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AI-based algorithm for clinical decision support system in colonoscopy

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ABSTRACT *AIM: to estimate the implementation of the original method that uses artificial intelligence (AI) to detect colorectal neoplasms.*

MATERIALS AND METHODS: we selected 1070 colonoscopy videos from our archive with 5 types of lesions: hyperplastic polyp, serrated adenoma, adenoma with low-grade dysplasia, adenoma with high-grade dysplasia and invasive cancer. Then 9838 informative frames were selected, including 6543 with neoplasms. Lesions were annotated to obtain data set that was finally used for training a convolution al neural network (YOLOv5).

RESULTS: the trained algorithm is able to detect neoplasms with an accuracy of 83.2% and a sensitivity of 77.2% on a test sample of the dataset. The most common algorithm errors were revealed and analyzed.

CONCLUSION: the obtained data set provided an AI-based algorithm that can detect colorectal neoplasms in the video stream of a colonoscopy recording. Further development of the technology probably will provide creation of a clinical decision support system in colonoscopy.

KEYWORDS: *colonoscopy, endoscopy, artificial intelligence, computer vision, machine learning, adenoma, cancer, neoplasm*

CONFLICT OF INTEREST: *the authors declare no conflict of interest*

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INTRODUCTION

Colorectal cancer (CRC) is a socially significant oncological disease, occupying leading positions in the rate of detection and causes of death from neoplasms in different countries of the world. In the Russian Federation, more than 38 thousand deaths from this pathology are registered annually, and the number of newly detected cases of CRC exceeds 71 thousand [1]. CRC in the majority of cases passes the stage of benign neoplasm — adenoma. Large epidemiological studies have shown that timely endoscopic removal of adenomas reduces the risk of colorectal cancer by 90% [2]. In this regard, great importance is attached to screening colonoscopy, during which the rate of detection of adenomas (in English-language literature –adenoma detection rate, ADR) ranges from 30% to 64% [3–6]. At the same time, various studies demonstrate a relatively high percentage of lost neoplasms. Thus, the rate of adenomas missed during colonoscopy, according to Hassan, C.'s meta-analysis, is 37.5% [4]. The omission of adenomas during colonoscopy depends on the size of the neoplasm — in the study by van Rijn, J.C., the rate of missed polyps was 2.1%, 13% and 26% for adenomas over 10 mm, 5–10 mm and less than 5 mm, respectively [5]. In addition, poor bowel cleansing, as well as the human factor, are considered possible reasons for skipping [6,7].

Thus, an increase in the information content of colonoscopy is expected to reduce morbidity and mortality from CRC due to the timely performance of endoscopic polypectomy.

One of the tools for solving this problem is artificial intelligence (AI) technology for processing and preliminary analysis of video colonoscopy data [8–11]. According to the papers, the use of automation of video processing of colonoscopy during screening colonoscopy will help to level the subjectivity of the endoscopist and increase diagnostic accuracy and sensitivity regarding the detection of adenomas and adenocarcinomas of the large intestine, as well as reduce the time of the study description [10]. This technology is not an independent diagnostic option, but is considered as a clinical decision support system (CDSS).

In the world literature, every year more and more attention is paid to the use of AI in colonoscopy. The data obtained inspire some optimism.

In the study by Luo, Y., et al. [11], based on a survey of 150 patients, it was shown that the AI system increases the rate of detection of polyps in real clinical conditions (38.7% vs. 34.0%, $p < 0.001$). At the same time, colonoscopy using an AI system significantly increases the detect ability of polyps smaller than 6 mm (91% vs. 69%, $p < 0.001$), but does not detect differences in relation to larger neoplasms.

Wallace, M.B., et al. [12] conducted a study with two consecutive colonoscopies — standard and using AI. The rate of missed adenomas was 32.4% and 15.5%, respectively. The average number of adenomas during repeated colonoscopy was determined less in the group in which AI was used in the first study, compared with the group in which AI was not used in the first study (0.33 ± 0.63 vs. 0.70 ± 0.97, P < 0.001). The rate of false false-negative results was 6.8% and 29.6% at the first colonoscopies with and without the use of AI, respectively (OR 0.17; 95% CI 0.05–0.67). Thus, AI provided approximately a twofold reduction in the rate of colorectal neoplasia skipping, reducing the perception errors of small and inconspicuous neoplasms.

In the study by Xu, H., et al. [13], in addition to ADR, the average number of adenomas per colonoscopy was estimated, the correlation of ADR with the experience of the endoscopist and the time of removal of the device during colonoscopy.3,059 patients were randomly assigned to a group for colonoscopy using the AI system ($n = 1{,}519$) and without it ($n = 1{,}540$).In the process of colonoscopy using AI, the Eagle-Eye polyp detection system was used, with real-time notification on the same monitor of the endoscopic system. The level of total ADR (39.9% vs. 32.4%; $p < 0.001$), ADR in experts (42.3% vs. 32.8%, $p < 0.001$) and non-specialist endoscopists (37.5% vs. 32.1%; P = 0.023) were significantly higher during colonoscopy using the AI system. The average withdrawal time of the device (8.3 minutes vs. 7.8 minutes; P = 0.004) was slightly longer in the AI group. It was concluded that in asymptomatic patients, colonoscopy using AI increased the overall ADR level, as well as the rate of detection of adenomas by both experts and less experienced specialists [13].

An increase in the detection of adenomas during colonoscopy has a significant economic effect. For example, Areia, M., et al. [14], based on modeling the use of machine vision technology in colonoscopy, concluded that this tool would reduce the number of colorectal cancer cases in the United States by 7,194 cases annually, and the number of deaths from this disease by 2,089 people. At the same time, the economic benefit from the implementation of AI in colonoscopy is estimated to be US$ 290 million annually due to the reduction of costs for the diagnosis and treatment of colorectal cancer and other costs associated with the development of colorectal tumors.

The available Russian literature provides a single experience of using artificial intelligence technology in colonoscopy, while there is no data on the widespread use of the described approach in clinical practice [15,16].

Thus, the development and implementation of the domestic CDSS in colonoscopy based on AI is relevant from a scientific and practical point of view. Such study was started in the RNMRC of Coloproctology of the Health Ministry of Russia in 2022.

MATERIALS AND METHODS

The material of the study was an electronic archive of video recordings of colonoscopies performed at the RNMRC of Coloproctology of the Health Ministry of Russia. The studies included in the work were performed on the Pentax 7010 (Japan) and Olympus Exera-III (Japan) with high definition (HD) in the period from January 2021 to October 2022.

The design of the study is shown in Figure 1.

Video recordings of the studies, during which were detected colorectal tumors subsequently removed and pathomorphologically examined in accordance with the protocol in force at the Center, were selected for the work. Neoplasms belonging to one of the five types listed below were subjected to marking:

1) Hyperplastic polyp
2) Serrated neoplasm
3) Adenoma with low-grade dysplasia
4) Adenoma with high-grade dysplasia
5) Invasive cancer

The allocation of these classes is due to the rate of occurrence and their clinical significance, which is determined by different approaches to the treatment of such neoplasms. At the same time, cases were excluded from further analysis when the colorectal neoplasm did not correspond to the above classes by histological structure or was not confirmed. Video recordings of colonoscopy of patients

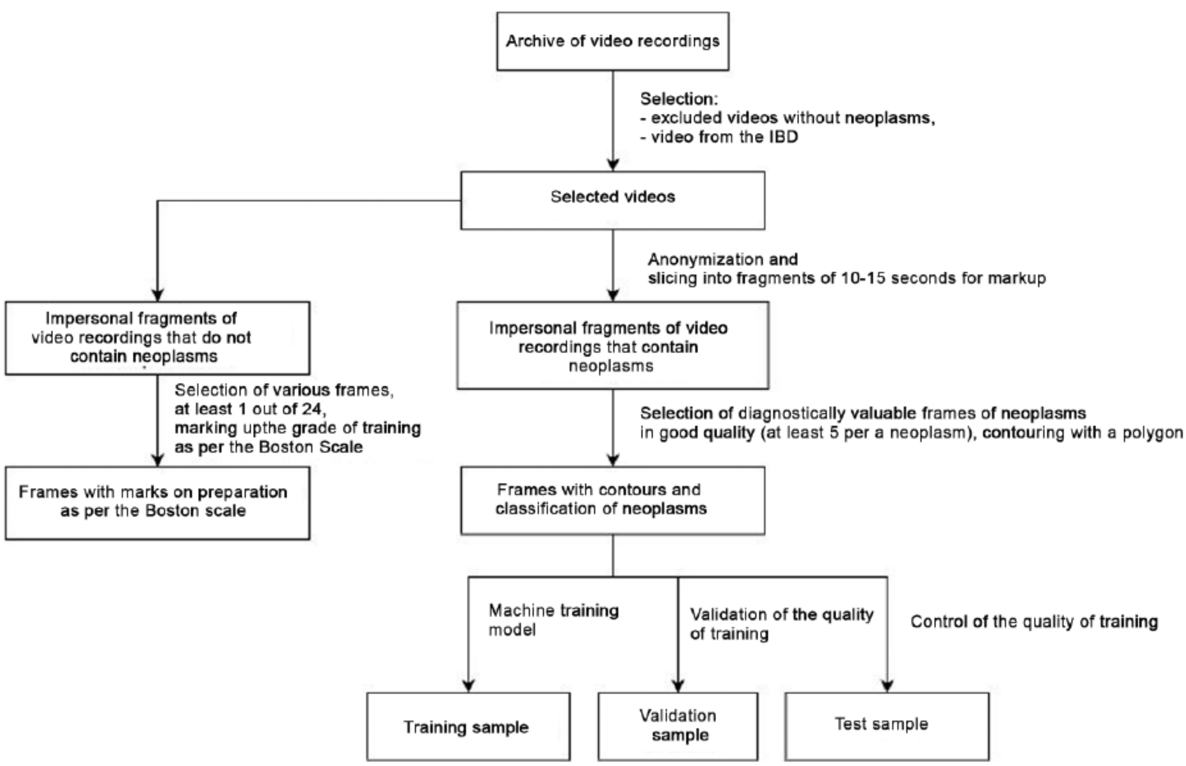

Figure 1. *Flow-chart of preliminary work for the creation of CDSS in colonoscopy*

Table 1. *Marking main characteristics*

№	Class	Label Name	Markup Color
Main classes (slices on the frame)			
1	Hyperplastic polyp	Hyperplastic polyp	
2	Serrated neoplasm	Serrated neoplasm	
3	Adenoma with low-grade_dysplasia	Adenoma with low-grade_dysplasia	
4	Adenoma with high-grade_dysplasia/ early_cancer	Adenoma with high-grade_dysplasia/ early_cancer	
5	Carcinoma_cancer	Carcinoma_cancer	
Additional classes			
6	Clean_frame	Clean_frame	

suffering from inflammatory bowel diseases were also excluded.

Thus, for further study, 1070 videos of colonoscopy were selected, corresponding to the selected criteria, with a total volume of 46 gigabytes.

Video colonoscopy recordings were characterized by a rate of 29, 30 or 50 Hz. The frame height was at least 1,080 pixels — the source videos are overwhelmingly presented in a definition of 1300x1080 (66.4%) or 1920x1080 (27.3%).

The frames that meet the quality criteria were selected from these video fragments:

- clear;
- without dimming;
- without seriousblurring of neoplasm;
- out of the moment of switching between modes (white light/NBI);
- out of the moment of irrigation.

For the subsequent marking of the identified neoplasm, at least 5 frames of good quality were selected from different angles for each study mode (white light / NBI), while the time interval between frames was at least 1 second. Also, frames that did not contain neoplasms were randomly selected in a ratio of 1:2 as a norm control. These frames were marked with video quality and a score of bowel cleansing according to the Boston scale.

In total, 9838 frames were selected in accordance with the above approach, which served as the material for the final data set.

All the data have been anonymized (depersonalized) in order to ensure the protection of personal data by deleting the frame area containing information about the patient.

The marking of the selected and depersonalized data was performed by 12 endoscopists at the Center with 5–24 years of independent practical work experience. The 3 most experienced specialists with over-15-year experience validated the markup and were involved for a "second opinion" in difficult cases.

Each study was marked up by one endoscopist. Markup validation was carried out selectively by a specialist of higher qualification, and in 20% of cases cross-validation was performed by a second expert.

The markup was carried out in accordance with the following strategy. For each neoplasm, the endoscopist selected at least 5 diagnostically most informative frames on the video fragment. Then, with the help of a graphic editor, he outlined the neoplasm with a polygonal line on each of the selected frames and assigned a class label in accordance with the table below (Table 1). In all the cases, the conclusion of the pathomorphology removed specimen was used as a method of verification and final

Table 2. *Interpretation of the algorithm results on the test sample*

Algorithm output	Opinion of 2 experts	The result of the work
The neoplasm isolated	The neoplasm is present in the frame	True positive
There is no isolation	There is no neoplasm	True negative
The neoplasm isolated	There is no neoplasm	False positive
There is no isolation	The neoplasm is present in the frame	False negative

attribution of the neoplasm to a particular class.

The marking of neoplasms was performed by polygons with a large number of points corresponding to the contours of neoplasms. Since rectangles adjacent to the boundaries of neoplasms were needed for training and testing the machine training algorithm, polygons were converted into rectangles.

The marked-up data set was divided into training, test and validation samples in the proportions of 70%, 15% and 15%, respectively. The distribution of frames by samples was carried out in proportion to the distribution by class.

To evaluate the possibility of machine training in order to automate the detection of neoplasms during colonoscopy in real time, the YOLOv5 neural network algorithm was used, which is one of the most common algorithms for detecting objects, due to its speed and accuracy [17].

Machine training of a neural network was carried out by downloading a training sample of a data set (4668 marked-up frames). An independent validation sample (957 marked-up frames) was used to optimize the algorithm, increase its accuracy by fine-tuning the neural network.

$$\text{Sensitivity} = \frac{\text{TP}}{\text{TP + FN}} \times 100\%$$

$$\text{Accuracy} = \frac{\text{TP + TN}}{\text{TP + TN + FN + TN}} \times 100\%$$

Figure 2. *Formulas for the sensitivity and accuracy of a diagnostic test. TP — true positive; TN — true negative; FP — false positive; FN — false negative*

The most significant parameters characterizing the effectiveness of the algorithm in detecting colorectal neoplasms are sensitivity and accuracy. To calculate these parameters, we used the generally accepted formulas for diagnostic tests (Fig. 2) and the following interpretations of the results of the algorithm (Table 2).

RESULTS

We have studied the distribution of frames with neoplasms by class (Fig. 3). It is necessary to note a pronounced imbalance of classes due to the natural difference in the rate of occurrence of neoplasms of these types. The structure of 4140 (58.3%) marked neoplasms corresponded to adenoma without high-grade dysplasia.

The recognition of neoplasms by the algorithm was influenced by the number of objects in the frame. In 414 (6.4%) cases, 2 or more neoplasms were present on the marked frames (Fig. 4).

In order to assess the quality of the obtained data set, as well as to predict the possibility of developing a CDSS based on it, the action of the trained algorithm was tested on 828 marked frames that made up the test sample.

The sensitivity of the algorithm was 77.2%, the accuracy of detecting neoplasms was 83.2%.

We analyzed the errors of the model and identified the most common causes of missing neoplasms on the frame or false positive triggering.

Thus, the model tends to skip the neoplasm that is in the foreground of the frame: this may be due to an insufficient number of marked neoplasms close to the borders of the frame (Fig. 5).

A similar problem occurred with multiple neoplasms in one frame, when the model recognized only one of several objects (Fig. 6).

Another situation when polyp omissions were recorded was neoplasms of a small size (Fig. 7). During testing, we recorded false positive triggering when the model identified areas on the frame that did not contain neoplasms — these are folds, glare, dirt. At the same time, during the testing of the model, we noted 5 cases when the model detected neoplasms that were not taken into account during the initial marking by a specialist (Fig. 8). The presence of objects of interest in such cases was confirmed when considering the frame by two experts, as well as by reviewing the original video fragment of the colonoscopy recording.

Thus, errors in the operation of the algorithm are registered in the following cases:

1. Neoplasm in the foreground
2. Small size of the neoplasm
3. “Blurred” neoplasm
4. Neoplasm on gaustra
5. Multiple neoplasms

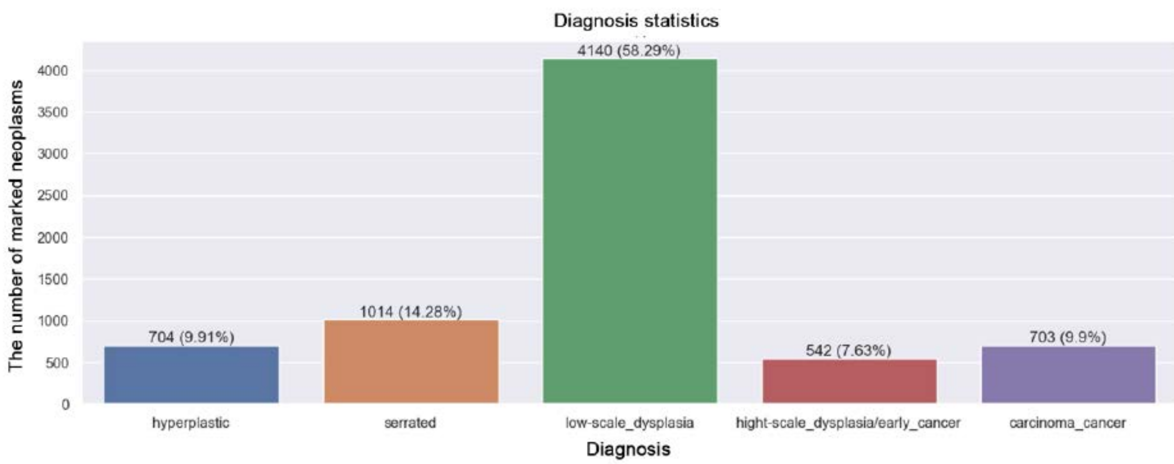

Figure 3. *Distribution of annotated lesions by classes*

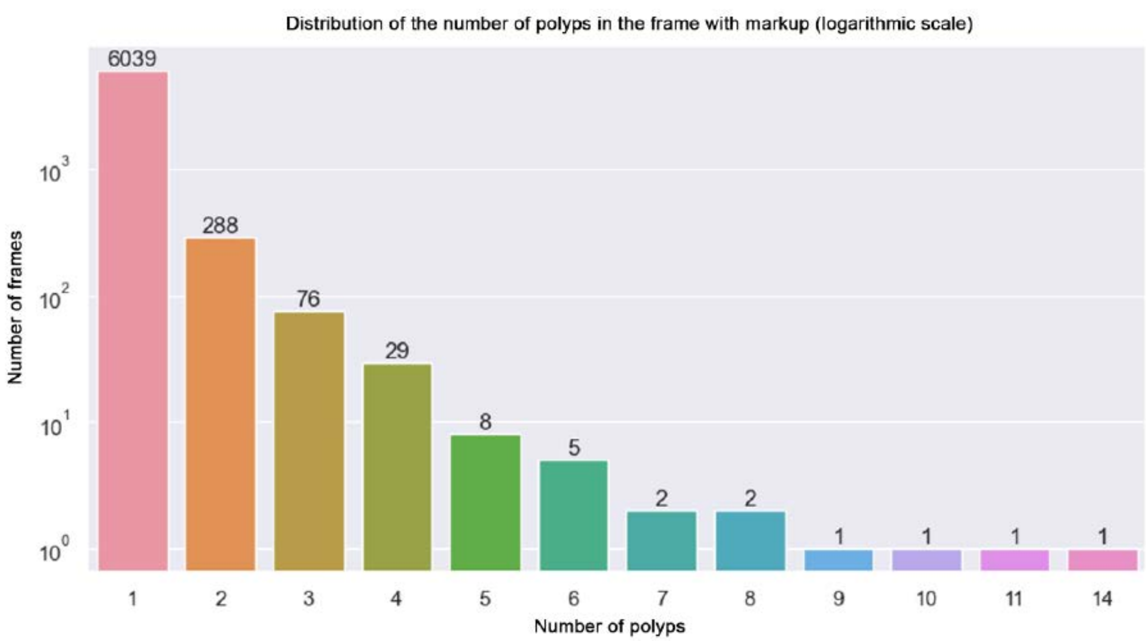

Figure 4. *Distribution of frames by amount of annotated lesions*

6. Colonoscopy in NBI mode;
7. The presence of foreign objects (biopsy cap, clip) in the frame.

DISCUSSION

Artificial intelligence technology is one of the most actively developing fields of science, the widespread use of which is expected to have a significant impact on various aspects of life. In healthcare, this technology has also been actively used in recent years, with the greatest success achieved in medical imaging. The first reports about the use of artificial intelligence to help a doctor perform a colonoscopy are encouraging. At the same time, the technology requires further development, technical issues of unification of the corresponding software have not been resolved, the effectiveness of the clinical decision support system based on artificial intelligence has not been sufficiently studied. In addition, the regulatory framework for the application of this technique in everyday medical practice has not been developed.
Our study is aimed at creating an original universal algorithm based on machine training, which will allow providing support to an endoscopist during colonoscopy in real time, highlighting neoplasms in the video stream. It is assumed that the algorithm will classify the detected neoplasms, and in the future also

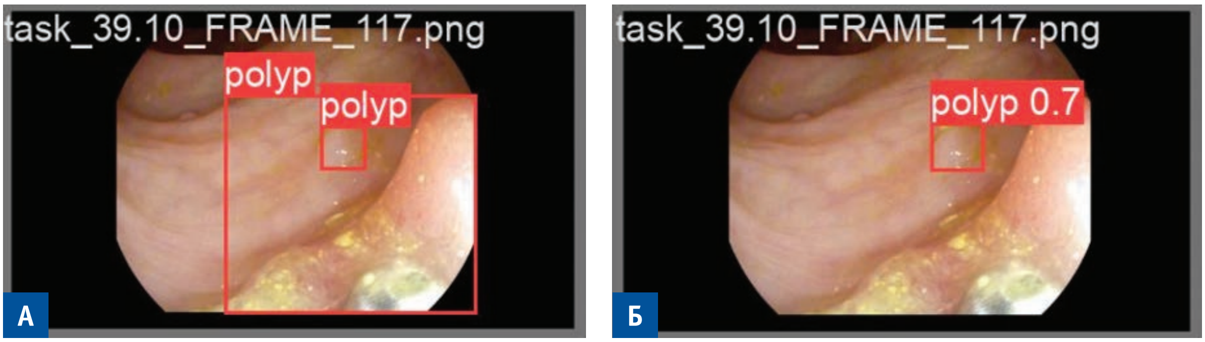

Figure 5. *An example of an algorithm error. Missing of the lesion in the foreground. A. Annotation by specialist. Б. Algorithm output*

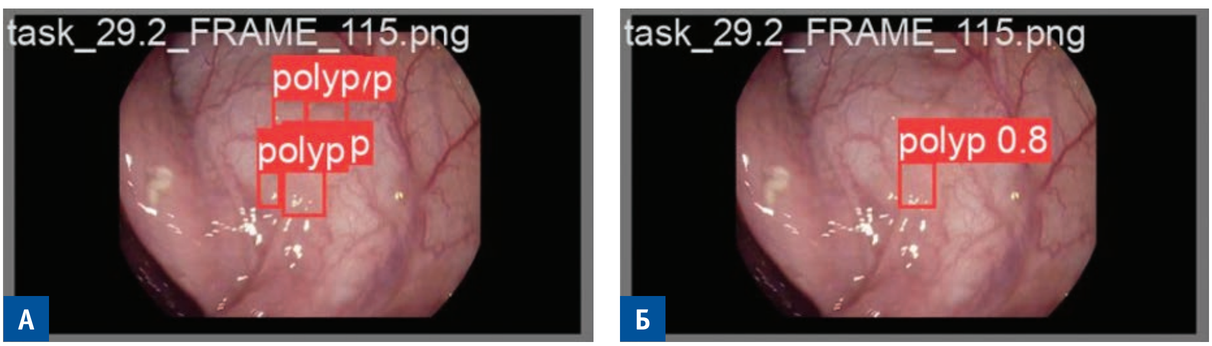

Figure 6. *An example of an algorithm error. Missing of the multiple lesions. A. Annotation by specialist. Б. Algorithm output*

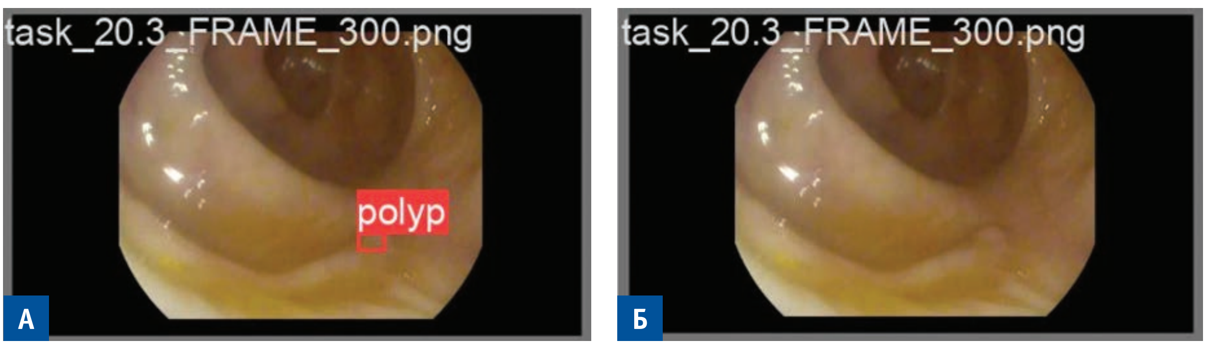

Figure 7. *An example of an algorithm error. Missing of the small lesion. A. Annotation by specialist. Б. Algorithm output*

Table 3. *Comparative characteristics of different data sets*

Data-set	Description	Format	Image Definition	Object of Detection
Kvasir-SEG / Hyper Kvasir	1,000 images	Image	Different	Masks, BBox
PICCOLO	3,433 images (2,131 WL and 1,302 NBI) of 76 neoplasms from 48 patients	Image	854 × 480, 1920 × 1080	Masks. Classification: Paris and NICE, Adenocarcinoma, Adenoma, Hyperplastic
KUMC	Collected from several datasets; more than 30,000 images	Image	Different	BBox. Classification: Adenoma, Hyperplastic
SUN	49,136 images; 100 neoplasms; 109,554 images without neoplasms	Image	N/A	BBox polyp, non-polyp annotations
Colorectal Polyp Image Cohort (PIBAdb)	~31,400 images (~22,600 WL and ~8,800 NBI); 1,176 neoplasms; ~17,300 images without neoplasms	Video and Image	768 × 576	BBox BBox Classification: Adenoma, Hyperplastic, Sessile Serrated Adenoma, Traditional Serrated Adenoma, Non Epithelial Neoplastic, Invasive
Data-set by RNMRC of Coloproctology	1,070 videos, 6,453 images with neoplasms	Video and Image	Different, at least 1,080 in height	Masks. Classification: Hyperplastic, serrated, low-grade_dysplasia, high-grade_dysplasia/ early_cancer, carcinoma_cancer

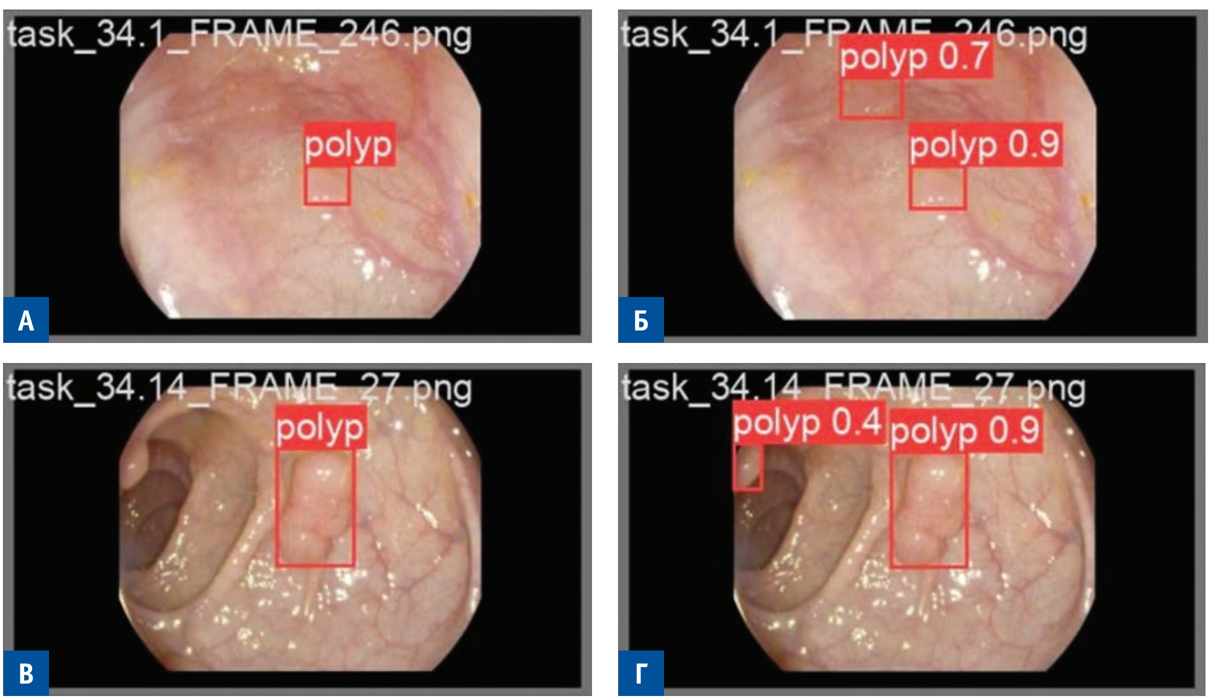

Figure 8. *An example of revealing by the algorithm not annotated lesions. А,В. Primary annotation by specialist. Б,Г. Algorithm output*

Table 4. *Comparative characteristics of artificial intelligence algorithms in the detection of neoplasms during colonoscopy*

Authors	Year	Data-Set	Sensitivity	Accuracy
Pacal et al.	2022	Training and test: piccolo	79.9%	92.6%
Nogueira-Rodríguez et al.	2022	Training: private Test: piccolo	60.0%	76.0%
Li K. et al.	2021	Training and test: kumc	86.2%	91.2%
RNMRC of Coloproctology	2022	Collected data-set	77.2%	83.2%

form a preliminary examination protocol, noting the level of examination of the intestine and the quality of its preparation, the number, size and class of detected changes.

At this stage of our study, the algorithm of a promising CDSS demonstrated an acceptable level of sensitivity and accuracy on a test sample — 77.2% and 83.2%, respectively. At the same time, an interesting observation is the cases of the allocation of neoplasms by the algorithm that were not mistakenly annotated by an endoscopist. We also analyzed various situations that are difficult to interpret with machine vision, which makes it expedient to retrain the program by expanding the data set by including additional marked frames.

When comparing with the data sets published in the public domain, it can be stated that our data set is assembled from higher-definition frames, contains a large number of images of neoplasms, while 5classes of objects are differentiated (Table 3).

The potential operability of a promising CDSS based on the obtained algorithm trained on this data set is illustrated by the relatively high specificity and accuracy of the test. At the same time, according to these characteristics, the developed algorithm in the current version is inferior to a number of the most developed analogues (Table 4).

The presented data should be interpreted with caution, since the sensitivity and accuracy of the algorithm were determined on test samples, while the declared parameters can be significantly improved by further training the model. The real effectiveness of the algorithm and the CDSS created on its basis should be studied through comparative clinical trials. Developing the design of this kind of research is a non-trivial task, since colonoscopy does not have a verification method for the detection of adenomas, and performing two consecutive endoscopic examinations in one patient is not entirely ethical. In this regard, it seems appropriate to abandon direct comparison in favor of large studies on homogeneous groups of patients.

CONCLUSION

The marked-up data set made it possible to develop an algorithm based on artificial intelligence technology that determines colorectal neoplasms in the colonoscopy recording video stream with an accuracy of 83.2%. The technology seems promising. However, it requires further development, improvement to the CDSS and study of effectiveness from the standpoint of evidence-based medicine.

AUTHORS CONTRIBUTION

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Collection and processing of the materials: *Aleksei A. Likutov, Dmitri A. Mtvralashvili, Darya I. Suslova, Aleksandr A. Borodinov, Oleg I. Sushkov*

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