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Split Brain Cats Prepared by Radiosurgery




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## RESUME

Dans la recherche sur le système nerveux central, des chats dont le chiasma optique et la commissure ont été disjoints le long de la coupe sagittale moyenne, présentent un intérêt particulier. L'on a voulu savoir s'il était possible d'obtenir des chats dont le cerveau est scindé de la sorte, en utilisant la radiation à particules lourdes. Des ions d'hélium à 910 MeV, provenant du cyclotron de Berkeley, ont été convergés et restreints à un faisceau en forme de lame, orienté afin de passer entre les hémisphères cérébraux. En raison de leur qualité supérieure de non-dispersion, les particules d'hélium conservaient leur formation de faisceau nettement défini, même après leur passage à travers le tissu cérébral le long du sillon longitudinal. Des méthodes électrophysiologiques ont été employées pour éprouver le rendement de blocage des ions d'hélium dans le transfert interhémisphérique. Des électrodes métalliques inamovibles, ont été implantés en paires dans le genu et le splenium du corpus callosum, de chaque côté du

sillon interhémisphérique. On a étudié le rapport de temps/dosage nécessaire pour supprimer les potentiels d'activité transcallosaux (TCAP) déclenchés électriquement. A la suite de l'irradiation, l'intervalle nécessaire pour entraver le TCAP était en fonction inverse du logarithme de la dose de radiation absorbée en excès de 10 krad d'ions d'hélium. Le TCAP a pu être entravé de manière isolée, soit dans la région du genu, ou dans celle du splenium. La transmission du corpus callosum tout entier, a pu être bloquée par un faisceau d'ions d'hélium de 2 x 25,4 mm. Le TCAP n'a pas été entravé lorsque le corpus callosum absorbait moins de 10 krad d'ions d'hélium. Un faisceau très étroit d'ions d'hélium, de 0,5 x 25,4 mm, n'a pas pu interrompre le TCAP malgré le fait que le corpus callosum absorbait 50 krad de radiation. On discute la vulnérabilité à la radiation des fibres nerveuses fines (1µ au maximum) qui constituent le corpus callosum.

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## Übersicht

Katzen, deren optische Linien und Nervenfibern längs der mittleren Pfeilebene getrennt sind, sind von besonderem Wert in der Erforschung des zentralen Nervensystems. Die Möglichkeit, solche gespaltenen Gehirne in Katzen zu produzieren, wurde durch Elementarteilchenbestrahlung versucht. Gebündelte, 910 MeV Helium-Ionen des Berkeley Zyklotrons wurden zu einem messergleichen Strahl eingeschränkt welcher ausgerichtet war, zwischen den Grosshirnhälften hindurch zu gehen. Als Folge ihrer überlegenen, nicht zerstreuenden Eigenschaft, behielten Heliumatome ihren scharfen, bestimmten Strahl sogar nach dem Durchgang der Gehirnmasse, entlang der Katzen Längsspaltung. Der Wirkungsgrad der Helium-Ionen, eine Übertragung zwischen den Gehirnhälften zu verhindern, wurde mit elektro-physiologischen Methoden versucht. Drahtelektrodenpaare wurden bleibend im genu und splenium des corpus callosum, an jeder Seite der Grosshirnhälftenspaltung, eingepflanzt. Die Zeit: Mengen-Beziehung, elektrisch begonnene TCAP (transcallosal action potentials; transcallosale Funktionsmöglichkeiten) aufzuheben, wurde untersucht. Der Nachbestrahlungszeitraum, TCAP zu unterbinden, war eine umgekehrte Logarithmenfunktion der absorbierten Dosis von mehr als 10 krad der Heliumausstrahlung. TCAP konnte wahlweise unterbrochen werden, entweder im Bereich des genu oder des splenium. Übertragung des gesamten corpus callosum konnte mit einem 2 x 25.4 mm grossem Helium-Ionenstrahl unterbunden werden. TCAP wurde nicht aufgehoben wenn das corpus callosum weniger als 10 krad Helium-Ionen aufnahm. Ein sehr dünner Helium-Ionen strahl, 0.5 x 25.4 mm, konnte TCAP nicht aufheben, selbst wenn das corpus callosum 50 krad bestrahlung absorbierte. Die Radioempfindlichkeit der Nervenfibern von kleinem Durchmesser, (1 μ und geringer), welche das corpus callosum bilden, ist erörtert.

# Split Brain Cats Prepared by Radiosurgery

by

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## ABSTRACT

Cats with their optic chiasma and commissural system disconnected along the midsaggital plane are of special value in central nervous system research. The feasiability of producing such split brain cats with heavy particle radiation was attempted. Focused, 910 MeV helium ion particles from the Berkeley cyclotron were restricted to a blade-like beam that was oriented to pass between the cerebral hemispheres. As a consequence of their superior nonscattering property, helium particles retained their sharply defined beam even after passage through brain tissue along the cat's longitudinal fissure. The efficiency of helium ions in blocking interhemispheric transfer was tested using electrophysiologic techniques. The corpus callosum was permanently implanted with pairs of wire electrodes in the genu and splenium on either side of the interhemispheric fissure. The time-dose relationship to abolish electrically initiated transcallosal action potentials (TCAP) was investigated. The postirradiation interval to inhibit TCAP was an inverse function of the logarithm of the absorbed dose above 10 krad of helium ion radiation. TCAP could be selectively inhibited either in the region of the genu, or the splenium. Transmission of the entire corpus callosum could be blocked by a 2 x 25.4 mm helium ion beam. When the corpus callosum absorbed less than 10 krad of helium ions, TCAP were not abolished. A very fine helium ion beam, 0.5 x 25.4 mm, was not successful in halting TCAP, even though the corpus callosum absorbed 50 krad of radiation. The radiovulnerability of the small caliber nerve fibers (1μ and less) that constitute the corpus callosum is discussed.

1. Introduction

Modern brain research involves the surgical invasion of the optic chiasma and commissure system, i.e., the corpus callosum (CC), the anterior commissure, and the hippocampal or psaltrium commissure. Such midline surgery produces a split brain organism. The unique advantage in central nervous system experimentation of split brain animals was first exemplified by Myers and Sperry (1953). Much of the present knowledge about memory, learning, single hemispheric dominance, and interhemispheric integration was acquired while employing split brain organisms (Elltinger 1965; Gazzaniga 1967, 1970, 1972; Mountcastle 1962; Sperry 1961, 1964, 1968). Prior to the pioneering work of Myers and Sperry (1953), brain lesions were made bilaterally, a procedure that was frequently incapacitating to the test animal. Half of the brain serves as a control in split brain preparations, maintaining the vital processes, while the other half of the brain is explored in test stituations. In humans sufferint with intractable epileptic convulsions a complete commissurotomy relieves these attacks (Bogen and Vogel 1963; Gazzaniga 1967, 1970, 1972; Sperry 1962, 1968).

Conventional bisection of the CC by cutting involves not only a threat from infection, but a very real risk of brain impairment due to bleeding (Gazzaniga, 1970). Ligation of large veins results in severe swelling of the exposed hemisphere, and subsequent damage. Incompleteness is a potential fault involved in commissure slicing. Partial commissurotomies have been discovered in postmortem checks where complete commissurotomy was intended (Voneida, 1971; Beal *et al*. 1972). If discrete lesions can be generated with narrow, focused atomic nuclei beams, and if vascular reaction can be controlled, then the prospect of generating split brain animals by a technique that is free of routine surgical hazards and faults is attractive.

Tomasch (1954) reports that human CC is formed of 100 million myelinated nerve fibers, 1.5μ diameter being the most frequent. In cats two-thirds of the myelinated CC fibers are less than 1μ in diameter (Naito *et al*. 1971). Unfortunately, scant information is available about the radiovulnerability of small caliber fibers. The CC would appear to be an excellent material for the aquisition of electrophysiologic data of the radiosensitivity of small caliber nerves *in vitro*.

## 2. Methods

### 2.1 Chronic implantation of electrodes

The technique for stereotaxically implanting cat brain structures with stimulating and recording leads (0.2 mm diam. nichrome wire, Driver-Harris Co.) was previously described (Gaffey, 1964). CC contact was made with a pair of wires separated by 2 mm and oriented in a frontal plane. Pairs of electrodes were chronically implanted in the genu and splenium of each hemisphere (Figure 1). The terminals of these eight wires were soldered to a 9-pin head socket. A wire from the inion of the skull went to the ninth socket pin; this latter connection served as an animal ground. The cocket-wire assembly was imbedded in dental plastic.

2.2 Single CC responses to stimulation

Two months after electrode implanation alert cats were restricted to an electrically shielded room. A cable attached to each cat's head socket connected the CC to electrophysiologic equipment. Single, monophasic pulses, 0.1 msec in duration, generated by a stimulator were delivered to the CC through one pair of electrodes. A transcallosal action potential (TCAP), evoked by an individual stimulus pulse, was detected from the CC in the opposite hemisphere, amplified, and displayed on an oscilloscope. The strength of the stimulus pulse was adjusted to yield a maximal TCAP.

Prior to radiation treatment the TCAP from the genu and splenium of each cat was tested for stability two or three times per week for two weeks. Forty three animals were considered worthy of experimentation by this criteria.

2.3 Averaging of CC responses

The computer of Average Transients (Minematron Corp., Model 400) was used to sum maximal, TCAP evoked from alert, constrained cats. The stimulus, repeated at 1/sec, also served as a trigger pulse for the computer. The computer's analysis epoch per evoked response was 125 msec. This analysis period consisted of 400 discrete storage channels, or memory locations. An electronic counter was fixed to have the computer average exactly 50 TCAP. The computer displayed the sum of all samples fed into its 400 channels during readout as an average TCAP. The computer's display was transferred to an oscilloscope and photographed.

2.4 Helium ion irradiation

The 184-inch Cyclotron at Lawrence Berkeley Laboratory generated helium ions, i.e., positively charged nuclei of helium atoms, used to irradiate cats. The maximum helium ion energy was 910 MeV.

The range of these particles was 40 $gm/cm^2$ in tissue, and their linear energy transfer was 1.6 keV/μ in tissue. Particle-absorbing collimators restricted the cyclotron's beam to narrow slits. The dimensions in millimeters of the aperatures used were: 0.5 x 25.4, 2.0 x 6.0, 2.0 x 10.0, and 2.0 x 25.4.

Each anesthetized cat (40 mg of sodium pentobarbital per kg of body weight) was placed in a stereotaxic headholder at the 184-inch cyclotron and oriented to intercept helium ions that exited from a slit aperature (Figure 2). Skull, polaroid roentgenograms gave information to precisely position each head so that the brain's midsaggital plane was coincident with the cyclotron's thin helium beam (Figure 3).

An ionizing chamber measured the helium ion dose absorbed by each cat (Birge _et al_. 1956). The dose rates ranged from 0.70 to 1.35 krad/min with an average of 1.02 krad/min.

## 3. Results

### 3.1 _TCAP as a function of the electrical stimulus_

When the electric stimulus to the CC reaches threshold, an action potential is initiated at the cathode and travels toward the recording electrodes located in the opposite hemisphere. As the stimulus intensity is gradually increased above threshold, the size of the propagated TCAP attains a maximum (Figure 4). The relationship between the amplitude of the TCAP and the intensity of the stimulus shock is depicted in Figure 5. TCAP are measured two ways: first, as the voltage from the zero baseline to the first negative peak, and second as the amplitude from the summits of the first negative and positive peaks. The form of the strength-response curve (Figure 5) reflects the proportion of myelinated CC fibers obtaining excitation.

3.2 Reversal of stimulating and recording electrodes

The role of stimulating and recording electrodes in the CC could be interchanged (Figure 6). This technique was a useful aid in confirming blockage of transcallosal conduction in irradiated cats.

3.3 Delayed suppression of TCAP after irradiation

The postirradiation interval required to inhibit TCAP for each cat was established as a function of the absorbed radiation dose. In Figure 7, for example, 17.0 krad of radiation was delivered by a 2.0 x 25.4 mm helium ion beam along the entire midline of the CC. Control records of average TCAP (Figure 7, oscillogram C) were obtained prior to radiation. Shortly after radiation (Figure 7, oscillogram 0) the average TCAP was recorded from an anesthetized cat. On subsequent postirradiation days TCAP oscillograms were made on alert, drug-free cats.

The time course for the change in TCAP in Figure 7 is plotted in Figure 8. It is concluded that 17.0 krad of helium ions produced an inhibition of interhemispheric transfer at six days postirradiation (DPI).

The TCAP amplitude was enhanced by about 10 per cent within 12 to 24 hours after 17.0 krad of radiation (Figure 8). Radiation-heightened TCAP amplitudes occurred in 6 our of 20 cats administered 15 to 40 krad of helium ions. Augmented TCAP did not appear in any preparations absorbing greater than 40 krad of helium ions.

A summary of 20 experiments is presented in Figure 9 in which a 2.0 x 25.4 mm helium ion beam traversed the CC of cats. The absorbed helium ion dose (logarithmic scale) is plotted against the postirradiation time (linear scale) for the complete loss of TCAP conduction. The postirradiation delay to eliminate interhemispheric transfer of impulses is an inverse function of the absorbed dose. The delay time to inhibit TCAP is a simple exponential curve in the dose range from 20 to 100 krad.

When the CC of cats absorbed only 10 to 20 krad of radiation, the TCAP persisted for longer periods than anticipated by the data in the higher dose range, i.e., another exponential curve is required to explain the findings in the lower dose range. It can be hypothesized that dose-time curve in Figure 9 is an index of the radiosensitivity of different CC fibers.

3.4 Threshold and subthreshold doses of helium ion radiation

When 10 krad of helium ions (2.0 x 25.4 mm aperature) intercepted the CC of one cat, interhemispheric activity was fully depressed at 54 DPI. In another animal given the same dose, the TCAP amplitude was reduced to 20 per cent of its preirradiation value of 56 DPI, but ultimately vanished at 70 DPI. In other experiments the TCAP amplitude was not abolished with either 3, 5, or 8 krad of particle radiation, even after 18 months. These findings support the view that 10 krad of 910 MeV helium ions is the threshold dose to inhibit bioelectric transmission by the CC. The data from Table 1 and the dose-response curve in Figure 9 lend credence to this estimate.

3.5 Side effects of helium ions

Helium ion doses in excess of 20 krad provoked detectable hemorrhages considered minor in nature along the beam path. Cats receiving more than 50 krad of helium ions demonstrated obvious hemorrhages, and 100 krad or greater generated serious hemorrhages and circulatory arrest adjacent to the path of the beam. Five cats in these cases were sacrificed 60 to 90 DPI. Two other cats died of massive hemorrhages 7 DPI after absorbing 200 and 250 krad of radiation. Since it is possible to avoid a vascular reaction and yet block TCAP by limiting the absorbed helium ion dose to 20 krad (or less), this is the obvious procedure to recommend when considering these atomic nuclei as a neurosurgical tool to produce split brain cats.

### 3.6 Pupillary dilation

A noticeable effect of cutting the optic chiasma in cats is a marked dilation of the pupils (Sperry et al. 1960). The reason for this surgical defect is unknown (Gazzaniga, 1970).

When the CC of a cat was irradiated with a 2.0 x 25.5 mm beam, the optic chiasma as well as the CC was irradiated. Pupillary dilation did not appear in cats receiving 40 krad or less of helium ions. Only one eye exhibited dilation at 50 krad; both eyes were dilated with 100 krad. The effects of radiation on the cat's pupillary dilation center has been reported (Gaffey, 1966).

## 4. Discussion

The results presented illustrate that a blade-like beam of helium ions can block conduction in the small caliber fibers (1μ and less) that form the CC in the cat. Loss of electrically evoked TCAP is taken as an index of interhemispheric dissociation. The delay time for the inhibition of TCAP is an inverse function of the logarithmic dose absorbed by the CC. Part of this research was oriented to evaluate the feasibility of generating split brain cats on the basis of electrophysiologic data. It is recognized that there is an informational need to estimate the risk of radiation damage to non-target tissue, as well as the possible hazard of vascular impairment to the central nervous system.

In the case of cranial exposure to narrow fields of radiation, h gh-energy, monoenergetic beams of atomic nuclei travel in approximately straight tracks, suffer negligible beam divergence in intercepting living matter, and have relatively insignificant sidescatter (Tobias et al. 1952, 1954; Larsson et al. 1958; Lanzi 1959; and Raju et al. 1969). Conventional X-ray and gamma ray beams would be unsatisfactory for brain radiosurgery because of their high lateral sidescatter. The scattering angle for helium ions relative to electrons of the same velocity in theory is reduced by 7,344 to 1, the ratio of their masses. The measured scattering of a 185 MeV proton beam is reported by Larsson (1960) to contribute to less than 5% of the radiation dose as determined by photographic dosimetry. Such minor sidescatter from atomic nuclei beams permits radiation fields to be shaped with great precision, a distinct advantage in intracranial radiosurgery.

Rabbit spinal cord, when transceted by a 1.5 x 43 mm beam of 185 MeV protons, produced a narrow, sharply delimited zone of destruction corresponding to the path of the beam on 9 DPI after absorbing 20 krad (Larsson et al. 1958, 1959; Andersson et al. 1962). Serious hemorrhages were not produced in any of the 20 krad intercepted spinal cords, although minimal hemorrhages were found at the borderline of the lesions in some animals. No histologic or clinical changes were generated within a year after exposure to 12 krad of protons. Spinal cord irradiations in which the beam width was increased to 10 mm while the dose remained at 20 krad showed severe vascular reaction (ibidem). Large hemorrhages appeared 3 DPI. Adjacent to the radiation field were degenerate areas caused by vascular occlusions. These observations indicate the practical value of restricting the size of the impact area with thin beams of accelerated heavy particles when discrete lesions and a lack of vascular reaction is desired.

Both frontal lobes of rabbits were crossed in a coronal plane by a 1.5 x 43 mm beam of 185 MeV protons reported by Larsson et al. (1958), Rexed et al. (1960), and Andersson et al. (1962). A finely demarcated lesion was generated with 20 krad at 14 DPI. Microscopic examination revealed a very narrow, necrotic zone restricted to the beam path (ibidem). Large hemorrhages were not caused by 20 krad of protons, but some microscopic hemorrhages could be observed in some of the lesions. Using a 3 mm wide beam of the same particles and dose Larsson (1960) found that radiolesions of the rat cerebral cortex and thalamus occurred 13 - 19 DPI. Death of nerve cells in these rat experiments was preceded by impaired circulation and blood brain damage. It would appear that a 3 mm beam of protons is too wide for safe radiosurgical use in the rat brain, since vascular involvement can not be evaded.

Malis _et al_. (1957) first noted that laminar lesions in the cerebral cortex of cats could be created by the ionization at the termination of a nuclear beam, or Bragg peak. The striking feature of Bragg peak radiation is that destruction occurs in a zone of maximum ionization about 100 to 200 µ wide. This band of cerebral cortex which is devoid of nerve cells, is the only sign of radiation damage. Exquisite lesions are produced with 25,000 rad from a 10 MeV proton beam. Neurons and vascularity adjacent to these finely demarcated lesions appear substantially intact (Malis _et al_. 1960, 1962; Rose _et al_. 1960; Kruger and Malis 1964). Van Dyke and Janssen (1963) made a comparative study between lesions produced by Bragg peak, helium ion radiation and the approved sharp cutting knife technique; they concluded that helium ions generated superior lesions. As others, they demonstrated that radiolesions at certain doses were free of circulatory disturbances for narrow radiation fields. Within the zone of the Bragg peak, necrosis occurs while neighboring cells remain normal and circulatory insult is not present because of the delay time required for the formation of a radiolesion. Occulusion of blood vessels intercepted by the nuclear beam occurs, but only after a latency related to the dose. By avoiding massive doses of radiation collateral circulation develops across the radiated zone during the latent period, thus preserving circulation to adjacent tissue (ibidem). The findings of Janssen _et al_. (1962) and Brighman (1959) on the histopathogenesis of brain lesions with radiation is in harmony with this observation. Janssen et al. (1962) considered radiation an important tool for the production of lesions since as brain tissue disappeared, healing occurred without gross or microscopic evidence of scar formation, i.e., with little connective tissue reaction. Brighman (1959) emphasized the absence of hemorrhages in rat brains to 20 krad of 10 MeV protons with a 1.5 mm wide beam. Leksell et al. (1960) found at most only scant vascular effects in goat's brains administered 20 krad of protons with either a 2 x 7 mm, or a 2 x 10 mm beam. Samorphi et al. (1967) found minor vascular defects in mouse cerebellar tissue given 68 krad of 20 MeV deuterons in a 0.025 x 9.0 mm beam.

In summary, the postirradiation period to completely block impulse propagation in the very small fibers (1μ and less) that constitute the CC is a function of the helium ion dose. The minimal radiation that the CC must absorb to suppress interhemispheric conduction is 10 krad of 910 MeV helium ions. Functionally split brain cats can be produced when a 2 mm wide radiation field is used as a neurosurgical tool. TCAP blocking doses are recommended to be restricted to no more than 20 krad to avoid serious vascular insult. In future experiments it is suggested that Bragg peak ionization be employed to deposite radiation locally in the CC.

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# LEGENDS

Figure 1. Schema illustrating the corpus callosum electrode arrangement in the cat's head. Each pair of electrodes is represented by two dots and is identified by a Roman numeral. Electrodes I and II contact the genu; III and IV contact the splenium. Frontal plane distance is measured from the intra-aural line connecting the center of each external auditory meatus. The skull's midline is the conventional longitudinal axis of reference.

Figure 2. Schema showing the medial aspect of the cat's brain. The corpus callosum and other midline structures which intercept the 910 MeV helium ion beam are designated.

Figure 3. Superimposed on an X-ray roentgenogram of a cat's head is an exposure from a 2.0 x 25.4 mm helium ion beam, which intercepts the skull's midline. No significant divergence of the beam is detected in passing through the head. Ear bars appear as prominent, dark rods. A radiosocket secured to the cat's skull is near the intersection of the cross-hairs. Dark spots are the bone screws.

Figure 4. Each TCAP is initiated by a single stimulus pulse. As the strength of the electric stimulus is increased in successive records, the TCAP amplitude attains its maximum. In these oscillograms negative voltage is upward. The vertical calibration discharge is 200 μV; the horizontal calibration bar is 10 msec.

Figure 5. The amplitudes of the TCAP in Figure 4 are plotted as a function of the stimulus strength. The method of measuring TCAP amplitudes is given in the text.

Figure 6. TCAP can cross the CC in either direction (A or B at the genu, C or B at the splenium) by reversing the roles of the stimulating and recording electrodes. Positive voltage is upward for these single TCAP. The vertical calibration discharge is 200 μV; the horizontal calibration bar is 10 msec.

Figure 7. Each oscillographic trace is the average of 50 TCAP (AV-TCAP). The oscillogram labelled C is the nonirradiated, control AV-TCAP. After a cat is irradiated with 17 krad of helium ions from a 2.0 x 25.4 mm beam, the AV-TCAP response is recorded (labeled 0). The postirradiation time in days is marked in the upper, left-hand corner of each oscillogram. Positive voltage is upward. The vertical calibration bar is 10 mV; the horizontal calibration bar is 10 msec.

Figure 8. The average transcallosal action potentials (AV-TCAP) presented in Figure 7 supplied the information for the construction of this diagram. The letter C indicates the control (nonirradiated) amplitude values of AV-TCAP, 0 indicates that the cat has absorbed 17 krad of helium ion radiation. The postirradiation changes in the amplitude values of AV-TCAP are followed to extinction. The manner of measuring TCAP amplitudes is described in the text.

Figure 9. A semilogarithmic plot of the dose of 910 MeV helium ions absorbed by the corpus callosum from a 2.0 x 25.4 mm beam

versus the postirradiation time for the complete loss of electrically-evoked transcallosal action potentials. Information obtained from Figure 8 is represented by one dot in this diagram.

REFERENCES


ANERSSON, B., LARSSON, B., LEKSELL, L., MAIR, W., REXED, B., and SOURANDER, P., 1962, Response of the Nervous System to Ionizing Radiation, edited by T. J. Haley and R. S. Snider (New York: Academic Press), p. 345.

BEALE, I. L., WILLIAMS, R. J., WEBSTER, D. M., and CORBALLIS, M. C., 1972, Nature, 238, 348.

BIRGE, A. C., ANGER, H. C., and TOBIAS, C. A., 1956, Radiation Dosimetry, edited by G. J. Hine and G. L. Brownell (New York: Academic Press), p. 623.

BOGEN. J. E., and VOGEL, P. J., 1963, Surg. Form., 14, 43.

BRIGHTMAN, M. W., 1959. Exp. Neurol. , 1, 97.

ETTLINGER, E. G., editor, 1965, Function of the Corpus Callosum (Boston: Little, Brown & Co.), p. 1.

GAFFEY, C. T., 1964, Response of the Nervous System to Ionizing Radiation, edited by T. J. Haley and R. S. Snider (Boston: Little, Brown & Co.), p. 243.

GAFFEY, C. T., 1966, Acta Radiolog. Therapy, Phy. Biol.,5, 105

GAZZANIGA, M. S., 1967, Sci. Am., 217 (no. 20), 24.

GAZZANIGA, M. S., 1970, The Bisected Brain (New York: Appleton-Century-Crofts, Educational Div.). p. 1

GAZZANIGA, M. S., 1972, Am. Scientist, 60, 311.

JANSSEN, P., KLATZO, I., MIQUEL, J., BRUSTAD, T., BEHAR, A., LYMAN, J., HENRY, J., TOBIAS, C., and HAYMAKER, W., 1962, Response of the Nervous System to Ionizing Radiation, edited by T. J. Haley and R. S. Snider (New York: Academic Press), p. 383.

KRUGER, L., and MALIS, L. I., 1964, J. Exp. Neurol., 10, 509.

LANZI, L. H., 1959, Atomic Medicine, Edited by C. F. Behrens (Baltimore: The Williams and Wilkin Co.), p. 378.

LARSSON, B., 1960, Acta Soc. Med. Upsalien., 65, 61.

## REFERENCES


ANERSSON, B., LARSSON, B., LEKSELL, L., MAIR, W., REXED, B., and SOURANDER, P., 1962, Response of the Nervous System to Ionizing Radiation, edited by T. J. Haley and R. S. Snider (New York: Academic Press), p. 345.

BEALE, I. L., WILLIAMS, R. J., WEBSTER, D. M., and CORBALLIS, M. C., 1972, Nature, 238, 348.

BIRGE, A. C., ANGER, H. C., and TOBIAS, C. A., 1956, Radiation Dosimetry, edited by G. J. Hine and G. L. Brownell (New York: Academic Press), p. 623.

BOGEN. J. E., and VOGEL, P. J., 1963, Surg. Form., 14, 43.

BRIGHTMAN, M. W., 1959. Exp. Neurol. , 1, 97.

ETTLINGER, E. G., editor, 1965, Function of the Corpus Callosum (Boston: Little, Brown & Co.), p. 1.

GAFFEY, C. T., 1964, Response of the Nervous System to Ionizing Radiation, edited by T. J. Haley and R. S. Snider (Boston: Little, Brown & Co.), p. 243.

GAFFEY, C. T., 1966, Acta Radiolog. Therapy, Phy. Biol.,5, 105

GAZZANIGA, M. S., 1967, Sci. Am., 217 (no. 20), 24.

GAZZANIGA, M. S., 1970, The Bisected Brain (New York: Appleton-Century-Crofts, Educational Div.). p. 1

GAZZANIGA, M. S., 1972, Am. Scientist, 60, 311.

JANSSEN, P., KLATZO, I., MIQUEL, J., BRUSTAD, T., BEHAR, A., LYMAN, J., HENRY, J., TOBIAS, C., and HAYMAKER, W., 1962, Response of the Nervous System to Ionizing Radiation, edited by T. J. Haley and R. S. Snider (New York: Academic Press), p. 383.

KRUGER, L., and MALIS, L. I., 1964, J. Exp. Neurol., 10, 509.

LANZI, L. H., 1959, Atomic Medicine, Edited by C. F. Behrens (Baltimore: The Williams and Wilkin Co.), p. 378.

LARSSON, B., 1960, Acta Soc. Med. Upsalien., 65, 61.

LARSSON, B., LEKSELL, L., REXED, B., SOURANDER, P., MAIR, W., and ANDERSSON, B., 1958, Nature, 182, 1222.

LARSSON, B., LEKSELL, L., REXED, B., and SOURANDER, P., 1959, Acta Radiol., 51, 52.

LEKSELL, L., LARSSON, B., ANDERSSON, B., REXED, B., SOURANDER, P., and MAIR, W., 1960, Acta Radiol., 54, 251.

MALIS, L. I., LOEVINGER, R., KRUGER, L., AND ROSE, J. E., 1957, Science, 126, 302.

MALIS, L. I., BAKER, C. P., KRUGER, L., and ROSE, J. E., 1960, J. Comp. Neurol., 11, 219.

MALIS, L. I., ROSE, J. E., KRUGER, L., and BAKER, C. P., 1962, Response of the Nervous System to Ionization Radiation, edited by T. J. Haley and R. S. Snider (New York: Academic Press), p. 359.

MOUNTCASTLE, V. B. , editor, 1962, Conference on Interhemispheric and Cerebral Dominance (Baltimore: The Johns Hopkins Press), p. 1.

MYERS, R. E., and SPERRY, R. W., 1953, Anat. Record. 175, 351.

NAITO, H., MIYAKAWA, F., and ATO, N., 1971, Brain Research, 27, 369.

RAJU, M. R., LYMAN, J. T., BRUSTAD, T., and TOBIAS, C. A., 1969, Radiation Dosimetry, edited by F. H. Attix and E. Tochilin (New York: Academic Press), p. 151.

REXED, B., MAIR, W., SAURANDER, P., LARSSON, B., and LEKSELL, L., 1960, Acta Radiol., 53, 289.

ROSE, J. E., MALIS, L., KRUGER, L., and BAKER, C. P., 1960, J. Comp. Neurol., 115, 243.

SAMORAJSKI, T., ZEMAN, W., and ORDY, J. M., 1967, J. Neuropathol. & Exp. Neurol., 62, 40.

SPERRY, R. W., 1961, Science, 133, 1749.

SPERRY, R. W., 1962, Interhemispheric Relations and Cerebral Dominance, edited by V. B. Mountcastle (Baltimore: The Johns Hopkins Press), p. 43

SPERRY, R. W., 1964, _Sci. Am._, _210_, 42

SPERRY, R. W., 1968, _The Harvey Lecture Series_, _62_, 293.

SPERRY, R. W., MYERS, R. E., and SCHRIER, A. M., 1960, _Quart. J. Exptl. Psychiat._, _12_, 65.

TOBIAS, C. A., ANGER, H. O., and LAWRENCE, J. H., 1952, _Amer. J. Roentgenol._, _67_, 1

TOBIAS, C. A., VAN DYKE, C. C., SIMPSON, M. E., HUFF, R. L., and KONEFF, A. A., 1954, _Amer. J. Roentgenol., Radium Therapy, Nucl. Med._, 74, 1.

TOMASCH, J., 1954, Anat. Record, _119_, 119.

VAN DYKE, D., and JANSSEN, P., 1963, _J. Neurosur._, _20_, 289

Table 1

The number of cats administered 910-MeV helium ion treatment, the size of radiation field, the doses of radiation absorbed, and the biological effect on transcallosal action potentials is listed.

| Number of cats | Helium ion beam size | Radiation dose (krad) | Influence on CC transmission |
|---|---|---|---|
| 4 | 0.5 x 25.4 mm | 20, 30, 40, 50 | Not blocked |
| 3 | 2.0 x 6.0 mm | 20, 40, 60 | Blocked |
| 2 | 2.0 x 10.0 mm | 5, 7.5 | Not blocked |
| 3 | 2.0 x 10.0 mm | 15, 30, 45 | Blocked |
| 3 | 2.0 x 25.4 mm | 3, 5, 8 | Not blocked |
| 21 | 2.0 x 25.4 mm | 10 to 100 | Blocked |
| 3 | 2.0 x 25.4 mm | 130, 150, 180 | Blocked plus adverse effects |
| 2 | 2.0 x 25.4 mm | 200, 250 | Blocked and feline death |