NERVE STIMULATION BY IMPLANTED MICROWAVE DIODE

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Abstract

Damage to nerves in the body can cause loss of voluntary muscle function, such as the arms and legs, and loss of involuntary muscle function such as heart contraction, control of urination, etc. In many cases, if appropriate nerves could be stimulated by external means, these functions could be restored. This paper describes experimental work to develop an extremely small implanted device which, when located close to a viable impaired nerve, can restore its function. The device is activated by RF electromagnetic waves passing through the skin which do not damage the intervening tissue.

Introduction

Schuder and Gold [1,2] reported using solid-state diodes to produce DC currents in nerves by a radio frequency electrical field established in the surrounding tissue. If this phenomenon can be made practical many processes within the body that require DC currents may be easily controlled. Guy [3] has reported similar experiments in synthetic muscle tissue and with Chou has succeeded in stimulating the frog sciatic nerve. Thalen et.al. [4] reported stimulation of the heart by electromagnetic impulse transmission using a coil and diode, essentially a similar approach.

Experimental Program

The feasibility of surgically implanting RF receiving diodes and then irradiating the diode from an external RF source to create voltages necessary to excite mammalian nerves was investigated. The diode used was the HP 5082-2800, which exhibits 95% rectification efficiencies in the UHF frequency band. The diode package was approximately 4 millimeters long by 2 millimeters in diameter, and was placed in the leg of a rat. The leads of the diodes served both as an antenna to receive the RF energy and as stimulating electrodes in contact with the sciatic nerve. Following recovery from surgery, the rats were exposed to pulsed microwave irradiation and the response, in terms of the force of the muscle contraction, was measured. In an effort to expose as much of the leads as possible to the radiation and at the same time contain the diode and leads in as small a package as possible, the diode and leads were formed into a folded dipole. After the folded diode configuration had been shaped it was dipped in a polymer plastic solution to insulate the leads. This was determined to be necessary in order to prevent the voltage developed across the diode from exciting the thigh muscle of the rat and to assure that the sciatic nerve was stimulated.

Biological Tests

Nembutal (sodium pentobarbital) was used to anesthetize the rats. The dosage was 50 mg. per kilogram weight of the rats. The nembutal was administered by intraperitoneal injection. The animals were placed on their side and an incision was made parallel to the femur on the lateral surface of the thigh. The incision was about two centimeters long and began about one centimeter from the proximal terminus of the femur and ended about half way to the knee. All of the surgery including the incision was done with care to prevent trauma to the muscle tissue. The skin was pulled back and the groove which marks the separation of the two muscles, the biceps femoris and the vastus lateralis, was located. Using glass probes to avoid damage to the nerve and muscle, the two muscles were separated exposing the groove in which the sciatic nerve is located. About 1.5 centimeters of the nerve was teased away from the surrounding tissue so that insertion of the diode could be easily accomplished. The previously-prepared diode was lightly attached to the sciatic nerve by crimping the ends of the leads around the nerve. The diode and nerve were allowed to fall into the groove left by the separation of the two muscles. An effort was made to allow the nerve to rest in as natural a position as possible. The diodes were prepared so that when the nerve was in place, the diode itself was resting just below the surface of the skin, next to the femur. A single stitch was made around the diode and the femur to secure the diode in place. The incision was then sutured and the rat left to recover for a period of three to five days.

Following the recovery period, the rats were tested for force of contraction in response to RF radiation at 1GHz from a yagi antenna. The animal was anesthetized, and the foot attached to a Statham force transducer. The antenna was brought into close proximity to the surface of the leg over the implanted diode. Force of contraction was measured as a function of distance between the leg surface to the tip of the antenna. Single pulses of RF radiation 100 microseconds long were used, and the peak force developed during contraction is plotted in Fig. 1 for a 250 gram rat versus distance between the leg surface and the antenna. Fig. 2 shows similar data for a larger 410 gram rat. The response of the second rat was much stronger than the first, which could be a result of animal size. Some difference in the shape of the response curves was also noted. It is estimated that the skin surface peak RF power density at contraction threshold is of the order of 1 mW/cm^2. Clearly the procedure requires an average RF exposure orders of magnitude below the recommended safety exposure level.

The first rat responded well under test for 115 days. The rat died on the 115th day presumably from suffocating while under anesthetic. The rat was autopsied to retrieve the diode and to note the long-term effects of the diode on the tissues. The autopsy revealed the following: 1. no evidence of infection, 2. there was slight tissue buildup around the leads of the diode, 3. some bleeding had taken place near the ends of the leads of the diode where they had been cut and crimped, 4. the leads of the diode were very brittle, 5. no visible damage to the nerve itself was noticed. Overall, the diode caused little trauma to the rat and was well tolerated.

Conclusions

These experiments have shown the feasibility of stimulating a mammalian nerve using implanted RF diodes, using RF power at low power levels. With careful surgery but only modest concern about the implant mechanical and material compatibility problems, successful nerve stimulation was achieved for about four months in a rat.

Further experiments are now in progress to 1) minimize the size of the diode and associated antenna structure, 2) improve the mechanical-electrical contact between the electrodes and the nerve, 3) investigate the effects of repeated DC stimulation on nerve and surrounding tissue viability, and 4) determine if long-term use of such a system is feasible.

References

1. J.C. Schuder and H. Stockle, Transactions American Society Artificial Organs, 10, 366, 1964.

2. J.H. Gold, J.C. Schuder, "Theoretical Analysis of Tissue Stimulation by Implanting Solid-State Diode," Proc. 26th Annual Conference Engineering in Medicine and Biology, p. 94, Minneapolis, Minnesota, 1973.

3. A.W. Guy, J.F. Lehmann, J.B. Stonebridge,"Therapeutic Applicationsof Electromagnetic Power,"IEEE Proceedings, Vol. 62, January 1974.

4. H.J. Thalen, J. Vanden Berg, J.N. van der Heide, The Artificial Pacemaker, C.C. Thomas, 1969.

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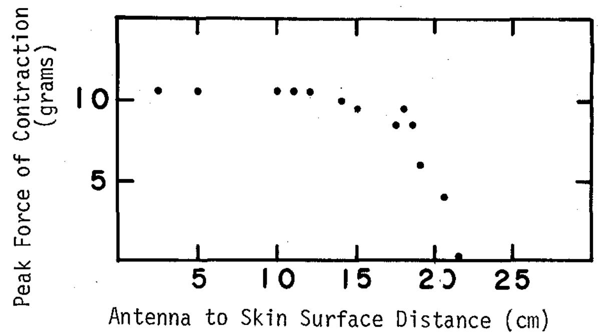

Figure 1. Peak force of contraction in the rat leg measured versus antenna-to-skin surface distance. Threshold stimulation occurs at about 20 cm distance. This data was taken from 100 μsec duration single pulses, 1GHz, in a.280 gm anesthetized rat 30 days post surgery.

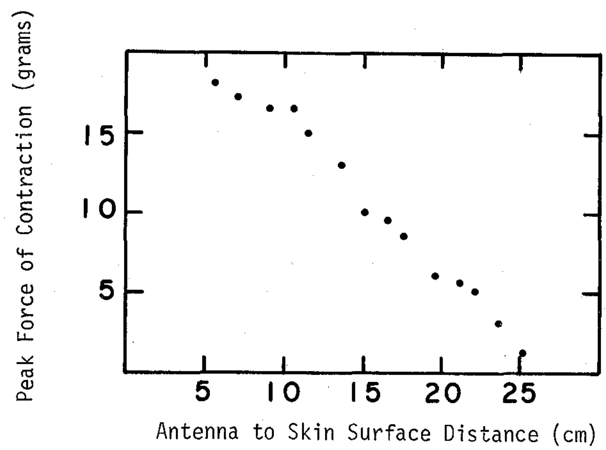

Figure 2. Force of contraction data in an anesthetized 410 gram rat 61 days following surgery. At distances less than 5 cm stimuli produced sensory excitation and muscle spasms above the point of insertion of the diode.