The results of the experiment are shown in Table 1. All of the samples smaller than 150 cells include all scorable cells in the sample. The 72-hour sample is included here in spite of its small size, because it shows a significant drop in the frequency of aberrations over the 42- and 49-hour samples, probably because the cells scored in the 72-hour sample were in early interphase at the time of irradiation. The differences between the irradiated samples and the controls for the 42- and the 49-hour samples are significant at the 1-percent level. The differences between the 42- and the 49-hour samples are not significant.

It is, of course, very obvious that before any definite conclusions can be drawn about the sensitivity of human tissues to radiation, the present preliminary work must be repeated on the same and other tissues. However, in the absence of other data and in view of the importance of the subject, it seems proper to point out that the present work indicates that human tissues may be much more sensitive to ionizing radiation than was previously suspected. If one combines the 42- and 49-hour data, the control rate is one break per 100 cells. The slope of the dosage versus breakage curve is about 0.3 break per 100 cells per roentgen. The doubling dose, for the types of aberrations scored and for this material, is thus about 3.3 roentgens. This is roughly one third of the maximum permissible dose recently recommended by the National Academy of Sciences' report on the Biological Hazards of Atomic Radiation. It should be pointed out that the National Academy's recommendation was based on estimates of gene mutations, which may not be as easily induced by x-rays as chromosome aberrations.

Work is in progress in this laboratory to determine induced gene mutation frequencies in normal diploid human cells *in vitro*. Although there is no proof that cells in tissue culture respond to radiation in the same manner as rapidly reproducing tissues in the body, there is no evidence that they do not. It is clear that if the rates of this and other types of radiation damage to human cells are found to be correspondingly high in further experiments, a sharp revision will have to be made in our estimates of "safe" doses of radiation, if, indeed, any dose can be called "safe" from a genetic point of view.

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References and Notes

1. J. S. Younger, *Proc. Soc. Exptl. Biol. Med.* 85, 202 (1954).
2. T. C. Hsu and C. M. Pomerat, *J. Heredity* 44, 23 (1953).
3. These studies were carried out under U.S. Atomic Energy Commission contract AT (30-1) 1939 with H. B. Glass and aided by a research fellowship from the National Institutes of Health, U.S. Public Health Service.
4. I am indebted to the staff of the Brady Clinic and especially to its director, W. W. Scott, for this and other tissue specimens.
5. R. S. Chang, *Proc. Soc. Exptl. Biol. Med.* 87, 440 (1954).
6. The irradiations were performed at the Public Health Service Marine Hospital in Baltimore through the courtesy of L. B. Garbe and B. Hathoway.

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Pressure-Sensitive Telemetering Capsule for Study of Gastrointestinal Motility

Existing methods for the accurate measurement and recording of pressure changes within the human gastrointestinal tract require the passage of tubes through the mouth, nose, or anus, or through an artificial opening provided by gastrostomy, ileostomy, or colostomy. The principal objections to these methods are (i) that the distal small intestine and proximal colon are relatively inaccessible for study and (ii) that normal gastrointestinal motility may be altered by reflex changes induced either by the physical presence of the tube or by the discomfort experienced by the patient.

An instrument has been devised which will permit the recording of gastrointestinal motility under more physiologic conditions. This instrument is sensitive to intraluminal pressures and records these pressures without connecting wires or tubes. It consists of a rigid, plastic, cylindrical capsule 3.0 cm in length and 1.0 cm in diameter (Fig. 1). The capsule contains a transistor radio transmitter powered by a battery having a "life" of 15 hours. A screw-on cap at one end of the capsule permits replacement of the battery. The opposite end of the capsule is a flexible rubber membrane which covers a pressure transducer. Pressure applied to the transducer modulates the frequency of the oscillations generated by the transmitter. These signals are accepted by the antenna of a frequency-modulation receiver. The receiver demodulates the signals, and the pressure variations are displayed on an oscilloscope and recorded photographically. The capsule detects pressures ranging from 0 to approximately 50 cm of water and responds to frequencies between 0 and 100 cy/sec.

This pressure-sensitive device has been used to record pressures within the gastrointestinal tract in normal human subjects. Prior to ingestion of the capsule, the entire detecting and recording apparatus is calibrated in an external system. The capsule is placed in a bottle, which is rendered air-tight by a two-hole stopper. One opening admits a water manometer, and the other permits injection of increments of air. The pressures developed within the bottle are recorded in the usual fashion by means of the frequency-modulation receiver and the antenna which is placed near the bottle. A given excursion of the photographic record corresponds to the pressure change indicated by the water manometer. Such calibration permits accurate derivation of relative intraluminal pressures from the final record.

The recording of gastrointestinal pressures in man is accomplished with the subject in any comfortable position and with the antenna secured loosely to the abdomen. Respirations are recorded simultaneously by a pneumograph attached to a strain-gage manometer. Both the intraluminal pressures and the respiratory excursions are recorded by a multichannel photographic recorder and displayed on an oscilloscope. The capsule may be swallowed without difficulty, and it passes through the gastrointestinal

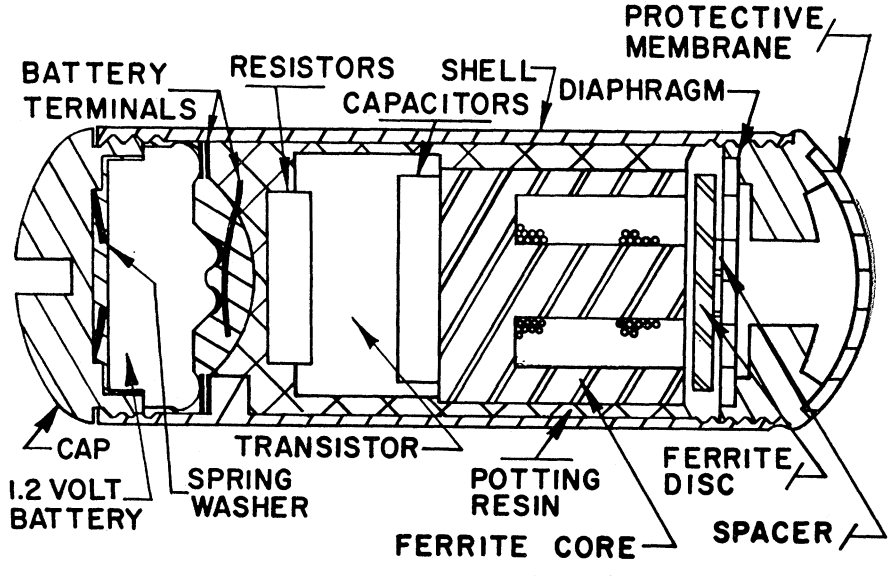

Fig. 1. Cross-section of the pressure-sensitive radio transmitter.

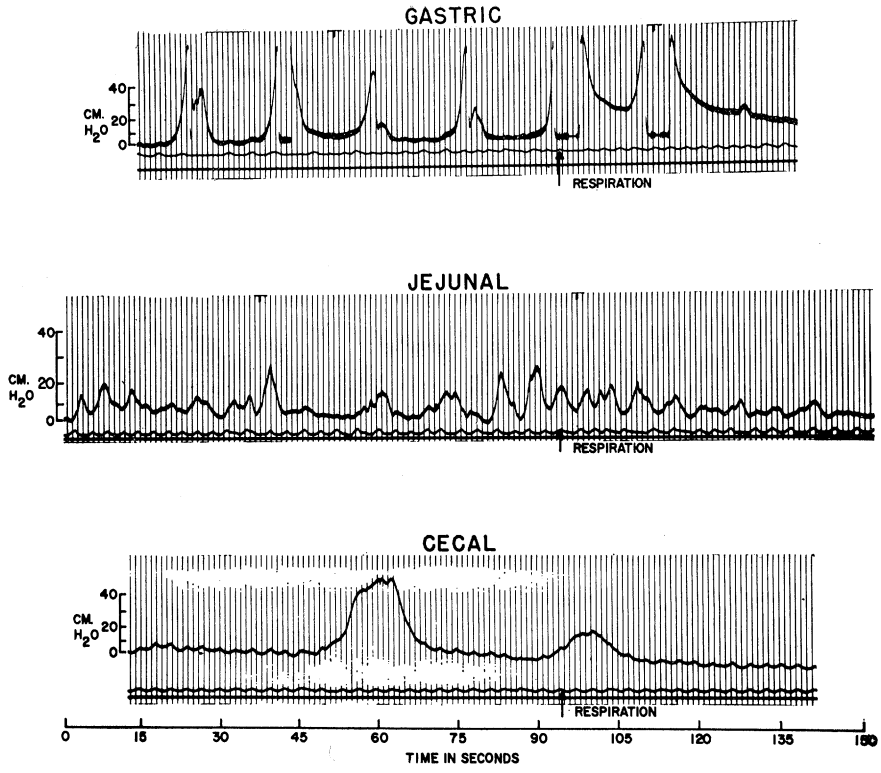

Fig. 2. Records of intraluminal pressure from three different portions of the gastrointestinal tract.

tract without causing discomfort. It is radioopaque and can be followed fluoroscopically. The radio transmitter sends signals constantly until the battery charge is exhausted. During a 15 to 20 hour period, therefore, intraluminal pressure changes are continuously displayed on the monitoring oscilloscope whenever the antenna is near the subject. Permanent records may also be made continuously or at intervals.

Records have been obtained of gastric and small intestinal intraluminal pressures in four subjects, and in two of them colonic records have also been obtained (Fig. 2). Preliminary studies in these four subjects indicate that the gastric and small intestinal phasic pressure changes correspond in frequency and general appearance to those phasic patterns recorded by other methods. If the capsule is swallowed when the subject is fasting, very little activity of the stomach is noted. After the ingestion of food, gastric pressure waves occur at an approximate rate of three per minute. Records of pressure fluctuations in the small intestine show periods of activity alternating with periods of quiescence. During the active phases, the waves occur at a rate which varies between 7 and 14 per minute.

Precise analysis of records of activity in the small and large intestine will be complicated because the detecting capsule is constantly moving "downstream" rather than recording the activity of a single segment. If it is desired, the capsule may be anchored in one locus for periods of time by means of a very thin thread which passes through the mouth and is anchored externally.

The pressure-sensitive radio transmitting capsule appears to possess considerable potential for the study of gastric, small intestinal, and proximal colonic motility since it does not alter normal physiological processes.

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Lack of Dependence of Pyridine Nucleotide Reduction on High-Energy Phosphates in Chloroplasts

Experimental evidence accumulated in recent years indicates that photosynthetic CO_2 fixation and reduction to the carbohydrate level mainly depends on the availability of reduced pyridine nucleotide and of high-energy phosphate bonds ($\sim$ P). The requirement for both factors is fulfilled by a mechanism specifically localized in the chloroplasts. This mechanism comprises (i) the splitting of water into an oxidizing and a reducing agent by means of light energy, (ii) the conversion of some of the chemical potential energy thus produced into $\sim$ P of adenosine triphosphate (ATP) during the step-wise transfer of electrons from the primary reducing agent to the oxidizing agent, and (iii) the use of the remaining part of the chemical potential energy for the reduction of a pyridine nucleotide, probably triphosphopyridine nucleotide (TPN). The presumed utilization of reduced triphosphopyridine nucleotide (TPNH) and ATP in photosynthesis is illustrated by the following equations:

$$\text{ATP} + \text{ribulose-5-phosphate} + CO_2 \rightarrow 2(\text{3-phosphoglycerate}) + \text{ADP} \quad (1)$$

$$2(\text{3-phosphoglycerate}) + 2\text{TPNH} + 2\text{ATP} \rightarrow 2\ \text{triosephosphate} + 2\text{TPN}^+ + 2\text{ADP} + 2\ P_{\text{inorg.}} \quad (2)$$

The question then arises whether TPN is on the pathway of electron transfer from the primary acceptor of reducing power to the oxidizing agent produced by the photolysis of water, thus participating in the electron-transferring, phosphorylating system, as suggested by Bassham and Calvin, (*1*), or whether it is outside the phosphorylative chain, and secondarily reduced by some element of the same, as suggested by Kandler (*2*), Arnon (*3*), and Wessels (*4*).

The tentative schemes proposed by Kandler and by Arnon are based on the fact that ATP synthesis by illuminated chloroplasts is stimulated by flavin mononucleotide, vitamin K, and ascorbate, and not by pyridine nucleotides. In these schemes, either vitamin K or flavin mononucleotide would be directly reduced by the chlorophyll-light system through a one-quantum process. Pyridine nucleotide reduction by a part of the reduced flavin mononucleotide or reduced vitamin K that is formed would then follow, the energy for such an endergonic reaction being supplied by ATP generated during the oxidation of the residual reduced flavin mononucleotide or reduced vitamin K.

It seemed to us that an indication about the position of TPN in the photosynthetic electron-transfer mechanism could be obtained by testing the dependence of TPN reduction by illuminated chloroplasts on the availability of high-energy phosphate in the system. In fact, utilization of $\sim$ P in a coupled reaction appears to be by far the most probable mechanism by which electrons could be moved from a more positive to a more negative system (as from flavin monocleotide or vitamin K, with E_0 near -0.0 v, to TPN, with E_0 near -0.32 v). If, therefore, reduction of TPN by illuminated chloroplasts could proceed unimpaired under conditions in which high-energy phosphate production was suppressed, or immediately deviated to