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NEUROSONIC SURGERY

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Research conducted during the past four years at the Bioacoustics Laboratory of the University of Illinois in the design of precision ultrasonic focusing instruments and their application in biological investigations has made it possible to employ ultrasonic energy in research in neuroanatomy, neurophysiology and neuropathology and now opens the way for extensive application of this tool to therapeutic procedures in clinical neurologic disorders. By proper monitoring of ultrasonic dosage relatively reversible as well as enduring lesions of predetermined size, shape, selectivity and loci in the cortical ribbon, sub-cortical and deep-lying structures (e.g., internal capsule and mammillo-thalamic tract) have been produced in cats and monkeys. Over 250 animals have been subjected to such experiments and it has been possible to establish (a) that the procedure is extremely well tolerated by the animals and (b) that, when judged by currently-available histologic criteria, structures not intended for alteration by ultrasound energy can be spared.

A serious limitation in the field of bioacoustics is the complete lack of precision ultrasonic instrumentation and auxiliary equipment designed specifically for biological research. To surmount this difficulty, a completely new laboratory designed specifically for ultrasonic irradiation of selective regions of the central nervous system of mammals, has been constructed in the Bioacoustics Laboratory at the University of Illinois. The electrically shielded irradiation room (Fig. 1) contains apparatus for supporting the animal, calibration instrumentation for determining the acoustic output of the transducers, and controls for positioning the focused ultrasonic beam as well as stimulators, amplifiers, oscilloscopes and cameras and other recording devices for observing electrical activity of central nervous systems during irradiation. Projecting through the ceiling of this room is a metal tube (10 feet long and 7 inches in diameter) which supports the focusing transducer. The precise positioning of the sound beam is accomplished by the motor driven coordinate system supporting the transducer. This system permits translational motion in three mutually perpendicular directions and two rotational motions. The coordinate system itself, which weighs about 3500 lbs., is mounted on a steel girder framework in the room (Fig. 2) directly over the irradiation room. The controls for the

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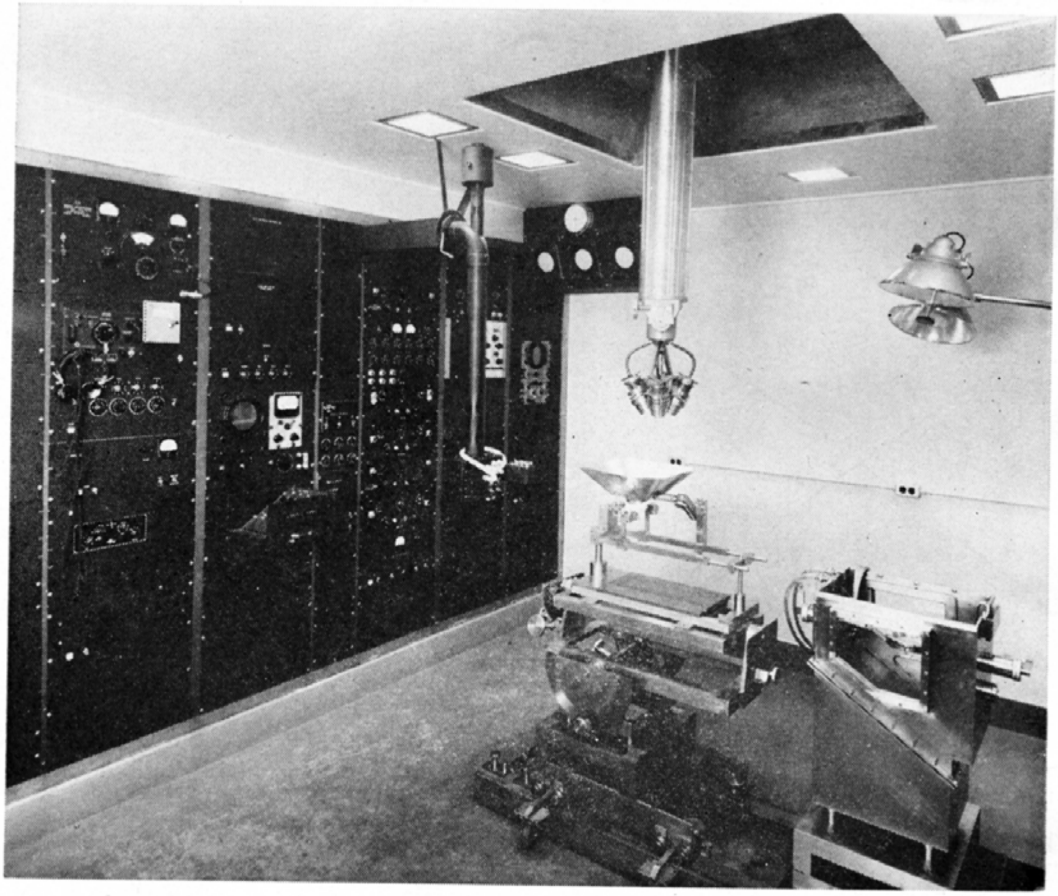

Fig. 1. Partial view of the irradiation room showing control panels, irradiator and head holder.

coordinate system are placed in the irradiation room below. The upper room also houses the electronic driver for supplying electrical power to the transducer.

This instrumentation setup makes possible accurate location of the acoustic radiation in any desired region of the central nervous system under precisely controlled dosage conditions.

A four-beam ultrasonic focusing irradiator (Fig. 3) has been designed and is in routine use in this laboratory. In this instrument the focused beams from each of four transducer heads are adjusted so that the focal regions are brought into coincidence. The most intense region of the ultrasonic field can produce lesions as small as a few cubic millimeters.

To produce a precisely localized lesion by ultrasound, the head of the anaesthetized animal (cat, monkey) is engaged in a stereotaxic substructure in which the usual interaural, Frankfort and midsagittal planes are employed as "zero-references." The skull cap is removed and

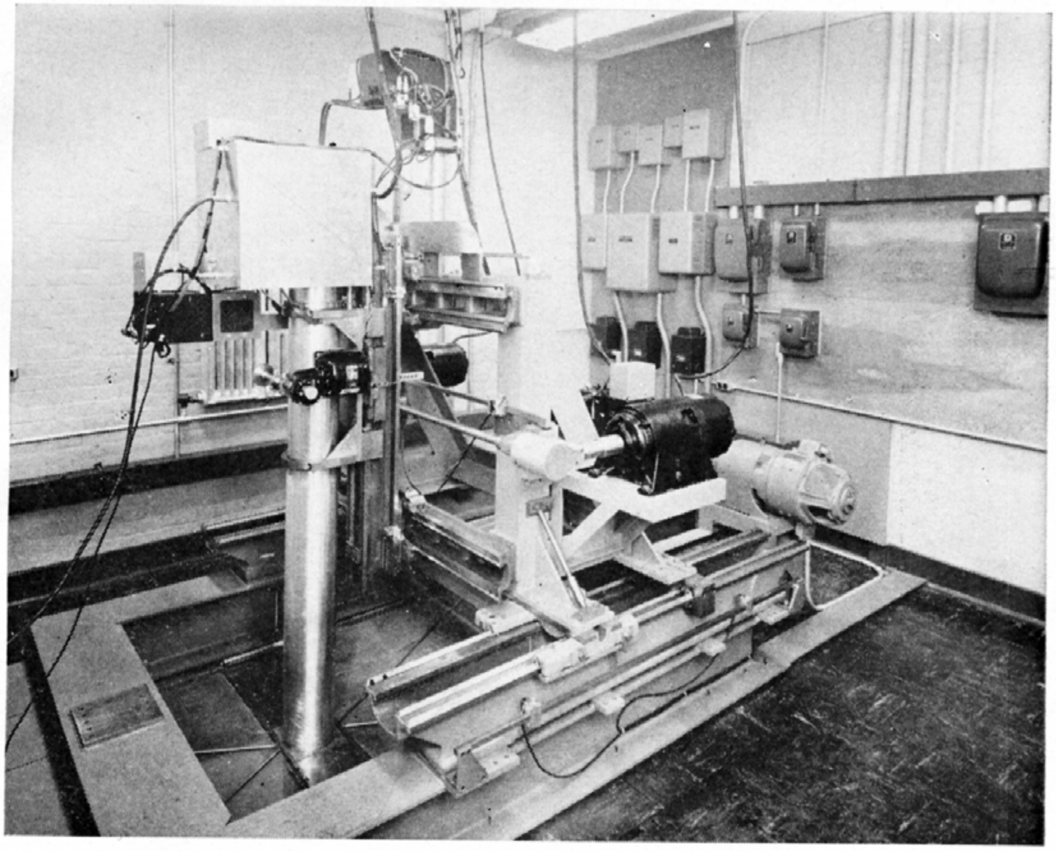

Fig. 2. Motor driven system for moving the irradiator. This system, which is housed above the irradiation room, provides the motions for positioning the irradiator.

the dura mater exposed. The bone must be removed because of its high acoustic absorption coefficient, which results in excessive heating, and its disturbance of the beam shape. At this point of the procedure no definitive surgical measures beyond those of achieving hemostasis are required.

The next step consists of attaching the skin of the animal to a special metallic hopper in such fashion as to provide a "pan," the bottom of which consists of the exposed dura mater. This "pan" holds the degassed physiological saline which acts as the transmitting medium for the sound.

The substructure of the stereotaxic instrument (and the engaged animal) is now moved under the superstructure which supports the four-beam ultrasonic focusing transducer which generates the acoustic waves.

The sterilized four-beam transducer is supported on and moved by a single carriage (Fig. 2). All parameters are suitably checked at this point. The ultrasonic dosage is now delivered. At the highest intensi-

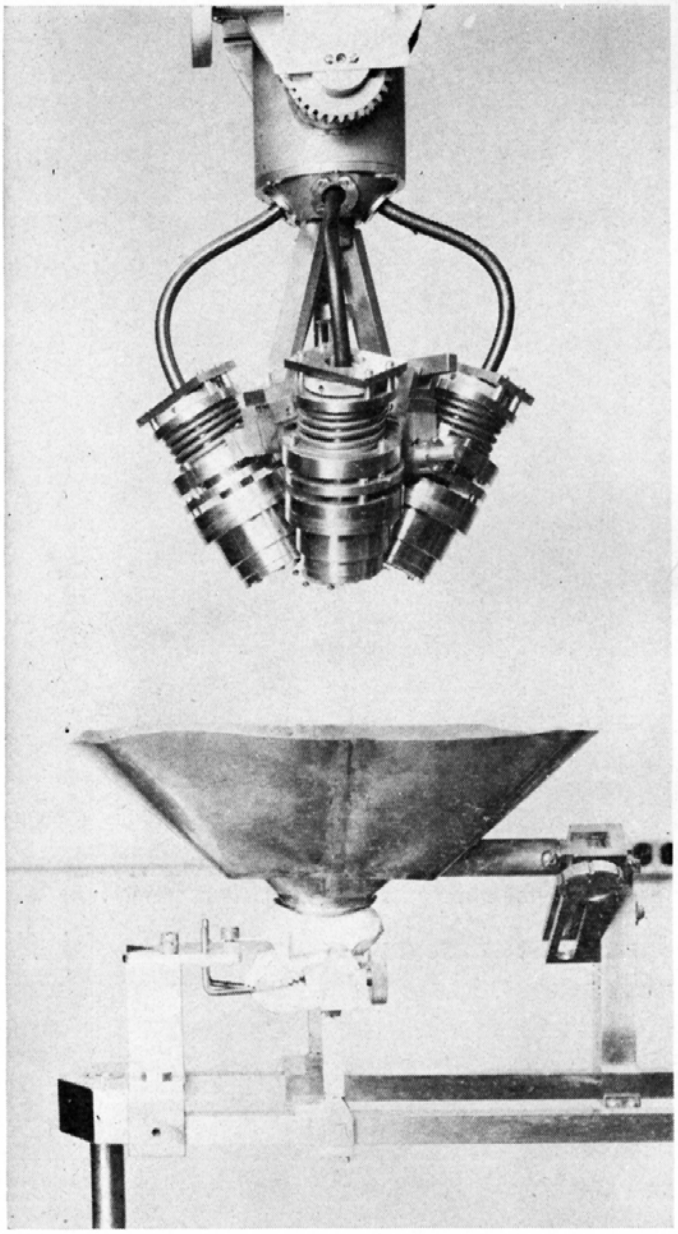

Fig. 3.
The head holder, with the skull of a monkey mounted in position, and the four beam ultrasonic irradiator. The pan, which holds the sterile degassed saline, in position over the skull of a monkey.

ties used the duration of irradiation is usually in the range from one to three seconds. The frequency employed is close to 1 megacycle. For the smallest lesions the tissue is irradiated with the focal spot in a single position but for larger lesions the focal spot is placed successively in a number of positions.

The substructure is now disengaged from the superstructure and the animal returned to the operating room where closure of the cranial muscles and scalp is accomplished.

The animals are observed for varying periods of minutes to weeks following such experiments, during which time physiologic and/or psychologic aberrations may be noted. The animals are sacrificed minutes to hours, days or weeks after irradiation, the brains removed, fixed and ultimately sectioned, and stained.

A unique advantage of such procedure is the susceptibility of the fiber tracts of the nervous system to alteration by ultrasound as compared with gray matter and blood vessels at the irradiated locus (Fig. 4). This makes it possible to make anatomic, physiologic and pathologic

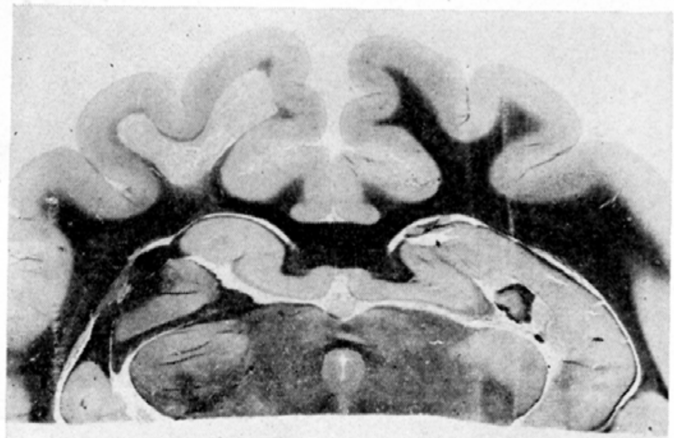

Fig. 4a.
Large ultrasonically shaped lesion in the subcortical fiber tracts of the brain of a cat. (Dosage at each position 250 watts/cm² for 4.00 seconds.)

Fig. 4b.
Small ultrasonically produced lesion in ~~manillo-~~ mammillo-thalamic tract of the brain of a cat. (Dosage 1200 watts/cm² for 1.75 seconds.)

differentia among neural components which, when attacked by the older mechanical, chemical and electrolytic technics inevitably underwent non-differentiated alterations. The advantages of this to research endeavors are self-evident.

It appears that at the parameters employed reversible and irreversible lesions are produced by direct alteration of intercellular structures of the tissues rather than by indiscriminate coagulation by heat. Blood vessels running through a felt-work matrix of ultrasonically damaged tissues are left intact and exhibit no hemorrhaging.

Fig. 4c.
Large ultrasonically shaped lesion in deep fiber tract (internal capsule) of the brain of a cat. The sound entered the brain from the top.

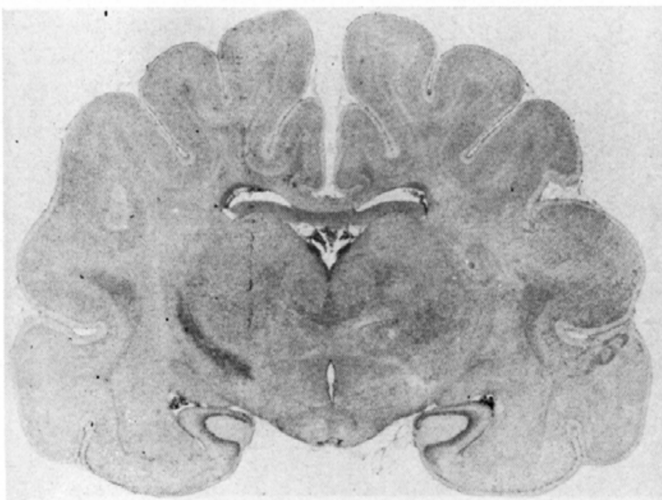

Fig. 4d.
Small ultrasonically produced lesion in the cortical gray matter of the brain of a cat. (Dosage 1150 watts/cm^2 for 4.00 seconds.)

It is envisioned that a variety of neurosurgical procedures can be implemented by ultrasound. These include the hyperkinetic and hypertonic disorders (e.g., Parkinsonism, athetosis, ballism, chorea, dystonia); psychosurgery and intractable pain.