of the ear and prevented infection from penetrating between the free edge of the skin and the molded disk. The operation of implantation was completed by painting 10% chloramphenicol emulsion on the skin around the chamber.

Biomicroscopic investigations showed that a regenerating network of microvessels was observed in all the implanted chambers 21-23 days after the day of the operation, and it completely filled the space in the chamber at the end of the fourth week. No case of ejection of the chamber or necrosis of the tissues around the chamber was observed. The optical properties of the chamber proved to be highly satisfactory and they remained essentially unaltered throughout the period of implantation (Fig. 3). The designed features of the chamber also enabled the regenerating tissue to be used for subsequent histological study.

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RHEOGRAPHY OF THE STOMACH

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A practical method of rheography is suggested for studying the state of the human gastric circulation. The theoretical aspects of the use of a bipolar system of electrodes (external and internal) with essentially different sizes of contact surface are examined with respect to the stomach. A scheme and brief description of the simple apparatus are given. Control experiments were carried out on animals to confirm the validity of the basic assumptions. Mean values of some rheographic indices frequently used in clinical practice, based on rheograms of the stomach of 30 healthy subjects, are given.

KEY WORDS: *rheography; stomach; animals; man; sensitive probe.*

Rheography [17], electroplethysmography [4], and impedance plethysmography [19] are widely used at the present time in clinical investigations, mainly to assess the state of the regional circulation: in the limbs [3, 18, 20], the skull [1, 5, 16], the thorax [11], and the region of the liver [6] and other organs [10]. However, the method of rheography, with electrodes placed on the surface of the human body, frequently cannot be used to assess the state of the circulation in the internal organs, with the consequent need for introducing electrodes inside the lungs [7, 8], kidney [15], and rectum [2].

Todorov [12], who placed one electrode freely inside the lumen of the stomach and the other on the skin of the epigastrium, concluded that the motor activity of the stomach can be assessed in this way but not the state of its circulation. Yet assessment of the state of the circulation in the stomach is a very important matter in clinical practice.

The object of this investigation was to attempt to use the method of rheography to investigate the state of the gastric circulation. To record a rheogram of the stomach wall reproducible under identical conditions reliable electrical contact must be ensured with the

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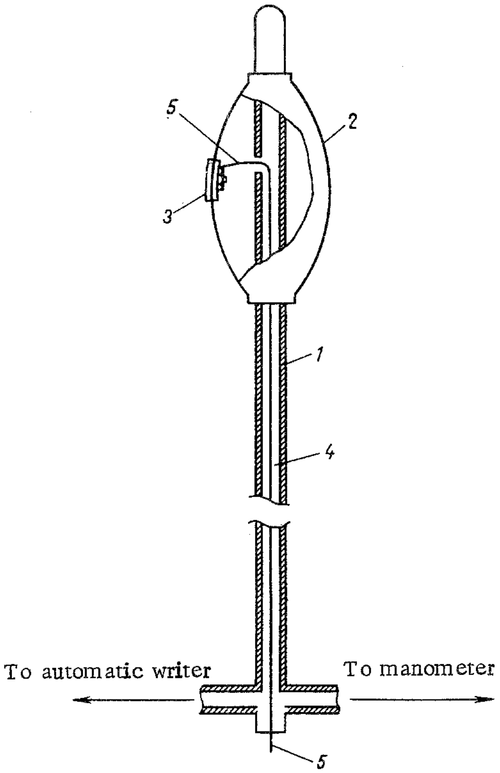

Fig. 1. Sensitive probe for recording rheogram of the stomach (scheme): 1) gastric tube; 2) rubber balloon; 3) active electrode made from rustproof material; 4) air passage; 5) conducting wire. Further explanation in text.

gastric mucosa and measurements of electrical resistance must be localized to the region of the stomach wall. In other words, a method of measurement must be provided so that its results can be ascribed purely to the state of the circulation in the stomach. It is best to use electrodes with substantially different sizes for this purpose. One electrode, located in the lumen of the stomach, must have a small area whereas the other, located on the body surface, is many times larger. By placing two electrodes of appropriate size on a balloon a short distance apart, the zone of the wall of the stomach studied in the rheogram can be enlarged to some extent, but if the electrodes are placed a substantial distance apart this reverts again to the recording of a local (subelectrode) type of rheogram, but in this case the aggregate from two electrodes. To simplify the calculations let us assume that the internal electrode is spherical in shape and that its surface area is equal to the area of a real disk electrode. The dimensions of the human body and the surface area of the second electrode will be regarded as infinitely greater than the area of the internal electrode. In that case, by the laws of electrostatics [13], it follows that the measured resistance (R) is related to the specific resistance of the isotropic medium (P), the radius of the spherical electrode (r) and the distance (l) to the second electrode (of equipotential surface) by the simple equation:

$$R = \frac{\mathrm{P}}{4\pi r}\left(1 - \frac{r}{2l - r}\right), \tag{1}$$

where the term in brackets on the right-hand side of the equation is the value of the resistance (R_i) at the boundary between the internal electrode and the medium. It will be clear from this equation that if the radius of the spherical electrode is relatively small, about 0.28 cm for example (the surface area of the sphere equivalent to the area of a thin disk electrode measuring 1 cm^2), and the distance (l) between the nearest part of the gastric wall and the body surface is not less than 4-5 cm, the value of the resistance measured will depend for practical purposes only on the resistance of the medium in the immediate vicinity of the active electrode:

$$\frac{R}{R_i} = 0.963 - 0.971, \text{ i.e., } R \approx R_i .$$

Increasing the distance l (when the rheogram is recorded from parts of the stomach wall further from the reference electrode), as will be clear from Eq. (1), improves the result a little.

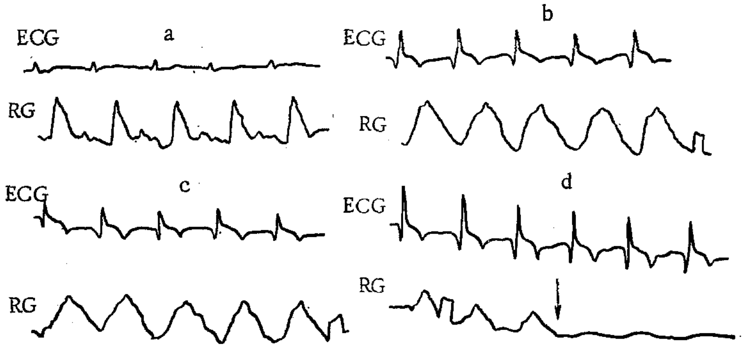

Fig. 2. Rheograms of dog's stomach under different experimental conditions. ECG in standard lead II; RG) rheogram of stomach; a) intact animal; b) after deep anesthesia and preparatory laparotomy; c) after application of reference electrode to exposed stomach through a layer of cotton soaked with physiological saline; d) before and after application of clamp to cardial portion of stomach. Moment of application of clamp shown by arrow.

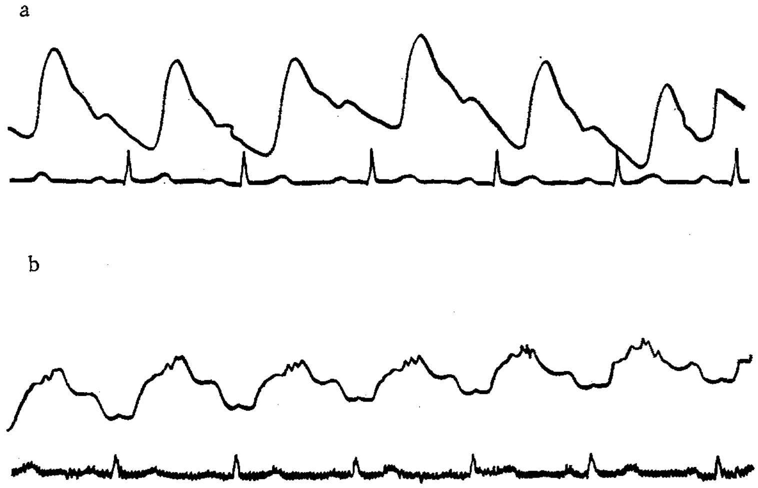

Fig. 3. Rheogram of stomach of a healthy subject (a) and patient with peptic ulcer (b). Top curve) RG; bottom curve) ECG.

The resistance of a disk electrode can be calculated by the equation $R = P/4r$, where R is the resistance of the disk electrode, P the resistivity of the tissues between the electrodes; and r the radius of the thin disk electrode. The ratio of the resistance at the boundary between the stomach wall and the internal electrode (R_i) to the resistance at the boundary between the skin and the external electrode (R_e) is inversely proportional to the radii of the disk electrodes:

$$\frac{R_i}{R_e} = \frac{r_e}{r_i}.$$

If the internal electrode has a radius of about 0.565 cm (area 1 cm^2), and the external electrode a radius of about 8 cm, the resistance beneath the external electrode will be about 7% of that beneath the internal electrode. Considering that at rest the blood flow through the skin is several times less than that through the organs of the gastrointestinal tract [14], with this method of recording the rheogram it will be determined for practical purposes purely by the dynamics of the electrical conductivity of the tissue beneath the internal electrode, i.e., by the state of the circulation in the stomach wall.

TABLE 1. Mean Values of Indices of Gastric Rheogram in Healthy Subjects

Index	Symbol	M ± m
Velocity of spread of pulse wave, cm/sec	$Q - x$	0.127 ± 0.007
Duration of anacrotic phase, sec	α	0.017 ± 0.009
Duration of catacrotic phase, sec	β	0.432 ± 0.036
Anacrotic/catacrotic ratio	α/β	0.390 ± 0.028
Time of appearance of venous wave, sec	$Q - y$	0.356 ± 0.009
Rheographic systolic index	I_s	2.72 ± 0.195
Rheographic diastolic index	I_d	1.63 ± 0.132
Ratio between amplitude of systolic wave and amplitude of diastolic wave	A_s/A_d	1.76 ± 0.091
Amplitude—frequency systolic index	$A_r n_s$	5.00 ± 0.606
Amplitude—frequency diastolic index	$A_r n_d$	2.80 ± 0.327
Sphygmic velocity index, %	$\alpha/RR \times 100$	17.63 ± 1.083

The rheogram is recorded by means of an ordinary thin gastric tube (Fig. 1), on the end of which is mounted an inflatable rubber balloon with the electrode (area 1 cm^2) fixed on the wall of the balloon and connected to the input of the rheograph by a wire located inside the tube. The air passage of the tube connects the cavity inside the balloon through a simple switching device to the air pump and to an instrument for visual inspection of the pressure in the balloon and also to an apparatus for recording fluctuations of pressure in the balloon graphically when it is necessary to record the motor function of the stomach at the same time. The second thin disk reference electrode, with a radius of 8 cm (area 200 cm^2) is placed on the body surface usually on the abdomen, and rests on a pad moistened with salt solution. The two electrodes are connected to the input of a mass-produced rheograph with carrier frequency of not less than 30 kHz (the RG-1-01 or, better still, the 4RG-1A), connected to a standard light-spot, pen, or jet automatic writer.

Since assumptions regarding the isotropism of the interelectrode medium and substitution of a spherical for a disk electrode, and so on, which may appear to rest on an insufficiently solid basis, were made above it was clearly desirable to confirm the practical validity of these assumptions experimentally.

The sensitive probe was introduced into the stomach of an anesthetized dog through the mouth, the balloon was inflated, the rheogram recorded (Fig. 2a), the anesthesia deepened, and laparotomy performed. The exposed stomach was covered with a thick layer of cotton soaked in physiological saline, the reference electrode was placed on the cotton, and the rheogram recorded (Fig. 2b). The wound edges were again apposed and the rheogram of the stomach was recorded by the adopted method (Fig. 2c). While the rheogram was being recorded a clamp was applied to the cardial portion of the stomach (Fig. 2d). As will be clear from Fig. 2, rheograms b and c differ only a little in shape and amplitude. Application of the clamp to the cardial portion of the stomach causes the virtual disappearance of the rheographic curve, i.e., exclusion of all tissues except the stomach from the field of the electrodes does not change the rheogram, whereas clamping the blood vessels supplying the stomach leads to almost total disappearance of the rheographic oscillations. It is also clear from Fig. 2 that the rheogram of the stomach changes in response to various procedures (anesthesia, laparotomy, etc.) capable of modifying the state of the circulation.

Investigations in man are usually carried out in a fasting state, with the subject in recumbency, after resting for 15-20 min, with the breath held in the phase of normal expiration and in the absence of gastric peristalsis. After the subject has swallowed the tube under x-ray control the site of contact of the electrode with the gastric mucosa is chosen and air is pumped into the balloon until complete contact is obtained between the electrode and the stomach wall. The level of the pressure in the balloon is chosen experimentally, for it depends on the volume of the stomach and on the size and elastic properties of the balloon. If the balloon is made from a finger stall (length about 70-80 mm, perimeter of base about 60 mm), a pressure of 70-80 mm Hg is usually sufficient to give good contact between the electrode and the gastric mucosa. The rheogram of the stomach of a healthy person aged 36 years, which is analogous to the rheogram recorded in other parts of the body, is shown in Fig. 3a. It can be analyzed by the usual method of analysis of rheographic curves. Mean values for some indices frequently used in clinical rheography [9], calculated from rheograms of the stomach recorded in 30 healthy subjects, are given in Table 1. Analysis of rheograms from persons of different ages and also from patients with peptic ulcer (Fig. 3b) revealed certain details that require further investigation and special analysis, outside the scope of this communication.

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