and at 3 weeks is already below 70 percent. At $-93° \pm 2°C$ a satisfactory recovery and survival are maintained for periods of at least 6 months, as shown in 13 transfusions.

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4. This work was carried out with funds from the Army Medical Research and Development Board and with the aid of a grant from the National Advisory Heart Council of the National Institutes of Health. We acknowledge the technical aid of Jean Bentz.

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Ionium-Thorium Chronology in Deep-Sea Sediments of the Pacific

Abstract. The ratio of ionium to thorium varies exponentially with depths in deepsea sediments of the Pacific Ocean and gives rates of accumulation of the order of millimeters per thousand of years. Surface values of the ratio were not constant over the eastern Pacific Ocean. This observation may result from differences in thorium isotope concentrations in near bottom waters which furnish these isotopes to the sediments.

The method of ionium-thorium chronology (*1*) of deep-sea sediments is based on the simultaneous removal of ionium (Th^{230}, $t_{1/2} = 80{,}000$ years, a member of the U^{238} radioactive series) and thorium (Th^{232}, $t_{1/2} = 1.4 \times 10^{10}$ years) from the water to one or more of the mineral components of the deposits. The critical assumptions for the application of the method follow. (i) The Io/Th ratio has remained constant in the waters adjacent to the sediments over the time intervals involved. (ii) The chemical species of Io and Th in the sea water are the same, and these isotopes have identical distributions among them. (iii) The analyzed materials do not contain detrital materials, of continental or volcanic origin, with significant contributions of Io or Th. This method appears preferable to the previous method of radium chronology (*2*) inasmuch as the observed diffusion of radium from the decay site of its parent ionium can invalidate any age determinations (*3*).

Table 1. Ionium-thorium ratios in three cores from the Eastern Pacific Ocean (Capricorn 50BG—latitude 14° 55'N, longitude 124° 12'W, 4270 m; Chinook 11—latitude 49° 39.5'N, longitude 177° 39'W, 4850 m; Downwind 49HG—latitude 42° 02'S, longitude 98° 01'W, 4350 m). The ratios are given in terms of disintegrations of Io per disintegration of Th per unit time.

Depth interval in core (cm)	Io/Th ratios		
	Capricorn 50BG	Chinook 11	Downwind 49HG
0–4	30	16	35
4–8	23	18	26
8–12	16	11	19
12–16	9.0	10	5
16–20	8.4	7.0	2
20–24	6.1	6.2	
24–28	5.3	4.4	

The isotopes of Th were isolated from sediment samples by previously described methods (*4*) and subsequently plated on a 1-in. platinum disc. Preferential solution of the nondetrital matter was accomplished with hot, concentrated hydrochloric acid. The principal detrital minerals, quartz and feldspars, were insoluble and were discarded following centrifugation. The recovery of the Th isotopes from the samples was determined with UX_1 (Th^{234}), and yields varied between 50 and 98 percent. The plated Io and Th were readily differentiated and quantitatively assayed with an alpha-ray spectrometer, a Frisch screen-grid ion chamber being used as a detector. The dominant alpha energies of Io and Th are 4.6–4.7 and 3.98, respectively (*5*).

Preliminary analyses (*6*) of a number of Eastern Pacific deep-sea cores have emphasized three significant results. First of all, exponential decreases in the ratio with depth have been observed in 10 of the 12 cores analyzed. Two South Pacific cores had values of the ratio that were both low and essentially invariant with depth. Whether such results indicate a lack of deposition over the last few hundred thousand years or a loss or disturbance of the upper section of the core during the handling has as yet not been determined. Table 1 gives typical analyses on three cores collected by expeditions of the Scripps Institution of Oceanography.

Secondly, determinations of the recent rates of accumulation of these Eastern Pacific clays, made on the basis of these data and of the half-life of ionium, are remarkably uniform, with values for the Capricorn, Chinook, and Downwind cores of 1, 2, and 1 mm per 1000 years, respectively, in the upper 10 cm. A dramatic drop in the Io/Th ratio, corresponding to nearly 2 half-lives of ionium over a few centimeters' distance, is observed in the Downwind core. Such a change has been observed in but one other core, also from these southerly latitudes.

Finally, *the surface ratios* fall into two distinct groups: a set in the region between the Aleutian Islands and Hawaii with values averaging about 15 and a second group, in the region between longitude 120° and 140°W and latitude 40°N and 40°S, with a ratio varying around 35. The cores given in Table 1 are representative of such groups. The isotopes of lead show a similar distribution pattern (*7*).

These results can be interpreted on the basis of the assumption that the deep-oceanic water masses, which are in contact with the sediment surfaces, furnish these isotopes to the sediments. Hence, these two regions should have circulating, overlying water masses which possess values for the Io/Th ratio which are similar to those found in the surface layers of the sediment deposits. The distinctive isotopic composition of thorium in a given water mass probably reflects the weathering processes responsible for the introduction of thorium and uranium into the water mass and the inorganic and biochemical processes in the ocean that cause their removal.

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18 June 1958

Radio Control of Ventricular Contraction in Experimental Heart Block

Abstract. This report describes a method for the stimulation of the ventricular myocardium by transmitting the stimulus over a radio-frequency carrier which is demodulated by a radio receiver enclosed within the animal's chest. The method can be applied in conjunction with experimental heart block.

Experimental heart block combined with electrical stimulation of the myocardium is a valuable technique in the study of the physiology and the pathology of the circulatory system.

Heart block can be created surgically, in dogs, with fairly uniform success and maintained for prolonged periods (*1*). In such animals the ventricular myocardium can be stimulated electrically for as long as 10 days, without serious injury. This procedure provides the means for driving the ventricles at various rates and for studying the relations between such ventricular rates and other variables in the circulatory system.

Folkman and Watkins have recently stimulated the ventricular myocardium, in dogs, by amplifying the pulses originating in the auricles with an external amplifier and using the output of the latter for stimulation (*2*).

The electrical stimulation used so far, in this kind of experiment, was provided by various types of electronic pulse generators connected *by wire* to the myocardium, the wires reaching the heart after passing through the thoracic wall. This required maintaining an opening in the skin and in the muscles during the investigative period, with constant danger of infection and considerable discomfort and limitation of movement for the animal.

Because of these disadvantages of connection by wire, an attempt has been made, in this laboratory, to stimulate the ventricular myocardium remotely, without any wires running from the stimulator to the animal. This was achieved by transmitting the stimulating pulses via an RF carrier and demodulating this carrier, within the animal's chest, by means of a suitably miniaturized receiver.

The experimental arrangement is shown in Fig. 1. A conventional 200-watt radio transmitter is electronically "keyed" at the desired frequency by means of a pulse generator and a keying system operating on the grid of the final RF amplifier. A transmission line takes the pulsed RF carrier so generated to a loop antenna placed underneath the cage in which the animal is kept, a strong RF field being thus generated inside the cage. The receiver is located within the thoracic wall.

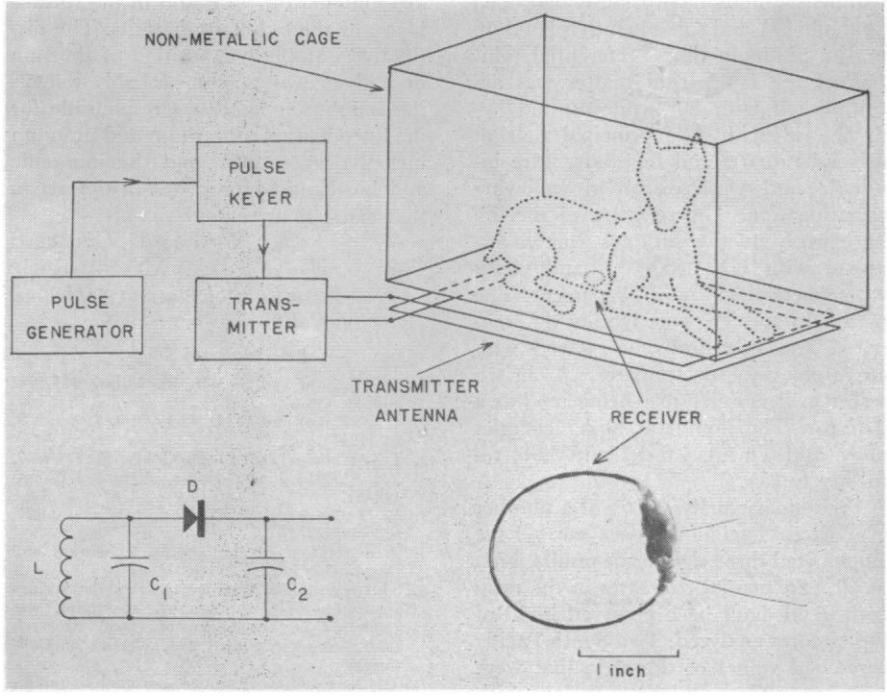

Fig. 1. (Top) Experimental arrangement for remote stimulation of the heart. Radio-frequency carrier 2.5 Mcy/sec; stimulating pulses, 2.5 to 3.7 v, 2 msec. (Bottom, left) Schematic diagram of receiver. L, 9 turns of No. 28 Belden enameled wire, approximately 2 in. in diameter; C_1, 200 μμf; C_2, 0.01 μf; D, Zener diode, 3.7 v. (Bottom, right) Receiver and output leads. The components are enclosed in a mass of dental cement, shown at extreme right.

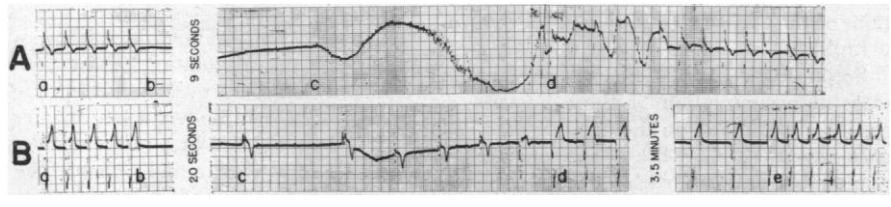

Fig. 2. (*A*) Electrocardiogram of a dog with experimental heart block. At *a*, the ventricles are driven by remote stimulator; at *b*, the stimulator is turned off; at *c*, the dog exhibits convulsion; at *d*, the stimulator is turned on and ventricular contraction resumes. (*B*) Electrocardiogram recorded 3 days later from the same animal. At *a*, the remote stimulator is operating; at *b*, the remote stimulator is turned off; at *c*, the ventricles show spontaneous contractions; at *d*, spontaneous contractions continue, at a higher rate; at *e*, the stimulator is again operating.

Figure 1 (bottom left) shows the schematic diagram of the receiver, which consists of a tank circuit, a Zener diode, and a bypass condenser. When the receiver is completely enclosed within the animal, the components of the tank circuit, instead of being immersed in air, are immersed in a medium of a different dielectric constant. As a consequence, there is a change in the distributed capacitance of the tank circuit and, therefore, in its resonant frequency. For this reason, in order to achieve a satisfactory transmission of the stimulus, the tank circuit has to be tuned to a frequency slightly higher than that of the RF carrier before the receiver is enclosed within the thorax, or the transmitter has to be tuned to a frequency slightly lower than that of the receiver after the latter is enclosed within the thorax. The Zener diode functions as a demodulator and, at the same time, limits the output voltage of the demodulated signal to a desired level, so that changes in the position of the animal which might bring him very close to the transmitting antenna will not result in high stimulating currents causing injury to the myocardium. The stimulating voltage is bound to remain between two limiting values: a maximum value (in these experiments, 3.7 v) determined by the Zener diode and a minimum value (in these experiments, 2.5 v) determined by the fact that the animal cannot remove himself from the transmitting antenna to a distance greater than 1 ft.

Heart block was created in dogs, under Nembutal anesthesia, by opening the right auricle and sectioning the bundle of His in the vicinity of the atrioventricular node. After the creation of the block the receiver was placed between the latissimus dorsi muscle and the rib cage over the 3rd, 4th, and 5th ribs, and its output was connected to the myocardium and to the latissimus dorsi muscle by stainless steel wires insulated with Teflon. During stimulation the lead connected to the heart was negative with respect to the other lead.

Figure 2*A* shows an electrocardiographic record taken 20 hours after the operation from a dog whose ventricular rate had dropped to 40 and who had occasional periods of asystole such that the circulation had to be maintained with the remote stimulator. At *a* the stimulator is functioning and the ventricles are

driven at a rate of approximately 120/min; at *b* the stimulator is turned off and the record shows the absence of ventricular contraction; at *c* the animal exhibits a tonic convulsion; at *d* the stimulator is turned on again, the ventricles are stimulated, and the convulsion ceases.

Figure 2*B* shows an electrocardiographic record taken from the same dog 3 days later. At *a* the ventricles are being stimulated; at *b* the stimulator is turned off and the ventricles stop contracting (only the P wave is visible on the record); at *c* the ventricles begin to contract spontaneously, first slowly, then faster, reaching, at *d*, a rate of approximately 66 per minute; at *e* the stimulator is turned on again.

Animals whose ventricular rate had dropped, after surgical block, below 60 were maintained at normal rates by remote stimulation for periods as long as 8 days (*3*).

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2 June 1958

Method of Polarographic in vivo Continuous Recording of Blood Oxygen Tension

Abstract. A catheter-type PO_2 electrode has been developed which permits the polarographic continuous recording of the blood oxygen tension in vivo. The electrode has been tested in model experiments in vitro and applied in animal experiments lasting several hours. It yielded a continuous tracing of PO_2 with good reproducibility.

The development of a new type of oxygen electrode by Clark (*1*) has given a fresh impetus to the polarographic determination of the oxygen tension in the blood by means of platinum electrodes. In a first step of our studies, we incorporated this electrode into a procedure for measuring the blood oxygen tension in vitro (*2*). This method was thoroughly tested (*3*) by comparing the results with (i) adjusted tonometer equilibrations with determination of the oxygen in the gas phase by the Van Slyke technique and (ii) data obtained from determinations by the Riley technique (*4*). The method is now in routine use for clinical purposes (*5*) and was also used for the calibrations in the new procedure described in this report (*6*).

We have constructed catheter-type PO_2 electrodes for the continuous recording of the blood oxygen tension in vivo by ordinary catheterization. The basic principle is similar to that employed in Clark's electrode (*1*). The catheter consists of Intramedic polyethylene tubing PE 160 (inside diameter, 0.045 in.; outside diameter, 0.062 in.) or PE 200 (inside diameter, 0.055 in.; outside diameter, 0.075 in.) of any desired length. Another thinner polyethylene tubing containing the platinum cathode and its connecting wire was surrounded by the silver anode wire and inserted into the catheter proper; the silver wire at the same time kept the inner tubing concentrically in place. The catheter was filled with saline free of air bubbles and, on the proximal end, was covered with Teflon membrane of thickness 0.001, 0.0005, or 0.00025 in.; the latter was fixed by a specially made very thin ring of stainless steel. The distal end of the catheter was plugged with Seal-All. For the application in animals, the whole catheter-electrode was coated with a thin coat of Velvasil; this procedure effectively prevented any coagulation in the vessel over experimental periods of several hours and did not result in any appreciable loss of sensitivity. The electrodes were freshly assembled and checked in vitro before every animal experiment; this enabled us to service the electrode parts thoroughly every time—that is, to polish the platinum surface and the silver wire.

The current developed by these electrodes was of the order of 1 to 4 μa, depending on the thickness of the Teflon membrane employed (that is, it was similar to or slightly higher than, the current in the case of the Clark electrode) for air at a voltage of 0.6 volts. It was amplified by a General Radio Company type 1230-A d-c amplifier (input resistance 10^4 ohm) and recorded by a Honeywell 906 Visicorder. The amplifier scale permitted immediate readings during the experiment, and the values from the continuous record yielded another set of data for the same conditions.

The performance of these electrodes was always first tested in vitro by taking the calibration curve in various gas mixtures at room temperature several times. Figure 1 shows such a calibration curve (Teflon membrane 0.0005 in. thick). With proper construction of the electrode, we always get straight lines which never go quite through zero but which intersect the ordinate at a rather low reading (the helium reading amounts to about, or less than, 15 percent of the air reading in vitro).

Model experiments were performed in order to explore the effect of various rates of flow and of varying static pressures on the electrode readings. With increasing rates of flow the readings go up slightly and become constant at and above a linear velocity of about 7 cm/sec. The readings remain constant for a range of static pressures between 0 and 120 cm of water. The standard deviation both in vitro and in vivo was never more than 3 percent for any reading, in most cases much less. The response time of these electrodes was about 1.5 sec for 95 percent amplitude and roughly 7 sec for approximately 100 percent amplitude. It depends very much on proper construction of the unit.

A number of dog experiments were carried out in order to test these electrodes in vivo (*7*). The dogs were anesthetized with Nembutal (30 mg/kg). The trachea was intubated or cannulated in order to administer various inspiratory oxygen mixtures. Ventilation was kept constant throughout the experiment, which lasted 2 to 5 hours, by means of an Etsten ventilator (checked by a Bennett ventilation meter) or by a Starling pump; the minute volume of ven-

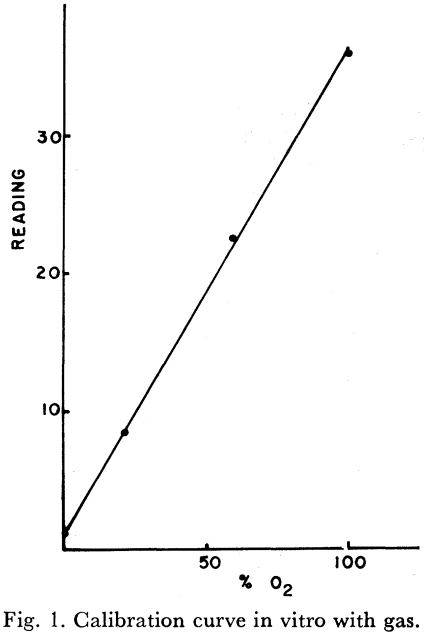

Fig. 1. Calibration curve in vitro with gas.

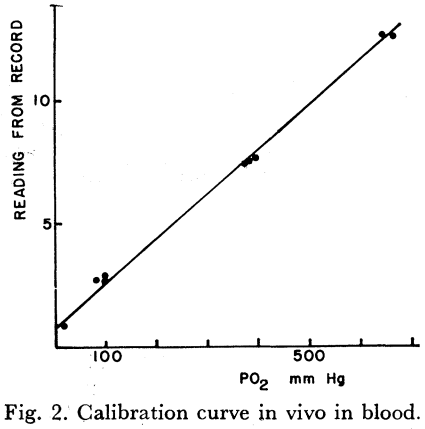

Fig. 2. Calibration curve in vivo in blood.