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Artificial intelligence-tailored bowel preparation reduces laxative burden and promotes sustainable endoscopy

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MESSAGE

Artificial intelligence (AI) has proven effective in assessing bowel preparation adequacy, but its role in guiding personalised laxative dosing is untested. In this prospective, multicentre, endoscopist-masked randomised trial, 1650 participants were assigned to AI-assisted or conventional groups using self-evaluation (SE) by patients during a 3 L split-dose polyethylene glycol (PEG) regimen. The AI group used significantly less PEG (mean difference −496.1 mL; p<0.001) while maintaining similar bowel cleanliness, polyp detection rates (PDR) and withdrawal times. Right colon scores were slightly higher, with less nausea and bloating reported in the AI group. AI-assisted assessment (AIA) offers an effective personalised approach to colonoscopy and warrants evaluation with other regimens.

IN MORE DETAIL

Colonoscopy plays a vital role in early detection of colorectal cancer (CRC), with adequate bowel cleansing being essential for mucosal visualisation.[1] Our team previously developed an AIA tool capable of real-time evaluation of rectal effluent images, providing instant feedback and matching conventional self-assessment in quality.[2] Given growing interest in sustainable practices in gastrointestinal endoscopy, and the burden of high-volume purgative regimens, a more individualised, eco-friendly approach to bowel preparation is warranted. No randomised controlled trials (RCTs) have explored real-time, AI-guided titration of purgative volume. We hypothesised that AIA could efficiently reduce PEG intake to individuals' needs while maintaining preparation adequacy.

We conducted a prospective, endoscopist-blinded RCT at Xiamen Chang Gung Hospital and Shenzhen Hospital of Southern Medical University from July 2023 through July 2024 (ChiCTR2300067499). Eligible patients aged 18–75 scheduled for colonoscopy were randomised 1:1 to either a traditional SE groupor an AIA group. All patients received 1 L of PEG the night before colonoscopy. The SE group ingested a mandatory additional 2 L, guided by photographic comparisons of rectal effluent, while the AIA group ingested a titrated volume from the remaining 2 L, stopping once the AI system returned a 'pass' after defecation photo upload. All participants used a QR code to access preparation instructions and uploaded defecation photos using a smartphone. Laxative volume was recorded using a designated 500 mL (=1 cup) measuring cup provided to all participants (online supplemental figure S1). Endoscopists (>1000 procedures) were blinded to group assignment. The primary outcome was total PEG volume consumed. Secondary outcomes included total Boston Bowel Preparation Scale (BBPS) score, with adequate preparation having a total BBPS score ≥6, with all segments ≥2.[3] Other outcomes included adenoma detection rate (ADR), polyp detection rate (PDR), withdrawal time (excluded therapeutic manoeuvres, in accordance with guidelines), water irrigation volumes as an indicator of cleansing effort (details in the online supplemental methods) and patient-reported adverse effects. Comprehensive methods are described in the online supplemental appendix. Statistical analyses included t-tests, Wilcoxon rank-sum tests and χ^2tests as appropriate. Analyses were conducted in both intention-to-treat (ITT) and per-protocol (PP) populations.

Of 1697 screened patients (figure 1), 1650 were randomised (AIA: 833; SE: 817) and included in ITT analysis; groups were comparable with regard to age, sex and other parameters; 1603 were included in PP analysis (online supplemental table S1). The AIA group consumed significantly less PEG (mean±SD: 2504±522 mL vs 3000±0 mL; difference –496 mL, 95% CI –532 to –460; p<0.001). Median volume was 2500 mL in AIA versus 3000 mL in SE. In the SE group, all patients were instructed to consume 3 L of PEG according to institutional standard, and adherence was reinforced via the bowel preparation app, which required participants to confirm full intake before proceeding to subsequent steps. On the examination day, nursing personnel reviewed the app completion screenshot as part of intake verification. Accordingly, the reported volume of 3000±0 mL reflects protocol-enforced intake confirmed via the app-based verification process among SE participants, although unreported non-compliance may still occur in real-world practice (details in the online supplemental

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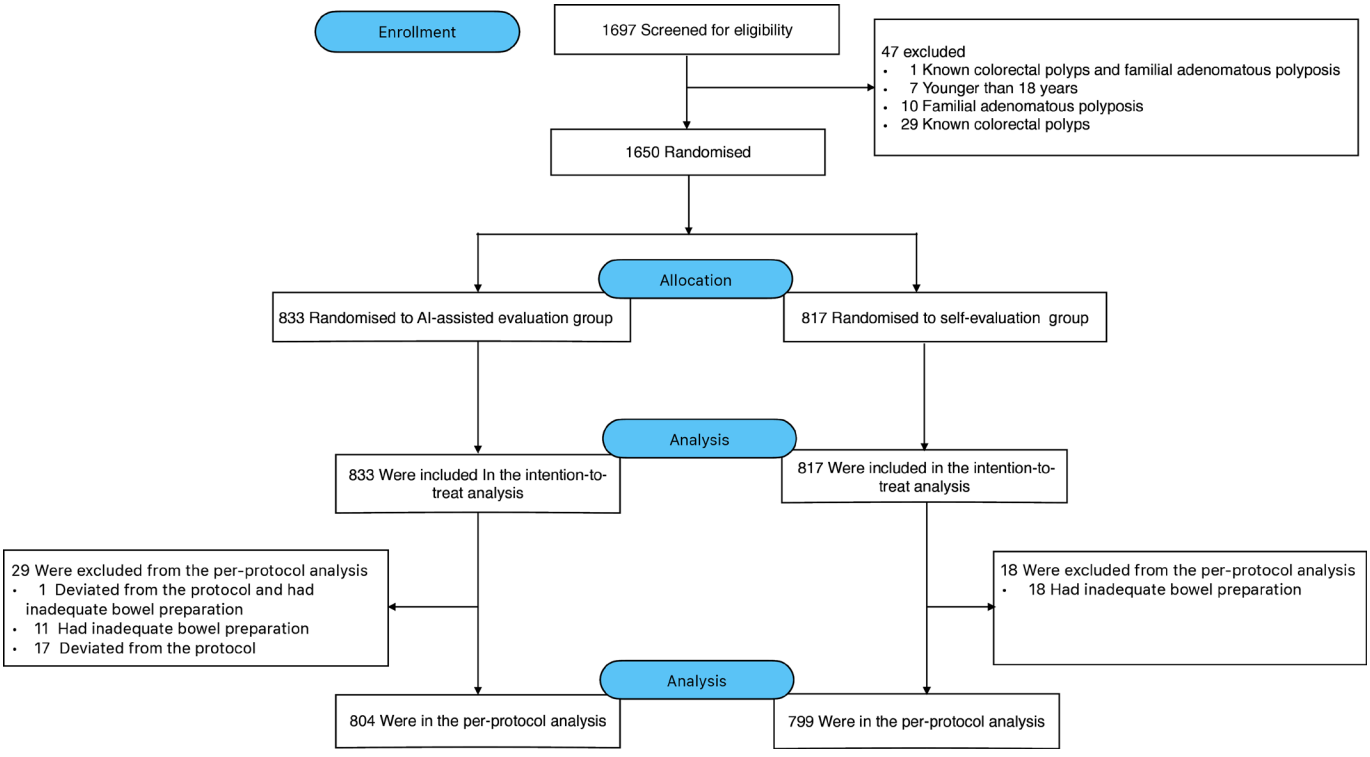


Figure 1 Allocation, enrolment and participant flow through the trial. AI, artificial intelligence.

methods). Over half (55.1%) of AIA participants required <6 cups (table 1). Water irrigation volumes used for debris clearance were comparable between groups, suggesting similar procedural cleansing effort (table 2). BBPS scores were also similar between groups; right colon scores were slightly higher in AIA (table 2). The proportion of adequate bowel preparation showed no significant differences in both groups. No significant differences were observed in PDR, ADR or withdrawal time. AIA participants reported significantly less nausea and bloating (online supplemental table S2). Subgroup analyses showed PEG

Table 1 Primary endpoint: comparison of the volumes of laxative consumed between groups

Characteristics	AIA group	SE group	Difference (95% CI)	P value*
ITT population	**n=833**	**n=817**		
Volumes, mL	2503.9 (522.1) (2500)	3000.0 (0.0) (3000)	−496.1 (−531.93 to −460.27)	<0.001†
Number of cups‡, n (%)				<0.001
1	0 (0.0)	0 (0.0)	0 (−0.46 to 0.47)	
2	0 (0.0)	0 (0.0)	0 (−0.46 to 0.47)	
3	96 (11.5)	0 (0.0)	11.5 (9.45 to 13.85)	
4	143 (17.2)	0 (0.0)	17.2 (14.74 to 19.91)	
5	220 (26.4)	0 (0.0)	26.4 (23.48 to 29.50)	
6	374 (44.9)	817 (100.0)	−55.1 (−58.45 to −51.67)	
PP population	**n=804**	**n=799**		
Volumes, mL	2515.1 (518.1) (2500)	3000.0 (0.0) (3000)	−484.90 (−520.85 to −448.95)	<0.001†
Number of cups‡, n (%)				<0.001
1	0 (0.0)	0 (0.0)	0.0 (−0.48 to 0.48)	
2	0 (0.0)	0 (0.0)	0.0 (−0.48 to 0.48)	
3	90 (11.2)	0 (0.0)	11.2 (9.15 to 13.57)	
4	132 (16.4)	0 (0.0)	16.4 (13.95 to 19.12)	
5	215 (26.7)	0 (0.0)	26.7 (23.72 to 29.86)	
6	367 (45.6)	799 (100.0)	−54.4 (−57.81 to −50.91)	

Data are mean (SD) (median) or n (%).
*Comparison between AI-guided and control groups.
†A Wilcoxon rank-sum test was used due to non-normality of the data, and the 95% CI of the difference was examined to determine whether the minimum clinically important difference of 450 mL was achieved.
‡1 cup is defined as 500 mL, with incomplete consumption rounded up.
AI, artificial intelligence; AIA, artificial intelligence-assisted assessment; ITT, intention to treat; PP, per protocol; SE, self-evaluation.

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Table 2 Secondary endpoints: comparison of other outcomes between groups

Characteristics	AIA group	SE group	Difference (95% CI)	P value*
ITT population	**n=833**	**n=817**		
BBPS score				
Total	7.9 (1.0)	7.9 (1.0)	0.0 (−0.10 to 0.10)	0.055
Right	2.5 (0.5)	2.4 (0.5)	0.1 (0.05 to 0.15)	0.031
Transverse	2.8 (0.4)	2.8 (0.4)	0.0 (−0.04 to 0.04)	0.410
Left	2.6 (0.5)	2.6 (0.5)	0.0 (−0.05 to 0.05)	0.069
Withdrawal time, min	7.1 (1.6)	7.1 (1.6)	0.0 (−0.15 to 0.15)	0.651
Water irrigation volume†	79.1 (83.4)	78.3 (85.3)	0.8 (−7.35 to 8.95)	0.554
Adequate‡, n (%)	821 (98.6)	799 (97.8)	0.8 (−0.52 to 2.19)	0.246
Polyp detection rate, n (%)	401 (48.1)	414 (50.7)	−2.6 (−7.40 to 2.22)	0.292
Adenoma detection rate, n (%)	190 (22.8)	190 (23.3)	−0.5 (−4.56 to 3.56)	0.829
PP population§	**n=804**	**n=799**		
BBPS score				
Total	8.0 (0.9)	7.9 (0.9)	0.1 (0.01 to 0.19)	0.070
Right	2.5 (0.5)	2.4 (0.5)	0.1 (0.05 to 0.15)	0.033
Transverse	2.8 (0.4)	2.9 (0.3)	−0.1 (−0.15 to −0.05)	0.194
Left	2.6 (0.5)	2.6 (0.5)	0.0 (−0.05 to 0.05)	0.072
Withdrawal time, min	7.1 (1.6)	7.1 (1.6)	0.10 (−0.07 to 0.27)	0.622
Water irrigation volume†	77.2 (82.4)	77.4 (84.1)	−0.2 (−8.36 to 7.96)	0.750
Adequate‡, n (%)	804 (100.0)	799 (100.0)	0.0 (−0.48 to 0.48)	NA
Polyp detection rate, n (%)	385 (47.9)	406 (50.9)	−3.0 (−7.87 to 1.89)	0.231
Adenoma detection rate, n (%)	184 (22.9)	183 (22.9)	0.0 (−4.11 to 4.11)	0.993

Data are mean (SD) or n (%).
*Comparison between AIA and SE groups was performed using t-tests or Wilcoxon tests for continuous outcomes (if normality was violated) and χ^2tests for categorical data.
†The water irrigation volume used to clear debris during insertion and withdrawal phase.
‡Defined as a BBPS cut-off value of 6 or higher, with all segment scores of 2 or higher.
§Inadequate bowel preparation patients are excluded in PP population.
AIA, artificial intelligence-assisted assessment; BBPS, Boston Bowel Preparation Scale; ITT, intention to treat; NA, not applicable; PP, per protocol; SE, self-evaluation.

reduction with AIA among male participants, individuals aged <60 years and those with body mass index (BMI) <24 kg/m^2 (online supplemental figure S2). Among those with BMI ≥24, AIA was associated with a significantly higher rate of adequate cleansing compared with SE (online supplemental figure S3).

DISCUSSION

This randomised trial showed that AI-guided colon preparation significantly reduced PEG volume (mean difference −496.1 mL; 95% CI −531.93 to −460.27) while maintaining comparable bowel preparation adequacy. In contrast, the SE group adhered to a fixed 3 L regimen, with intake strictly enforced per institutional protocol and reinforced through app-based checkpoints. While this uniformity ensured a reliable comparator for volume reduction, it also underscores the inherent inflexibility of fixed-volume regimens, which fail to account for individual variability such as age, BMI, mobility, diet, comorbidities, compliance and tolerance.[4] These factors likely contributed to volume differences and highlight the limitations of a one-size-fits-all approach. The AI-adaptive approach aligns more closely with patient tolerability and enhances flexibility across diverse clinical settings. The observed reduction in laxative volume likely reflects active, individualised guidance, rather than passive comparison to static visual reference materials.

Split-dose regimens outperform day-before protocols, and high-volume (≥3 L) PEG remains a reference standard.[5 6] However, large volumes reduce adherence, prompting development of low-volume (≤2 L) regimens with mixed efficacy results.[7] Meta-analyses[5 8] yield conflicting findings due to varying protocols. Our trial applied a standardised, real-time, AI-guided titration. Over half (55.1%) in the AIA group used <3 L and reported fewer adverse effects (eg, nausea, bloating), while achieving similar cleansing outcomes. This approach balances efficacy and comfort, offering an effective alternative to fixed regimens. Broader patient-centred outcomes, such as sleep disturbance and acceptance, warrant future evaluation and will be incorporated in subsequent studies.

Comparable levels of cleansing effort were observed, as reflected by water irrigation volumes. Notably, AIA also improved right colon BBPS scores, which is clinically relevant given the prevalence of subtle proximal lesions like serrated adenomas linked to interval CRC.[9] Better right colon prep aligns with image-enhanced and wide-angle endoscopy techniques aiming to boost right-sided ADR.

Beyond clinical benefits, AIA supports sustainable endoscopy. Reducing unnecessary PEG minimises environmental impact from drug production, packaging and transport—consistent with American Society of Gastrointestinal Endoscopy, European Society of Gastrointestinal Endoscopy and British Society of Gastroenterology green endoscopy guidelines.[10 11] With 12.9 million colonoscopies in China[12] and 18 million in the USA,[13] the impact is substantial. Cutting PEG by 500 mL per patient could save 368–36800 g CO_2e.[10] For 1000 patients, this equals a 368 kg CO_2e reduction—comparable to driving 1430 km in a gasoline car.[14]

Improved prep may also reduce early repeat colonoscopies. Inadequate preparation is linked to 42% and 27% miss rates for adenomas and advanced adenomas, respectively.[15] By improving prep quality, AIA could lower repeat procedures, optimise resources and enhance diagnostic yield. Additionally, AIA may serve as a scalable education tool in regions with disparities in preparation quality.

Strengths include a large sample size, balanced baseline characteristics and extension of prior AI work.[2] Unlike earlier studies focusing

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on preparation assessment, this trial used AI to tailor laxative dosing. Limitations include reliance on smartphones and internet, limiting feasibility in underserved settings. Although PEG-based preparation supports standardised practice across many medical centres, its use may limit generalisability. Future investigation is required to determine whether the AI-driven benefits extend to alternative and lower volume regimens. While applied to a general population, future studies should assess AI in high-risk groups like the elderly and constipated patients. Ongoing trials are addressing this. Although operator dependent, water irrigation volume serves as a practical surrogate for cleansing effort due to its consistent use across groups. In summary, AIA safely individualises PEG dosing, improves patient experience and reduces environmental burden—supporting a paradigm that benefits physicians, patients and the planet.

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Contributors Y-BL, S-CL, Y-NH, Y-CW, T-YC, P-TC, P-HL and C-TC conceptualised and designed the study. P-TC, Y-CW, T-YC, P-HL, C-TC, X-BC, HX and SC collected the data. ATC, DC, RSYT, X-BC, HX, SC, JJYS and TYTL analysed and interpreted the data. Y-NH, T-YC, X-BC and WG obtained funding. Y-BL, S-CL and Y-NH assessed and verified the data and prepared the first draft of the manuscript. Y-BL, S-CL, C-TC, ATC, DC, RSYT, X-BC, HX, SC, JJYS, TYTL and WG contributed to the critical revision of the manuscript for important intellectual content. All authors had access to the data and had approved the final version before submission. WG had the final responsibility for the decision to submit for publication.

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Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

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Individual deidentified participant data that underlie the results reported in this article and study protocol can be shared with investigators for research purposes. All data requests should be submitted to the corresponding author for consideration.

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REFERENCES

1 Sung JJY, Ng SC, Chan FKL, *et al*. An updated Asia Pacific Consensus Recommendations on colorectal cancer screening. *Gut* 2015;64:121–32.
2 Lu Y-B, Lu S-C, Huang Y-N, *et al*. A Novel Convolutional Neural Network Model as an Alternative Approach to Bowel Preparation Evaluation Before Colonoscopy in the COVID-19 Era: A Multicenter, Single-Blinded, Randomized Study. *Am J Gastroenterol* 2022;117:1437–43.
3 Hassan C, East J, Radaelli F, *et al*. Bowel preparation for colonoscopy: European Society of Gastrointestinal Endoscopy (ESGE) Guideline – Update 2019. *Endoscopy* 2019;51:775–94.
4 Dolovich C, Unruh C, Moffatt DC, *et al*. Mandatory vs. optional split-dose bowel preparation for morning colonoscopies: a pragmatic noninferiority randomized controlled trial. *Endoscopy* 2023;55:822–35.
5 Martel M, Barkun AN, Menard C, *et al*. Split-Dose Preparations Are Superior to Day-Before Bowel Cleansing Regimens: A Meta-analysis. *Gastroenterology* 2015;149:79–88.
6 Cheng P, Chen Q, Li J, *et al*. 3 liters of polyethylene glycol vs. standard bowel preparation have equal efficacy in a Chinese population: a randomized, controlled trial. *Am J Transl Res* 2022;14:5641–50.
7 Barkun AN, Martel M, Epstein IL, *et al*. The Bowel CLEANsing National Initiative: High-Volume Split-Dose Vs Low-Volume Split-Dose Polyethylene Glycol Preparations: A Randomized Controlled Trial. *Clin Gastroenterol Hepatol* 2022;20:e1469–77.
8 Spadaccini M, Frazzoni L, Vanella G, *et al*. Efficacy and Tolerability of High- vs Low-Volume Split-Dose Bowel Cleansing Regimens for Colonoscopy: A Systematic Review and Meta-analysis. *Clin Gastroenterol Hepatol* 2020;18:1454–65.
9 le Clercq CMC, Bouwens MWE, Rondagh EJA, *et al*. Postcolonoscopy colorectal cancers are preventable: a population-based study. *Gut* 2014;63:957–63.
10 Rodríguez de Santiago E, Dinis-Ribeiro M, Pohl H, *et al*. Reducing the environmental footprint of gastrointestinal endoscopy: European Society of Gastrointestinal Endoscopy (ESGE) and European Society of Gastroenterology and Endoscopy Nurses and Associates (ESGENA) Position Statement. *Endoscopy* 2022;54:797–826.
11 Sebastian S, Dhar A, Baddeley R, *et al*. Green endoscopy: British Society of Gastroenterology (BSG), Joint Accreditation Group (JAG) and Centre for Sustainable Health (CSH) joint consensus on practical measures for environmental sustainability in endoscopy. *Gut* 2023;72:12–26.
12 Jiao Y-F, Cheng Z-Y, Gao Y, *et al*. Development, quality, and influencing factors of colonoscopy in China: results from the national census in 2013 and 2020. *Front Oncol* 2023;13:1276520.
13 Gayam S. Environmental Impact of Endoscopy: "Scope" of the Problem. *Am J Gastroenterol* 2020;115:1931–2.
14 United States Environmental Protection Agency. Comparison: your car vs. an electric vehicle. 2025.
15 Lebwohl B, Kastrinos F, Glick M, *et al*. The impact of suboptimal bowel preparation on adenoma miss rates and the factors associated with early repeat colonoscopy. *Gastrointest Endosc* 2011;73:1207–14.

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