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FOCAL HEAVY CHARGED PARTICLE BEAMS AS NEURAL PROBES OF CENTRAL NERVOUS SYSTEM PHYSIOLOGY AND PATHOLOGY

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Accelerated heavy charged particle beams can be used to produce focal and selective lesions in the central nervous system. At the Lawrence Berkeley Laboratory, narrow focused beams of helium, neon, carbon, and argon ions have been produced at the Bevalac accelerator, and have been demonstrated to be effective neural probes for the selective ablation of intracranial targets for both animal studies and clinical research in patients. The biophysical properties of heavy charged particle beams result in their unique depth-dose profiles; the radiation dose is nearly constant during the initial portion of the particle's path (the plateau region), but increases sharply just before the particle stops resulting in a large local energy deposition (the Bragg peak) [1]. Dose levels at the Bragg peak are 3-5 times greater than dose levels in the plateau region, and the width of the unmodulated Bragg peak can be as narrow as 2 mm. The dose at the distal end of the peak falls sharply; the distance between the 90% and 10% peak dose is approximately 3-5 mm depending on the ion. By altering the energy of the particles, the range of the beam may be adjusted to place the Bragg peak in the desired target volume. The sharp lateral edges of the beam can also be shaped to conform with the cross-sectional contour of the target.

Focal lesions of volume 1 $cm^3$ with sharply demarcated boundaries have been produced in the rabbit cerebral cortex with accelerated neon ions; the transition zone between damaged and normal brain was less than 1 mm [2]. For larger lesions, the Bragg peak can be spread to ensure uniform dose distribution throughout the target volume but abruptly stopped to prevent injury to critical brain structures. Hemibrain helium ion irradiations in rabbits to examine the spatiotemporal patterns of delayed radiation injury in the brain demonstrate that the Bragg peak can be effectively spread to cover the desired brain volume but spare the hypothalamus and the critical nuclei of the midbrain [3,4]. Focal heavy charged particle beams have also been applied to induce selective lesions in the brainstem of rats [5].

In clinical research patients, accelerated helium ion beams are modulated and shaped precisely to obliterate inoperable intracranial vascular lesions and tumors while sparing the surrounding normal brain tissue from injury [6,7].

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