GASTRIC ELECTROMYOGRAPHY : PAST, PRESENT AND FUTURE

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THE PAST:

The history of gastric electromyography is brief. Although it was recognized that a resting electrical potential existed across the wall of the stomach about 1850, Alvarez, in 1922, was the first person to record the varying electrical waves of the stomach. He correctly recognized the myogenic origin of these slow alternating potential variations of the stomach, but because of his concern for the accuracy of the recordings, other workers apparently were not stimulated to continue his work. After a lapse of twenty-five years, the study of the electrical wave of the stomach in man was renewed by a number of workers, for example, Sobakin in the U.S.S.R., Goodman and colleagues in the United States and Morton and colleagues in Canada. A large portion of the effort of these later workers was devoted to recording the waves from the surface of the abdomen by cutaneous electrodes, a method fraught with difficulties until very recently. During the time of his active investigative period, Morton coined the term *electrogastrogram* for the recorded waves at the surface. Although all of these workers successfully recorded electrical potentials generated by the stomach, their success was not consistent for the following reasons.

a. The recording was usually carried out with amplifiers which amplified both D.C. and slow alternating current potential variations. The D.C. amplifiers available at that time did not permit a stable baseline. Electrodes were generally of poor quality for chronic recording.

b. Variations in tissue electrode contact produced potential variations which resembled the true electrical wave thus often confusing interpretation when mechanical activity occurred.

c. Contamination with signals from the heart, intestine, skeletal muscle, etc., rendered interpretation of the recordings extremely difficult, especially those recordings obtained from the surface of the abdomen.

d. Perhaps the most serious problem of all was the fact that the prevailing concepts of the normal electrophysiology and mechanical physiology of the stomach did not permit the interpretation that the electrical wave actually preceded the mechanical wave and that the degree of coupling between the electrical and mechanical waves ranged from none to complete. Most of the workers in the past felt that the electrical wave was generated by the mechanical contraction of the stomach.

e. Analysis of recorded waves was largely based on past experience with the electrocardiogram and the electroencephalogram, both of which are different in frequency content, type of generator and ease of recording. A great deal of emphasis was placed on interpretation of waveform amplitude and waveform configuration, two characteristics of the wave which are most easily destroyed by noise, tissue transmission inhomogeneities and other distortions. Concentration on the rhythmicity of the recorded electrical information was not evident except that average rates were determined.

In summary, it may be said that, in spite of enormous technical difficulties, particularly with electrodes and the electronic assemblies available, the normal human gastric electrical activity was successfully recorded but not well characterized, except as to mean rate.

THE PRESENT:

Today a number of workers in Japan, Europe and the United States are carrying out serious studies of the gastric electrical activity based on what is considered a more fundamental concept of the electrophysiology of the stomach. This approach might be summarized as considering the electrical wave of the stomach as arising in the body of the stomach and passing aborally as a moving annulus of electrical depolarization, in other words, a propagated action potential.

A pacemaker exists at the upper end of the body of the stomach where the electrical waves begin; this pacemaker controls the repetition rate and the stability or timing of the electrical and peristaltic waves. Much evidence exists that any portion of the stomach is capable of acting as a pacemaker. The normal dominant (highest order) pacemaker appears to be located somewhere on the lesser curvature in the region of the esophagogastric junction.

The electrical rate is the same in all portions of the stomach in the normal situation; i.e., no gradient of rate exists normally. Since all portions of the stomach are capable of acting as pacemakers (are automatic when independent), one must assume the entire gastric musculature is electrically entrained and driven by the highest order pacemaker.

A large amount of difficulty in interpretation of recordings is caused by variations in electrodes and in electrode-tissue contact. For this reason, considerable experience is needed when interpreting monopolar type recordings and this fact alone renders amplitude and configurational analysis of the recorded waves most difficult with the monopolar connection.

Our own particular contributions in this area have been based upon the hypothesis that the electrical rate is related to physiologic organ function of the stomach in both the dog and man. Several series of experiments and studies, initially in the dog, later in man, have tended to confirm this hypothesis. Mean rate of electrical activity and its statistical variation appears to be a meaningful indicator of physiologic function in the stomach. It is this material which I would like to present for your consideration today.

Our studies have been carried out with the following features:

1. Improved electronics utilizing amplifiers constructed of solid state components, and intentional recording of only the gastric slow alternating potential (A.C. coupled) to stabilize the baseline and permit easier interpretation of the rhythmic potential fluctuations

in the recorded signal.

2. Improvement of electrodes. This is due to better methods of fabricating silver-silver chloride electrodes for surface recordings and to improvement in insulating materials and knowledge of techniques of implantation. We have studied 40 dogs and 15 patients with implanted electrodes in addition to 40 patients with cutaneous electrodes.

3. A serious attempt has been made to apply modern data processing methods and signal retrieval techniques to enhance the recording and analysis of the gastric electrogram and the cutaneous electrogastrogram. Throughout all of these studies the emphasis has been on the detection of rhythmicity and the study of long recorded segments, viz., twenty minutes to several hours.

Before presenting the actual details of our methods and the results, I would like to mention the important work done in Japan. These studies have served as basic support for our studies, although the methods are entirely different, in fact, complementary to each other. The use of bipolar swallowed electrodes has many advantages over the methods to be presented from our laboratory. In particular, the simplicity of electrodes, relative ease of recording and straight forward design of the electronics needed to retrieve the wave should be mentioned. Direction of propagation of the electrical wave is also easier to determine with the bipolar technique.

Our method using implanted electrodes requires a surgical operation to achieve good recordings. These implanted electrodes are usable almost one hundred percent of the time and yield excellent quality tracings for many days. The cutaneous methods offer the poorest quality recordings, but are the easiest for the patient; they can be carried out on most subjects provided the electronics are satisfactory and the investigator is skilled in the use of the equipment.

Our own studies have proceeded along three lines; a) characterization of the normal electrical function of the stomach in dog and man, b) the application of signal analysis techniques for retrieval of the electrogastrogram in man and c) the effect of denervation in both species. All techniques used were designed to facilitate rhythmic analysis. The following methods have been used for signal retrieval and analysis.

i. Autocorrelation with a digital computer program has proven extremely useful for determination of the mean rate in noisy data.

ii. Phaselock detection of the cutaneous gastric electromyogram. This has proved to be the most powerful filtering technique available for use on noisy data.

iii. On-line determination of mean rate and its standard deviation with the computer. This direct technique is useful only when the signal is strong and easily recorded. It has the advantage that the analysis is carried out simultaneously with the recording of the signal (on-line).

iv. Digital computer programs have been written to determine the best electrode combinations automatically and to guide in the selection and adjustment of filters in use during the recording. More experience needs to be gained before this method can be adequately evaluated.

v. Plots of the joint interval histogram have discerned hidden rhythmicities in the data with relative ease. This has been useful for the detection of multiple pacemakers and arrhythmias.

vi. Long-term studies in the dog and man indicate that a stable gastric rate for 20 minutes or longer is probably a sufficient baseline of rate for physiologic testing.

vii. The stomachs of man and the dog display characteristic rate responses to feeding and probably to insulin hypoglycemia.

viii. Studies have indicated that vagotomy and certain surgical incisions in the stomach produce characteristic alterations of the rhythmic rate and its statistical variation.

ix. Very limited experience indicates that in diabetic neuropathy of the stomach a rhythmic disturbance which is episodic can be recorded in the gastric electrogram.

In summary, it may be stated that recording of the gastric electromyogram, either by the swallowed two electrode technique, the implanted electrode technique, or the cutaneous multiple electrode technique will yield useful recordings of the electrical waves in man whose rhythmic characteristics can be interpreted with some certainty, and that these interpretations will lead to useful diagnosis in a certain percentage of patients.

THE FUTURE:

It is believed that the study of a large number of patients with varied gastric disease will permit characterizations of the normal and certain disease patterns which will be useful as diagnostic criteria. Present information permits the prediction that patients with gastric ulcer, neuropathies of various sorts, and vagotomy can be distinguished from the normal by standard statistical methods.

The future undoubtedly will see improvement and refinement of methods and techniques with discarding of the poorer ones and adoption of new, better ones.

Of the automated data analysis procedures now under trial, certain of them will prove to be reliable and useful, others will prove cumbersome and too expensive.

There is a reasonable expectation that new fundamental knowledge of the electrical physiology of the stomach will make interpretation of the crude gastric electromyogram recorded from patients much easier and more readily related to the actual electrophysiologic events occurring in the muscle.

It may also be assumed that certain operations will be refined and improved by the knowledge gained from these studies so that postoperative emptying defects will be rarer.

Eventually, gastric electromyography may take its place with other new techniques used in gastric diagnosis.

I would like to express my great appreciation for the honor accorded me by the Officers and Members of the Japan Society for Smooth Muscle Research in being asked to present this lecture.