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ORIGINAL ARTICLE

Can the Adenoma Detection Rate Reliably Identify Low-Performing Endoscopists? Results of a Modeling Study

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Abstract
Background Experts have stated that adenoma detection rates (ADR) of individual endoscopists should be measured to assess colonoscopy quality.
Aim The purpose of this study was to quantify the reliability of the ADR as a quality marker.
Methods We simulated a population of endoscopists and patients using published data on adenoma prevalence and adenoma miss rates. For each endoscopist, the ADR was calculated. The proportion of ADR variance attributable to endoscopist and the area under the ROC (AUROC) curve for low-performing endoscopists (lowest quartile or decile) were also calculated.
Results In the base-case analysis (200 patients per endoscopist, miss rate 22 %, adenoma prevalence 24 %), only 13 % of ADR variance was attributable to endoscopist performance (AUROC up to 0.73). An ADR cutoff of <16.5 % identified approximately half of endoscopists in the lowest performance decile (test sensitivity = 53 %), but most (79 %) of the endoscopists identified by this cutoff were NOT low performers (i.e., false positives). In sensitivity analysis, increasing the number of patients per endoscopist, reducing the variance of adenoma prevalence between endoscopists (i.e., performing case-mix adjustment), and increasing the variance in performance between endoscopists all improved ADR test characteristics (AUROC up to 0.88). However, regardless of assumptions, a substantial proportion of endoscopists would be misclassified if a simple ADR cutoff were utilized.
Conclusions The ADR has limited reliability as a quality marker under real-world assumptions. Simple cutoffs are likely to either be insufficiently sensitive or have high false positive rates. Future studies should identify alternative means for assessing endoscopist performance.

Keywords Quality improvement · Colonoscopy · Adenoma detection rate

Abbreviations

ADR	Adenoma detection rate
CRC	Colorectal cancer
AUROC	Area under receiver operating characteristic

Introduction

Colorectal cancer (CRC) is the second-leading cause of cancer-related death in the United States today [1]. This malignancy is thought to be the end-result of a gradual, multi-step process in which the adenoma is an intermediate stage [2]. Current clinical practice guidelines recommend that average-risk patients undergo periodic screening for CRC starting at age 50 [3]. Observational studies report up to a 77 % reduction in CRC incidence in patients undergoing colonoscopy [4]. However, concurrent studies have raised concerns about the quality of colonoscopy [5, 6]. Colonoscopy is known to be an imperfect test. For adenomatous polyps <10 mm in size, colonoscopy has a

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sensitivity of approximately 80 % [7]. For adenomatous polyps ≥10 mm in size, the sensitivity is believed to be >95 % [7]. Studies suggest that missed neoplasia is a major cause of interval cancers in patients undergoing colonoscopy [8]. Furthermore, the sensitivity of colonoscopy has been shown to differ in the hands of different endoscopists [9]. For this reason, the ASGE/ACG Task Force on Quality in Endoscopy has recommended that endoscopists measure the proportion of patients in their practice undergoing screening colonoscopy who were found to have one or more adenomatous polyps of the colon [10]. This measure, called the adenoma detection rate (ADR), has been embraced as a practical surrogate for the more difficult to measure miss rate. Data from a large retrospective study in Poland has suggested that post-colonoscopy CRC occurred infrequently in patients who underwent colonoscopy by an endoscopist with a high ADR (≥20 %; i.e., an ADR ≥20 % was highly specific for high-performing endoscopists) [11]. However, this study did not address the issue of the *reliability* of the ADR as a tool for profiling endoscopists in usual practice. A sufficiently high or low cutoff for ADR can always be found to ensure its specificity, but this will come at the expense of its sensitivity (and vice versa). Despite the paucity of data on ADR reliability, the ACG, ASGE, and American Gastroenterological Association (AGA) proposed that the ADR be utilized as a formal quality indicator by the Centers for Medicare and Medicaid Services Physician Quality Reporting System in August 2012. Fortunately, the direct mathematical relationship between the ADR and the adenoma miss rate, both of which have been well documented in prospective studies, makes it possible to assess the reliability of the ADR through simple modeling techniques.

The purpose of this study was to determine whether simple cutoffs such as those suggested by the ASGE/ACG Task Force can be *reliably* used to identify low-performing (high miss rate) endoscopists. We hypothesized that due to random variation at the patient level and the limited number of average-risk screening exams from which to draw data for each endoscopist, reliable ADR cutoffs would be difficult to establish. Through this study, we hoped to demonstrate the potential pitfalls of using simple ADR cutoffs and encourage the development of more reliable measures of colonoscopy quality.

Methods

Overview

In an ideal world, endoscopist technical performance would be assessed by quantifying each provider's adenoma miss rate. Unfortunately, measuring the miss rate is technically cumbersome, requiring an external reference standard such as tandem colonoscopy or CT colonography. As a result, performance measurement in colonoscopy has focused on the surrogate measure of ADR. Though the ADR is easy to measure, it is also affected by factors other than endoscopist performance (the "signal" of interest). Separating this "signal" from other differences between endoscopists ("noise" introduced by random variation in the proportion of an endoscopist's patients who actually have adenomas) is critical if we are to use this surrogate measure reliably. For instance, if a very high-performing endoscopist (miss rate = 0 %) performs colonoscopies on ten patients, and only one of these patients has an adenoma, this endoscopist's ADR will be 10 %. Similarly, if a very low-performing endoscopist (miss rate = 90 %) performs colonoscopies on ten patients, *all* of whom have adenomas, this endoscopist's ADR will again be 10 %. In these extreme but illustrative examples, each endoscopist's performance ("signal") is lost amidst differences in patient populations ("noise"). In general, if we increase the number of patients per endoscopist, random differences in patient mix will diminish (i.e., the noise will be reduced), and the signal will become more clear.

To quantify these parameters in detail, we generated a dataset of 10,000 hypothetical endoscopists, each with a specified adenoma miss rate (sampled from a defined distribution). For each hypothetical endoscopist, we then generated a population of patients assuming a known population prevalence of adenomas. We then calculated the ADR for each endoscopist. Using this approach, we developed a dataset of endoscopists, each with a known miss rate, a population of patients with known adenoma prevalence, and a calculated ADR. We did not examine long-term patient outcomes (such as CRC incidence or death), choosing instead to focus on the more proximal outcome of *reliability* of the ADR in predicting endoscopist miss rates. All modeling and statistical analyses were performed using the Stata 10 statistical package (Stata Corporation, College Station, TX, USA). The basic assumptions of the model are shown in Table 1.

Colonoscopy Volume

To define the impact of colonoscopy volume on the test characteristics of the ADR, we assumed that each endoscopist performed the same number of procedures, varying this number in sensitivity analysis. Specifically, in the base-case, we assumed that each endoscopist performed 200 average-risk screening colonoscopies (mean annual volume for long-term participants in the National Endoscopic Database) [12]. This number was varied between 50 and 500 in sensitivity analysis based on the observed range of these data.

Table 1 Variables used in model

Variable	Estimate	Range	Reference
Colonoscopy volume[a]	200	50–500	[12]
Adenoma prevalence (mean)	0.24	0.19–0.29	[17]
Adenoma prevalence (SD)	0.025	0.00–0.10	[17]
Adenoma miss rate (mean)	0.22	0.15–0.32	[7]
Adenoma miss rate (SD)	0.05	0.01–0.10	[7]

[a] Number of average-risk screening colonoscopies performed by each endoscopist per year

Probability of Missed Adenoma

The probability of missing an adenomatous polyp during colonoscopy has been documented in numerous tandem (back-to-back) colonoscopy studies. A meta-analysis of tandem colonoscopy studies on this topic (6 studies, $n = 465$ patients) reported an adenoma miss rate of 22 % (95 % CI 15–32 %) [7]. In our dataset, we sampled the miss rate for each endoscopist from a beta distribution reflecting these characteristics. The beta distribution is commonly used to model variables that are probabilities (i.e., bounded between 0 and 1). Of note, CT colonography studies have shown similar results to tandem colonoscopy studies when examining the miss rate for *any* adenoma [13, 14].

Adenoma Prevalence

The prevalence of adenomatous polyps in average-risk patients undergoing screening colonoscopy has been reported in several prospective and population-based studies. Autopsy studies [15], though an attractive source of adenoma prevalence due to their high sensitivity for adenomas, reflect prevalence in an elderly population in the pre-screening and pre-NSAID era, one that presumably overestimates the prevalence seen in a modern-day screening population [16]. We therefore utilized prospective data from screening colonoscopies to obtain our model inputs. A meta-analysis of prospective screening trials that pooled data on over 68,000 patients reported an adenoma prevalence of 19 % (95 % CI 15–23 %) [17]. Similar numbers were reported by a recent large European study of screening colonoscopy [18]. However, these data reflect ADR themselves rather than underlying adenoma prevalence. To estimate adenoma prevalence from these data, we divided this observed point estimate (0.19) and these confidence interval limits (0.15 and 0.23) by the point estimate for colonoscopy sensitivity (1−miss rate, or 1–0.22 = 0.78), yielding an estimated adenoma prevalence of 24 % (95 % CI 19–29 %). To generate our dataset, we then sampled the adenoma prevalence for each endoscopist from a beta distribution reflecting these characteristics. Because the distribution of adenoma multiplicity is not well defined, we assumed that patients had either 0 or 1 adenoma (i.e., multiple adenomas were not included in our primary analysis). By removing an additional source of between-endoscopist variation ("noise") from our model, this assumption biased our results in favor of the ADR as a quality marker.

Base-Case Analysis

The primary outcomes of interest were: (1) the characteristics of the ADR as a "diagnostic test" for identifying low-performing endoscopists (i.e., endoscopists in the bottom decile or quartile), summarized using the area under the receiver-operator characteristic (ROC) curve, and (2) the proportion of variance in ADR that is attributable to endoscopist characteristics (i.e., endoscopist miss rate) versus non-endoscopist characteristics (i.e., patient characteristics or random variation). We first determined the sensitivity and specificity of various ADR cutoffs for identifying low-performing endoscopists. We then calculated the area under the ROC (AUROC) curve as a summary statistic. To determine the proportion of variance in ADR attributable to endoscopist, we performed a simple linear regression (unit of analysis = endoscopist) with the ADR as the dependent variable and the miss rate (endoscopist characteristic) and the prevalence of adenomas in the endoscopist's patient population (patient characteristic) as the predictor variables. We then calculated the standardized beta coefficient (B) for miss rate, reporting B^2 as an estimate of the proportion of variance in ADR attributable to endoscopist. To more clearly demonstrate the clinical impact of using the ADR as a quality marker, we also calculated the "false positive" rate for various ADR cutoffs.

Sensitivity Analysis

One-way sensitivity analyses were performed on each variable in the model (Table 1). Specifically, we varied the base-case point estimates for our three variables (colonoscopy volume, adenoma prevalence, and miss rate) within the specified sensitivity analysis ranges. Furthermore, because the characteristics of the ADR are also likely to be affected by assumptions about *differences* between endoscopists and patients, we also widely varied the standard deviations of adenoma prevalence (reflecting the impact of case mix) and miss rate (reflecting the range of endoscopist skill). Two-way and three-way sensitivity analyses were performed based on the results of our one-way analysis.

Results

Base-Case Analysis

In the base-case analysis, the mean adenoma prevalence was 24 % (95 % of values between 19 and 29 %) and the

Table 2 One-way sensitivity analysis: annual colonoscopy volume

Variable	Annual colonoscopy volume		
	50	200	500
Mean ADR ± SD	19 ± 5 %	*19 ± 3 %*	19 ± 3 %
% ADR variance due to endoscopist	5	*13*	19
AUROC			
Bottom 25 %	0.61	*0.69*	0.71
Bottom 10 %	0.64	*0.73*	0.76

ADR adenoma detection rate, *SD* standard deviation, *AUROC* area under receiver operating characteristic

Italicized values indicate the base-case analysis

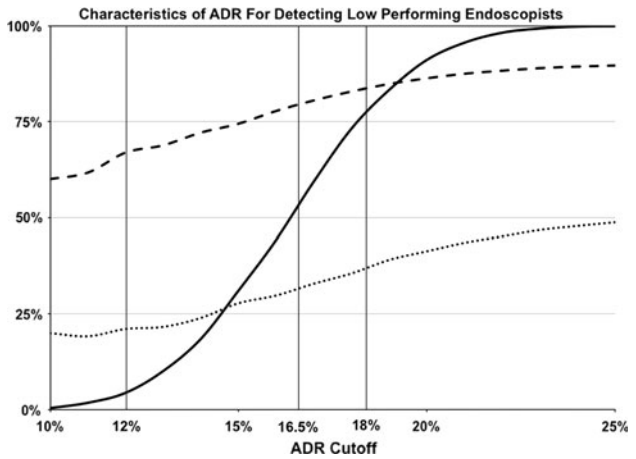

Fig. 1 Characteristics of ADR for detecting low performing endoscopists (base-case scenario). *Solid line* indicates *sensitivity* of ADR for detecting low-performing endoscopists across a range of ADR cutoffs. *Dashed line* indicates the *false positive rate* across ADR cutoffs (i.e., proportion of endoscopists identified who were *not* low performers). *Dotted line* indicates proportion of endoscopists identified who were actually *above average* performers

mean miss rate was 22 % (95 % of values between 13 and 32 %). The mean ADR was 19 ± 3 %, and only 13 % of the observed ADR variance was attributable to endoscopist performance (Table 2, column 2). The AUROC of the ADR for identifying low-performing endoscopists ranged from a minimum of 0.69 (for identifying endoscopists in the lowest quartile of performers) to a maximum of 0.73 (for identifying endoscopists in the lowest decile of performers).

An ADR cutoff of less than 16.5 % identified approximately half of endoscopists in the lowest performance decile (test sensitivity = 53 %; Fig. 1). If 10,000 endoscopists participated in an ADR-based pay-for-performance program that used this cutoff, 2,498 would have a low ADR (<16.5 %). However, of these 2,498 endoscopists with low ADRs, only 527 (21 %) would *truly* be low performers while the remaining 1,971 endoscopists (79 %) would NOT be low performers (i.e., false positives).

Table 3 One-way sensitivity analysis: variance of adenoma prevalence between endoscopists

Variable	Standard deviation of adenoma prevalence (mean prevalence = 24 %)		
	0.0	0.025	0.10
Mean ADR ± SD	19 ± 3 %	*19 ± 3 %*	19 ± 8 %
% ADR variance due to endoscopist	21	*13*	2
AUROC			
Bottom 25 %	0.72	*0.69*	0.56
Bottom 10 %	0.77	*0.73*	0.60

ADR adenoma detection rate, *SD* standard deviation, *AUROC* area under receiver operating characteristic

Italicized values indicate the base-case analysis

Furthermore, 795 of these endoscopists with low ADRs (32 %) would actually be *above average* performers (Fig. 1). Lowering the ADR cutoff to 12 % only slightly reduced the false positive rate to 67 % but markedly reduced the sensitivity of the ADR for identifying low-performing endoscopists to 4 %. Similarly, increasing the ADR cutoff to 18 % increased the sensitivity of the ADR for low-performing endoscopists to 73 % but also increased the false positive rate to 83 % (Fig. 1). Regardless of the cutoff used, the false positive rate remained high, meaning that endoscopists participating in ADR-based quality improvement programs would frequently be rewarded or punished inappropriately (Fig. 1).

Sensitivity Analysis

In one-way sensitivity analysis, results were found to be most sensitive to three variables: (1) number of patients per endoscopist (colonoscopy volume; Table 2), (2) variance of adenoma prevalence between endoscopists (Table 3), and (3) variance of miss rates between endoscopists (Table 4). *Mean* adenoma prevalence and miss rate had smaller effects on test characteristics (Appendix).

Decreasing the number of patients to 50 per endoscopist diminished test performance, with only 5 % of ADR variance explained by endoscopist performance and an AUROC of 0.64 at best (Table 2). Increasing the number of patients to 500 per endoscopist improved test characteristics, with 19 % of ADR variance attributable to endoscopist and an AUROC curve of up to 0.76 (Table 2). Under this assumption, an ADR cutoff of <16 % resulted in a test sensitivity of 45 % for endoscopists in the lowest decile of performance but a false positive rate of 73 % (Fig. 2). Reducing the variance of between-endoscopist adenoma prevalence to zero (i.e., perfect case-mix adjustment) resulted in 21 % of ADR variance explained by endoscopist performance and an AUROC of up to 0.77 (Table 3).

Table 4 One-way sensitivity analysis: variance of adenoma miss rate between endoscopists

Variable	Standard deviation of miss rate (mean miss rate = 22 %)		
	0.01	0.05	0.10
Mean ADR ± SD	19 ± 3 %	*19 ± 3 %*	19 ± 4 %
% ADR variance due to endoscopist	1	*13*	38
AUROC			
Bottom 25 %	0.55	*0.69*	0.83
Bottom 10 %	0.55	*0.73*	0.88

ADR adenoma detection rate, *SD* standard deviation, *AUROC* area under receiver operating characteristic

Italicized values indicate the base-case analysis

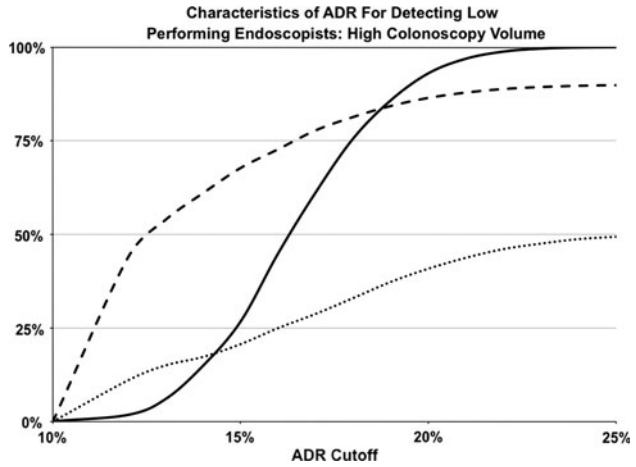

Fig. 2 Characteristics of ADR for detecting low performing endoscopists (high colonoscopy volume scenario). *Solid line* indicates *sensitivity* of ADR for detecting low-performing endoscopists across a range of ADR cutoffs. *Dashed line* indicates the *false positive rate* across ADR cutoffs (i.e., proportion of endoscopists identified who were *not* low performers). *Dotted line* indicates proportion of endoscopists identified who were actually *above average* performers

However, under this assumption, the false positive rate remained high (72 %) when test sensitivity was set at 50 %. Increasing the variance of miss rates in the endoscopist population to 0.10 (resulting in 95 % of endoscopists with miss rates between 6 and 44 %) resulted in the best test performance, with 38 % of ADR variance attributable to endoscopist and an AUROC of up to 0.88 (Table 4). However, under this assumption, the false positive rate remained high (54 %) at a test sensitivity of 50 %. Under a "best case" scenario, assuming perfect case mix adjustment (adenoma prevalence variance = 0) and a wide variance of miss rates (miss rate variance = 0.10), 50 % of ADR variance was attributable to endoscopist, and the AUROC curve was 0.92. Under this scenario, at an ADR cutoff sensitivity of 50 %, the false positive rate was 37 % (Fig. 3).

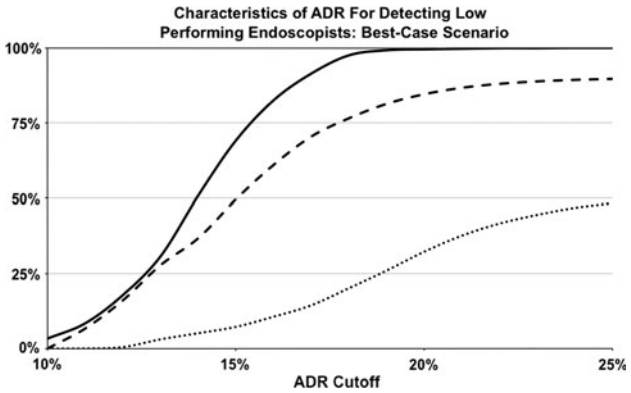

Fig. 3 Characteristics of ADR for detecting low performing endoscopists ("best-case" scenario). *Solid line* indicates *sensitivity* of ADR for detecting low-performing endoscopists across a range of ADR cutoffs. *Dashed line* indicates the *false positive rate* across ADR cutoffs (i.e., proportion of endoscopists identified who were *not* low performers). *Dotted line* indicates proportion of endoscopists identified who were actually *above average* performers

Discussion

Summary of Key Findings

The ADR has been widely recommended as a measure of colonoscopy quality, with professional GI societies suggesting simple cutoffs as a way of assessing endoscopist performance [10]. However, the statistical properties of this measure have not been examined or validated. Furthermore, little guidance has been provided on the optimal number of colonoscopies needed for robust measurement of the ADR or the impact of case-mix differences on ADR reliability. In our study, we used modeling techniques to examine the reliability of the ADR as a quality measure under real-world assumptions, finding that simple cutoffs were either insufficiently sensitive to be useful or insufficiently reliable to be acceptable (i.e., high false positive rates). Under assumptions of high colonoscopy volume, uniformity of patient case-mix between endoscopists, or very wide variation in real-world endoscopist performance, test characteristics improved. However, even under a "best case" scenario, the false positive rate remained high (37 %). It is important to note that sensitivity to volume and case-mix are not unique to the ADR, but rather are general and fundamental properties of outcome measures of quality [19].

Literature Review

We performed a MEDLINE search for studies investigating the reliability of ADR as a quality indicator in colonoscopy (keywords *adenoma detection rate* OR *polyp detection rate*, AND *colonoscopy*). Though this search yielded

multiple studies that utilized the ADR as an outcome measure of colonoscopy quality, only one study specifically examined the role of the ADR as a *predictor* of quality [11]. In this large retrospective study, authors reported that post-colonoscopy CRC occurred infrequently in patients who underwent colonoscopy by an endoscopist with a high ADR (≥20 %). However, this study did not address the issue of the *reliability* of the ADR as a tool for profiling endoscopists in usual practice (which is the focus of our study). Notably, we were unable to identify studies that have examined the association of the ADR and miss rate, presumably due to the technical difficulties in measuring the latter.

Limitations

Several important limitations of our study should be noted. First, this was a modeling study, the results of which are dependent on the structure of the model and its assumptions. Our sensitivity analysis, however, demonstrates the robustness of the findings, with the ADR remaining at best marginally reliable for identifying low-performing endoscopists. Additionally, because of limitations in available input data, we did not model multiple adenomas per patient. However, in an exploratory analysis examining the impact of adenoma multiplicity, we found that allowing for multiple adenomas actually *reduced* the reliability of the ADR. We also did not model long-term outcomes (such as CRC incidence and death) or the impact of missing adenomas of different sizes (large adenomas are clinically more important than small adenomas, for instance). Second, we did not examine the impact of profiling at the level of the GI practice or health system rather than at the level of the individual endoscopist. Though it would be tempting to conclude that practice-level or system-level profiling is likely to be more reliable (due to the increased number of procedures available for analysis), clustering effects may limit the power that can be gained by pooling data from multiple endoscopists. Until such clustering effects can be better quantified, analyzing the reliability of the ADR at a practice level will be largely speculative. However, such data could be obtained from large endoscopic databases and may form the basis for future research. It is also important to note that the ADR can vary widely in different populations [20, 21] (an issue that can be partly addressed through population-level benchmarking efforts, such as those that are currently underway in the United States). The variance in miss rates between endoscopists also remains poorly defined. Estimates from research (tandem colonoscopy) studies are likely to be biased due to selection of highly-skilled endoscopists. Furthermore, such studies are also limited by the relatively small number of colonoscopies available for analysis. Nonetheless, examining the adenoma miss rates from these studies at the endoscopist level could be important for better understanding the reliability and role of the ADR as a profiling tool. Finally, the ADR is not the only marker of quality [22, 23], though it is one that has gained significant traction in recent years and lends itself well to a modeling approach. Combining the ADR with other quality markers may prove to further enhance reliability.

Conclusion

In summary, our study suggests that the ADR is likely to be unreliable in identifying low-performing endoscopists under real-world assumptions. At the individual endoscopist level, reliability could be increased by performing case mix adjustment (i.e., customizing the goal ADR for each endoscopist according to characteristics of their patient population) and increasing the number of colonoscopies analyzed. Furthermore, if the variance in endoscopist miss rates proves to be wider than that reported in tandem colonoscopy studies, the reliability of the ADR may be better than predicted. However, even under favorable assumptions, the false positive rate of the ADR for misclassifying endoscopists as low performers remains a concern. The ADR should be used cautiously in routine clinical practice until these issues have been resolved.

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Conflict of interest None.

Appendix

Characteristics of adenoma detection rate (ADR) across various cutoffs (base-case assumptions)

Characteristics	ADR cutoff			
	12 %	15 %	18 %	21 %
Sensitivity for detecting endoscopists in bottom 10 %	4	31	73	96
Endoscopists identified who were not in bottom 10 %	67	74	83	87
Endoscopists identified who were in top 50 %	21	28	36	44

One-way sensitivity analysis: adenoma prevalence

Variable	Adenoma prevalence		
	19 %	24 %	29 %
Mean ADR ± SD	15 ± 3	*19 ± 3*	23 ± 3
% ADR variance due to endoscopist	9	*13*	17
AUROC			
Bottom 25 %	0.65	*0.69*	0.71
Bottom 10 %	0.69	*0.73*	0.74

ADR adenoma detection rate, *SD* standard deviation, *AUROC* area under receiver operating characteristic

Italicized values indicate the base-case analysis

One-way sensitivity analysis: adenoma miss rate

Variable	Adenoma miss rate		
	15 %	22 %	32 %
Mean ADR ± SD	20 ± 4	*19 ± 3*	16 ± 3
% ADR variance due to endoscopist	12	*13*	17
AUROC			
Bottom 25 %	0.67	*0.69*	0.69
Bottom 10 %	0.71	*0.73*	0.73

ADR adenoma detection rate, *SD* standard deviation, *AUROC* area under receiver operating characteristic

Italicized values indicate the base-case analysis

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