

Fully automated computer analysis of intracolonic pressures

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SUMMARY A fully automated (PC compatible) software and hardware analysis system has been designed and developed to analyse colonic pressure records quickly and objectively. Eight hours of colonic pressure trace was analysed in 48 10 minute epochs manually and by computer for the variables of mean amplitude, % duration of activity, motility index, number of peaks and activity index. Agreement between methods was good for mean amplitude: (bias -0.5 mmHg; (36.8) (2 SD, limits of agreement); -5.8 to 4.8 , 95% CI of bias; $0-289$, average range of values by both methods), % duration of activity: (-0.9 ; (13.4) ; -2.9 to 0.9 ; $0-100$), motility index: (-55 ; (2072) ; -356 to 245 ; $0-26220$), number of peaks: (-20 ; (91) ; -44 to 3.5 ; $1-211$), and activity index bias -5.2 mmHg. min; (127.3) ; -23.7 , to 13.2 ; $0-2159$. The time taken for manual analysis was 889 minutes compared with 14 minutes for the automated system. Fully automated analysis of colonic pressure records is fast, objective, and shows good agreement with labour intensive manual analysis. Previously acquired data can be reanalysed using new definitions and criteria. Widespread use of the technique could introduce uniformity in colonic pressure record analysis. In addition this wave form analysis system can be adapted to record and analyse pressure data from other regions of the gastrointestinal tract.

Progress in colonic motility has been slow and the problem of colonic pressure trace analysis is a major factor. Manual analysis of intestinal pressure records is extremely laborious and there are no universally accepted methods, or criteria. In addition, comparisons of studies from different centres are usually impossible because of differences in the methods of analysis. To solve this problem we have designed and developed a fully automated computerised system to analyse pressure records quickly and objectively.

Methods

SYSTEM DESIGN

This system was developed by the 'top-down' method of program design divided into the basic units of: data acquisition, storage, retrieval, and analysis. Data acquisition required the design of specific hardware.

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The software was developed in modules for the functions listed previously.

DATA ACQUISITION

HARDWARE

An analogue to digital converter (PC-Polygram, *Synectics Medical*) with eight independent channels was made to convert the electrical signals from the polygraph's pen-galvanometer driver amplifiers into digital values. This required special preamplifiers which would allow smooth data conversion of voltage swings of the pen-galvanometer (Grass 7PD) from $+1.35$ V (zero pen deflection) to -1.35 V (full scale deflection). Data transfer from the PC-Polygram to the serial interface of the computer was made by fibreoptic cable, to ensure isolation of the patient from mains electricity. The PC-Polygram was equipped with offset and gain controls for each individual channel, to allow accurate baseline setup and calibration.

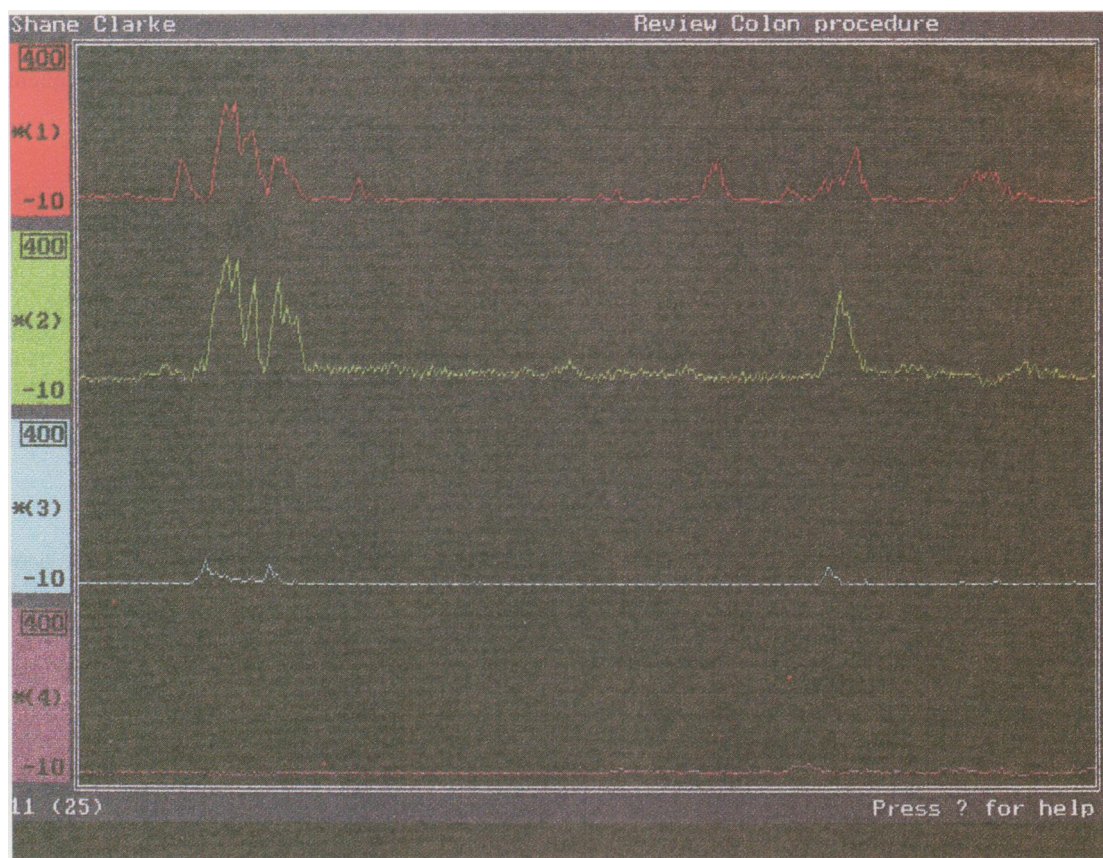


Plate Illustrates the appearance of the pressure trace on the computer monitor.

SOFTWARE

This module allows the digital byte values generated by the PC-Polygram for all channels to be read on screen (scale 0–254) along with a graphical (LED-type) display. This enables each channel baseline and gain to be set equally for complete accuracy between channels. Using this system, the magnitude of the variable being recorded per byte (the resolution) can be set to individual requirements of the user.

2 Individual channel calibration

This allows the baseline, the low and high calibration values for each channel to be entered and saved for the study protocol.

3 Study design programmable to users requirements

This module allows the user to define the variable

name and unit of measurement and to define which channels are to be used. Additionally, the sampling frequency can be selected from a minimum of 2 Hz to a maximum of 512 Hz. All these selections are saved to ensure that the same protocol is followed in subsequent studies.

4 Real time display

As recordings are made pressure waves are displayed for each channel in real time. The display time base may be altered without changing the sampling rate and event markers may be placed on the trace as the recording proceeds.

DATA STORAGE

Initially the acquired data are stored in the random access memory (RAM) and are then saved to magnetic disk when full. The length of uninterrupted recording is dependent on the amount of RAM

available and the sampling rate. Six hundred and forty kbytes of RAM is sufficient to store 166 minutes of uninterrupted four channel recording at a sampling frequency of 16 Hz per channel. As the data transfer time to hard disk for 640 kbytes is in the region of five seconds, very little data are lost even if prolonged recordings with a fast sample frequency are made.

Once data are stored on the hard disk, transfer of the data files and backups can be made to other magnetic or opticomagnetic media by standard DOS commands.

DATA RETRIEVAL

Data can be retrieved and displayed to screen or printer.

Screen

The screen mode allows viewing of all channels simultaneously (Plate), or individually. The time scale (X-axis) and the unit scale (Y-axis) can be increased or decreased by the user. Measurements of amplitude, mean amplitude, duration, integrals, and the area under the curve of individual or groups of wave forms can be done by selecting combinations of the function keys on the computer keyboard. This 'interactive analysis' is done by using two movable vertical and one horizontal cursors. In this mode readings can be taken from the true baseline (zero at start of study), or from the position of the horizontal cursor as directed by the user.

It is in the screen mode that portions of the trace can be marked accurately for automated analysis. Cursors may be placed with reference to event marks (entered on the computer record during the study) and by means of the time base.

Printer

Display to printer allows printing of the whole record, or parts of selected channels. The time scale can be varied to give an output similar to that of the pen and ink trace output of a polygraph (Fig. 1), or a more compressed or expanded time scale.

AUTOMATED ANALYSIS

The program will automatically analyse the marked trace for the variables of: mean amplitude, % duration of activity, motility index, number of peaks, and activity index producing a numerical tabular output to the printer for each individual channel and epoch.

In addition a graphical display of the amplitude spectrum¹ for each channel for the selected part of the study may be chosen from the study design module of the program. This module allows the user to enter the analysis criteria: peak definition, epoch length, and

limits of the amplitude spectrum. These criteria are saved as part of the study design, or protocol, to ensure repeatability of methods in subsequent studies.

Apparatus

The apparatus is shown schematically in Figure 2. Electrical signals driving the pen-galvanometers of a Grass 7PD polygraph (Grass Instruments) are converted into digital values by the custom made analogue to digital converter (Synectics Medical, Stockholm, Sweden) and held in the random access memory (RAM) of an IBM PS/2 Model 50. The data are stored on magnetic disk for permanent record and subsequent automated analysis by custom written software (Polygram Ver 3.0B3, Gastrosoft Inc, Stockholm, Sweden).

Analysis criteria

The criteria for manual and automated methods of analysis are illustrated in Figure 3, which shows a diagram of a pressure wave for one epoch.

Analysis is dependent on the defining what constitutes a peak and defining the baseline from which the measurements were made.

A peak was defined as a data point preceded by a change in pressure greater or equal to +20 mmHg, and succeeded by a change in pressure greater or equal to -20 mmHg. The diagram illustrates this by the 20 mmHg grid drawn over the pressure trace. Those points marked with a box fulfil the definition. The choice of 20 mmHg was made, because the range of intracolonic pressure wave amplitudes normally recorded in our laboratory is up to 400 mmHg.¹

As it is not uncommon to get some baseline variability from subject movement and respiration, the system was set to ignore variation within 10 mmHg of the true baseline or zero (illustrated by the dotted line).

Mean amplitude is calculated as the average amplitude of the defined peaks in the epoch. Per cent duration is calculated as the sum of the duration of individual pressure waves expressed as a per cent of the epoch. Motility index is calculated as the product of mean amplitude and % duration of activity in each epoch. Number of peaks is calculated as the number of defined peaks (30 minute epochs were used for this variable). Activity index or area under curve is calculated by integration of the curve.

Manual analysis followed the same criteria, but area under curve was estimated by counting the number of deflections on the paper trace made by separate integrating preamplifiers (Grass 7P10), reading each pressure channel of the polygraph. (Fig. 2.)

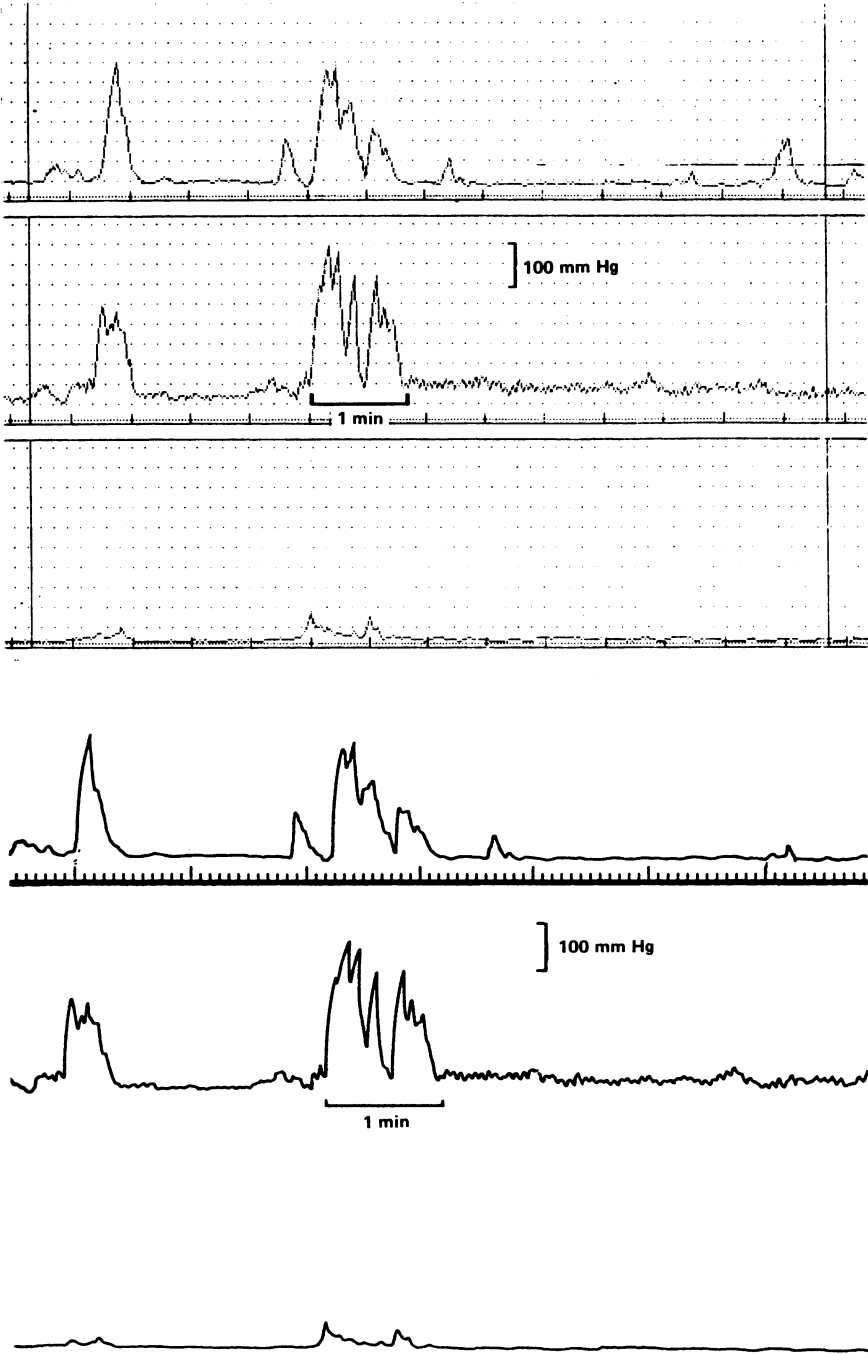


Fig. 1 Example of computer printed record (top) and corresponding polygraph record. (Time base not same scale.)

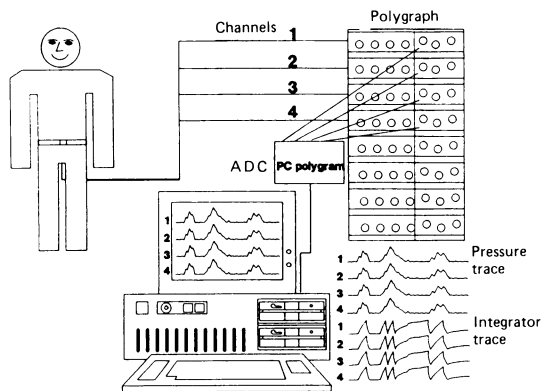


Fig. 2 Diagram of experimental set-up illustrating synchronous recording of manometric data on polygraph and computer.

Results

To test the system, a two hour four channel intracolonic pressure study was recorded simultaneously on the polygraph and the computer. The eight hour pressure record was analysed in 48 10 minute epochs manually, and by computer. The variables derived were: mean amplitude, % duration of activity, motility index, number of peaks and activity index. The time spent analysing the pressure record manually was the sum of each period of work measured by stop watch. The time taken by computer (IBM PS2 Model 50 running an Intel 80286 at 10 MHz) was taken from the start of the analysis program to the production of a completed printout of the variables.

STATISTICAL ANALYSIS

The statistical method for calculating agreement between the two methods was taken from Bland and Altman (1986).² The bias is the mean difference between the two methods for the measurement of the variable. The 95% confidence intervals (CI) show the precision of the estimate.

SPEED OF ANALYSIS

It took 889 minutes or 14.8 hours to analyse the two

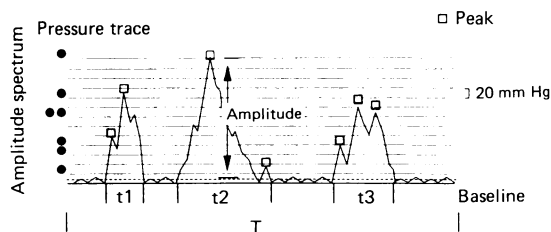


Fig. 3 Diagram illustrating analysis criteria.

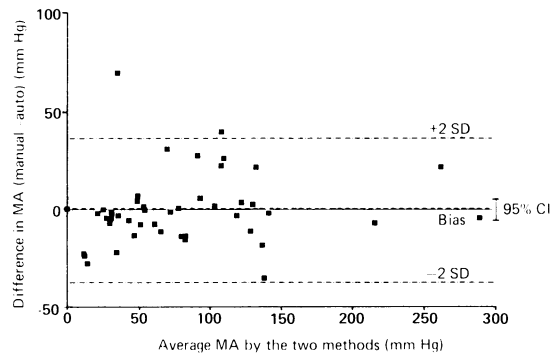


Fig. 4 Agreement between the two methods for mean amplitude. The x-axis shows the average value by the two methods and the y-axis the difference between the two methods. Zero bias is indicated by the dotted line.

hour four channel pressure record manually. This was done in several periods of work, as it was difficult to maintain concentration for more than a few hours at a time. Automated analysis took 14 minutes which was 63 times faster.

AGREEMENT BETWEEN METHODS

The results for agreement between the two techniques are summarised in the Table. The bias, or mean difference between the two techniques, shows how close the methods agree. The two standard deviations about the bias shows the limits of agreement. The 95% CI of the bias, the precision of the estimate, and the range of values are important in interpreting the bias, as it shows the order of magnitude of the variables recorded during the study.

MEAN AMPLITUDE

The agreement between the two methods for mean amplitude is shown in Figure 4. The bias for mean amplitude over a range of 0–289 mmHg was -0.5 mmHg and the 95% CI encompassed zero. Most of the data points fell within the limits of agreement and there was very good agreement between the two methods.

Table Summary of results

	Bias	95% CI bias	(2 SD)	Range
MA (mmHg)	-0.5	-5.8 to 4.8	(36.8)	[0–289]
%DA	-0.9	-2.9 to 0.9	(13.4)	[0–100]
MI (MA.%DA)	-55	-356 to 245	(2072)	[0–26 220]
No peaks	-20	-44 to 3.5	(91)	[1–211]
AI (mmHg.min)	39.9	21.4 to 58.5	(127.7)	[0–2073]
AI (mmHg.min)*	-5.2	-23.7 to 13.2	(127.3)	[0–2159]

*AI independent of peak definition.

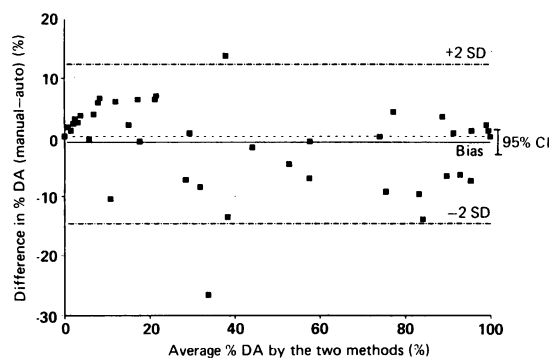


Fig. 5 Agreement between the two methods for % duration activity.

% DURATION OF ACTIVITY

Agreement between the two methods for % duration activity is shown in Figure 5. The bias for % duration of activity over a range of values of 0–100% was -0.9% , showing very good agreement between the two methods.

MOTILITY INDEX

Agreement between the two methods for motility index is shown in Figure 6. As motility index was derived from the product of mean amplitude and % duration of activity, it was not surprising to see a small bias of -55 over a range of 0–26 220 and good agreement for this variable.

NUMBER OF PEAKS

Agreement between the two methods for number of peaks is shown in Figure 7. The bias for this variable was -20 , for a range of 1–211. The bias was larger than that of the previous variables, but was consistent and the 95% CI encompassed zero.

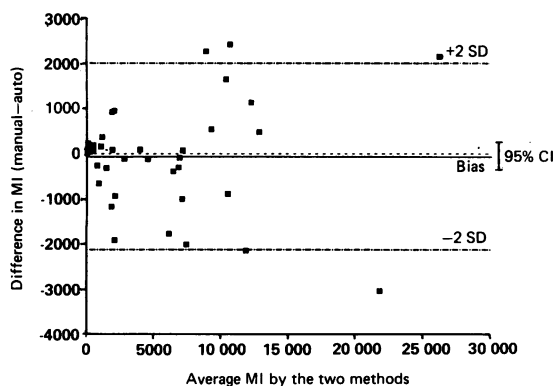


Fig. 6 Agreement between the two methods for motility index.

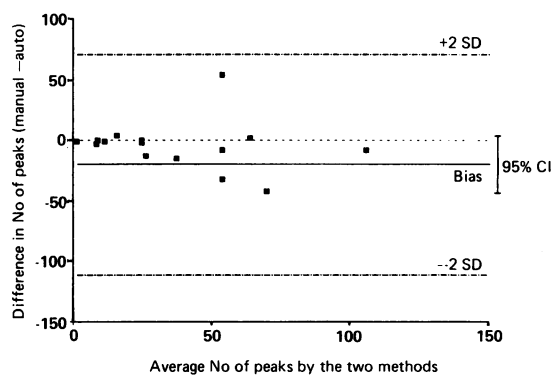


Fig. 7 Agreement between the two methods for number of peaks.

ACTIVITY INDEX

Agreement between the two methods for activity index is shown in Figure 8. The bias was large at 39.9 mmHg.min and not consistent. The 95% CI for the bias did not encompass zero and the results were significantly different.

The difference between the methods increased in direct relationship with the increased estimate of activity index. Thus the difference between the two methods may have occurred because area under the curve calculation by the program was dependent on peak definition, calculating the sum of the area under defined peaks ≥ 20 mmHg, while in manual analysis the integrating amplifiers calculate total area under the curve, irrespective of peak definition. Thus a high number of subthreshold peaks (<20 mmHg) would increase the area calculated by the integrating amplifiers in the manual analysis but not the area calculated by automated analysis and thus account for the large positive and inconsistent bias.

To test this hypothesis the automated analysis was

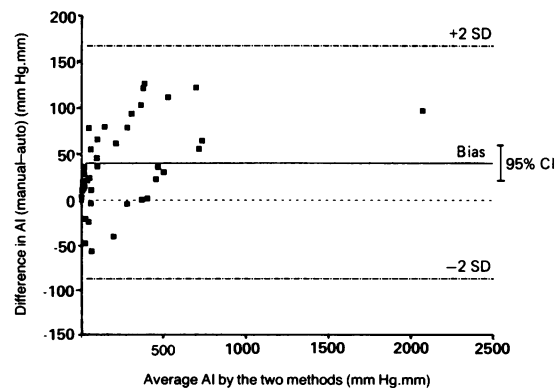


Fig. 8 Agreement between the two methods for activity index.

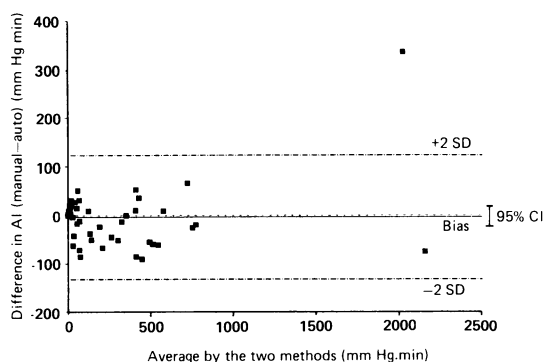


Fig. 9 Agreement between the two methods for activity index (Peak definition zero).

repeated for activity index independent of peak definition (effective peak definition of zero). The results (Figure 9) showed very good agreement: a bias of -5.2 mmHg.min with 95% CI from -23.7 to 13.2 and limits of agreement (2 SD) of (127) about the bias over an average range of 0 – 2073 mmHg.min.

This means that the original difference between the two methods for this variable was due directly to the difference in the method of calculation, and was not as a result of a sampling, or program error.

Discussion

Using the present system, the time spent analysing the pressure record manually was 14.8 hours, compared with 14 minutes by computer. The central processing unit (CPU) used by the computer was an Intel 80286 with a clock speed of 10 MHz. Speed of analysis is dependent on the speed of the CPU, hard disk access time and the amount of digital information processed. As each channel acquired digital information at 16 samples per second (16 Hz), the number of digital samples processed from the eight hour pressure record in the 14 minute period was 460 000. It is perfectly possible to achieve faster analysis using computers with more powerful processors, faster disk access time or selecting lower sampling rates.

There was excellent agreement for the variables of mean amplitude, % duration of activity, motility index and number of peaks. Initially the activity index data showed an appreciable divergence, but further experimentation showed that this difference occurred because area under the curve calculation by the program was dependent on peak definition, while in the manual analysis the integrators calculated total area under the curve, irrespective of peak definition. This hypothesis was tested and proved to be correct by repeating the analysis with an effective peak

definition of zero. The results of this test showed good agreement between the two methods for activity index, and emphasise the importance of pressure peak definition in analysis of this type. Pressure peaks can be defined according to the requirements of the study by the operator for each analysis of a given pressure record, which can be interpreted in the light of the definition adopted. It is suggested that peak definition be in future included in all reports of colonic pressure activity analysis.

Although only one two hour, four channel recording was used for comparison it was selected at random from a number of similar recordings and represents a considerable amount of colonic pressure data spanning the full range of values normally encountered in the normal colon for the variables of mean amplitude, % duration of activity, motility index, activity index and number of peaks.

Computer analysis of colonic pressures is not a new idea. Twenty years ago a program was written to allow a multifactorial analysis of digitally converted colonic pressure records.³ The system failed because the analogue pressure data were still recorded by ink on polygraph paper. Digital conversion was by a semimanual technique, using a static digitiser which quantified the important x and y coordinates of a pressure record, after they had been edited by an experienced operator. This technique was only marginally less laborious than ordinary manual analysis.

A more recent attempt to analyse colonic myoelectrical and pressure records by computer uses an algorithm to 'recognise' individual pressure waves in a similar way to the experienced operator.⁴ It acts as a filter reading 'significant' and ignoring 'non-significant' waves. The algorithm is sample rate dependent, but is most suited to the analysis of myoelectrical waveforms.

The advantages of the present system of colonic pressure recording and analysis are that the analogue pressure data are acquired, converted into digital values and stored while the study is in progress. The sampling frequency may be varied to allow very short pressure events to be recorded in high resolution, or alternatively prolonged records of pressure events can be stored without interruption. Very high resolution of rapid pressure changes will be useful in the interpretation of disorders of swallowing, activity of the upper or lower oesophageal sphincter, and of oesophageal peristalsis. Prolonged records of, for example colonic motility, can be made as shown in this study. Intermediate range of resolution can be useful in studies of small intestinal activity, or in investigation of anal sphincter pressures.

Individual study design parameters may be selected by the user and saved for serial repetition.

The program incorporates a number of analysis variables, which may be selected. Additionally, it allows epoch lengths and peak amplitudes to be defined by the user: these are independent of the sampling frequency.

The system may be used for any type of data capture and wave form analysis. It can record up to eight channels simultaneously for the same or different variables. Variable name, unit of measurement, range, time scale, resolution and calibration signal may be defined for each channel.

For short records the 'on-screen' interactive analysis allows the user to inspect the pressure record directly on the screen and obtain all the variables available by automated analysis. Propagation velocity of wave forms can be calculated in this way, using the vertical cursors. The good quality printouts of selected portions of the pressure record make synchronous recording on a polygraph unnecessary.

Finally, but very importantly, this system removes observer bias from the analyses of the pressure records. It abolishes the immense labour and tedium of manual analysis and produces calculated print out of data within a few minutes of completion of each study. Moreover, the data can be reanalysed later using different criteria, or definitions, in the light of new ideas.

The hardware and software is now generally available and the program will run on an IBM PC, or compatible. The system does not require the use of a standard polygraph but can be setup to take data from a variety of transducers directly. Data storage and transfer is straightforward allowing results or data to be shared and compared between centres. This opens the possibility of pooling data to establish normal ranges of colonic pressure activity.

Improvements in the specification under development include on-screen editing of the data to eliminate base-line-drift, and output of data to comma separated value (CSV) files, to allow integration with statistical and spreadsheet software. The system has also been adapted to acquire and analyse manometric data from other regions of the gastrointestinal tract such as oesophagus, small bowel, and anorectum.

The implications of fully automated analysis of colonic pressure records are considerable. The release of valuable research time presently expended on labour-intensive manual analysis; complete objectivity and uniformity of analysis of serial studies; repeatability of analysis using new criteria as new ideas develop and the exchange of data between different centres make fully automated analysis of colonic pressure records a fundamental requirement for future research and understanding of colonic motility.

The fully automated colonic motility analysis system specification, analysis criteria, and definitions were designed by JR and the program was written by Dr Jan Backstrom of Gastrosoft Inc, USA. The custom made hardware was designed and built by Synectics Medical, Sweden. The author is grateful for the help and encouragement of Mr Chris Blythe, Synectics Medical, UK, Mr Anders Essen-Moller and Mr Torbjorn Edmundsson, Synectics Medical, Sweden. This work was supported by the Medical Research Council.

AVAILABILITY

The hardware and software of this system is available in the United Kingdom from Synectics Medical UK, 215 Willow Road, Enfield, Middlesex EN1 3BT. Tel: 01-805 1424.

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