimental determination of the oxygen enhancement ratio (OER) of 1.6 for 14 MeV neutrons indicates that a small fraction of dose due to alpha particles produced by 14 MeV neutrons in tissue is mainly responsible for reducing the OER (NEARY & SAVAGE 1964, BARENDSEN & BROERSE 1966). It is of interest to find out how a small fraction of dose due to high LET components at the broadened Bragg peak region would affect the radiobiologic properties of therapeutic interest such as relative biologic effectiveness (RBE) and oxygen enhancement ratio. Such measurements will be helpful

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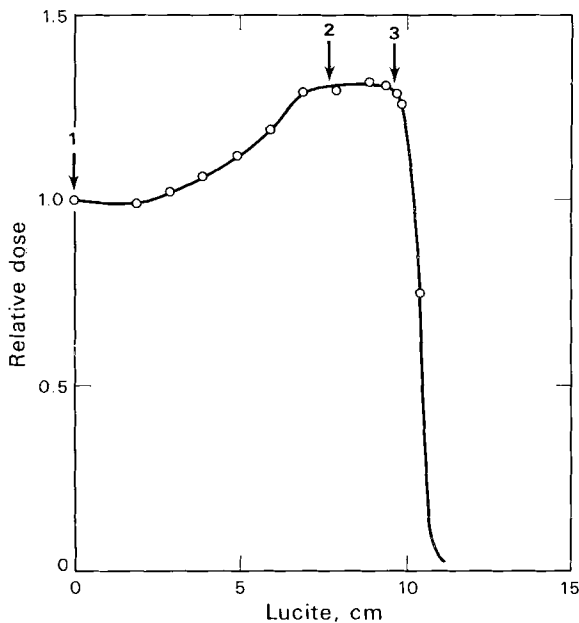


Fig. 1. Modified depth-dose distribution of a 910 McV helium ion beam used with a ridge filter, showing the three exposure positions.

in assessing the therapeutic capabilities of this radiation. With this in view, preliminary experiments were performed with cultured human kidney cells.

Materials and Methods. The tissue-culture techniques for human kidney cells (T-1) used by BARENSEN et coll. (1960) and TODD (1964) were used in this investigation. Feeder cells exposed to 4 000 to 5 000 rad of roentgen rays were plated in 35-mm Petri dishes (5×10^4 per dish) and they were incubated overnight. Cells in early logarithmic growth phase were plated in these dishes in appropriate numbers so that surviving colonies would be about 100 on each dish. The dishes were placed in the incubator at 37°C for 4 to 7 hours, before exposure to radiation.

The 'sample loading wheel' as described by TODD et coll. (1968) was used. The medium was removed from the dishes before they were mounted in the wheel. Air or nitrogen saturated with water vapor was admitted into the wheel and circulated over the dishes during exposure. In the case of nitrogen, the cells were nitrogenated for at least 5 minutes before exposure to radiation.

The Bragg peaks of monoenergetic charged particle beams are narrow when compared with typical tumor sizes. The technique for modifying the depth-dose distribution of monoenergetic charged particles to uniformly irradiate the treatment volume is usually to use ridge filters (KARLSSON 1964, RAJU et coll. 1969).

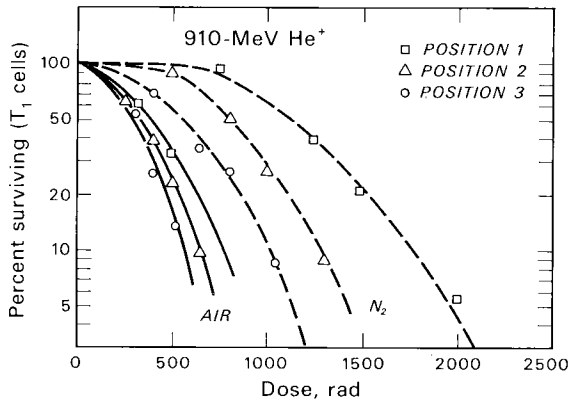


Fig. 2. Survival curves for T-1 cells exposed under aerobic and anoxic conditions at the three positions.

A 910 MeV helium ion beam has a range of about 32 cm in water. This energy is much higher than is necessary for radiotherapeutic applications. Such high energy heavy charged particle beams give a lower ratio of doses at the peak to the entrance because of multiple scattering effects and the loss of the particles before they reach the peak. The beam is first degraded by using 3.2 cm of copper. The residual energy of the beam after passing through copper is a little over 500 MeV. This residual beam is further modified by using a ridge filter so that the peak of the depth-dose distribution is broad enough to cover about 4 cm of lucite. Such a distribution is shown in Fig. 1. Dishes containing cells were exposed to different doses of radiation at three positions marked 1, 2, and 3 in Fig. 1. Three dishes containing cells were exposed for each dose point. Twelve to 15 days after exposure, the colonies were fixed in Bouin's fluid and stained with Harris' hematoxylin. All the visible colonies were counted and the percentage survival calculated.

Results

Figure 2 gives the survival curves obtained for the three positions on the depth-dose distribution mentioned above. Biologic effectiveness compared with that of the plateau position (marked 1 in Fig. 1) and OER were calculated in the surviving-fraction region of 10 %.

The biologic effect at the plateau is very similar to that of conventional radiation. The biologic effectiveness at positions 2 and 3 compared with position 1 is 1.1 and 1.3 respectively. The OER values at positions 1, 2, and 3 are 2.5, 2, and 1.8 respectively. These preliminary results indicate that there is a significant reduction in OER in the broad peak region. If the exposures were made with two opposing fields one could obtain an average OER of 2 over a 4 cm wide region.

The trend of this variation of RBE and OER over the peak region can be expected from variation of LET, which increases with depth. Early experiments with mammalian tumor cells that are anoxic, studied *in vivo*, indicate that the dose response was significantly altered at the broadened Bragg peak of a 910 MeV helium ion beam when compared with that at the entrance (BERRY & ANDREWS 1964).

A high energy helium ion beam may have a radiotherapeutic application in the treatment of deep-seated tumors located near sensitive and vital structures because of its depth dose characteristics. In addition, the significant reduction in OER indicates an additional advantage of high energy helium ion beams in treating tumors containing anoxic cells.

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SUMMARY

The relative biologic effectiveness (RBE) and oxygen enhancement ratio (OER) at different points on the ridge-filter modified depth-dose distribution of a 910-MeV helium ion beam is measured by using human kidney cells (T-1). The results indicate that the RBE at the broad peak region is about 1.2 compared to that at the beam entrance (plateau), and the OER is found to be about 2.0. This significant reduction in OER may be helpful in treatment of deep seated tumors containing anoxic cells.

ZUSAMMENFASSUNG

Die relative biologische Wirksamkeit (RBW) und das Verhältnis des durch Sauerstoff gesteigerten Strahleneffektes (OER) an verschiedenen Punkten einer durch einen gewölbten Filter veränderten Tiefen-Dosis-Verteilung eines 910-MeV Helium Ionenstrahls wurden unter Anwendung menschlicher Nierenzellen (T-1) gemessen. Aus den Ergebnissen geht hervor, dass die RBW verglichen mit derjenigen des Eingangsplateaus des Strahlenganges im Bereich des breiten Gipfels etwa 1,2 und die OER etwa 2,0 beträgt. Die signifikante Erniedrigung der OER mag bei der Behandlung tiefliegender Tumoren, die anoxische Zellen enthalten, nützlich sein.

RÉSUMÉ

Les auteurs ont mesuré l'efficacité biologique relative (RBE) et l'effet oxygène (OER) en différents points de la distribution de dose en profondeur d'un faisceau ionique d'hélium de 910 MeV modifiée par un filtre de crête au moyen de cellules de rein humain (T-1). Les résultats montrent que l'efficacité biologique relative dans la région du pic large est de 1,2 par rapport à celle de l'entrée du faisceau (plateau) et que l'effet oxygène est d'environ 2,0. Cette importante réduction de l'effet oxygène peut être utile pour le traitement de tumeurs situées en profondeur contenant des cellules anoxiques.

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