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Cent. Eur. J. Med. • 3(4) • 2008 • 438-445
DOI: 10.2478/s11536-008-0065-3

Central European Journal of **Medicine**

Optimizing the degree of distension and reducing discomfort in CT colonography by means of a microprocessor interface system for air insufflation

Research Article

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Received 29 March 2008; Accepted 1 September 2008

Abstract: The patients' discomfort during CT colonography determines which method is used and its frequency of use. The discomfort is largely associated with the colon's insufflation with gas. A system for an automatic room-air insufflation has been developed that ensures a continuous and steady air insufflation and an increase in colonic pressure and enables a relatively fast decompression. This system provides constant pressure monitoring and can alert the operator, if necessary. The degree of discomfort was evaluated for 36 patients, who were subjected to manual and automated air insufflation. The degree of the colonic distension achieved by the two methods was compared. The data analysis showed a significantly lower level of discomfort in patients with automated air insufflation. The degree of colonic distension was evaluated by comparing the diameters of similar segments of the colon, as well as by the subjective opinion of the operator. The distension with automated air insufflation was higher than that with manual air insufflation. In some cases there was a significant difference ($P<0,05$). In conclusion, the results show that the automatic insufflation of air at room temperature can be used to optimize CT colonography.

Keywords: *CT colonography • Automatic air insufflation • Discomfort • Distension*

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1. Introduction

The application of CT colonography is constantly expanding, and the number of CT colonographic investigations is increasing. CT colonography has become an important method of studying a variety of diseases involving the wall structure of the colon, [1] and the requirements for the use of this method are increasing. An essential component for a quality CT colonography is optimal distension of the colon, which is achieved by insufflation of air [2] or carbon dioxide (CO_2) [3]. Insufflation can be performed either by manual administration of air [3] or CO_2 [4] or by automatic administration of CO_2 [4]. The supporters of each method of insufflation point out certain advantages concerning the image quality of CT colonography on the one hand and the patients' comfort and safety on the other. The majority of publications point out the shortcomings of manual insufflation, [5] such as those associated with the lack of precise quantitative information on the volume of the insufflated air and the value of intracolonic pressure and its alteration in the course of the investigation. The inconstant air delivery [6] has been mentioned as a disadvantage directly related to the patient discomfort level. Evaluation at a higher level allows patient-controlled manual insufflation, mostly because it enables the patient to influence the introduction of air into the colon. In both cases,

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however, insufflation is discontinued on a subjective basis. It is therefore impossible to determine the range of intracolonic pressure values or gas volume providing optimal distension. The patients judge the situation as bearable when a volume of approximately 2.5 l of gas is introduced; however, Bretthauer *et al.*, [7] are of the opinion that further studies should be performed in this respect. Still unsolved is the problem of gas elimination after completion of the radiographic investigation and the associated discomfort.

As evaluated by patients, CO_2 insufflation reduces the level of discomfort because of its more rapid resorption [4], especially after completion of the investigation [8]. However, folding of the mucosa has been reported to occur when CO_2 is used, [9,10] which results in the deterioration of the quality of CT colonography. This raises the question of an appropriate insufflation method to provide optimal conditions for CT colonography.

The aim of the present study was to propose an automated room-air insufflation system, describe the effect of its application on the quality of CT colonographic investigation, and compare the degree of distension, comfort, and safety of patients achieved with automatic insufflation to that achieved with the manual method.

2. Material and Methods

2.1. Patients and methods of study

The study involved 20 women and 16 men. They were divided into two groups: Ist group (n=20; average age 55.00±2.16), in which air insufflation was applied manually, and IInd group (n=16; average age 61.00±4.88), in which air was insufflated automatically. There was no significant difference in the average age of both groups (p=0.209), as well as in the male-to-female ratio of each group (p=0.288).

Prior to the colonography, X-Prep bowel evacuant was given as preparation. The patients started a clear-fluid diet 24 hours before the investigation and did not take any food and water for the last 7 to 8 hours. Because of the wide application of hyoscine (Buscolysin) in CT colonography [1,11], the latter was used as a means for preliminary relaxation of the colonic smooth muscle in both types of insufflation. Twenty minutes before initiation of the investigation, each patient was given an intravenous injection of 20 mg of Buscolysin by means of a cannula (20/22 gauge, Vygon Bulgaria Ltd.).

Evaluation of the degree of distension was made on a two-dimensional colonic reconstruction for each anatomical area of the colon: caecum, ascending colon, transverse colon, descending colon, sigmoid colon, and rectum. It was performed by comparing the size of bowel segments representative of each anatomical area in all the patients from both groups. The evaluation of the degree of distension involved a 4-point grading scale [12] with the patient in both the supine and prone positions. The evaluation was made by the operator immediately after the investigation.

Manual insufflation was performed by an assistant. Automated room-air insufflation was performed by means of a system designed by the authors and described in the Results section.

With both methods, the air was introduced into the colon while the patient was in the lateral position by means of a small flexible rectal catheter with a retention balloon.. The automatic insufflation continued until the predetermined intracolonic pressure was reached. In cases where severe discomfort or pain occurred before the predetermined pressure value was reached, insufflation was to have been discontinued. However, this did not occur in the present study.

Manual insufflation was discontinued whenever the patient signaled an increased level of discomfort.

The patients subjectively determined the degree of discomfort caused by CT colonography with a 10-point grading scale [12] that had been introduced to them in advance, and the data were recorded in a special protocol that referred to the period of investigation.

CT colonographic images were obtained by an axial Siemens Emotion CT scanner with the following working parameters: 110 kV, 140 mAs and 1 mm reconstruction interval.

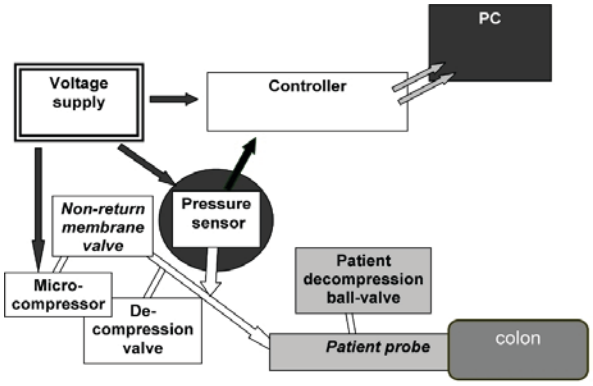
2.2. Drugs and chemicals

In the course of the study, the following medications were used: hyoscine (Buscolysin; 20mg/1ml - Sopharma) and X-Prep (Mundifarma, GmbH).

2.3. Statistical analysis

The continuous variables were expressed as mean ± SEM (standard error of the mean). The statistical association between the results was assessed by an ANOVA (analysis of variance) test (Tukey HSD post-hoc test). A value of $P < 0.05$ was considered for a significant difference. Since the groups included a small number of subjects, the significance of the results was evaluated by non-parametric analysis (Kruskal-Wallis test), as well.

Figure 1. A device for air insufflation in CT colonography – a block scheme.



3. Results

3.1. Elements, construction, and operating parameters of a system for automated room air insufflation

The system has electronic and mechanical components that instantaneously register and trace the pressure value within the colon. It provides a gradual, uniform air introduction into the colon by means of a pump to a predetermined level of pressure that ensures a better CT colonographic image. The basic elements of the system are shown in Figure 1. The power supply block provides voltages of ±12 V and 5 V with maximum current values of 100 mA and 400 mA, respectively.

The controller consists of a repeater, an amplifier, an instrumentation amplifier, a filter, a microprocessor, and a parallel communication scheme. It constantly indicates the pressure value in the system, and whenever this pressure falls below a given level, it allows for the restoration of the required pressure. In this way, constant pressure is maintained within the colon throughout the entire investigation.

The pressure sensor has an operating range of 0-100 mm Hg. It indicates the relative increase of the pressure above the value of atmospheric pressure. It is a type of semiconductor that works in a 4-wire bridge scheme and is supplied by an extremely precise voltage source (10.005 V), with low noise production and a temperature stabilization scheme. Since the silicon resistors of the sensor are temperature-dependent, the accuracy is reduced to 0.1 mm Hg on premises with temperature variations of $\pm 3^0$C (24 ± 3^0C).

The output voltage of the pressure sensor is applied to an instrumentation amplifier with a regulative gain coefficient (G = 800 – 1000) and a high common mode rejection ratio (CMRR = 115 dB).

After filtration of frequencies above 200 Hz by means of an active filtering system, the signal is digitally converted by a 10-bit analog-to-digital converter (ADC), based on a programmable microcontroller. After the analog-to-digital conversion and the establishment of the conversion calibration function, the pressure values are recorded in mm Hg with an accuracy of 0.5 mm Hg at a correlation coefficient R = 0.998 and P < 0.05. With the aim of increasing accuracy, 10 measurements are performed every 20 ms, and the mean value is calculated and sent to a personal computer (PC) by means of a specialized parallel communication scheme.

The software graphic design was developed with Visual Basic 6.0 that makes it possible to record the discreteness interval and data in the exported file. The instantaneous pressure value and the time elapsed from the initiation of the process can also be checked by means of this program. The system is capable of performing the following operations: (a) it traces the pressure data coming through the PC parallel port (LPT1), (b) it visualizes them at a chosen discreteness time (50 ms - 5000 ms), and (c) it makes a two-dimensional recording that makes it possible to plot the dependence (Pressure = Pressure [time]) with the database processing programme Excel 2003 (Microsoft, US).

For the patient's safety, change in the color of the display background is provided to signal an excessive increase in the pressure.

Measurement duration may vary within a wide range, from 100 ms to 10 h. A non-return valve makes possible the maintenance of constant pressure in the system: device – air-conducting installation – colon.

The decompression valve is connected immediately to the air-conducting installation involving the lumen of the colon and the adjacent space.

The air-conducting installation consists of polyurethane tubes with hard walls, 0.8 mm in diameter.

3.2. Evaluation of degree of distension in manual and automated air insufflation

The size of the colonic lumen (as a parameter characterizing the distension degree in manual and automatic insufflation with the patient in the supine and prone positions) was measured in centimeters. The values for each area of the colon studied are shown in Figure 2A and B.

Similar ratios of lumen sizes of the respective areas of colon with both manual and automated air insufflation were obtained by the Kruskal-Wallis test as well.

The degree of distension of the entire colon, achieved in manual and automated insufflation in each patient by

Figure 2. Comparison of colon lumen sizes [cm] (manual vs automatic air insufflation (P colon = 10 mm Hg)) in the supine position – A, and in the prone position – B. Comparisons are made separately for each area studied (ANOVA test), * - P < 0.05; ** - P < 0.001.

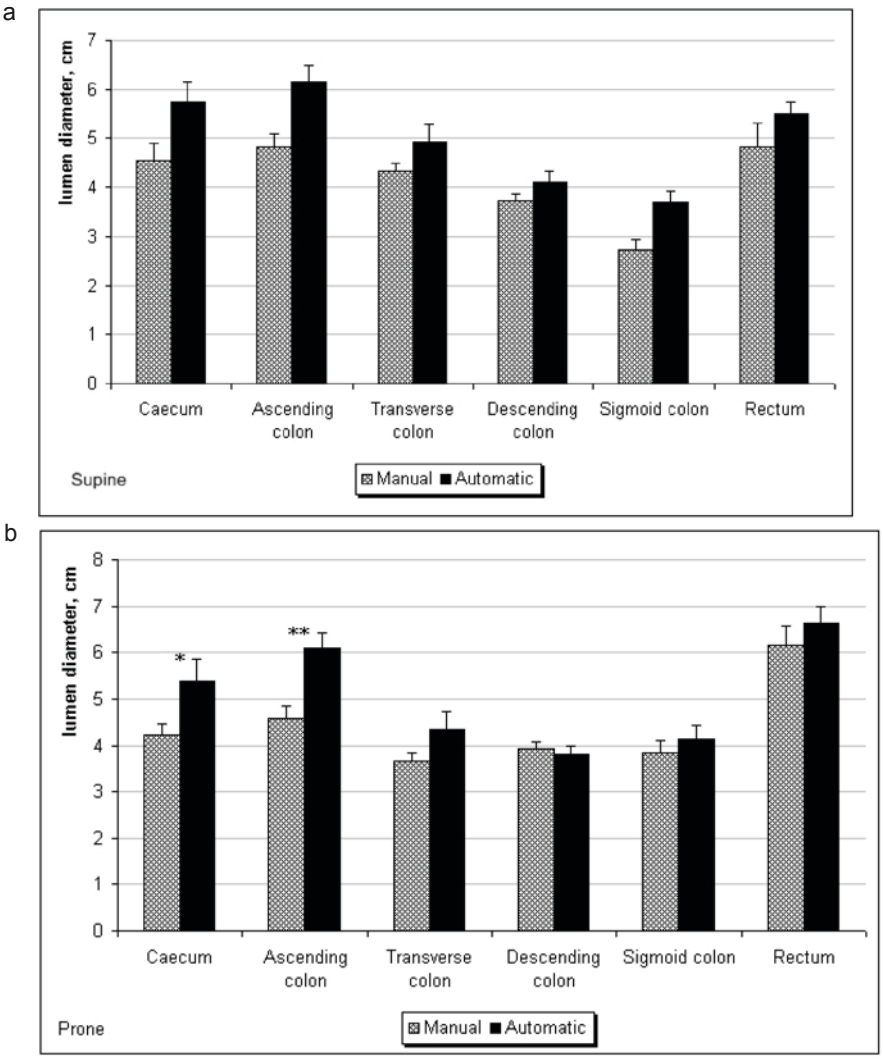


Table 1. Evaluation of the distension degree made by the operator of CT colono graphy.

Distension level	Distension degree, %			
	Prone		Supine	
	manual, n=20	automatic, n=16	manual, n=20	automatic, n=16
optimal	31.25 %	64.30 %	20.00 %	66.70 %
sufficient	43.75 %	28.60 %	50.00%	33.30 %
insufficient	25.00 %	7.10 %	30.00 %	0 %
collapsed	0 %	0 %	0 %	0 %

means of the system described above, was subjectively evaluated by the operator, via a 4-point grading scale. The generalized evaluation data obtained with the patient in the prone and supine positions are given in Table 1.

3.3. Patient's evaluation of discomfort during CT colonography with manual insufflation (performed by an assistant) and automated room-air insufflation

The sensation of discomfort in CT colono graphy after manual and automated air distension was evaluated by the patients themselves on a 10-point grading scale.

Table 2. Patient discomfort levels with manual and automated room-air insufflation.

Discomfort level	Type of insufflation	
	Manual, n =16	Automatic, n =14
Lack of discomfort – zero discomfort	0	0
Insignificant	0	0
Minimum	0	5
Mild	0	5
Moderate 1	1	1
Moderate 2	4	2
Moderate 3	5	1
Severe 1	4	0
Severe 2	2	0
Particularly severe	0	0

Those results are given in Table 2.

The statistical data processing with the t-test showed a level of subjectively determined discomfort of 7.13 ± 0.287 in manual insufflation versus 3.93 ± 0.286 in the automatically insufflated patients. According to the chi-square test, this is a significant difference; the χ^2 value is 12.14, and the degree of significance is P = 0.0023 (P < 0.01).

The automated insufflation system makes possible the immediate reduction of the amount of air in the colon (reduction of intracolonic pressure and discomfort) under extreme conditions and/or at the end of the study. This ability is demonstrated in Figure 3 by comparing the two CT colonographic images, one obtained during CT colonography and the other obtained immediately after its completion (after use of the decompression valve).

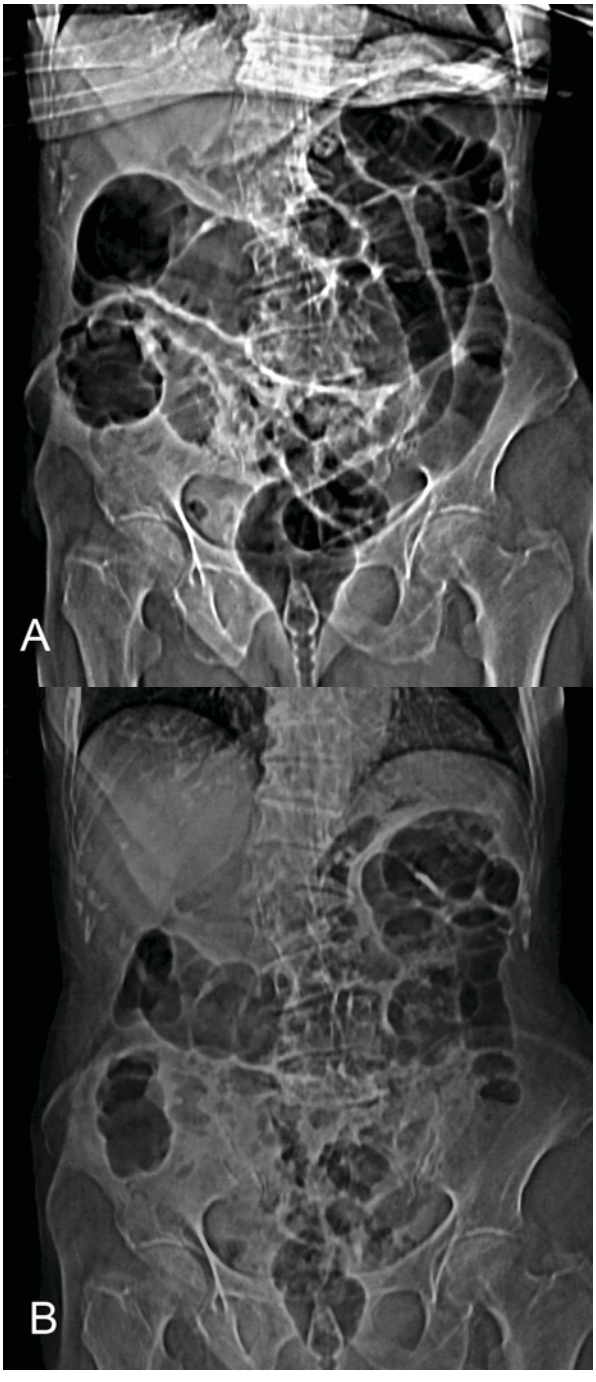
4. Discussion

We used in our study a microprocessor interface system for automatic insufflation of room-temperature air on CT colonography.

An effective way to evaluate its advantages is to compare indices achieved with it to similar ones achieved with traditional manual air insufflation. The indices characterize the distension level and the patients' sensation of comfort (discomfort), which includes elements associated with their safety, during the investigation.

Adequate distension of the colon is essential for obtaining more information of improved quality on CT colonography [13]. With manual insufflation, the air is introduced into the colon in pulses, and the pressure inside constantly changes. Peak changes arise, causing the smooth muscles of the intestinal wall to become irritated. When they are subjected periodically to mechanical irritation, they respond with a series of contractions [14]. The contractions bring about a local increase in tonus (spasms) and/or increase of motility

Figure 3. CT image of a patient's colon insufflated by the system for automated room-air insufflation. A – during the investigation, and B – after it (3 min after using the decompression valve). The reduced amount of air is well visualized, particularly in the distal segments of the colon.



[15], particularly in the rectum and sigmoid colon. This is due to their proximity to the site of air inflow where the change in pressure (*i.e.*, the degree of irritation) is the greatest. The spastic areas hinder the air inflow into the upper segments of the colon. This causes bloating of the rectal segment and a sensation of pain on initiation of insufflation, as well as irregular distension of the different areas of the colon. Besides increasing motility, irregular distension results in a lower quality investigation.

Our data indicated that automated room-air insufflation resulted in a significantly larger size of bowel lumen in the areas of the caecum and the ascending colon in both patient positions, as well as in the sigmoid colon with the patient in the supine position. This may be associated with absence of spastic areas obstructing the inflow of gas in the upper segments of the colon due to the relatively constant delivery of insufflated air. In the remaining areas, the size of bowel lumen in the automatically insufflated patients tended to increase compared to that in the manually insufflated ones. This means that the distension of the entire colon was more consistent and relatively more satisfactory, particularly in its distal areas (the ascending colon and the caecum), resulting in a higher quality investigation [16].

The opinion of the operator performing the CT colonography, although subjective, was an important index in the evaluation of degree of distension. Operator opinion was stated immediately after completion of each individual study, and it supported the interpretation of the results that the automated room-air insufflation provided better conditions for optimum distension. According to the operators, the percentage of patients having optimal distension by automated insufflation was higher, whereas the percentage of those with insufficient distension was lower, compared to the respective values obtained by manual insufflation.

The issue of discomfort associated with CT colonography still remains to be resolved, and, to a certain extent, it is a subjective obstacle for mass application [6,16]. In most cases, it results from the gas insufflated into the colon. More specifically, it has been associated with pain due to the process of insufflation, sensation of bowel bloating, increased pressure in the abdominal area, and continual passing of gas [16].

Patients reported that the discomfort level by manual insufflation averaged 7.13 ± 0.29, which was rather high compared to averages by automated insufflation. In some publications, [17] the value for automated CO_2 insufflation is 3. A similar value (3.93 ± 0.28) was obtained in our patients who underwent automated insufflation. Patients' protocols contained no data on pain sensation during insufflation. The data allow us to conclude that the discomfort is significantly reduced in automated room-air insufflation as compared to manual air introduction by an assistant and is close to the value recorded with automated CO_2 insufflation. Besides the consistent air flow, in which smooth muscle spastic reactions are not very likely to occur and thus not cause pain, consideration can also be given to certain subjective factors regarding the sensation of greater comfort in automated insufflation, such as the tendency of modern man to trust technology and the absence of an assistant whose actions may contribute to the sensation of discomfort..

One of the most important advantages of the use of CO_2 for insufflation is the shorter period of discomfort after the investigation, which is due to the more rapid resorption of CO_2 as compared to air, and the resultant reduction of intracolonic pressure [17]. We achieved a similar effect on the discomfort level at the end of CT colonography, reducing intracolonic pressure by means of the decompression valve. At each insufflation stage, there is an air pressure gradient between the colonic lumen and the atmosphere that increases with the increasing amount of insufflated air. The opening of the valve cuts off air delivery to the colon and reestablishes the connection with the outside atmosphere . A portion of the air that has been pumped into the colon is eliminated, the pressure within the colon decreases, and the discomfort caused by the excessive bowel bloating resulting in increased abdominal pressure is reduced. Also, the patient is able to cause decompression at any time during the investigation by pressing a decompression button, which is a psychological factor that suggests a feeling of safety and comfort.

The possibility of a relatively rapid decrease in intracolonic pressure and in the discomfort after CT colonography reduces the differences in this index between our system and CO_2 insufflating systems. From a physiologic point of view, it can be assumed that the use of air has some advantages over that of CO_2. Resorption of CO_2 into the blood and increase in its partial pressure can cause an acidosis, particularly in patients with respiratory obstruction. This process does not occur after air insufflation, which shows that the latter is more of a physiological response. From a financial point of view, CT colonography with air insufflation is less expensive than that with CO_2.

Patient safety is essential in every investigation. In CT colonography, safety issues may arise because of bowel perforation with subsequent hemorrhage, caused by the excessive intracolonic pressure [18] and the extended increased intra-abdominal pressure resulting from increased colonic volume. Increased intra-abdominal pressure can be viewed as a risk factor for the development of intra-abdominal compartment syndrome

[19]. The automated insufflation system used in our studies reduces the risk of such conditions. This risk reduction is achieved by combining information on the value of intracolonic pressure, which is instantaneously and constantly available to the operator, and the possibility of rapid decompression, which can be used under extreme circumstances.

An additional advantage to the automated insufflation system is its ability to maintain a relatively constant intracolonic pressure, predetermined by the operator (*i.e.*, to ensure constant observation conditions that preserve uniform lumen sizes and bowel wall thickness in any colonic section) throughout the investigation.

With this discussion, the use of an automated room-air insufflation system can be considered to optimize CT colonography.

In conclusions:

1. The room-air insufflation system improves the accuracy of CT colonography by creating conditions for optimal distension by maintaining a consistent air flow, instantaneously registering and tracing the value of intracolonic pressure, and making correction possible both into and out of the colon.
2. It reduces patient discomfort that is inevitable in manual insufflation by abolishing one of the main causes of pain in insufflation (the inconsistent gas delivery) and providing rapid reduction of intracolonic pressure during and after CT colonography by evacuating the compressed air into the atmosphere.
3. It reduces the danger of bowel perforation caused by the high intracolonic pressure in the course of the investigation.
4. The computed data processing of insufflation to an optimum intracolonic pressure allows the creation of a database and the standardization associated with it, development of a laboratory protocol, and optimization of parameters.
5. The system allows the accumulation and statistical processing of information on the efficacy of various drugs used in the preliminary relaxation of colonic smooth muscle, as well as on the time required to achieve a maximum effect.
6. It facilitates the work of the medical staff.

Acnowledgements

We would like to thank to Medical University Plovdiv, Bulgaria for the financial support (Project 6/2006). We would also like to thank to Dr. Rumen Steffanov from the Department of Social Medicine and Health Management of MU – Plovdiv for helping with the statistical analysis of our results.

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