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Computerized Analysis of Spike-Burst Activity of the Upper Gastrointestinal Tract

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Although the electrical recording of spike-burst activity is a well-established technique, the visual–manual analysis of the electrical tracings is laborious and time consuming. Current automated methods for analyzing upper gastrointestinal spike-burst activity involve the use of computer systems capable of storing large quantities of data. We describe herein an automated system for counting myoelectrical spike bursts that provides online detection of spike bursts using a laboratory computer. Because only the parameters that describe each burst are stored, only a minimal amount of computer memory is required. Subsequent analysis of stored information yields tabular or graphical output of data. Results of the computer analysis are comparable with those obtained by visual–manual assessment.

Studies designed to investigate the fasting and fed patterns of myoelectrical activity in the upper gastrointestinal tract commonly yield multichannel tracings that are often 6–8 hr or longer in length (1, 2). The detailed visual–manual analysis of such tracings requires considerable time that often exceeds the finite capacity of available research personnel. For this reason, a workable computer method would be helpful for bulk analysis of gastrointestinal myoelectrical activity. This report describes a convenient method for computer analysis and display of gastrointestinal spike-burst activity. Advantages of the method include: (1) minimal data storage requirements due to online detection of spike-burst activity, (2) ease of operation by laboratory personnel, and (3) results that are comparable to those obtained by visual–manual analysis.

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MATERIALS AND METHODS

The opossum was selected as the experimental animal model. This animal was chosen because it exhibits well-defined migratory myoelectric complexes (MMCs) during fasting and its sphincter of Oddi is mostly extraduodenal allowing ready implantation of electrodes (3, 4). At laparotomy, paired bipolar electrodes were implanted on the gastric antrum (GA), proximal duodenum (D_1), mid duodenum (D_2), sphincter of Oddi (SO), proximal jejunum (J_1), and a distal jejunum (J_2). The electrodes consisted of nichrome wire of 120 μm inner diameter, insulated with trimel (Johnson Mathey Ltd., Toronto).

Recording sessions were begun 1–2 weeks after electrode implantation. The wire cable that was plugged into an interscapular connector led to an eight-channel polygraph (Beckman Instruments, Inc., Fullerton, California). Recordings were made within a bandpass frequency of 5.3–30 Hz (Figure 1A). The six channels of myoelectric data were recorded on a HP3968 instrumentation tape recorder (Hewlett-Packard, San Diego, California).

Bandpass Filtration. Additional filtering of the myoelectrical recording was done prior to computer analysis. Second-order Butterworth filters (5) with a bandpass frequency of 10–20 Hz (−3 dB) were used. These filters served two purposes. First, the filters caused attenuation of slow waves (Figure 1B). This attenuation yielded a clean, easily detectable spike-burst signal. Second, by setting a lower high-frequency cutoff of 20 Hz, as opposed to the initial cutoff of 30 Hz, analog to digital conversion sampling could be done at a lower rate. The

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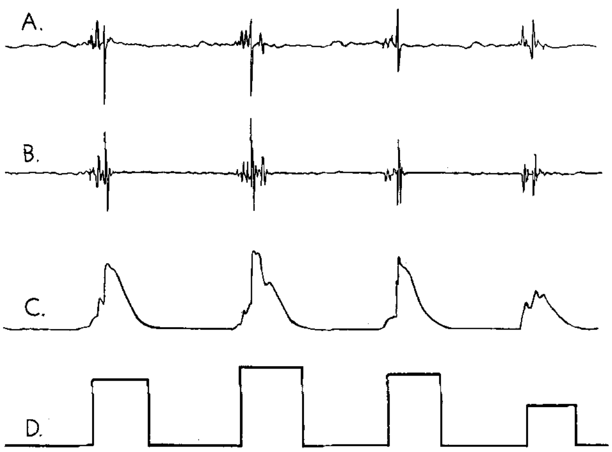

Fig 1. Example of computer processing for a 1-min tracing of duodenal myoelectric activity. (A) Analog recording. Slow waves and four spike bursts are present. (B) After bandpass filtration. Filtration through the 10- 20-Hz bandpass attenuates the slow waves while having minimal effect on the spike bursts. (C) After slope averaging. Following A to D conversion, the data is processed for changes in slope. The averaging of slope changes minimizes signals caused by noise or slow waves. (D) Square-wave representation of stored information. The temporal occurrence, duration, and amplitude of each detected peak are stored for subsequent analysis and counting.

Nyquist criteria allows sampling without aliasing or distortion, at twice the highest frequency component in a signal. Therefore, a sampling rate of 40–50 Hz was adequate.

Computer Analysis. Computer analysis was done on a DEC MINC-11 laboratory computer (Digital Electronics Corp., Marlboro, Massachusetts). This computer has 128 K bytes of main memory and dual RX02 floppy disk drives. The operating system used was RT-11, V 4.0. Software analysis programs were written in Fortran IV. These programs were responsible for four tasks: (1) A/D conversion of the filtered myoelectrical recording, (2) online processing and detection of probable spike bursts, (3) statistical separation of true spike bursts from other electrical activity, and (4) tabular and graphical output of analyzed data.

The online system specified a double buffer A/D conversion with a user-written completion subroutine that analyzed the most recently filled buffer while the other buffer was being filled. In this manner, A/D conversion analysis was done continuously. Six-channel digitalization was done at a rate of 50 Hz per channel.

The completion subroutine contained an algorithm that processed incoming data as well as detected and stored information from probable spike-burst activity. Initial computer processing involved calculating the second-order differential of the incoming data and then averaging the slope for a 0.2-sec interval. This process was applied as a modified moving average (6). The effect of this process was to sum the changes in slope that occurred during a time interval of 0.2 sec or greater and to attenuate those slope changes occurring for a short interval of less than 0.2 sec. Thus, the method gave a small signal for a single spike, but generated a large signal for a burst of spikes. The process sums individual spikes of a burst into a monophasic wave (Figure 1C) or less commonly a multiphasic wave, while attenuating noise or the initial fast-frequency component of slow waves.

Threshold detection of the processed data identifies probable spike-burst activity. For each processed wave, the following information was written into a direct access file: (1) channel at which the wave occurs, (2) time at which the wave went above threshold, (3) time at which the wave came below threshold, and (4) magnitude of the wave peak. Substantial data reduction between the incoming myoelectric recording and stored information made it possible to store processed information on a floppy disk (Figure 1D). The threshold levels were set low enough to detect most processed waves. Statistical analysis of the stored information allowed the separation of valid spike-burst activity from the occasional illicit electrical activity. Slow waves and noise that were detected as processed waves were generally separated from legitimate spike bursts by their lower amplitude and duration. Only illicit electrical activity that falls within the range of values for spike bursts will be erroneously detected as spike bursts.

Spike-burst rate was outputted in both tabular and graphical form. Storage of temporal occurrence of each spike burst enabled the outputs to be given as absolute number or rate (No./min) for any time increment desired.

Comparison with Visual–Manual Method. To compare the spike-burst counts generated by the computer with those given by the visual–manual method, we analyzed a 60-min segment from each of four separate recordings. For uniform test intervals of 2 min, the four 60-min samples yielded 120 samples of 2 min each for comparison. For each 2-min sample, the number of spike bursts outputted by computer as number per minute was compared to the number per minute assessed by visual inspection. This comparison was done in an unbiased fashion for four recording sites: gastric antrum, duodenum, sphincter of Oddi, and jejunum.

RESULTS

Measurements of spike-bursts obtained by the computer method compared favorably to the measurements done by the visual–manual method (Figure 2). For the four recording sites chosen for analysis: gastric antrum, duodenum, sphincter of Oddi, and jejunum, perfect agreement existed in 78–89% of 2-min samples between the spike-burst counts obtained by the computer and visual–manual methods. In another 10–23% of samples, depending on the specific site, the two methods agreed within one spike burst. Differences of three or more spike bursts between the two methods occurred for only 1% or less of the samples. For the 120 test samples, the differences in spike-burst counts between the computer and visual–manual methods were: 0.12 ± 0.35 (SD) for the gastric antrum, 0.23 ± 0.6 for the

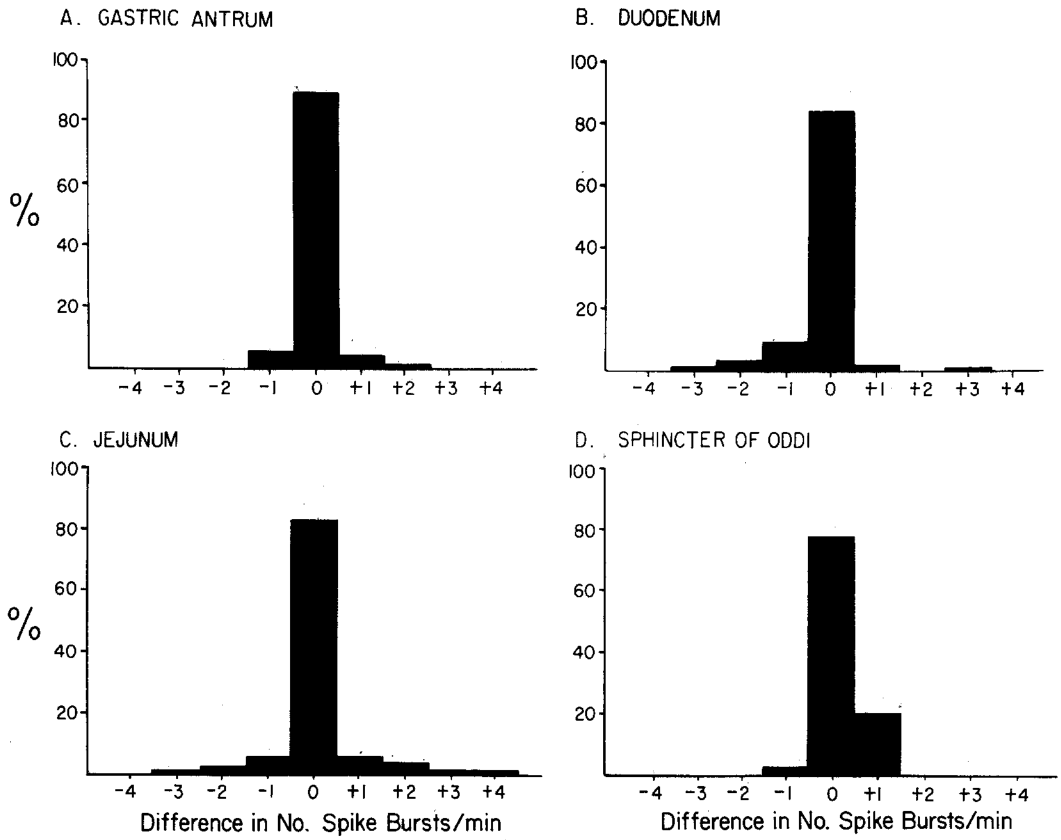

Fig 2. Comparison of spike-burst counts obtained by computer and manual methods. Comparisons were done for 120 samples of 2-min each for each of four recording sites. The frequency–distribution plots for each set of 120 samples are expressed in percent.

duodenum, 0.23 ± 0.41 for the sphincter of Oddi, and 0.29 ± 0.71 for the jejunum.

A graphic example of an 8-hr recording analyzed and plotted by the computer is shown in Figure 3. Execution of the computer program and plotting required only 30 min of technician time as compared to the 15 hr required for visual–manual measurement of six channels of recording and the graphing of the results.

DISCUSSION

Two major types of myoelectrical activity exist in the upper gastrointestinal tract: (1) slow waves, also known as electrical control activity, and (2) spike potentials, also referred to as electrical response activity or action potentials (7). In this study, we developed a computer method to count and plot spike bursts.

In the upper gastrointestinal tract and sphincter of Oddi, spike-burst activity is the myoelectrical equivalent of phasic mechanical contractile activity (4, 7). In the past, different methods have been used to quantitate electrical spike activity. Latour (8) and Wingate et al (9, 10) have used computer methods to count electrical spikes and generate temporal plots of changes in spike rate. This method, however, does not give a one-to-one profile of electrical and contractile activity because each contraction is heralded by a burst comprised of several spikes rather than a single spike. For this reason, the optimal method of estimating contractile activity from myoelectrical recordings is to count each spike burst as a single event. This later method has been adopted by Summers and coworkers (11).

Computer analysis of myoelectric spike bursts requires differentiation of the spike bursts from slow waves and recording artifacts. Two methods facilitate such a distinction: (1) initial bandpass filtration of the recorded analog data, and (2) processing of the digitalized data in the completion

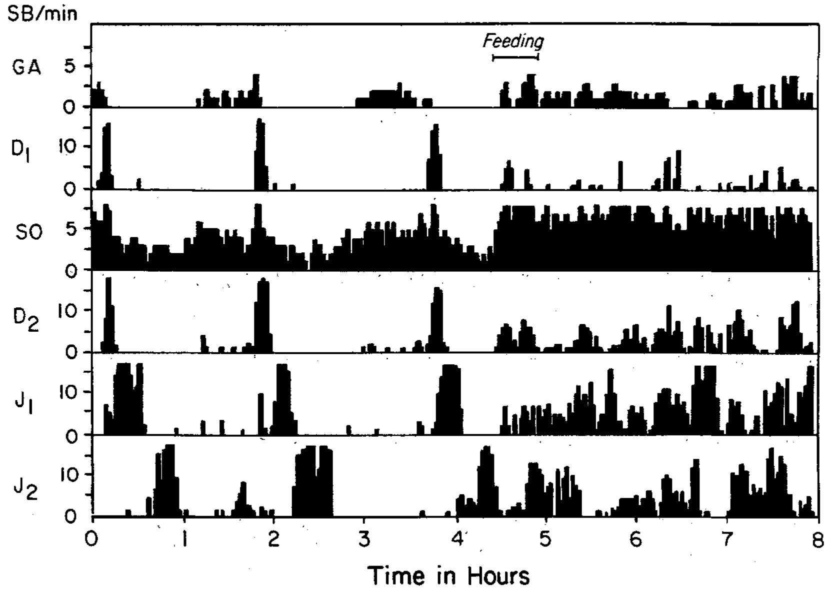

Fig 3. Computer plot of the rate of spike bursts in the upper gastrointestinal tract and sphincter of Oddi of a fasted opossum. Recordings were made from the gastric antrum (GA), duodenum (sites D_1 and D_2), sphincter of Oddi (SO), proximal jejunum (J_1), and distal jejunum (J_2). Spike-burst rate for each recording site is plotted for 2-min intervals as number per minute (No./min). During fasting, three migratory myoelectric complexes (MMCs) occurred. Changes in the rate of SO spike burst were synchronized with the duodenal MMC. Feeding caused a fed pattern of spike-burst activity in the stomach, small bowel, and sphincter of Oddi.

subroutine. Bandpass filtration is accomplished by interposing filters external to the computer in the chain of signal processing. The method of external filtering does not cause an increase in the computer processing time as does the digital filtration method used previously by other workers (11). Digital filtering of data is an effective technique, but is not the method of choice for an online detection system. The time requirements for digital filtering are too long to allow online processing of spike bursts. The processing of digitalized data in the completion subroutine allows the detection of spike bursts as a single wave form. Wave information (temporal occurrence, duration, and amplitude) is stored in a computer file. The information from one wave is stored in 16 bytes of computer memory. Thus, the processed data for all spikes that occur on eight channels of recording during a 6- to 8-hr interval can be stored on a conventional floppy disk with 512 K bytes of memory.

In summary, this report describes a convenient computer method for analyzing and displaying myoelectrical spike-burst activity of the upper gastrointestinal tract. The method: (1) provides accurate results comparable to visual–manual measurements, (2) requires minimal computer memory, thereby allowing implementation by medium-priced laboratory computers, and (3) eliminates the numerous hours needed for visual–manual analysis.

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