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SOLICITED REVIEW ARTICLE

# Improving the utility of colonoscopy: Recent advances in practice

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## Abstract

Colonoscopy is a frequently performed diagnostic and therapeutic test and the primary screening tool in several nationalized bowel cancer screening programs. There has been a considerable focus on maximizing the utility of colonoscopy. This has occurred in four key areas: Optimizing patient selection to reduce unnecessary or low yield colonoscopy has offered cost–benefit improvements in population screening. Improving quality assurance, through the development of widely accepted quality metrics for use in individual practice and the research setting, has offered measurable improvements in colonoscopic yield. Significant improvements have been demonstrated in colonoscopic technique, from the administration of preparation to the techniques employed during withdrawal of the colonoscope. Improved techniques to avoid post-procedural complications have also been developed—further maximizing the utility of colonoscopy.
The aim of this review is to summarize the recent evidence-based advances in colonoscopic practice that contribute to the optimal practice of colonoscopy.

## Introduction

Colonoscopy is a frequently performed diagnostic and therapeutic test and the primary screening tool in several nationalized bowel cancer screening programs.[1–5] While the cost of colonoscopy varies between countries, it is associated with a large health economic burden.[6,7] However, it remains the gold standard in the identification of colorectal cancer (CRC) and its precursor lesions,[1] as well as in diagnosing and evaluating other colonic mucosal disease such as inflammatory bowel disease (IBD).[8,9] Colonoscopy, screening[10–13], and colonoscopic polypectomy[14] have been associated with earlier detection of CRC and associated improvements in prevention and CRC survival.[15,16]

The need to optimize the use of colonoscopy is not merely health economic. Poor colonoscopic preparation[17,18] and technique[19–23] are associated with increased miss rates of polyps and CRC precursor lesions and, in turn, interval CRC (CRC appearing between scheduled colonoscopic screening visits). Furthermore, post-colonoscopy complications can occur at increased rates when optimal techniques are not employed.[24–32]

There has been a considerable focus on maximizing the utility of colonoscopy. This has occurred in four key areas. Optimizing patient selection to reduce unnecessary or low yield colonoscopy has offered cost–benefit improvements in population screening. Improving quality assurance, through the development of widely accepted quality metrics for use in individual practice and the research setting, has offered measurable improvements in colonoscopic yield. Significant improvements have been demonstrated in colonoscopic technique, from the administration of preparation to the techniques employed during withdrawal of the colonoscope. Improved techniques to avoid post-procedural complications have also been developed—further maximizing the utility of colonoscopy.

The aim of this review is to summarize the recent evidence-based advances in colonoscopic practice that contribute to the optimal practice of colonoscopy.

## Patient selection

Colonoscopy rates vary widely between countries and do not reflect variations in disease incidence.[6] The cost of unnecessary normal colonoscopy is substantial, and the potential cost saving of more efficient triage of colonoscopy is large. There is poor correlation between colonic polyps and lower gastrointestinal (GI) symptoms, and symptom-based screening is not recommended.[33–35] Current screening programs do not stratify for established risk factors other than age; such as family history, sex, smoking status, and body mass index (BMI). Some countries have adopted fecal occult blood test (FOBT) screening to decrease the burden of colonoscopy.[6] This approach is hampered by a low uptake of FOBT[36,37] and false positive and negative results,[38] yet remains effective.[16] Using flexible sigmoidoscopy for screening is being trialled[39] but has the obvious limitation of inability to detect proximal lesions.

Selecting patients to undergo priority screening using scoring systems has been investigated.[40–45] The Asia Pacific Colorectal Screening Score (APCS) developed by Yeoh *et al.*[40] is the most successful (Table 1) and has been validated in both Asian and Western populations. Patients identified as high risk by this score have a 14.9% rate of advanced adenoma at colonoscopy, with

**Table 1** The Asia Pacific Colorectal Screening Score

| Risk factor | Criteria | Points |
|---|---|---|
| Age (years) | < 50 | 0 |
| | 50–69 | 2 |
| | ≥ 70 | 3 |
| Gender | Female | 0 |
| | Male | 1 |
| Family history of CRC in a first degree relative | Absent | 0 |
| | Present | 2 |
| Smoking | Never | 0 |
| | Current or past | 1 |

A score of 0–1 defines average risk, 2–3 moderate risk, and 4–7 high risk. CRC, colorectal cancer.

advanced adenomas in 5.2% of moderate risk and 0.9% of average risk patients. This robust system will undoubtedly become an important feature in resource allocation.

Body mass index is known to be associated with CRC[46–50] and is not included in this scoring system, although has been in others.[41,44] In Western populations, addition of BMI does not augment the discriminative power of the APCS. A low BMI ($< 20\,kg/m^2$) is associated with a very low incidence of adenoma and may become a useful tool in patient selection.

A significant proportion of colonoscopy in patients with IBD is performed for dysplasia screening. Adherence to guidelines on dysplasia screening is variable and reflects widespread variations in physician knowledge.[51–55] As non-adherence to guidelines typically results in more frequent colonoscopy than is required in this setting, recent data suggesting that increasing physician knowledge[56] has resulted in improvements in adherence to guidelines is reassuring.

## Quality assurance practice

***Development of quality metrics.*** Without quality metrics in colonoscopy, there would be no way to measure the success of the practice of colonoscopy or a research intervention. Several quality metrics have evolved to become not only standard endpoints in trials seeking to improve quality of colonoscopy but have become standard practice audit parameters for academic and community endoscopists.[57,58]

The metrics most associated with improving the yield of colonoscopy are caecal intubation rate[59–63] and adenoma detection rate (ADR). Other measures of optimizing colonoscopy technique are covered in the succeeding paragraphs. Caecal intubation rate is the percentage of all colonoscopies attempted where the caecal pole is able to be touched with the tip of the colonoscope.[59–63] Low caecal intubation rates correlate with higher rates of interval cancer.[64] This measure exhibits a learning curve,[65] correlates with endoscopist's annual case volume,[66] and is a measure of competence of the endoscopist, with experienced operators achieving 95% or greater.[67,68]

Adenoma detection rate is the percentage of screening colonoscopies in which at least one adenoma is identified.[69] This measure varies with colonoscopist's experience and training, exhibits a learning curve, and correlates inversely with the incidence of interval CRC.[64,70–73] ADR is the primary outcome measure in most colonoscopic research.[69]

Alternatives to ADR are the polyp detection rate (PDR)[74–76] or the number of adenomas detected per colonoscopy (APC).[77,78] Neither of these has been as extensively validated and correlated with outcomes as the ADR. Variations in case-mix affect ADR, as well as PDR and APC offering limited advantage of these metrics in this respect.

As ADR can vary with case-mix in non-screening populations, measuring the number of adenomas per patient with adenomas may be a more robust metric in the future. Adoption of this measure would also account for the "one and done" phenomenon wherein an endoscopist undergoing audit may be unconsciously less inclined to identify second and subsequent adenomas as they do not contribute to the ADR.

Adenoma detection rate targets are 25% (30% for males, 20% for females) for screening colonoscopies, although increasing benefit has been shown at all levels of ADR higher than this.[73] ADR does not address sessile serrated lesions (SSA), which do not count toward ADR.[69] Missed sessile serrated and hyperplastic lesions in the proximal colon confer an elevated risk of CRC, and targets relating to these lesions (5% of screening colonoscopies) have been proposed.[79] Ongoing issues with histologic nomenclature make these lesions a less attractive audit tool. Continuous audit of intubation rates, withdrawal times, and ADR is recommended to ensure optimal quality.

***Adoption of audit practices.*** Adoption of ADR, withdrawal time, and caecal intubation rate as standard audit parameters is becoming more widespread.[80] Data on the impact of audit are compelling,[80] demonstrating a positive effect on colonoscopy quality merely by applying a self-reported audit that is reproducible and sustainable over years.[81]

Audit adoption has been tied to funding and resource management of bowel cancer screening in several health services—most notably in the National Health Service.[82]

## Technique

The technique of colonoscopy is focused on increasing the amount of visualized mucosa, the amount of time spent examining that mucosa, and adopting mechanical, optical, or imaging strategies to enhance the interpretation of the visualized mucosa. Standardized reporting tools enhance the findings of colonoscopy by making them more reliably communicable, and aid in determination of outcomes of observed lesions.

***Operator.*** Multiple studies have demonstrated better colonoscopic technique among gastroenterologists than surgeons, as measured by CRC in follow up.[64,72,83–85] This most likely reflects differences in caecal intubation rate and ADR.

***Preparation.*** Among the most obvious requirements for colonoscopy is adequate preparation. Despite the evident necessity of adequate preparation, substantial proportions (at least 15%) of colonoscopies remain inadequately prepared[17]—decreasing the yield of those colonoscopies[17,18,86] and adding cost and inconvenience

to the procedure.[87] Poor preparation can also delay diagnosis of progressive neoplastic lesions.

Split dosing of preparation (administration of the last dose of preparation on the morning of the procedure) has improved overall preparation rates,[88–91] and is now standard care. Adverse preparation related events are less frequent as phosphate-based preparations are now avoided in patients with poor renal function, or at risk for renal dysfunction.[92]

### Withdrawal technique

*Withdrawal time.* Withdrawal time is the time taken to withdraw the colonoscope following a completed inspection of the caecum and ileum, to the anus—excluding the time taken to remove the polyps. Longer withdrawal times (independent of other factors) are associated with improved ADR,[20,93,94] although one study has shown no benefit of increasing withdrawal times.[95] Withdrawal time is often standardized in colonoscopy trial protocols as a result of this, and multivariate adjustments for prolonged withdrawal time must be performed as this is an independent factor affecting ADR. Withdrawal time of at least 6 min is advised as an audited quality measure of colonoscopy.[69]

*Position change.* Most colonoscopy is performed in the left lateral position. Improved visualization of the colonic mucosa is obtained by routinely moving the patient during the procedure.[96,97] Not only are small residual pools of effluent moved, but repositioning can bring previously eclipsed portions of bowel into view. Increased visualization results in improved ADR of 34% *versus* 21% ($P = 0.01$)[98]. Where necessary and possible, position change should be made to improve adenoma detection.

*Retroflexion.* A large portion of missed polyps, interval cancers, and (harder to identify) flat hyperplastic or SSA are detected in the right colon.[99–101] The anatomy of the right colon (tall haustral folds) potentially decreased maneuvrability of the colonoscope and the nature of the lesions in the right colon (more likely to be flat) contribute to this phenomenon. Several studies have examined the effect of routine retroflexion of the colonoscope in the caecum on ADR, and found a positive effect,[102,103] while an older study[104] failed to identify an effect. Where possible and safe (over 95% in one study),[103] retroflexion in the right colon significantly increases adenoma detection.[105]

*Transparent cap.* Transparent caps or hoods can be fitted to the tip of the colonoscope (cap assisted colonoscopy (CAC)) to theoretically improve visualization of colonic mucosa, and aid in navigation past folds. CAC is also used in difficult polypectomy, variceal band ligation, per-oral endoscopic myotomy, and other advanced endoscopic procedures. CAC was found to slightly (48 s) improve caecal intubation time in a meta-analysis.[106] The effect of CAC on caecal intubation has been studied[107–118] and at meta-analysis[106] has not been found to improve caecal intubation rates.

Due to variable reporting, meta-analysis on the effect of CAC on polyp detection is not possible, but seven of the aforementioned 12 trials have identified improvements in polyp detection.[109–113,116,117] This marginal demonstrated benefit, in association with concerns regarding impairment of complete mucosal inspection due to reduction in field of view with imperfect bowel preparation adhering to the cap, have hampered universal uptake of CAC.

Endocuff (Endocuff AEC120 or AEC140, Arc Medical, Leeds, UK) is a device fitted like a cap to the end of the colonoscope coated with rubber arms.[119,120] It has been demonstrated to improve polyp detection in one randomized trial.[121] As it has similar limitations to the transparent cup, widespread uptake is not yet recommended.

*Chromoendoscopy/image enhancement.* Image enhancement with dye (methylene blue or indigo carmine), results in superior visualization of subtle mucosal lesions. Methylene blue is taken up preferentially by normal colonocytes, and dysplastic mucosa is left variably stained or unstained.[122] Indigo carmine is a non-absorbed dye highlighting mucosal topography.[122] Both of these dyes have been shown to aid in detection of dysplasia in patients with longstanding IBD.[123–126] Targeting biopsies with dye-spray in this setting is clearly superior to random biopsies of colonic mucosa and is now recommended by national societies.[127]

Outside the setting of IBD, the evidence for dye-spray chromoendoscopy is less strong. A marginal increase in small and flat, but not advanced adenomas was found in one study,[78] and this is counterpoised by the prolonged procedure time required for routine chromoendoscopy.[78,128] A systematic review of five studies indicates similar conclusions.[129] The time taken to administer dye-spray could be reduced by a colonic release formulation of methylene blue (Methylene Blue MMX; MMX Cosmo Technologies, Ireland), which has proof of concept in a preliminary trial[130], but awaits validation.

The use of dye-spray chromoendoscopy in the detection of SSA has more compelling evidence.[131] One study summarizing the impact of chromoendoscopy on right-sided "hyperplastic" polyp detection in the right colon before the clinical relevance of SSA were identified demonstrated an increase in detection rate from 9% to 16% with chromoendoscopy (when looking only at the right colon)[132]. These findings have been echoed in two further studies, demonstrating increase in serrated lesion detection with chromoendoscopy (29.5% *vs* 46.2%, $P < 0.001$)[128] and an increase in the mean number of non-neoplastic lesions per patient with chromoendoscopy (1.0 *vs* 1.8, $P < 0.001$)[78]. A clinical trial to evaluate chromoendoscopy to increase yield of serrated polyps in the right colon in the FOBT positive population is now underway (CONSCOP Study; ClinicalTrials.gov identifier: NCT01972451).

Fluorescent probes allowing improved targeting of endoscopic examination to dysplastic areas have been developed and show great clinical promise in Barrett's oesophagus.[133] While similar results have not yet been obtained in the colon, fluorescent labeling to improve dysplasia detection seems likely to emerge.

Electronic image enhancement uses either limitation of the wavelengths of emitted light (narrow band imaging (NBI); Olympus) or changes the reflected light intensity in processing (flexible spectral imaging color enhancement (FICE); Fujinon, iScan; Pentax). Most research has been performed on NBI, which uses light absorbed by hemoglobin, accentuating vasculature, capillary pattern, and pit-pattern in polyps.

A meta-analysis[134] and systematic review[135] demonstrated no difference in ADR between standard colonoscopy and NBI-assisted

colonoscopy. Technology has since progressed with high-definition colonoscopy becoming commonplace, and a newer generation of NBI (190-NBI) that allows a broader field of view appears to offer some benefit.[136] One recent tandem colonoscopy study of high-definition white light endoscopy (HD-WLE) and 190-NBI demonstrated superior ADR with 190-NBI (48.4% *vs* 34.4%; $P = 0.01$), but no difference in adenoma miss rates between the groups.[136]

Autofluorescence imaging (AFI) detects adenomatous tissue by capturing fluorescence between 500 and 630 nm using an excitation light source of 442 nm using two charge-coupled devices (CCD). AFI increased ADR in a tandem colonoscopy study (26% *vs* 18%; $P < 0.05$), but the baseline ADR is low in this study (no difference has been found among experienced endoscopists on a sub-analysis).[137]

Electronic image enhancement in the detection of IBD-related dysplasia has been compared with dye-spray chromoendoscopy (as the standard of care). One cross-over trial of 60 patients with chronic colitis comparing dye-spray chromoendoscopy with indigo carmine and NBI (first generation) demonstrated no significant difference in lesion detection, although there was a statistically insignificant higher miss rate in the NBI arm (6/13 *vs* 2/13; $P = 0.2$). Withdrawal times were significantly longer in the indigo carmine arm (16 *vs* 30 min; $P < 0.01$), and false positives were higher in the NBI arm (196 *vs* 126; $P < 0.0001$).[138]

A second randomized controlled trial of 108 patients with chronic colitis revealed similar rates of lesion detection in an NBI (first generation) arm and a methylene blue arm (18/112 *vs* 26/156; $P = 0.39$). Withdrawal times were again significantly shorter in the NBI arm (20 *vs* 27 min; $P = 0.003$)[139]. A third study[140] compared NBI (first generation) to HD-WLE and demonstrated comparable dysplasia rates only, confirming the results of other previous trials.[141–143]

Two recent studies have examined electronic image enhancement in the detection of IBD-related dysplasia, published only in abstract form,[144,145] both identifying improvements in electronic image enhancement when compared against white light endoscopy. No evidence exists demonstrating superiority of electronic image enhancement over chromoendoscopy for the detection of IBD-related dysplasia. The second generation of NBI may offer some improvements in this area. AFI in IBD-related dysplasia has been examined in one study[143] but there is a technical hurdle in that inflammation and adenoma fluoresce similarly.

*Hyoscine butylbromide.* Hyoscine butylbromide (scopolamine) is an antimuscarinic, anticholinergic, and antispasmodic agent with a quaternary ammonium structure. It has been used for many years and has a good safety profile. Typically, side effects from hyoscine butylbromide are mild and self-limiting.[146,147] Anaphylaxis is rare,[148,149] and its central muscarinic effects are limited as it does not significantly cross the blood–brain barrier.[146]

Antispasmodic agents (such as hyoscine butylbromide, glucagon, and hyoscyamine) are commonly employed in gastrointestinal endoscopy, in particular, colonoscopy. Use of hyoscine butylbromide in colonoscopy has been examined as it relates to speed and ease of colonoscope insertion,[150–160] patient comfort during and post procedure,[152–154,156,157,159–164] and ileal intubation.[165,166]

Hyoscine butylbromide may increase mucosal view and polyp detection.[167] No fewer than four systematic reviews and meta-analyses[168–171] have been published on the eight trials in this area,[154,172–178] which draw differing conclusions. While meta-analysis does not demonstrate increased polyp detection with hyoscine butylbromide, several of the analyzed studies[154,178] did not have polyp detection or adenoma detection as their primary endpoint, and some are of low quality. An interesting observation from one trial[177] is that antispasmodics may hamper detection of flat polyps, although this has not been noted in other studies. In patients with marked colonic spasm, there is sufficient evidence to recommend the use of hyoscine butylbromide to aid polyp detection.

***New cameras/instruments.*** High-definition white light endoscopy, when combined with a high-definition camera, provides superior images of the colon. Five trials have compared HD-WLE with standard WLE with conflicting results. A meta-analysis of these trials including 4422 patients demonstrated an absolute improvement of 3.5% in ADR.[179] HD-WLE has become the standard of care in colonoscopy.

Other technology has focused on measures to overcome the limited field of view in a standard forward viewing colonoscope. Newer generation colonoscopes employ a 170-degree forward-viewing lens, however, even with greater flexibility in the tip of the colonoscope, lesions behind folds can be missed.

The third-eye retroscope (TER; Avantis Medical Systems, Inc., Sunnyvale, CA, USA) is an auxillary imaging device inserted through the working channel of the colonoscope and fixed into place to inspect at 180 degrees to the tip of the colonoscope. A back to back colonoscopy study of 488 patients demonstrated a 23% increase in ADR with TER.[180] Examinations are typically longer with this device, which needs to be removed prior to using any other devices down the colonoscope (for polypectomy) and inhibits suctioning, a significant problem in the colon. A cost–benefit analysis of this equipment is yet to be performed.

Full spectrum endoscopy (FUSE; Endochoice, Alpharetta, GA, USA) is an endoscopy system offering colonoscopes with two auxillary cameras perpendicular to the forward-viewing lens and a three-screen viewing platform. The resulting effect is 330 degrees of mucosal view,[181] and a decrease in adenoma miss rate from 41% to 7% ($P < 0.0001$) in one trial of 197 patients.[182] A further trial of FUSE in dysplasia detection reported preliminary results demonstrating dysplasia miss rates of 0% *versus* 77% ($P < 0.05$), but has only been published in abstract form.[183] These results are yet to be replicated, but they represent a significant advance in adenoma detection, and increasing mucosal view is an ongoing challenge for device developers.

Ultra-magnifying technologies, confocal light endomicroscopy (CLE) and endocytoscopy (EC), have advanced considerably in recent years. CLE is now commercially available (Cellvisio, Mauna Kea Technologies, Paris, France). These technologies allow *in vivo* "histological assessment,"[184] and in colonoscopy may offer most in correct histological classification of polyps prior to resection and retrieval or discard, or in IBD dysplasia screening.

***Validated reporting tools.*** After completion of the colonoscopy, the only ongoing information available is photodocumentation and report text. Communication between practitioners and recall of the colonoscopist is enhanced by the use of validated reporting terminology, which has undergone some advances in recent years.[185]

*Paris classification.* Large polyps are often referred to subspecialized colonoscopists for removal. Standard reporting terminology is important for effective preparation for such technically demanding procedures. More importantly, precise phenotyping of polyps using the Paris classification[186] has allowed for accurate correlation with histology, outcomes, and prognosis,[187] to allow for more evidence-based utilization of colonoscopic techniques.

Recent findings suggest that interobserver variability makes the Paris classification unreliable in community gastroenterology practice and that further systems may need to be developed.[188]

*Image enhanced endoscopy.* The histological type of most polyps can be determined with some accuracy by examination of morphology and pit pattern. The classification by Kudo *et al*.[189] has gained the most traction, and interobserver variability is low.[190] Despite this, image enhanced evaluation is reported in only a minority of community gastroenterology centers, and the majority of polyps are sent for definitive histology rather than being resected and discarded. Further, classification systems have increased accuracy by using magnifying colonoscopes (Sano *et al*.,[191] Kanao *et al*.,[192] Wada *et al*.,[193] and Saito *et al*.),[194] however, they are largely used in academic centers with routine access to magnifying colonoscopy. Pit pattern assessment, when accurate, offers the prospect of resecting and discarding benign polyps without the cost of histology and the time taken to retrieve the polyp.[195–197]

Hewett *et al*. propose a simplified classification system for the endoscopic diagnosis of small polyps using NBI[198] (Table 2). This validated system allowed identification of colonic polyp histology with 89% accuracy, 98% sensitivity, and 95% negative predictive values. Subsequent study has validated an extension of this classification system to identify submucosal invasion in colorectal tumours.[199]

**Table 2** The NBI International Colorectal Endoscopic Classification

| NICE criterion | Type 1 | Type 2 |
|---|---|---|
| Color | Same or lighter than background | Brown relative to background (verify color arises from vessels) |
| Vessels | None or isolated lacy vessels coursing across the lesion | Brown vessels surrounding white structures* |
| Surface pattern | Dark or white spots of uniform size, or homogenous absence of pattern | Oval, tubular, or branched white structures* surrounded by brown vessels |
| Most likely pathology | Hyperplastic | Adenoma |

Taken from Hewett *et al*.[198] Can be applied using colonoscopes both with or without optical (zoom) magnification.

*These structures may represent the pits and the epithelium of the crypt opening.

NBI, narrow band imaging; NICE, NBI International Colorectal Endoscopic Classification.

*Ulcerative colitis endoscopic index of severity.* Almost a dozen indices for the endoscopic assessment of ulcerative colitis (UC) have been developed, largely for use in clinical trials.[200] Two studies have reviewed these areas, one study evaluating these indices[200] (without direct comparison), and one comparing a small number of frequently used indices (Simple Clinical Colitis Index (SCCI), Mayo Clinic Index, and Seo Index)),[201] only one of which is purely endoscopic (SCCI). The Pediatric Ulcerative Colitis Activity Index has been validated and correlated with symptom severity in children.

The ulcerative colitis endoscopic index of severity (UCEIS) is the first validated index for assessing UC and accounts for 86–88% of the variance between observers in the overall assessment of endoscopic severity.[202,203] This score is compiled at flexible sigmoidoscopy and assessed in the most severely affected colonic segment. The score is determined by assessing mucosal vascular pattern, mucosal bleeding, and erosions or ulceration and assigning the appropriate Likert scale anchor points to each descriptor. These scores are then added (Table 3). The score ranges from 0 (normal) to 8 (worst colitis), and studies have demonstrated accurate prediction across a range of endoscopic severity judged by visual analogue scale. [202,203] The UCEIS is largely unaffected by knowledge of clinical information.[204]

The UCEIS has now been correlated with clinical outcomes in acute severe colitis (ASC), and accurately predicts patients likely to fail first-line therapy (intravenous corticosteroids) and require rescue therapy with cyclosporine or infliximab, or surgery.[205] Of patients with a UCEIS of 7 or 8, 92.9% required rescue therapy, colectomy, or readmission. Fifty percent of those with UCEIS of 5 or greater required rescue therapy *versus* 27% of those with UCEIS less than 5 ($P < 0.05$).[205] The use of a validated tool to reliably report endoscopic appearance in IBD is recommended.

## Reduce complications

Complications are rare events in colonoscopy, however, where they occur, they result in significant morbidity and associated health care costs. The most feared complication of colonoscopy and colonoscopic polypectomy is perforation. Due to the low point incidence of this complication, and indeed the low rate of colonoscopic complications for all non-therapeutic procedures,[206–209] studies of techniques to reduce complications in colonoscopy are rare. Most complications are associated with colonoscopic polypectomy, and the most frequently occurring of these is post-polypectomy hemorrhage (PPH), occurring in between 0.3% and 6.1% of polypectomies.[210–215] PPH is more common in larger polyps.[213,214] Recently, attention has been focused on polypectomy technique and reducing the risk of PPH.

***Hot biopsy/cold snare.*** Most polyps encountered at colonoscopy (up to 90%) are diminutive (5 mm or less), or small (6–9 mm).[216–218] Hot biopsy forceps removal of small and

**Table 3** The UCEIS© is freely available for use, acknowledging that the copyright of the terminology is registered to Watson Laboratories, NJ, successors in interest to Warner Chilcott Pharmaceuticals

| Descriptor (score most severe lesions) | Likert scale anchor points | Definition |
|---|---|---|
| Vascular pattern | Normal (0) | Normal vascular pattern with arborisation of capillaries clearly defined or with blurring or patchy loss of capillary margins |
| | Patchy obliteration (1) | Patchy obliteration of vascular pattern |
| | Obliterated (2) | Complete obliteration of vascular pattern |
| Bleeding | None (0) | No visible blood |
| | Mucosal (1) | Some spots or streaks of coagulated blood on the surface of the mucosa ahead of the scope, which can be washed away |
| | Luminal mild (2) | Some free liquid blood in the lumen |
| | Luminal moderate or severe (3) | Frank blood in the lumen ahead of endoscope or visible oozing from mucosa after washing intra-luminal blood, or visible oozing from a hemorrhagic mucosa |
| Erosions & ulcers | None | Normal mucosa, no visible erosions or ulcers |
| | Erosions (1) | Tiny ($\leq$ 5 mm) defects in the mucosa, of a white or yellow color with a flat edge |
| | Superficial ulcer (2) | Larger ($>$ 5 mm) defects in the mucosa, which are discrete fibrin-covered ulcers when compared with erosions, but remain superficial |
| | Deep ulcer (3) | Deeper excavated defects in the mucosa, with a slightly raised edge |

The score is calculated by adding the number corresponding to the appropriate Likert levels for vascular pattern, bleeding, and ulceration to give a total with a range from 0 to 8.[203]
UCEIS, ulcerative colitis endoscopic index of severity.

diminutive polyps relied on the concept that passing electrocautery through the polypectomy site would ablate any residual tissue, and perhaps diathermy any potentially bleeding vessels. Evidence has accumulated recently that this technique is hampered by three issues, and it has fallen out of favor. The quality of the specimens obtained is often poor, having been subjected to electrocautery and being biopsy sized (rather than a complete polypectomy specimen).[219] The risk of thermal injury and the resulting risk of complication is elevated; hot biopsy having been associated with an increased risk of perforation.[218,220] The ablation of remnant polyp is no more successful in hot biopsy than in cold biopsy[221] (remnants of diminutive polyps removed by cold biopsy are common (up to 61% of polypectomies with this technique),[222] and this cold forceps polypectomy is not recommended for any but the smallest of polyps—1–3 mm, able to be removed with one bite of the forceps).[223]

As removal of small and diminutive polyps with forceps has become less popular, cold snare has become the technique of choice. This technique has been described in detail elsewhere.[224] This technique is superior to forceps removal of lesions in that it removes the lesion and a rim of tissue surrounding the lesion to ensure complete removal, and has a shorter procedure time. Histologic eradication of the polyp is superior for polyps over 4 mm.[225]

Cold snare polypectomy has significant advantages over hot snare polypectomy for a significant proportion of lesions. While two studies comparing these techniques demonstrated increased rates of immediate (intraprocedural) bleeding with cold snare polypectomy, this bleeding was typically mild and self-limiting.[226,227] The bleeding related to hot snare is typically delayed and has been shown to be more likely than cold snare in a third comparative study of these two techniques.[228] Bleeding at the time of the procedure has the clear advantage of being amenable to immediate therapy, rather than necessitating re-admission and sedation, and occurring outside of the hospital environment. It is perhaps for this reason that cold snare polypectomy has been adopted in anticoagulated patients.[228]

***Post-polypectomy hemorrhage prophylaxis.*** Post-polypectomy hemorrhage is more common in large polyps.[213,214] Adrenaline injection[229] and mechanical hemostasis[230] are effective in controlling immediate PPH and are widely used. The use of prophylactic measures like adrenaline injection[25,27,28,31,231,30] or mechanical hemostasis[27,31,231] to prevent PPH have been studied, but not widely adopted, or incorporated into guidelines. One meta-analysis examined the use of prophylactic hemostasis to prevent PPH,[32] but included smaller polyps ($<$ 10 mm), which are less likely to bleed.[213,214]

Given the number of small and diminutive polyps encountered, administering prophylactic hemostasis may not be practical, and a second meta-analysis including only polyps greater than 10-mm diameter was performed.[24] Comparing any prophylactic hemostasis to none, the pooled risk ratio (RR) for PPH was 0.35 (0.21–0.57; $P < 0.0001$) number needed to treat (NNT) 11.9, cost to prevent one PPH $547(USD). Any prophylactic mechanical hemostasis compared with epinephrine injection produced an RR for PPH of 0.28 (0.14–0.57; $P < 0.0001$) NNT 13.9, cost to prevent one PPH $1547. For polyps over 20 mm in diameter, the pooled RR comparing any mechanical hemostasis with epinephrine alone was 0.33 (0.12–0.90; $P = 0.03$) NNT 16.9, cost to prevent one PPH $2308.

## Summary

Substantial improvements in colonoscopic practice have occurred in recent years. Enhanced patient selection and triage are now available, and providers of colonoscopy should be encouraged to look for more reliable and efficient ways to implement these. During colonoscopy, a number of measures to improve colonoscopic

yield have been developed, and many are incorporated into quality assurance programs—rapidly becoming standard practice in many countries. High-level evidence supports the use of routine audit of completion rate, preparation adequacy adenoma detection rate, and complication rates to improve outcomes and ensure quality. Similarly, improvements such as split preparation, increased withdrawal time, right colon retroflexion, chromoendoscopy for IBD surveillance, and the use of high-definition colonoscopes are supported by high-level evidence. With experience, the use of validated reporting tools and image enhancement provide superior information and can guide management and prognosis. Prevention of complications has largely been focused on polypectomy technique, although high-level evidence now exists demonstrating the efficacy of prophylactic haemostatic measures in large polypectomy.

Spasmolytic agents, AFI, routine chromoendoscopy, the transparent cap, and other devices mentioned are yet to accumulate high-level evidence, and their routine use is controversial. Position change is not yet routine despite substantial evidence in support of this practice, perhaps due to difficulties moving the sedated patient. Screening populations with scores such as the APCS is evidence-based, but so far this tool has not been recommended by government bodies or national gastroenterology societies.

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