

FORMATION OF GASTRIC ULCER IN RABBITS FOLLOWING MICROWAVE
IRRADIATION OF THE EPIGASTRIUM

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Following application of electromagnetic microwaves of superhigh frequency (SHF) and with an intensity of over 10 mW/cm^2 , thermal injury to certain organs and tissues may take place. No evidence of injury to the digestive organs from SHF waves has been described. All that has been reported so far is that rabbits die rapidly from shock following local irradiation of the abdomen [1]. The object of this investigation was to determine experimentally whether pathological changes may arise in the gastrointestinal tract following irradiation of the abdomen with microwaves of an intensity insufficient to cause visible thermal injury to the abdominal wall.

EXPERIMENTAL

Experiments were conducted on rabbits weighing from 1.8 to 2.5 kg, fixed in the supine position. The epigastric region was irradiated by means of a type Luch-58 apparatus (λ 12.6 cm, exposure 10 min, distance from abdominal wall to aperture of cylindrical source 10 cm). The intensity of the SHF rays was determined from the power of the apparatus, namely 40, 60, and 80 W. Experiments by the authors using the method of equivalent thermal effects with known flux density of power, measured by means of the P-01 (Medik-1) apparatus showed that these dose rates, at a selected distance from the source, correspond to power flux density rates (PFD) of 70, 110, and 160 mW/cm^2 .

In order to define the thermal effect of the electromagnetic energy penetrating into the lumen of the stomach, several series of experiments were carried out to measure the temperature of water in the organ (by introducing per os a polyvinyl chloride tube into the stomach of the fasting rabbits. To the end of the tube was attached a thin, rubber balloon, filled with water (20 ml) warmed to 35°C . The water temperature was taken after 20 min, when it usually had reached its maximal level. The animals were then irradiated for 10 min, after which the temperature of the water in the balloon was taken again. The rectal temperature was also investigated, and in a few experiments the temperature of the rectus abdominis muscles also (at a depth of 3-4 mm) in the epigastric region before and after irradiation.

All the irradiated rabbits were sacrificed after 2, 10, 20, and 24 days for postmortem examination. The experiments were conducted on 91 rabbits.

RESULTS

Measurement of the water temperature in the stomach showed that SHF energy penetrates readily into the abdominal cavity. The more the water warmed, the higher the power of the microwave generator. However, the water temperature did not rise sufficiently (only to no more than 40.5°) to make serious thermal injury to the gastrointestinal tract likely. Nevertheless, postmortem examination of the rabbits sacrificed at various times after irradiation revealed ulcers of the gastric mucosa. The muscular and serous membranes, and also the abdominal wall, i.e., all the layers through which the microwave energy had to pass on its course to the mucous membrane, usually remained intact. The postmortem findings showed that the ulcer (in most cases only one was formed) was located as a rule on

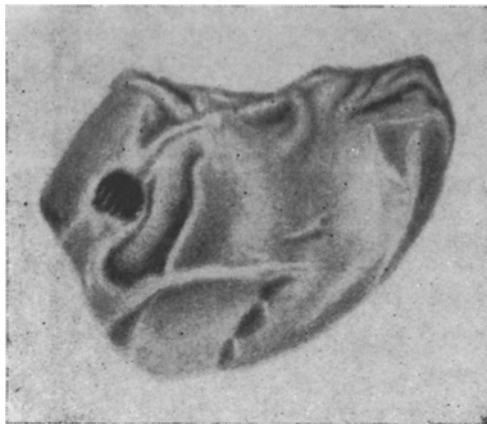


Fig. 1. Recent ulcer of the gastric mucous membrane of a rabbit (exposure 10 min, power of generator 80 W, distance 10 cm).

the irradiated side of the stomach. It was usually fairly typical in appearance: round or oval in shape, 0.3-2.3 cm in diameter or occasionally bigger (Fig. 1). The edges of the ulcer were dark red in color and raised above the surface because of edema of the submucosal layer. This gave it the appearance of a crater. The ulcer usually extended down to the muscular layer, but in some cases it penetrated as far as the serous membrane.

Microscopic examination revealed a comparatively localized area of necrosis of the mucous membrane with a very sluggish leukocytic reaction (Fig. 2). In isolated cases necrosis of the superficial layers of epithelium only was observed, but as a rule it reached the submucosa and, in rare cases, it involved the muscular layer. In the tissue remaining intact near the necrotic area groups of leukocytes were seen, unrelated to blood vessels. The submucosa was looser in structure and permeated with a pale pink, homogeneous fluid. Edema was also observed in the serous membrane, although less marked in degree. The blood vessels of the stomach wall were widely dilated and filled with blood, while some of them had thrombosed.

The changes described above were observed on the second day after irradiation. As the period after irradiation grew longer, the investigation showed sharp changes in the pattern. For example, postmortem examination of the rabbits on the 10th day after exposure to irradiation for 10 min revealed that the edges of the ulcer were firmer. Under the microscope an abundant leukocytic infiltration of all the layers of the stomach wall and the formation of a barrier of granulation tissue at the periphery of the area of necrotic tissue were observed. When the investigation was carried out later still, typical chronic ulcers were seen, with firm, raised edges, and with their base filled with crumbling, dirty gray masses. Microscopic investigation of the ulcer at this stage showed the presence of fibrinous inflammation of its edges with fibrinoid necrosis of the base of the ulcer, outside which was a barrier of granulation tissue separating it from normal tissue. Significant changes were also observed in the epithelium of the mucous membrane, reparative in character but with some signs of structural modification (Fig. 3).

In its histological structure the ulcer thus produced resembled a chronic ulcer of the human stomach



Fig. 2. Localized necrosis of the gastric mucosa of a rabbit and marked edema of the submucosa (24 h after irradiation). Hematoxylin-eosin. Magnification 12x.



Fig. 3. Edges of a gastric ulcer on the 24th day after irradiation. Structural changes in the mucous membrane. Hematoxylin-eosin. Magnification 60 x.

Since the rubber balloon containing water is a foreign body for the stomach, experiments were necessary in which the animals were irradiated but no balloon was introduced. In these cases ulcers developed in the mucous membrane just as often as after irradiation and introduction of the balloon into the stomach. The temperature of the food masses in direct contact with the mucous membrane rose by 1.0-1.5° more than the temperature of the water in the balloon introduced into the empty stomach.

Consequently, the injury to the mucous membrane occurring during irradiation of the epigastric region is selective and probably bears little relationship to the degree of heating of the gastric contents. This was concluded from the results of another control series of experiments (in which warm water was passed through a rubber balloon by means of a double catheter). In the same experimental conditions (fixation, exposure for 10 min) thermal ulcers developed only when the water temperature reached 60°.

To determine the frequency of ulcer development in relation to the power of the generator and certain other conditions, a further eight series of experiments were carried out (see table).

It is clear from the table that when the power of the generator was 60 W, ulcers developed in the unfed rabbits and in the animals irradiated in the course of more than one daily session. When the power was 80 W, lesions of the mucous membrane developed more often, and they were independent of these conditions. When the experiments were performed in this manner the power of 100 W was critical, for it led to the death of some rabbits. It may be asked why ulcers were not observed in all the animals. One reason for this may have been the anatomical and topographical peculiarities of the liver. In some rabbits, for example, the liver almost completely shielded the stomach.

Likewise it is not clear why in different experimental conditions repeated irradiation produced lesions of the mucous membrane whereas a single exposure did not. It may be that during the first application of the procedure certain changes develop in the mucous membrane which do not always lead to the formation of an ulcer, but which, in the course of later exposures, act as a point of least resistance (for example, a microfocus of inflammation in the wall of the stomach). To test this hypothesis the following experiments were carried out.

A rabbit was irradiated from a generator with a power of 80 W, and 1-2 h later laparotomy was performed and the stomach examined from the side of the serous membrane. The injured place could be clearly distinguished in the form of a round stain from the highly edematous stomach wall. The temperature was measured (by means of a needle thermocouple) in the injured and normal areas of the wall. After the normal topographical anatomical relationships of the organs had been restored, the abdominal wall was closed with two or three silk sutures and the

Relationship between Incidence of Gastric Ulcers and Power of Generator, Number of Sessions of Irradiation, and Presence or Absence of Food in Rabbits' Stomach

Series no.	No. of animals in series	Whether fed or not	Power of generator (in W)	No. of sessions of irradiation	Result of autopsy
19	5	Fed	80	1	Gastric ulcer in 4 cases
20	5	Not fed	80	1	" " 4 "
5	5	(balloon in stomach)	80	1	" " 3 "
16	5	Fed	60	1	No ulcers
6	5	Not fed	60	1	Gastric ulcer in 2 cases
17	5	(balloon in stomach)	60	3 ¹	Edema of gastric mucosa in 1 case
8	5	»	60	7 ¹	Gastric ulcer in 3 cases
15	7	Fed	40	1	No ulcers

* One session of irradiation per day.

animal was again irradiated from a generator of the same power. At the end of the exposure the sutures were quickly removed and the temperature measured once again at the same place. The rise in the temperature of the tissues in the affected area was greater (in some experiments by 1°) than in the normal tissues. Consequently, the edematous tissue warms more rapidly, most probably because of the circulatory disturbance and the higher content of water in this tissue.

During irradiation of the epigastric region the muscles of the abdominal wall were heated still more intensively. The rise in temperature of the rectus abdominis muscles after irradiation for 10 min was considerable. However, if irradiation was given repeatedly at the rate of once daily, the warming effect was reduced, and a picture of local temperature adaptation of microwave irradiation developed.

Hence, the lesions arising in the course of repeated irradiation of the mucous membrane were probably associated with summation of the changes arising from each preceding and succeeding session of irradiation. Meanwhile manifestations of adaptation to the thermal action of microwave irradiation may develop in the abdominal wall.

What is the immediate mechanism of selective injury to the mucous membrane of the stomach? It was first supposed that the selective injury to the mucous membrane containing hydrochloric acid was associated with the higher permeability of this membrane. However, special experiments (carried out jointly with A. I. Semenov) did not confirm this hypothesis. The rise in temperature of a 1% solution of hydrochloric acid and of physiological saline, in two identical receivers cut out of gelatin blocks, was practically the same. The mechanism of injury to the mucous membrane thus remains unexplained. Several conditions may be important here: first, the anatomical peculiarities of the mucous membrane, with its many folds and crypts filled with gastric juice and covered with mucus (such a membrane must cool much more slowly than the muscular and serous membranes); second, its histological peculiarities, characterized by high intensity of its physiological regeneration. Young cells are known to be more sensitive to SHF irradiation than mature cells. Because there are many more young cells in the mucous membrane than in the muscular and serous coats, there is another possible mechanism of ulcer formation—by the blocking of physiological regeneration. Finally, the resistance of the mucous membrane of the stomach to autodigestion may possibly be disturbed by SHF irradiation directly or indirectly, for example, as a result of its more intensive warming.

LITERATURE CITED

1. H. M. Hines and J. E. Randall, *Electr. Enging.*, 71 (1952), p. 879.