



Bowel Preparation for Colonoscopy in 2020: A Look at the Past, Present, and Future

Valentine Ongeri Millien¹ · Nabil M. Mansour¹

© Springer Science+Business Media, LLC, part of Springer Nature 2020

Abstract

Purpose of this Review Colorectal cancer is the third most common cancer in the USA. Colonoscopy is considered the gold standard for colorectal cancer screening and can offer both diagnosis and therapy. The bowel preparation remains a significant barrier for patients who need to undergo colonoscopy and is often cited as the most dreaded aspect of the colonoscopy process. Inadequate bowel preparations still occur in 10–25% of colonoscopies, and this in turn can lead to increased procedural times, lower cecal intubation rates, and shorter interval between colonoscopies. From a quality standpoint, it is imperative that we do what we can to decrease the rate of inadequate bowel preparations. This review will focus on recent data regarding bowel preparation and offers a glimpse into what may be coming in the future.

Recent Findings Recent advances in the field have been made to improve tolerability of bowel preparations and allow for more adequate colonoscopies. Newer, lower volume, flavored preparations, the use of adjuncts, and using split-dose preparations all can help with tolerability, compliance, and, in turn, preparation quality. Edible bowel preparations may become available in the near future. Early data on the use of artificial intelligence for assessment of preparation quality has been promising. Additionally, utilization of smartphone technology for education prior to the bowel preparation has also been shown to improve the adequacy of bowel preparations.

Conclusions Ongoing efforts to improve the tolerability and palatability of colonoscopy bowel preparations are important from a quality improvement standpoint to ensure the adequacy of colonoscopy. Incorporating patient-specific factors and comorbidities is also an essential aspect of improving the quality of bowel preparation. Leveraging technology to better communicate with and educate patients on the bowel preparation process is likely to play a larger role in the coming years.

Keywords Bowel preparation · Polyethylene glycol · Sodium picosulfate · Split prep dosing · Education · Smartphones

Introduction

Colorectal cancer is the third most common cause of cancer death in the USA in women and the second leading cause of death in men. Colonoscopy is considered the gold standard for detection of colonic lesions including precancerous and cancerous lesions. This procedure not only allows diagnosis but, in many situations, also allows for removal of lesions that if left may become cancerous. Quality measures for adequate colonoscopy include the cecal intubation rate and adenoma

detection rate which are affected by bowel preparation [1•]. An adequate bowel preparation is essential for complete visualization of the colonic mucosa and for detection of precancerous lesions. Inadequate colon preparations are associated with longer procedures, incomplete colonoscopy, potential for missed pathology, increased cost (decreased interval to repeat examination), and potential risk for increased complications [2, 3]. Studies have shown that up to 25% of patients have inadequate bowel preparation [4••]. Suboptimal bowel preparation may also result in missed flat and/or serrated lesions, thereby increasing the risk of post-colonoscopy colorectal cancer.

Colonoscopy preparations tend to be disliked and poorly tolerated, which represents a major barrier toward screening and surveillance. It is not uncommon for patients who have undergone the procedure to state that the bowel preparation is the worst part of the experience and evidence suggests that

This article is part of the Topical Collection on *Large Intestine*

✉ Nabil M. Mansour
nabil.mansour@bcm.edu

¹ Section of Gastroenterology and Hepatology, Baylor College of Medicine, 7200 Cambridge St., Suite 8B, Houston, TX 77030, USA

fear of the bowel preparation is a major reason why a significant proportion of the population avoids colonoscopy [5–7]. The taste of the bowel preparation formulations, volume required for adequate colon preparations, patient-specific factors, and lack of a standardized patient education system during the bowel preparation process are some of the factors implicated in inadequate bowel preparations. This review will discuss some of these factors in depth and explore different solutions that have been proposed to improve them.

Bowel Preparation Scoring System

The most established, validated, and commonly used bowel preparation scoring systems are the Aronchick scale, the Ottawa Bowel Preparation Scale (OBPS), and the Boston Bowel preparation Scale (BBPS) (Table 1) [2, 5, 8, 9]. The Aronchick scale was the first scoring system developed and rates the bowel preparation from 1 (excellent) to 5 (inadequate). This scale is limited since scoring is performed prior to any washing or suction, does not divide the colon into segments, and also does not have a specific cutoff to determine adequate versus inadequate bowel preparation. The OBPS not only assesses stool burden but also residual fluid in the colon. Unlike the Aronchick, this scale divides the colon into three different segments: the right colon, the middle segment, and the rectosigmoid, each with a score of 0 (without residual stool) to 4 (significant amount of stool). The fluid content score is a score of the fluid content in the entire colon from 0 to 2 with 0 being no fluid. After combining these two factors, the OBPS ranges from 0 to 14 with 0 considered excellent. Similar to the Aronchick, this scale is applied prior to washing and suctioning and also does not have a cutoff number at which bowel preparation is considered adequate. The BBPS is graded from 0 to 9 with 9 considered an excellent bowel preparation. It is applied after cleaning and suctioning of colonic segments, and the colon segments are

divided into right, transverse, and left colon. This scoring scale provides a cutoff number of greater than or equal to 2 (in each segment) at which the bowel preparation is considered adequate. Among the available scoring systems, we feel that the BBPS is the most useful and the most reliable scale currently available, and we use it routinely in our procedures. However, as technology improves and becomes more integrated into endoscopy practice, the way we assess the quality of bowel preparations may change considerably. Specifically, there has been increasing interest to generate an objective assessment of bowel preparation which would allow for consistency in interpretation among all endoscopists in a real time fashion. Most recently, there was a comparative study from China which proposed the use of an artificial intelligence (AI)-based system called ENDOANGEL that allowed for real time and objective assessment of bowel preparation quality during colonoscopy [10•]. There was not only significantly higher accuracy of calculating the BBPS by ENDOANGEL as compared to novices (<1-year endoscopy experience), seniors (1–3 years' experience), and experts (>3 years' experience), but the program also provided prompts for bowel preparation scoring every 30 seconds during the withdrawal phase which allowed for more accurate calculation of the cumulative BBPS score. It is likely that AI will play a larger role in colonoscopy overall in the future, with automated assessment and scoring of bowel preparation quality being one aspect of that.

Types of Bowel Preparation

Several bowel preparation formulations have been developed. These formulations are mainly characterized by the main active ingredients with the majority containing polyethylene glycol (PEG), sodium sulfate, sodium picosulfate, or sodium phosphate (Table 2). The most commonly used formulations are the isosmotic PEG containing electrolyte preparations (PEG-ELS) which were introduced into market in the 1980s

Table 1 Comparison of the three most commonly used bowel preparation scales [2, 5, 8, 9]

Scale	Scale range	Segments which contribute to scoring	Timing of Scoring	Excellent preparation	Poor preparation	Limitations	Advantages
Aronchick Scale	Excellent to inadequate	Stool in entire Colon	Prior to washing and suctioning	Excellent 1	Inadequate 5	No score at which preparation is considered adequate, no validation	Ease of use
Ottawa Bowel Preparation Scale (OBPS)	0–14	Stool in different segments of colon (0–4 each segment), fluid in entire colon (0–2)	Prior to washing and suctioning	0	14	No score at which preparation is considered adequate	
Boston Bowel Preparation Scale (BBPS)	0–9	Stool in entire colon divided into 3 segments	After washing and suctioning	9	0	Ambiguity of intermediate scoring which results in mixed recommendations for repeat colonoscopy intervals	

Table 2 Characteristics of the most commonly used bowel preparation solutions [5, 8, 11–14]

Bowel Preparation	Instructions	Considerations	Limitations	% Adequate colonoscopy	ADR/PDR	Cost ^{\$}
PEG-ELS	Drink 2 L on night prior to and 2 L on morning of colonoscopy	Preferred in patients with IBD, renal failure, CHF or liver disease. Consider in elderly and hospitalized patients	High volume and unpleasant side effects including nausea and vomiting Avoid in patients with glucose-6-phosphatase deficiency	71.3%–92.1% 74.4%–93.5%	ADR, 27.8%–34.3% ADR, 18.8%–25.8%	\$16–\$20 \$120
PEG-ELS + ascorbic acid	1 L with 16 oz of water on evening prior and 1 L with 16 oz of water morning of colonoscopy	Consider in otherwise healthy ambulatory patients	Avoid in severely constipated patients and patients with lower gastrointestinal hemorrhage due to its slower onset of action	67.8%–81.8%	PDR, 47%	\$18.99
PEG 3350 without ELS in Gatorade®	Mix 238–255 g of MiralAX in 1.9 L of Gatorade, and drink 1/2 on evening prior and other half on morning of colonoscopy	Consider in young otherwise healthy patients	Avoid in elderly patients, those on NSAIDs or ACEi due to risk of nephrotoxicity; avoid in patients with suspicion of IBD or chronic diarrhea since it may cause aphthous ulcers	84.3%–90%	PDR, 54.2% ADR, 27.1%–36%	\$256.74
Sodium phosphate	20 tablets with 40 oz of water on evening prior and 12 tablets with 24 oz of water on morning of colonoscopy (other formulations not used as often in the USA)	Effective in otherwise healthy patients with chronic constipation	Avoid in gout due to concern of increase serum uric acid	93.5%–98.4% (depending on formulation)	PDR, 50.9% ADR, 26%	\$60.96–\$104.71
Sodium sulfate	16 oz of preparation and 32 oz of water taken on evening prior and morning of the colonoscopy	Alternative to sodium phosphate	Avoid in elderly patients due to risk of hyponatremia	81.6%–87.9%	PDR, 38.5%–42.9% ADR, 23.8%–31.3%	\$155.82
Sodium picosulfate		Consider in patients with history of bariatric surgery given low volume				

^{\$} Obtained from GoodRx and rxpricequotes websites. PDR polyp detection rate, ADR adenoma detection rate, NSAID nonsteroidal anti-inflammatory, ACEi angiotensin converting enzyme inhibitors

and have a well-established safety profile and few restrictions [15••]. These are non-absorbable iso-osmotic solutions and do not lead to any significant fluid shifts or changes in electrolyte levels [8, 11, 12]. These bowel preparations are preferred in patients with inflammatory bowel diseases since they are not known to distort colonic mucosa and patients with cardiac, renal, or hepatic dysfunction since they do not cause electrolyte shifts [11••]. Although generally safe and effective at cleansing, the original formulations required drinking 4 liters (L) of total volume throughout a specified period and contained higher sodium content, as well as a sulfur component, resulting in poor tasting agents. These factors resulted in low tolerability and were associated with poor compliance and inadequate bowel preparations [16, 17]. Despite these shortcomings, these agents remain available on the market and are still widely used at some institutions, but from our experience, patients that have used them in the past often ask for an alternative.

Given these issues, lower volume, better-tasting PEG-ELS formulations with adjuncts were developed. One of these agents which contains an ascorbic acid adjunct requires ingestion of only 2 L of preparation due to ascorbic acid saturation at high doses resulting in a greater bowel osmotic effect allowing for a synergistic effect with PEG. The ascorbic acid component has also been shown to improve the taste of the PEG formulation, and in a randomized trial the PEG with ascorbic acid was non-inferior to the original PEG formulations in efficacy and safety [18]. A meta-analysis of 12 randomized control trials comparing low volume PEG with ascorbic acid to its high volume PEG counterpart concluded that not only was split dose of this low volume solution preferred but that it had an improved bowel preparation efficacy as compared to the high volume split-dose regimen [19].

Apart from ascorbic acid, other adjuncts are used to decrease the volume of PEG-ELS required for optimal bowel preparation including bisacodyl and magnesium citrate. However, bisacodyl can lead to ischemic colitis in high doses, and magnesium citrate is contraindicated in patients with significant kidney disease [11••]. Despite these limitations, adjuncts have been shown to improve tolerability of bowel preparations and should be considered on an individual basis in patients taking PEG-ELS solutions. Another regimen gaining popularity due to decreased nausea and improved taste is one which contains PEG-3350 without electrolytes, an over-the-counter laxative used to treat constipation, dissolved in a sports drink such as Gatorade prior to being taken as a split preparation. Studies regarding the efficacy of this bowel preparation as compared with the traditional PEG-ELS solution have been controversial. A meta-analysis of 5 randomized controlled studies concluded that the Gatorade formulation was inferior to traditional PEG in the quality of bowel preparation [20]. This formulation is not approved for use as a colonoscopy preparation agent by the Food and Drug

Administration. It remains commonly used in practice, however, particularly in patients who have been unable to tolerate more traditional bowel preparation formulations.

Very low volume bowel preparations have also been evaluated and are available for commercial use. The majority of these very low volume formulations are hyperosmotic sodium-based products such as sodium phosphate, sodium sulfate, and sodium picosulfate which are also FDA approved for colonoscopy preparations. These formulations require lower volumes of ingestion so theoretically have better tolerability than the PEG-ELS solutions. A British multicenter prospective single-blinded study showed that bowel preparation with similar low volume bowel preparations was comparable to conventional PEG but superior regarding compliance, safety, and satisfaction [21]. This was also verified in a most recent Italian study by Spadaccini et al. which showed comparable adequacy in colon cleanliness between the low volume and high volume preparations but again with better tolerability and compliance of the low volume preparations [22]. The sodium phosphate preparation involves ingestion of 20 tablets in 40 oz of water the night before colonoscopy and 12 tablets in 24 oz of water the morning of the procedure [8••]. A meta-analysis of 15 randomized controlled trials showed that there was better compliance, improved palatability, and better bowel preparation with sodium phosphate compared with PEG-ELS. Furthermore, sodium phosphate was found to be superior to PEG-ELS in regard to bowel cleanliness for patients with chronic constipation in randomized control trials and subsequent meta-analysis of randomized control trials [23, 24]. This formulation, unlike PEG-ELS, is contraindicated in patients with inflammatory bowel diseases due to concern that it may distort the colonic mucosa and impede proper evaluation. Although FDA approved for bowel preparations, the sodium phosphate preparation is not commonly used in the USA due high risk of nephrotoxicity which has led to a black box warning for use in elderly patients, renal disease patients, and patients on medications that can affect the kidneys [8, 12]. We generally advise against the use of oral sodium phosphate due to the risks of kidney injury.

An alternative to sodium phosphate is sodium sulfate which has not been shown to have the same nephrotoxic effect as its phosphate containing counterpart. This preparation is taken as a split dose with 16 oz of preparation and 32 oz of water on the evening prior to colonoscopy and 16 oz of preparation and 32 oz of water on the morning of the colonoscopy [8••]. A prospective randomized single-blinded non-inferiority trial showed that oral sodium sulfate was non-inferior to the gold standard 4 L split preparation PEG-ELS in achieving adequate bowel preparation (98% versus 96%) but there were increased incidences of abdominal pain in the oral sulfate group [25]. Another multicenter randomized trial showed that in elderly patients between age 65–75, the average BBPS of

entire colon and right colon were higher and patient reported more satisfaction with the oral sulfate preparation [26].

Another sodium-based formulation is one containing sodium picosulfate which offers a very low volume alternative [8, 12]. A ready to drink flavored formulation of sodium picosulfate with magnesium oxide and citric acid has been developed and has been shown to be have superior efficacy in bowel cleansing compared to its powdered counterpart [27]. The increased efficacy may be due to improved convenience although this was not addressed in that study. Comparisons between this low volume formulation and PEG-ELS have produced mixed results. In a comparative randomized study of 368 patients undergoing colonoscopy in Norway, there was no difference in bowel cleanliness but significantly better tolerability for patients who received the low volume formulation compared with the PEG-ELS [6]. Another recently published prospective randomized study showed that PEG-ELS was superior to sodium picosulfate in achieving colon cleanliness [28]. More studies are needed to address these conflicting results as low volume formulations gain popularity.

Apart from the volume of ingestion, the taste of bowel preparation formulations is another great cause of distress to patients. An Internet search regarding colonoscopy is highly populated with questions and suggestions for how to make the bowel preparation formulations taste better. The use of beverage mixes, candy, and chilling the formulations prior to drinking are some techniques which are proposed to improve palatability. A study from Singapore demonstrated that using Coca Cola Zero as a solvent for PEG as opposed to water resulted in a well-tolerated, more palatable bowel preparation with better quality cleansing [29]. A single-blind randomized controlled trial of 99 patients in Lebanon showed that sugar-free menthol candies resulted in improved palatability of PEG-E bowel preparation and also in more consumption of the bowel preparation and subsequently better bowel cleansing [30]. While this has not gained popularity, the use of menthol candy may be a very simple and convenient method to help improve the taste and tolerability of bowel preparations.

In 2016, a phase II dual center randomized single blind study of 65 patients was presented at the American College of Gastroenterology Annual Scientific meeting comparing edible colon preparation (ECP) which incorporated nutritional bars and beverages with PEG 3350 with standard FDA approved bowel preparation formulations [31]. The endoscopic visibility ratings were similar in both the ECP group and the standard formulations, but more patients in the ECP group reported a satisfactory experience as compared with those who used standard formulations. Currently, ECPs are in phase III clinical trials and may in the future be approved for use and decrease patient reluctance in undergoing colonoscopies due to bowel preparations.

Finally, it is also important to consider the cost of the different bowel preparation regimens when prescribing. The prices of prescription medications in general continue to increase with Americans spending approximately \$1200 a year on prescriptions according to the Organization for Economic Cooperation and Development. A 2019 study by the Kaiser foundation concluded that high costs of prescription medications resulted in 1/3 of patients not filling their prescription [32]. This is an important consideration when assessing factors that contribute to low compliance rates for colonoscopies in general. As shown in Table 2, the prices of bowel preparations vary vastly; therefore, providing patient assistance options may be needed if it is necessary to use a more expensive alternative to achieve adequate colonoscopy [11, 32].

Dosing Interval of Bowel Preparation

After choosing a bowel regimen, timing of bowel preparation is another important aspect to consider. The current standard of care is a split-dose bowel preparation, wherein half of the bowel preparation solution is taken the night prior to and half is provided on the day of the colonoscopy. The evidence supporting the superiority of a split-dose regimen over a single dose (day before) regimen is overwhelming. A meta-analysis of 5 randomized control trials of the split preparation versus standard preparations showed a significantly better number of bowel preparations and decreased number of preparation discontinuations as compared with the full-dose preparations [33]. Another meta-analysis of 29 randomized clinical trials showed that the split preparation resulted in significantly more adequate bowel preparations as long as the colonoscopy was performed within 5 hours after the last dose was ingested [34]. Finally, a recently published systematic review and meta-analysis of 28 randomized controlled trials showed superiority of split-dose regimen in adenoma detection and especially with detection of sessile serrated lesions [35••].

Same-day preparations have also been studied for afternoon colonoscopies. This same-day regimen involves ingesting a total of 4 L of the bowel preparation agent beginning on the morning of the procedure and subsequently undergoing colonoscopy in the afternoon. A randomized control trial of 339 patients who received either split dose or same-day bowel preparation found no significant difference between the two groups with regard to bowel cleansing quality and tolerability of the preparation [36]. Another single center endoscopist-blinded study comparing 4 L same-day preparation versus a 4 L split preparation showed no differences in the quality of the preparation as long as the colonoscopy was performed within 7 h of completion of the bowel preparation [37]. In this study, although there was no loss of sleep, patients who underwent same-day bowel preparation reported more nausea as compared to their split preparation counterparts.

Timing of bowel preparation likely needs to be individualized for each patient. In the hospitalized patient, for example, several modifiable factors such as timing of colonoscopy (prior to noon), clear liquid diet on the day prior to colonoscopy, and avoidance of constipating opiate medications on the day preceding the procedure were all identified in a large retrospective study of 8819 patients from the Cleveland Clinic [38]. Several studies have shown that patient factors including older age, male gender, and low socioeconomic status and comorbidities including obesity, history of constipation, abdominal pelvic surgery, and history of cerebrovascular accident/neurologic disease are some of the most important risk factors for inadequate bowel preparation [39–42]. Medications such as opiates, anticholinergics, antidepressants, antacids, iron, and diuretics to name a few have also been associated with constipation especially in elderly patients, and these may impact adequacy of bowel preparation and require a more extended preparation [43]. Understanding a patient's history and timing the bowel preparation and colonoscopy based on individualized factors may help improve tolerability and compliance and improve the quality of the bowel preparation in these patients. We often will preemptively prescribe extended bowel preparations and/or ensure thorough education regarding bowel preparation instructions in patients with some of these risk factors.

Diet and Bowel Preparation

There have been several controversies as to whether the guidelines which recommend a strict low residue diet (LRD) on the days preceding and a clear liquid diet (CLD) on the day prior to colonoscopy lead to better bowel preparations. Despite these recommendations, there are no standardized dietary instructions given to patients, and there exists a dearth in research as to what dietary components can significantly affect the adequacy of bowel preparation. Furthermore, there is a concern that too much dietary restriction prior to colonoscopy would not only lead to decreased patient satisfaction but also to less compliance. A meta-analysis of randomized control trials of patients undergoing colonoscopy with either LRD or CLD on the day preceding colonoscopy showed those on LRD tolerated the bowel preparation process better, were more willing to repeat the process, and had no differences in adequate bowel preparations as compared to their CLD counterparts [44]. Therefore, the common practice of having patients consume only a CLD on the day prior to colonoscopy may be unnecessary, and serious consideration should be given to being more liberal with this dietary restriction. A prospective observational study of 201 patients in the Boston area found no association between the foods consumed >1 day prior to colonoscopy and adequacy of bowel preparations [45]. Moreover, unlike previously thought, this study showed no difference between fiber intake in the day prior to

colonoscopy and adequacy of bowel preparations. Another single center randomized control trial of 390 patients from Spain on either a 1-day or 3-day LRD showed no significant difference in bowel cleanliness and, interestingly, no differences in adherence to diet or satisfaction [40•].

Despite research stating that LRD will not affect adequacy of bowel preparation, it remains unclear what constitutes LRD, and there needs to be continued efforts to truly define what constitutes an LRD and make sure that it is something patients can easily understand. Furthermore, the rates of satisfaction among patient populations may also depend on the predominant diet in that population wherein populations with a baseline higher fiber diet may have lesser satisfaction on restrictions as compared to those who do not ingest higher fiber. Further research on standardizing low residue diet is needed especially if this diet will improve compliance with bowel preparation. Anecdotally, we also notice that sometimes patients who did not follow the recommended dietary restrictions (i.e., had a normal diet rather than a CLD or LRD the day before their colonoscopy) but did take the full bowel preparation as prescribed and at the correct times can still have an excellent bowel preparation. This indicates that compliance with the preparation itself may more important than dietary restriction. Further research on liberalizing dietary restrictions as part of colonoscopy preparation would be useful.

Education and Bowel Preparation

Education regarding bowel preparation is another critical aspect for adequate bowel preparations. Instructions usually provided by nursing staff either in verbal or written form have been shown to be relatively ineffective. Consequently, there has been increased interest in developing ways to communicate effectively to patients regarding bowel preparation procedures. Direct personalized education by nurses and physicians, cartoon pictures, phone calls, social media applications, and smartphone applications have been developed to enhance the standard instructions received by patients. A meta-analysis of 8 randomized controlled trials showed that patients who received these enhanced instructions had significantly better bowel preparation quality than those who received the standard instructions alone [41].

One method that is utilized increasingly is the pre-colonoscopy counseling session which is conducted either by a physician or a nurse and reviews the importance of factors such as diet and hydration combined with written instructions. Physician-delivered education has been proposed to be an essential component of this enhanced educational approach. This approach allows for individualized recommendations which address patients' medical history and any concerns which may impede adherence to instructions. A prospective colonoscopist-blinded study of 105 outpatient patients who underwent screening colonoscopy showed a

significant improvement in the quality of bowel preparation after physician counseling [46]. This is difficult to implement with the current system in the USA, however, as a large proportion of screening colonoscopies have become “open access” with the patient not meeting the endoscopist prior to the day of the procedure.

Videos and cartoons as part of the enhanced educational approach have also been shown to assist in improvement of bowel preparation. A randomized controlled study of 502 patients wherein patients were randomized to view an educational video instruction on the day prior to colonoscopy showed that those who watched the video had better bowel preparation for colonoscopy than those who did not. However, the overall polyp detection rate was not significantly better in the patients who watched the video [47]. Another study, a single-blinded prospective study of inner-city patients undergoing colonoscopy, concluded that patients who watched an instructional video prior to colonoscopy had better bowel preparations as compared with their counterparts [48]. A randomized controlled study from Dartmouth comparing patients who received standard pre-colonoscopy handouts to those who used a web-based multimedia patient engagement program found that those who used the media program had less anxiety regarding the colonoscopy, required less medication, and had shorter procedural times compared to their counterparts [49]. Although more studies are needed to further delineate the importance of instructional videos to the quality of bowel preparation, there appears to be a trend that these may be beneficial.

Increased use of smartphones and advances in smartphone technology have led to studies to see how to utilize this technology in bowel preparation. In a prospective study from Korea, a smartphone application for colonoscopy reminders was used in 142 randomized patients and showed that the bowel preparation was significantly improved in the 71 patients who used the application [50•]. This study had limitations including that this was a single center small study, enrolled patients who were less than 50 years old, and was limited to those who only possessed an Android operating system. Given the promising early results, further research on using smartphones to help improve bowel preparation in a more standard screening population is warranted.

Conclusions

The “one-size-fits-all” model of medicine is quickly disappearing. As we recognize that patient factors and comorbidities determine not only efficacy but also compliance with medications, we are moving more toward personalization of medical management. It is important to apply that same concept of personalization in the approach to bowel preparation and colonoscopies. The most important aspect to adherence to

colon cancer screening and surveillance guidelines is the bowel preparation process. Therefore, it is important to have in depth discussions and education with patients regarding this process and evaluate patient factors and comorbidities that increase risk of inadequate preparation. This will allow for development of a bowel preparation plan suitable for a particular patient to increase compliance. Artificial intelligence is a promising technology for having objective, uniform, and seamless assessment of bowel preparation quality. The advent of newer, easily tolerated and better-tasting preparations is critical to improving the overall quality of bowel preparation and to also increase uptake for colonoscopy. The ability to leverage technology to better educate our patients on the bowel preparation process may help in decreasing the numbers of inadequate bowel preparations.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:

- Of importance
- Of major importance

1. Ketwaroo GA, Sawhney MS. *Quality measures and quality improvements in colonoscopy*. Curr Opin Gastroenterol. 2015;31(1): 56–61 **This review discusses quality measures in colonoscopy.**
2. Kastenberg D, Bertiger G, Brogadir S. Bowel preparation quality scales for colonoscopy. World J Gastroenterol. 2018;24(26):2833–43.
3. Park JH, Kim SJ, Hyun JH, Han KS, Kim BC, Hong CW, et al. Correlation between bowel preparation and the adenoma detection rate in screening colonoscopy. Ann Coloproctol. 2017;33(3):93–8.
4. Chokshi RV, et al. *Prevalence of missed adenomas in patients with inadequate bowel preparation on screening colonoscopy*. Gastrointest Endosc. 2012;75(6):1197–203 **This retrospective study originally highlighted the high percentage (25%) of patients who present for colonoscopies have inadequate bowel preparation.**
5. Sawhney, M.S., Bowel preparation for colonoscopy: assessing and improving quality. Gastroenterology and Endoscopy News, March 2016.
6. Leitao K, Grimstad T, Breithauer M, Holme Ø, Paulsen V, Karl森 L, et al. Polyethylene glycol vs sodium picosulfate/magnesium citrate for colonoscopy preparation. Endosc Int Open. 2014;2(4): E230–4.
7. Sharara AI, el Reda ZD, Harb AH, Abou Fadel CG, Sarkis FS, Chalhoub JM, et al. The burden of bowel preparations in patients

- undergoing elective colonoscopy. United European Gastroenterol J. 2016;4(2):314–8.
- 8.** Bechtold ML, et al. *Optimizing bowel preparation for colonoscopy: a guide to enhance quality of visualization*. Ann Gastroenterol. 2016;29(2):137–46 **This review highlighted bowel preparation recommendations for specific populations.**
9. Parmar R, Martel M, Rostom A, Barkun AN. Validated scales for Colon cleansing: a systematic review. Am J Gastroenterol. 2016;111(2):197–204 **quiz 205.**
10. Zhou J, et al. *A novel artificial intelligence system for the assessment of bowel preparation (with video)*. Gastrointest Endosc. 2020;91(2):428–435.e2 **Study describing a new artificial intelligence software to assist with real time grading of bowel preparation.**
- 11.** Harrison NM, Hjelkrem MC. *Bowel cleansing before colonoscopy: Balancing efficacy, safety, cost and patient tolerance*. World J Gastrointest Endosc. 2016;8(1):4–12 **This review highlighted the polyp and adenoma detections rate after using different bowel cleansing agents and the costs of these agents.**
12. Sweetser S, Baron TH. Optimizing bowel cleansing for colonoscopy. Mayo Clin Proc. 2015;90(4):520–6.
13. Lee YH, Jeong SY, Kim YS, Jung HJ, Kwon MJ, Kwak CH, et al. Randomized controlled trial of sodium phosphate tablets versus 2 L polyethylene glycol solution for bowel cleansing prior to colonoscopy. Korean J Gastroenterol. 2015;65(1):27–34.
14. Jung YS, et al. Randomized controlled trial of sodium phosphate tablets vs polyethylene glycol solution for colonoscopy bowel cleansing. World J Gastroenterol. 2014;20(42):15845–51.
- 15.** Burke DA, et al. *Oral bowel lavage preparation for colonoscopy*. Postgrad Med J. 1988;64(756):772–4 **This was the first article to describe polyethylene glycol based bowel preparations.**
16. Clark RE, Godfrey JD, Choudhary A, Ashraf I, Matteson ML, Bechtold ML. Low-volume polyethylene glycol and bisacodyl for bowel preparation prior to colonoscopy: a meta-analysis. Ann Gastroenterol. 2013;26(4):319–24.
17. Adamcewicz M, Bearely D, Porat G, Friedenberg FK. Mechanism of action and toxicities of purgatives used for colonoscopy preparation. Expert Opin Drug Metab Toxicol. 2011;7(1):89–101.
18. Ell C, Fischbach W, Bronisch HJ, Dertinger S, Layer P, Rünzi M, et al. Randomized trial of low-volume PEG solution versus standard PEG + electrolytes for bowel cleansing before colonoscopy. Am J Gastroenterol. 2008;103(4):883–93.
19. Tian X, et al. *Comparative efficacy of 2 L polyethylene glycol alone or with ascorbic acid vs. 4 L polyethylene glycol for colonoscopy: a systematic review and network meta-analysis of 12 randomized controlled trials*. Front Med (Lausanne). 2019;6:182.
20. Siddique S, Lopez KT, Hinds AM, Ahmad DS, Nguyen DL, Matteson-Kome ML, et al. Miralax with Gatorade for bowel preparation: a meta-analysis of randomized controlled trials. Am J Gastroenterol. 2014;109(10):1566–74.
21. Kim HG, Huh KC, Koo HS, Kim SE, Kim JO, Kim TI, et al. Sodium Picosulfate with magnesium citrate (SPMC) plus laxative is a good alternative to conventional large volume polyethylene glycol in bowel preparation: a multicenter randomized single-blinded trial. Gut Liver. 2015;9(4):494–501.
22. Spadaccini M, 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. 2019.
23. Dang J, et al. Sodium phosphate is superior to polyethylene glycol in constipated patients undergoing colonoscopy: a systematic review and meta-analysis. Journal of the Canadian Association of Gastroenterology. 2019;2:426–7.
24. De Salvo L, et al. The bowel cleansing for colonoscopy. A randomized trial comparing three methods. Ann Ital Chir. 2006;77(2):143–6 **discussion 147.**
25. Yang HJ, Park SK, Kim JH, Im JP, Yeom DH, Seo GS, et al. Randomized trial comparing oral sulfate solution with 4-L polyethylene glycol administered in a split dose as preparation for colonoscopy. J Gastroenterol Hepatol. 2017;32(1):12–8.
26. Kwak MS, Cha JM, Yang HJ, Park DI, Kim KO, Lee J, et al. Safety and efficacy of low-volume preparation in the elderly: oral sulfate solution on the day before and Split-dose regimens (SEE SAFE) study. Gut Liver. 2019;13(2):176–82.
27. Hookey L, et al. Efficacy and safety of a ready-to-drink bowel preparation for colonoscopy: a randomized, controlled, non-inferiority trial. Ther Adv Gastroenterol. 2019;12: 1756284819851510.
28. Rostom A, Dube C, Bishay K, Antonova L, Heitman SJ, Hilsden R. A randomized clinical prospective trial comparing split-dose picosulfate/magnesium citrate and polyethylene glycol for colonoscopy preparation. PLoS One. 2019;14(3):e0211136.
29. Seow-En I, Seow-Choen F. A prospective randomized trial on the use of Coca-Cola Zero® vs water for polyethylene glycol bowel preparation before colonoscopy. Color Dis. 2016;18(7):717–23.
30. Sharara AI, el-Halabi MM, Abou Fadel CG, Sarkis FS. Sugar-free menthol candy drops improve the palatability and bowel cleansing effect of polyethylene glycol electrolyte solution. Gastrointest Endosc. 2013;78(6):886–91.
31. D, K., et al., Edible colon preparation shows excellent efficacy and tolerability in a phase 2, randomized trial. 2016.
32. Loria K. *Assisting patients with rising costs of prescription drugs*. Medical Economics. 2019;96(20)).
33. Kilgore TW, Abdinoor AA, Szary NM, Schowengerdt SW, Yust JB, Choudhary A, et al. Bowel preparation with split-dose polyethylene glycol before colonoscopy: a meta-analysis of randomized controlled trials. Gastrointest Endosc. 2011;73(6):1240–5.
34. Bucci C, et al. *Optimal bowel cleansing for colonoscopy: split the dose! A series of meta-analyses of controlled studies*. Gastrointest Endosc. 2014;80(4):566–576.e2.
- 35.** Zawaly K, et al. *The efficacy of split-dose bowel preparations for polyp detection: a systematic review and meta-analysis*. Am J Gastroenterol. 2019;114(6):884–92 **This is a systematic review and metanalysis of 28 randomized control trials which confirmed that split-dose bowel regimens increased detection of adenomas, and particularly sessile serrated polyps, compared to day before regimens.**
36. Seo M, Gweon TG, Huh CW, Ji JS, Choi H. Comparison of bowel cleansing efficacy, safety, bowel movement kinetics, and patient tolerability of same-day and split-dose bowel preparation using 4 L of polyethylene glycol: a prospective randomized study. Dis Colon Rectum. 2019;62(12):1518–27.
37. Castro FJ, al-Khairi B, Singh H, Mohameden M, Tandon K, Lopez R. Randomized controlled trial: split-dose and same-day large volume bowel preparation for afternoon colonoscopy have similar quality of preparation. J Clin Gastroenterol. 2019;53(10):724–30.
38. Garber A, Sarvepalli S, Burke CA, Bhatt A, Ibrahim M, McMichael J, et al. Modifiable factors associated with quality of bowel preparation among hospitalized patients undergoing colonoscopy. J Hosp Med. 2019;14(5):278–83.
39. Martel M, Ménard C, Restellini S, Kherad O, Almadi M, Bouchard M, et al. Which patient-related factors determine optimal bowel preparation? Curr Treat Options Gastroenterol. 2018;16(4):406–16.
- 40.** Gimeno-García AZ, et al. *Impact of a 1-day versus 3-day low-residue diet on bowel cleansing quality before colonoscopy: a randomized controlled trial*. Endoscopy. 2019;51(7):628–36 **This randomized control trial of 390 patients showed that there was no difference in bowel cleansing in patients who were placed on 3 day low residue diet as compared to those who were placed on a 1 day low residue diet prior to colonoscopy.**

41. Guo X, et al. Enhanced instructions improve the quality of bowel preparation for colonoscopy: a meta-analysis of randomized controlled trials. *Gastrointest Endosc.* 2017;85(1):90–97.e6.
42. Mahmood S, Farooqui SM, Madhoun MF. Predictors of inadequate bowel preparation for colonoscopy: a systematic review and meta-analysis. *Eur J Gastroenterol Hepatol.* 2018;30(8):819–26.
43. Gallagher P, O'Mahony D. Constipation in old age. *Best Pract Res Clin Gastroenterol.* 2009;23(6):875–87.
44. Nguyen DL, et al. Low-residue versus clear liquid diet before colonoscopy: a meta-analysis of randomized, controlled trials. *Gastrointest Endosc.* 2016;83(3):499–507.e1.
45. Leszczynski AM, MacArthur K, Nelson KP, Schueler SA, Quatromoni PA, Jacobson BC. The association among diet, dietary fiber, and bowel preparation at colonoscopy. *Gastrointest Endosc.* 2018;88(4):685–94.
46. Shieh TY, et al. Effect of physician-delivered patient education on the quality of bowel preparation for screening colonoscopy. *Gastroenterol Res Pract.* 2013;2013:570180.
47. Park JS, Kim MS, Kim H, Kim SI, Shin CH, Lee HJ, et al. A randomized controlled trial of an educational video to improve quality of bowel preparation for colonoscopy. *BMC Gastroenterol.* 2016;16(1):64.
48. Pillai A, Menon R, Oustecky D, Ahmad A. Educational colonoscopy video enhances bowel preparation quality and comprehension in an inner city population. *J Clin Gastroenterol.* 2018;52(6):515–8.
49. Parker S, Zipursky J, Ma H, Baumblatt GL, Siegel CA. A web-based multimedia program before colonoscopy increased knowledge and decreased anxiety, sedation requirement, and procedure time. *J Clin Gastroenterol.* 2018;52(6):519–23.
50. Cho J, et al. The impact of patient education with a smartphone application on the quality of bowel preparation for screening colonoscopy. *Clin Endosc.* 2017;50(5):479–85. **Small study of patients less than 50 years old which showed that a smartphone application for precolonoscopy education improves the quality of bowel preparation.**

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.