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ARTICLE

The Application Value of an Artificial Intelligence-Driven Intestinal Image Recognition Model to Evaluate Intestinal Preparation before Colonoscopy

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Abstract

Aims/Background Artificial intelligence (AI), with advantages such as automatic feature extraction and high data processing capacity and being unaffected by fatigue, can accurately analyze images obtained from colonoscopy, assess the quality of bowel preparation, and reduce the subjectivity of the operating physician, which may help to achieve standardization and normalization of colonoscopy. In this study, we aimed to explore the value of using an AI-driven intestinal image recognition model to evaluate intestinal preparation before colonoscopy.

Methods In this retrospective analysis, we analyzed the clinical data of 98 patients who underwent colonoscopy in Nantong First People's Hospital from May 2023 to October 2023. Among them, 47 cases were evaluated based on the intestinal preparation map and the last fecal characteristics (Regular group), and 51 cases were evaluated using an AI-driven intestinal image recognition model (AI group). The duration of colonoscopy examination, intestinal cleanliness, incidence of adverse reactions, and satisfaction with intestinal preparation of the two groups were analyzed.

Results The time for colonoscopy in the AI group was shorter than that in the Regular group, and the intestinal cleanliness score in the AI group was higher than that in the Regular group ($p < 0.05$). The incidence of adverse reactions in the AI group (3.92%) was lower than that in the Regular group (10.64%), but the difference was not statistically significant ($p > 0.05$). The satisfaction rate of intestinal preparation in the AI group (96.08%) was comparable to that of the Regular group (82.98%) ($p > 0.05$).

Conclusion Compared with the assessment based solely on the intestinal preparation map and the last fecal characteristics, the application of AI intestinal image recognition model in intestinal preparation before colonoscopy can shorten the time of colonoscopy and improve intestinal cleanliness, but with comparable patient satisfaction and safety.

Key words: artificial intelligence; intestinal; image; colonoscopy

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Introduction

Colonoscopy is an important auxiliary diagnostic tool for intestinal diseases (Shahini et al, 2023). Colonoscopy examination enables effective detection of early

intestinal diseases, thus avoiding missed diagnosis and misdiagnosis, and the results of which provide guidance for early adoption of corresponding treatment measures in clinical practice (Chapman and Marshall, 2020; Shahini et al, 2023). Meanwhile, the accuracy of colonoscopy examination is closely related to the quality of intestinal preparation (Rosa et al, 2023). Adequate intestinal preparation before examination ensures the cleanliness of the intestinal mucosa, which has a direct influence on the examination results (Chapman and Marshall, 2020; Hammami et al, 2021; Rosa et al, 2023). Higher-quality intestinal preparation allows unobstructed observation of tumors, ulcers, polyps, and other conditions on the intestinal mucosa during colonoscopy (Rong et al, 2023; Sun et al, 2023). If the quality of intestinal preparation is poor (e.g., fecal adhesion to the intestinal wall), the accuracy of diagnostic evaluation could be affected, potentially delaying the implementation of optimal intervention (Matsumoto et al, 2021; Rong et al, 2023; Sun et al, 2023).

Several surveys have shown that 20% to 30% of patients undergoing colonoscopy have inadequate bowel preparation, which not only affects the examination process and results but also exacerbates patient pain and increases the risk of complications (Hsu and Chiu, 2023b; Sun et al, 2023; Zhou et al, 2021). Therefore, how to improve the quality of intestinal preparation before colonoscopy has become a research hotspot (Hsu and Chiu, 2023b; Zhou et al, 2021). In recent years, artificial intelligence (AI) has achieved gradual yet widespread adoption in various branches of the medical field. It has the advantages of automatic feature extraction and data processing capabilities and is not affected by fatigue (Hsu et al, 2023a). In the discipline of gastroenterology, AI can be applied to accurately analyze the images obtained from colonoscopy, evaluate the quality of intestinal preparation, and reduce the subjectivity of the operating physician, which may help to achieve the standardization of colonoscopy examination (Aoki et al, 2020; Ju et al, 2023).

In view of the above, this study was designed to retrospectively analyze the clinical data of patients who underwent colonoscopy, aiming to clarify the application value of AI intestinal image recognition models in evaluating intestinal preparation before colonoscopy and improve the quality of intestinal preparation.

Methods

Participants

This is a retrospective analysis. Clinical data from 98 patients who underwent colonoscopy in NanTong First People's Hospital from May 2023 to October 2023 were retrospectively reviewed. Among them, 47 cases who were evaluated based solely on the intestinal preparation map and the last fecal characteristics were assigned to the Regular group, while 51 cases who were evaluated using an AI-driven intestinal image recognition model were assigned to the AI group. This study was approved by the Ethics Committee of NanTong First People's Hospital (No. 2020KT085). The procedure of obtaining informed consent from the patients was exempted by the Ethics Committee of NanTong First People's Hospital given the retrospective nature of the study.

Inclusion and Exclusion Criteria

Only the patients meeting the following inclusion criteria were included: (i) patients aged ≥18 years old; (ii) patients taking laxatives for bowel preparation; (iii) patients or their accompanying family members who were familiar with using smartphones; and (iv) patients with complete clinical data.

The exclusion criteria of this study were as follows: (i) individuals with gastrointestinal bleeding or obstruction; (ii) individuals who had previously undergone intestinal surgery treatment; (iii) individuals with cardiovascular and pulmonary dysfunction; (iv) individuals with movement disorders who were unable to complete the intestinal preparation; (v) individuals with neurological or psychiatric disorders; (vi) individuals with allergic constitution; (vii) individuals with abnormal coagulation function; and (viii) patients with gastric emptying disorders.

Treatment Method

In the Regular group, the patients were evaluated based on the intestinal preparation map and the last fecal characteristics.

Patients in the AI group were evaluated using the AI intestinal image recognition model. During the period of intestinal preparation, which commenced at 8:00 PM the day before the examination, each of the patients was administered with 1 L of polyethylene glycol electrolyte powder (H20030827, WanHe Pharmaceutical Co., Ltd., Shenzhen, China) in divided doses within 60 minutes. On the day of the examination, if the patient undergoes the examination in the morning, they should start at 4:00 AM and take 2 L of polyethylene glycol electrolyte powder in divided doses within 60 minutes; if the examination is to be conducted in the afternoon, starting from 9:00 PM, the patient would be ordered to take 2 L of polyethylene glycol electrolyte powder in divided doses within 60 minutes (250 mL/time). After taking the polyethylene glycol electrolyte powder, the patients should drink plenty of water, increase walking time, and massage the abdomen clockwise. Colonoscopy was performed for those who showed quality intestinal preparation, and laxatives were added to those who failed until the preparation became suitable for examination. The examination was performed using the colonoscopy examination system CF-HQ290 (Olympus Medical Systems, Tokyo, Japan). The patients were assisted in taking a left lateral position and an electronic endoscope was inserted through the anus, slowly advanced to the end of the ileum, and then withdrawn to the anus by the end of the colonoscopy examination. During the image segmentation phase of model construction, fecal water images were captured using smartphones, and the images were segmented using the multi-threshold edge detection method. Gaussian smoothing was used for noise reduction. The Gaussian kernel size (usually 3 × 3, 5 × 5, 7 × 7) was determined based on the image noise level and the required smoothness level. Gaussian kernel was created and placed at the corresponding pixel position. All pixel values and corresponding Gaussian weights in the kernel were multiplied and summed to obtain new pixel values, and the images were saved and processed. The gradient values in each direction of the image were calculated and the maximum value was screened, and then the edge information of the fecal water image was obtained by referring to the preset high threshold. Contour maps

were generated using the preset low threshold and edge information, and the fecal water images were separated and extracted based on the contour maps. Next, a preset convolutional neural network (CNN) model was generated. The fecal water images in the database were divided into a training set and a validation set in a 7:3 ratio. The CNN model was trained with the training set data, and the results of multiple CNN models with different initializations but the same structure were averaged to obtain a preset CNN model. The fecal water images were identified and extracted, and the fecal images were compared with the fecal properties database images using the perceptual hashing algorithm to obtain intestinal preparation results. For the validation set, the model performance was verified based on ResNet Transformer, Vision, Visual geometry group network and ConvNext, and the accuracy and F1 value variation curve were clarified. The pre-configured CNN model was deployed on the mobile cloud, and patients were informed to send the last image of fecal fluid discharged to the cloud for evaluation through the WeChat mini program "Intestinal Preparation" on their smartphones. The mini program includes a photography module (capturing fecal water images through a smartphone), a processing module (using the central processor of the machine learning fecal water shape recognition method program to implement processing and generate intestinal preparation results), and a display module (connecting the processing module and the mobile phone display screen to present evaluation results). The model was successfully constructed (Fig. 1).

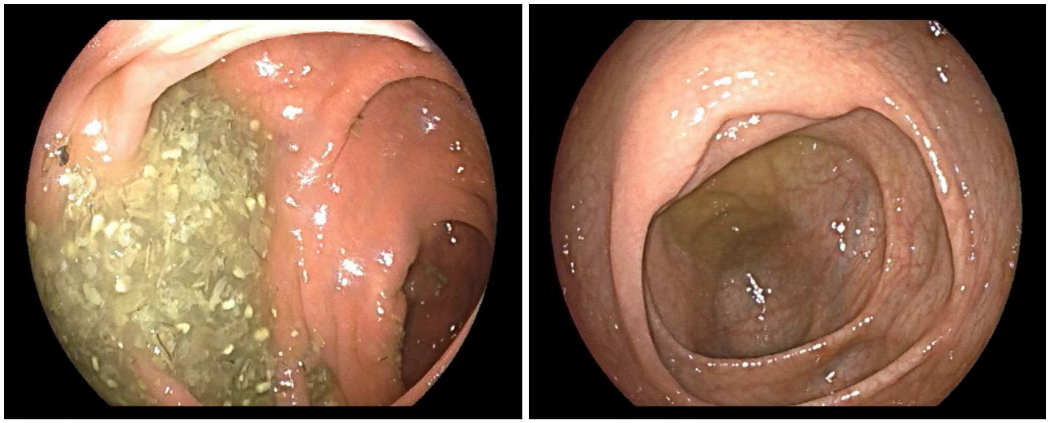

Fig. 1. Artificial intelligence (AI) intestinal image recognition model. (A) Unclean intestine. (B) Clean intestine.

Observation Indicators

Time and cleanliness of the intestine during colonoscopy. The time for colonoscopy refers to the time difference between capturing images of the anus while inserting and pulling out the endoscope. Intestinal cleanliness of the right, transverse, and left colon was evaluated using the Boston Bowel Preparation Scale. The examination needs to be terminated if it is impossible to insert the endoscope under the condition of poor intestinal preparation. The presence of a large amount of solid

feces in the intestinal cavity that block the view of intestinal mucosa is scored 0 on the scale. The presence of opaque liquid or residual feces in the intestinal cavity, which renders part of the intestinal mucosa visible, is scored 1 point. Two points are scored if there is a small amount of opaque liquid or feces in the intestinal cavity, which makes the intestinal mucosa moderately visible. Clear visibility of the entire intestinal mucosa, with no opaque liquid or feces in the intestinal cavity, is scored 3 points. The sum of the total scores of each bowel is the final score.

Incidence of adverse reactions during intestinal preparation. The incidence of adverse reactions during intestinal preparation, including vomiting, nausea, anal discomfort, and palpitations, was recorded.

Intestinal preparation satisfaction. Before discharge, a self-designed satisfaction questionnaire was used to evaluate patients' satisfaction with the intestinal preparation from three aspects: attitude of the staff, quality of operation, and any discomfort during intestinal preparation. The total score of the questionnaire is 100 points, which are divided into three categories: very satisfied (90–100 points), satisfied (70–89 points), and dissatisfied ($\leq$69 points). Overall satisfaction rate = (number of very satisfied + number of satisfied)/total number of responses $\times$ 100%.

Statistical Analysis

Data were analyzed using SPSS version 26.0 (SPSS Inc., Chicago, IL, USA). Normally distributed continuous data are expressed as mean and standard deviation (SD), based on the normality of distribution, assessed by the Shapiro-Wilk test. Independent sample *t*-test was used to compare the means of two independent samples, especially for continuous variables. The hypothesis of equal variance was examined and considered in the analysis. Categorical variables are expressed as frequency and percentage. The Chi-square test was used to compare categorical variables between two groups, such as gender and educational level. *p*-value less than 0.05 was considered statistically significant.

Results

In this retrospective analysis, a total of 98 patients were included, including 52 males and 46 females. The age of the patients ranged from 36 to 67 years old, with a mean of 52.26 $\pm$ 7.56 years. There were 47 cases in the Regular group and 51 cases in the AI group. There were no significant differences in gender, age, body mass index (BMI), education level, and reason for inspection between the two groups ($p > 0.05$) (Table 1).

It was shown that the time required for colonoscopy in the AI group was shorter than that in the Regular group, and the intestinal cleanliness score was higher in the AI group than that in the Regular group ($p < 0.05$) (Fig. 2).

In terms of adverse reactions, 2 patients in the AI group (3.92%) experienced adverse reactions compared to 5 patients in the Regular group (10.64%), but the difference was not statistically significant ($p > 0.05$) (Table 2).

In the AI group, 36 patients were very satisfied with the overall intestinal preparation procedure, with 13 and 2 individuals feeling satisfied and dissatisfied, respectively. Meanwhile, 24 patients were very satisfied, 15 were satisfied, and 8 were

Table 1. Comparison of baseline characteristics between the AI and Regular groups.

Variables	AI group (n = 51)	Regular group (n = 47)	t/χ^2	p
Gender				
Male	29 (56.86)	23 (48.94)	0.617	0.432
Female	22 (43.14)	24 (51.06)		
Age (year)	51.82 ± 7.17	52.72 ± 8.02	–0.587	0.559
Body mass index (kg/m^2)	23.61 ± 2.69	23.09 ± 3.08	0.886	0.378
Reason for inspection				
Constipation	5 (9.80)	7 (14.89)		
Inflammatory bowel disease	4 (7.84)	2 (4.26)		
Colonic polyps	26 (50.98)	26 (55.32)	3.145	0.534
Rectal bleeding	14 (27.45)	8 (17.02)		
Others	2 (3.92)	4 (8.51)		
Education level				
Below high school	29 (56.86)	22 (46.81)	0.991	0.320
High school and above	22 (43.14)	25 (53.19)		

Note: Except for age and body mass index which are expressed as mean ± SD, other variables are presented as count (percentage).
AI, artificial intelligence.

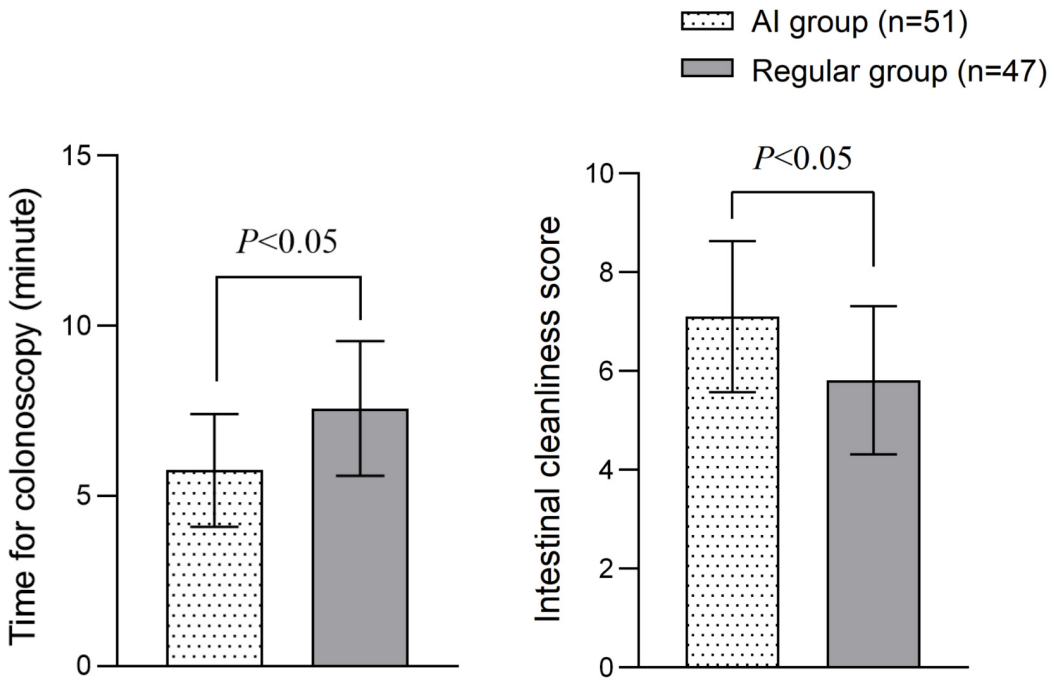

Fig. 2. Comparison of time taken for colonoscopy examination and intestinal cleanliness between the AI and Regular groups. AI, artificial intelligence.

dissatisfied with the overall intestinal preparation procedure in the Regular group. The overall satisfaction rate with intestinal preparation in the AI group (96.08%) was comparable to that of the Regular group (82.98%) ($p > 0.05$) (Table 3).

Table 2. Comparison of incidence rate of adverse reactions between the AI and Regular groups.

Group	*n*	Vomiting	Nausea	Anal discomfort	Palpitation	Overall incidence rate
AI group	51	0 (0.00)	0 (0.00)	1 (1.96)	1 (1.96)	2 (3.92)
Regular group	47	1 (2.13)	2 (4.26)	2 (4.26)	0 (0.00)	5 (10.64)
χ^2						0.805
p						0.370

Note: The variables are presented as count (percentage). AI, artificial intelligence.

Table 3. Comparison of satisfaction with intestinal preparation between the AI and Regular groups.

Group	n	Very satisfied	Satisfied	Dissatisfied	Overall satisfaction
AI group	51	36 (70.59)	13 (25.49)	2 (3.92)	49 (96.08)
Regular group	47	24 (51.06)	15 (31.91)	8 (17.02)	39 (82.98)
χ^2					3.263*
p					0.071

Note: The variables are presented as count (percentage). AI, artificial intelligence. *, Chi-square test with continuity correction applied.

Discussion

Colonoscopy is the mainstay of examination tool for screening colorectal cancer by virtue of its high screening sensitivity and specificity. Studies have shown that traditional approaches are constrained by technical shortcomings such as incomplete feature extraction and poor recognition performance (Chen et al, 2020; Shan et al, 2021). The extracted features are mainly limited to certain aspects, such as the shape of fecal water and the image color. Thus, with these approaches, it is difficult to fully capture the overall state of the intestines and accurately determine the actual intestinal cleanliness (Chen et al, 2020; Shan et al, 2021; Tkach et al, 2022). The usage of AI has been reported to be able to shorten endoscopic examination time, reduce blind spot rates, improve the successful detection rate of high-risk lesions, evaluate intestinal preparation, improve polyp detection rate, automatically collect maps, and generate reports (Song et al, 2021). At the same time, AI can conduct quality control evaluations for endoscopists, improve the detection rate of endoscopic lesions, and reduce the burden on endoscopists (Correia and Lourenço, 2021; Song et al, 2021). Therefore, in the present study, we explored the value of using an AI intestinal image recognition model to evaluate intestinal preparation before colonoscopy and found that the AI application indeed shortened the duration of colonoscopy examination and improved intestinal cleanliness, as compared to the usage of the regular approaches, although these two types of methods did not yield statistically significant differences in patient satisfaction and incidence of adverse reactions. This attests to the superior application value of the AI-driven intestinal image recognition model in intestinal preparation before

colonoscopy, which is beneficial to shorten the time of colonoscopy examination and improve the quality of intestinal cleansing.

Zhou et al (2020) used AI systems for the evaluation of intestinal preparation, providing intestinal preparation scores every 30 seconds and presenting the cumulative frame ratio of each score during the exit phase of colonoscopy, and the result confirmed that its evaluation accuracy was as high as 93.33%. Meanwhile, studies also demonstrated that in AI assessment, the application of grayscale conversion, noise reduction, and standardization on fecal water images can comprehensively extract the morphological features of fecal water, and can be used to train CNN models (Aoki et al, 2024; Zhou et al, 2020). Through the one-by-one comparison of fecal water images and fecal water shape database images, the quality of intestinal preparation can be accurately evaluated (Aoki et al, 2024; Hsu et al, 2023a), which can help to reduce the workload of medical staff and minimizing the relevant preparation work before examination (Aoki et al, 2024; He et al, 2019; Hsu et al, 2023a; Zhou et al, 2020).

Gimeno-García et al (2023) pointed out that patients undergoing colonoscopy can autonomously evaluate their intestinal preparation based on the intestinal cleanliness, but such evaluation could lead to subjective results. In addition, the quality of colonoscopy can be easily affected by insufficient intestinal preparation, and even lead to the termination of the examination. Thus, comparing and analyzing the last fecal map uploaded by patients using the AI-driven models on their mobile devices can allow for a more objective evaluation of intestinal preparation, thereby improving the quality of colonoscopy examinations. It is also demonstrated that using AI to identify intestinal structures, evaluate the quality of intestinal preparation, and obtain the retraction time, cecal insertion rate, and intestinal preparation quality through analysis of colonoscopy images can provide important reference basis for the evaluation of colonoscopy examination, which is conducive to improving its accuracy, safety, and effectiveness (Cardoso et al, 2022). O'Hara and Mc Namara (2023) also confirmed that AI technology can help improve the quality of intestinal preparation before colonoscopy, thereby ensuring its accuracy. The results of this study also support the conclusions of the aforementioned research.

The AI-based examination and evaluation systems can integrate a large amount of authoritative experience and knowledge from medical experts, and assist physicians lacking clinical experience in standardized and scientific evaluation of intestinal preparation quality, so as to achieve standardization and unity of colonoscopy examination (Cardoso et al, 2022; O'Hara and Mc Namara, 2023). Su et al (2020) developed a deep learning-based quality control system for colonoscopy, which can monitor the quality of intestinal preparation, retraction speed, and stability in real-time, and give out alerts when the intestinal preparation is poor (Boston Intestinal Preparation Scale score <2 points) or when the retraction is too fast, all of which are meant for quality control. Such quality control systems for colonoscopy have been touted for their ability to improve the quality of colonoscopy examination and facilitate the detection rate of adenomas and polyps (O'Hara and Mc Namara, 2023; Su et al, 2020). In addition, the application of AI-driven intestinal image recognition models in intestinal preparation before colonoscopy can help improve

the uneven level of endoscopic physicians in different regions, especially in underdeveloped regions, due to imbalanced allocation of medical resources and disparity in economic levels (Cardoso et al, 2022; O'Hara and Mc Namara, 2023; Su et al, 2020).

This study has certain limitations. Firstly, it is a single-center retrospective study with small sample size. Secondly, neither group was randomly assigned; therefore, the baseline information collected may be imbalanced and biased. Thirdly, the indicators of the colonoscopy examination may be influenced by human or technical factors. Finally, it is not clear whether there is a difference in the disease detection rate between the two groups. Therefore, further clinical exploration is needed.

Conclusion

Compared with the assessment based solely on the intestinal preparation map and the last fecal characteristics, the application of AI-driven intestinal image recognition model in intestinal preparation before colonoscopy can shorten the time of colonoscopy, and improve intestinal cleanliness, but with comparable levels of patient satisfaction and safety.

Key Points

- The application of AI-driven intestinal image recognition model in intestinal preparation before colonoscopy can shorten the time of colonoscopy and improve intestinal cleanliness.
- The AI-driven intestinal image recognition model delivers comparable levels of patient satisfaction and safety to those evaluated solely based on the intestinal preparation map and the last fecal characteristics.
- The application of AI-driven intestinal image recognition model in intestinal preparation before colonoscopy is a feasible strategy with a satisfactory safety profile.

Availability of Data and Materials

The data analyzed was available on the request for the corresponding author.

Author Contributions

ZMG and XRX designed the study. XRX, JHL, JWQ, BFF, TH and JJS conducted the study. TH provided significant assistance and suggestions for the artificial intelligence aspect of this research. SCF collected and analyzed the data. JJS participated in drafting the manuscript, and all authors contributed to the critical revision of the manuscript for important intellectual content. All authors gave final approval of the version to be published. All authors participated fully in the work, took public responsibility for appropriate portions of the content, and agreed to be

accountable for all aspects of the work in ensuring that questions related to the accuracy or completeness of any part of the work were appropriately investigated and resolved.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of Nantong First People's Hospital (No. 2020KT085). The procedure of obtaining informed consent from the patients was exempted by the Ethics Committee of NanTong First People's Hospital given the retrospective nature of the study. The study was in accordance with the Declaration of Helsinki.

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Conflict of Interest

The authors declare no conflict of interest.

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