



Increased Rate of Adenoma Detection Associates With Reduced Risk of Colorectal Cancer and Death

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See Covering the Cover synopsis on page 1; see editorial on page 8.

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BACKGROUND & AIMS: The quality of endoscopists' colonoscopy performance is measured by adenoma detection rate (ADR). Although ADR is associated inversely with interval colorectal cancer and colorectal cancer death, the effects of an increasing ADR have not been shown. We investigated whether increasing ADRs from individual endoscopists is associated with reduced risks of interval colorectal cancer and subsequent death. **METHODS:** We performed a prospective cohort study of individuals who underwent a screening colonoscopy within the National Colorectal Cancer Screening Program in Poland, from January 1, 2004, through December 31, 2008. We collected data from 146,860 colonoscopies performed by 294 endoscopists, with each endoscopist having participated at least twice in annual editions of primary colonoscopy screening. We used annual feedback and quality benchmark indicators to improve colonoscopy performance. We used ADR quintiles in the whole data set to categorize the annual ADRs for each endoscopist. An increased ADR was defined as an increase by at least 1 quintile category, or the maintenance of the highest category in subsequent screening years. Multivariate frailty models were used to evaluate the effects of increased ADR on the risk of interval colorectal cancer and death. **RESULTS:** Throughout the enrollment period, 219 endoscopists (74.5%) increased their annual ADR category. During 895,916 person-years of follow-up evaluation through the National Cancer Registry, we identified 168 interval colorectal cancers and 44 interval cancer deaths. An increased ADR was associated with an adjusted hazard ratio for interval colorectal cancer of 0.63 (95% confidence interval [CI], 0.45–0.88; $P = .006$), and for cancer death of 0.50 (95% CI, 0.27–0.95; $P = .035$). Compared with no increase in ADR, reaching or maintaining the highest quintile ADR category (such as an ADR > 24.56%) decreased the adjusted hazard ratios for interval colorectal cancer to 0.27 (95% CI, 0.12–0.63; $P = .003$), and 0.18 (95% CI, 0.06–0.56; $P = .003$), respectively. **CONCLUSIONS:** In a prospective study of individuals who underwent screening colonoscopy within a National Colorectal Cancer Screening Program, we associated increased ADR with a reduced risk of interval colorectal cancer and death.

Colonoscopy is widely used for the prevention and early detection of colorectal cancer.¹ The detection and removal of adenomas, which are major precursor lesions for colorectal cancer, is seen as a crucial aspect of cancer prevention. However, there currently exists a wide variation between endoscopists in terms of their success at detecting adenomas. Heterogeneity in adenoma detection rate (a metric defined as the proportion of colonoscopy examinations that detects ≥ 1 adenomas),² is particularly important given that it is associated inversely with the risk of interval colorectal cancer (ie, a cancer diagnosed before the next surveillance examination is due),³ and colorectal cancer death.⁴ These findings codified adenoma detection rate as a key quality indicator for the endoscopist's skill, and established this metric as a target for intervention in terms of quality control.^{5–8} However, it is unknown as to whether improved adenoma detection rate as measured by its longitudinal increase translates to risk reductions for interval colorectal cancer and death.

The aim of this study therefore was to investigate whether an improvement in adenoma detection rate for

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Abbreviations used in this paper: CI, confidence interval; ICD, International Classification of Diseases.

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EDITOR'S NOTES**BACKGROUND AND CONTEXT**

Although adenoma detection rate is established colonoscopy quality parameter, little was known about effect of adenoma detection rate improvement on risk of interval colorectal cancer and colorectal cancer death.

NEW FINDINGS

Individuals examined by endoscopists who reached or maintained their highest adenoma detection rate quintile (>24.6%) had significantly lower risk of interval colorectal cancer and death.

LIMITATIONS

Observational design of the study, and relatively small annual number of exams performed by endoscopists.

IMPACT

Increased adenoma detection rate results in decreased risk of interval colorectal cancer and colorectal cancer death after screening colonoscopy.

individual endoscopists would be associated with reduced risks of interval colorectal cancer and subsequent death.

Materials and Methods

Study Design

This was a prospective cohort study of individuals who underwent screening colonoscopy within the National Colorectal Cancer Screening Program in Poland, between January 1, 2004, and December 31, 2008. At that time, the National Colorectal Cancer Screening Program provided opportunistic, primary, colonoscopy-based screening aimed at asymptomatic individuals aged between 50 and 66 years (aged 40–66 y in case of a positive family history of colorectal cancer).^{9,10} The database for this screening program held demographic data, colonoscopy, and histopathology results, with detailed information on subsequent case management in instances in which lesions were detected. Individuals were included in the study only if their endoscopist participated in at least 30 screening colonoscopies and in at least 2 annually held screening program. Exclusion criteria included individuals with a screen-detected colorectal cancer, screen-detected polyps that were not removed, or suspected hereditary colorectal cancer syndrome or inflammatory bowel disease.

The personal identification number of the each participating individuals was matched against the National Cancer Registry and the Population Registry to identify any diagnoses of colorectal cancer (date of diagnosis, International Classification of Diseases, 10th revision [ICD-10] codes C18–C20, ICD-O-2 codes for adenocarcinoma), and causes of death (date and cause of death ICD-10 codes C18–C20). Colorectal cancers with available ICD codes, but with missing morphology codes (5%), were verified using hospital records. Colorectal cancers diagnosed at the time of screening were used to validate the completeness of registration of the National Cancer Registry.¹¹ An interval cancer was defined as a colorectal adenocarcinoma that was diagnosed between the

time of the screening colonoscopy, and the scheduled time of surveillance colonoscopy.^{3,12} Surveillance recommendations were applied according to the guidelines of the US Multi-society Task Force on Colorectal Cancer and the American Cancer Society.¹³

Individuals were followed up from the date of colonoscopy to a diagnosis of interval colorectal cancer, date of scheduled surveillance, death, or end of the follow-up period (December 31, 2013), whichever occurred first. The end of the follow-up period was determined by availability of data in the National Cancer Registry. To allow for at least 5 years of follow-up evaluation of the study cohort, we included individuals who underwent screening colonoscopy up to December 31, 2008, despite the fact that the National Colorectal Cancer Screening Program continued after that date.

Improvement in Colonoscopy Quality

Colonoscopy quality assurance has been embedded in the National Colorectal Cancer Screening Program since its inception in the year 2000. Initially, it included only an annual review of all colonoscopy reports, with checks for inconsistencies or missing data; these tasks were performed by a dedicated unit at the coordinating center. Since 2005, feedback has been included as part of quality assurance, with the addition of benchmarking with colonoscopy quality indicators (ie, adenoma detection rate, and cecal intubation rate).⁹ Finally, minimum entry criteria for screening centers applying for continuation in the program were set in 2006. Combined, these quality controls have resulted in a sustained 1.5% annual improvement in the overall adenoma detection rate.⁵

Adenoma detection rates, defined as the proportion of screenees with at least 1 adenoma identified,³ were determined using the National Colorectal Cancer Screening Program database. To assess quality improvement we first established 5 categories based on adenoma detection rate quintiles for our data set. We based the adenoma detection rate categorization on the whole data set to ensure a wider range of possible adenoma detection rate categories, achieve more reliable confidence intervals of the quintile estimates, and make the study results more applicable to current colonoscopy quality standards. We subsequently used these categories to stratify the annual adenoma detection rate for each endoscopist in successive years. Each screenee then was assigned an endoscopist's annual adenoma detection rate category from their baseline year (the year of entry of the endoscopist to the program), and from the current year (the year in which colonoscopy, for a given screenee, was performed). To measure improvement, the endoscopist's current annual adenoma detection rate category was compared with their baseline category. Improvement was defined as an increase by at least 1 adenoma detection rate category, or maintenance of the highest category (endoscopists in the highest category could not improve it but could maintain or even improve their actual adenoma detection rate). No improvement was defined as a decrease by at least 1 adenoma detection rate category or maintenance of categories 1–4. Screenees examined by endoscopists in their baseline year were assigned to the no improvement group (apart from the highest category). This definition then was expanded to examine the association between achieved category of adenoma detection rate

improvement and interval colorectal cancer (details are provided in Figure 1).

Study Oversight

This research proposal was reviewed by the local ethics committee for the authors' institutions and was judged to be exempt from oversight. Written informed consent was obtained from all individuals entering the National Colorectal Cancer Screening Program. This study was performed within the TEAM's consortium, which includes the Maria Skłodowska-Curie Memorial Cancer Center and Institute of Oncology and the Medical Center for Postgraduate Education (Warsaw, Poland).

Statistical Methods

Multivariable γ frailty models¹⁴ were used to assess the associations between improvement in adenoma detection rate and the risk of interval colorectal cancer, or death from colorectal cancer. The following predefined variables were included in our models: participants' age as a continuous covariate, participants' sex, family history of colorectal cancer (none, or at least 1 first-degree relative with colorectal cancer), adenoma detection rate improvement according to the standard and expanded definitions described earlier, and a frailty factor (the examining endoscopist). When associations were significant, an adjusted hazard ratio and a 95% confidence interval were reported for each of the predefined categories. To assess the robustness of our analyses we

performed 3 sensitivity analyses. First, we performed 2 multivariable γ frailty models with follow-up evaluation censored uniformly at 3 years and 5 years to account for differences in participants' follow-up time. Second, we additionally adjusted the model for baseline adenoma detection rate differences. Third, we used the multivariable γ frailty model to analyze effects of all possible changes between the baseline and current adenoma detection rate category on interval cancer risk when compared with the group that remained in the first quintile.

We used the log-rank test for trend to compare colorectal cancer incidence across annual screening editions. The chi-square test was used to compare the location of screen-detected and interval colorectal cancers. Standardized incidence rates were calculated as the observed number of colorectal cancers divided by the expected number according to sex and 5-year age group. Descriptive statistics were prepared with the use of means and SD, median and interquartile range, or contingency tables, depending on variable distribution.

A *P* value of less than .05 was considered statistically significant. All reported *P* values are 2-sided, and were not adjusted for multiple testing. Statistical analyses were performed with the use of Stata statistical software, version 13.1 (Stata Corporation, College Station, TX). Graphs were prepared with the use of R statistical software, version 3.01 (R Core Team, Vienna, Austria).

Results

Study Population

Of the 158,950 individuals who underwent colonoscopy in the National Colorectal Cancer Screening Program within the enrollment period, 12,090 (7.6%) were excluded for the following reasons: their screen detected colorectal cancer (1489; 0.9%), their screen detected polyps that were not removed (292; 0.2%), there was an underlying hereditary syndrome or a diagnosis of inflammatory bowel disease at the time of the screen (93; 0.1%), or their screen was performed by an endoscopist who was beneath the threshold of performing the 30 colonoscopies required to enter the study (10,216; 6.4%). The characteristics of the remaining 146,860 individuals and their screening procedures are summarized in Table 1.

Endoscopist Performance

Overall, 294 endoscopists were involved in this study. Characteristics for the endoscopists' performance are shown in Table 1. The median number of screening colonoscopies performed by each endoscopist was 332 (interquartile range, 187–623). We designated 5 categories of adenoma detection rate based on quintiles encompassing the entire data set. These quintiles were established at the following percentage detection rates, 1 ($\leq 11.21\%$), 2 (11.22%–15.10%), 3 (15.11%–19.17%), 4 (19.18%–24.56%), and 5 ($> 24.56\%$); these were used to stratify the annual adenoma detection rate of each endoscopist. Throughout the enrollment period, 219 (74.5%) endoscopists improved their current annual category compared with baseline (the definition of improvement is provided in

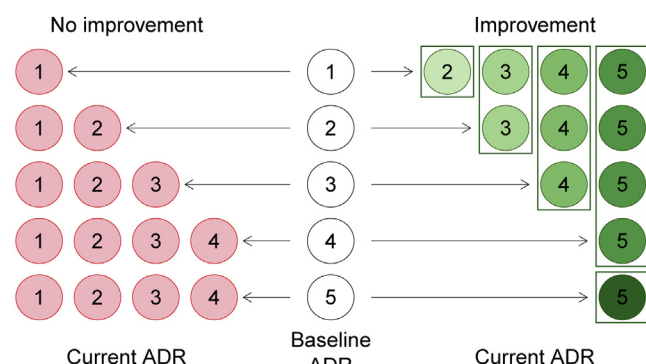


Figure 1. Definition of an improved ADR. Numbers in circles indicate the following ADR quintile categories: 1 ($\leq 11.21\%$), 2 (11.22%–15.10%), 3 (15.11%–19.17%), 4 (19.18%–24.56%), and 5 ($> 24.56\%$). White circles (central) indicate the baseline categories for endoscopists' ADR. Red circles, on the left side, indicate no improvement in ADR as defined by a current annual ADR category that is lower than baseline, or maintenance of category 1 to 4. Green circles, on the right, indicate an improved ADR, defined as a current ADR category that is higher than baseline, or maintenance of category 5. Green circles with different gradients indicate the category of ADR improvement. A green circle carrying labeled as "2" indicates an improvement from category 1 to 2. The "3" notation indicates an improvement from categories 1 or 2, to category 3. The "4" indicates a shift from categories 1–3, to category 4. The "5" with lighter green indicates an improvement from categories 1–4, to category 5. Finally, a dark green circle with "5" indicates maintenance of this category. Participants examined in the baseline year were assigned to the no improvement category (apart from the highest category).

Table 1. Characteristics of the Study Population and Endoscopist Performance Throughout the Enrollment Period (Years 2004–2008)

	Year 2004, N = 17,715	Year 2005, N = 23,004	Year 2006, N = 29,261	Year 2007, N = 39,453	Year 2008, N = 37,427	Overall, N = 146,860
Participant characteristics						
Age, mean (SD), y	55.1 (5.7)	55.1 (5.6)	55.6 (5.3)	56.0 (5.2)	56.0 (5.2)	55.7 (5.4)
Male sex, n (%)	5898 (33.3)	7926 (34.5)	10,793 (36.9)	15,071 (38.2)	14,515 (38.8)	54,203 (36.9)
Family history of colorectal cancer, n (%)	3932 (22.2)	5183 (22.5)	5806 (19.8)	7578 (19.2)	6474 (17.3)	28,973 (19.73)
Procedure variables						
Intravenous sedation, n (%)	7346 (41.5)	12,242 (53.2)	17,732 (59.2)	24,614 (62.4)	23,544 (62.9)	85,078 (57.9)
Adequate bowel preparation, n (%) ^a	16,602 (93.7)	21,581 (93.8)	27,686 (94.6)	37,278 (94.5)	35,373 (94.5)	138,520 (94.3)
Total colonoscopy, n (%)	16,723 (94.0)	21,905 (95.2)	27,922 (95.4)	37,773 (95.7)	36,132 (96.5)	140,455 (95.6)
At least 1 adenoma detected, n (%)	2435 (13.8)	3454 (15.0)	4650 (15.9)	7128 (18.1)	7366 (19.7)	25,033 (17.1)
Subjects with high-risk adenomas, n (%) ^b	1141 (6.4)	1467 (6.4)	1923 (6.6)	2635 (6.7)	2770 (7.4)	9936 (6.8)
Perforations, n (%)	0 (0.00)	4 (0.02)	5 (0.02)	9 (0.02)	9 (0.02)	27 (0.02)
Endoscopist performance						
Colonoscopies, median, n (interquartile range)	104 (62–184)	90 (58–164)	88 (53–162)	117 (70–203)	125 (77–206)	332 (187–623)
Endoscopists in adenoma detection rate category, n (%)						
Category 1 ($\leq 11.21\%$)	38 (30.7)	46 (28.1)	49 (21.6)	29 (12.0)	22 (10.2)	184 (18.9)
Category 2 (11.22%–15.10%)	32 (25.8)	41 (25.0)	47 (20.7)	51 (21.1)	30 (13.9)	201 (20.7)
Category 3 (15.11%–19.17%)	24 (19.4)	27 (16.5)	49 (21.6)	47 (19.4)	48 (22.2)	195 (20.0)
Category 4 (19.18%–24.56%)	20 (16.1)	30 (18.3)	42 (18.5)	53 (21.9)	49 (22.7)	194 (19.9)
Category 5 ($> 24.56\%$)	10 (8.1)	20 (12.2)	40 (17.6)	62 (25.6)	67 (31.0)	199 (20.5)

^aBowel preparation was assessed by the endoscopist.

^bHigh-risk adenomas denote adenomas of at least 10 mm in size, or with high-grade dysplasia, villous components, or at least 3 adenomas.

Figure 1). Notably, the fraction of endoscopists in the lowest annual adenoma detection rate category decreased from 30.7% in 2004 to 10.2% by 2008, whereas the fraction of endoscopists in category 5 increased from 8.1% to 31.0% over the same time period (Table 1). Endoscopists in the no improvement category scored a mean adenoma detection rate of 10.8%, those reaching categories 2, 3, 4, or 5, or those consistently in category 5, scored a mean adenoma detection rate of 13.1% (at least 11.22%), 17.1% (at least 15.11%), 21.6% (at least 19.18%), 28.8% (at least 24.57%), and 31.3% (at least 24.57%), respectively. There were 54 (18.4%) endoscopists who remained in the same ADR improvement category throughout the entire enrollment period, 97 (33.0%) who increased or remained in the same ADR improvement category, 47 (16.0%) who decreased or remained in the same ADR category, and 96 (32.7%) who fluctuated between categories throughout the enrollment period (eg, when there was an increase in 1 year and decrease in the following year, or any different nonmonotonic sequence). For detailed information see Supplementary Figure 1.

Interval Colorectal Cancers

Our study individuals were followed up for a median of 5.8 years (interquartile range, 5.0–7.2 y) to capture the

occurrence of interval colorectal cancer. After 895,916 person-years of follow-up evaluation, 168 interval colorectal adenocarcinomas were diagnosed, representing 10.1% of all detected colorectal cancers. The number of interval cancers per 100,000 person-years of follow-up evaluation decreased from 26.0 to 14.7 for individuals examined between 2004 and 2008 (P for trend = .024). For the cohort, the cumulative annual rate of interval colorectal cancer was stable throughout the maximum 9 years of follow-up evaluation (Supplementary Figure 2). A median time between the screening colonoscopy and the diagnosis of interval colorectal cancer was 3.5 years; interval cancers were more likely than screen-detected cancers to be located proximal to the splenic flexure (33.3% vs 24.4%; P = .011). The completeness of colorectal cancer registration, verified by assessed registration rates for our screen-detected cancers, was between 88% and 90% throughout the enrollment period. Interval colorectal cancers subsequently caused 44 deaths.

The Effect of an Improved Adenoma Detection Rate on Interval Cancer and Death

Figure 2 shows the increase in the overall annual adenoma detection rate and associated decrease in the standardized incidence rate of interval colorectal cancers throughout the enrollment period. By using multivariate

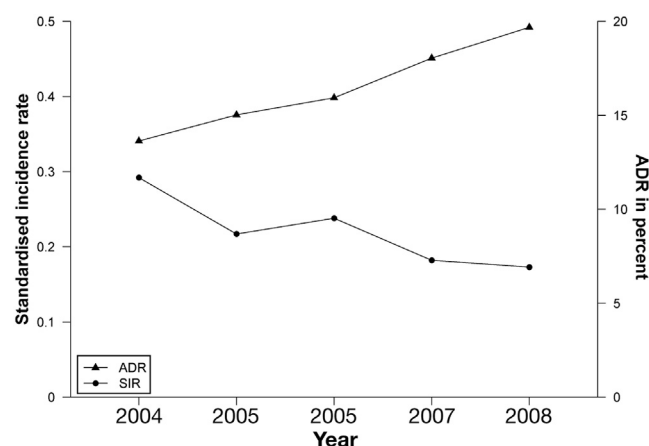


Figure 2. Time trend for the standardized interval colorectal cancer rates (per 100,000 patient-years of follow-up evaluation), and adenoma detection rates at the program level. SIR, standardized incidence rate.

frailty models, the improvement in the annual adenoma detection rate was associated with a significantly reduced risk of interval colorectal cancer (adjusted hazard ratio, 0.63; 95% confidence interval [CI], 0.45–0.88; $P = .006$), and colorectal cancer death (adjusted hazard ratio, 0.50; 95% CI, 0.27–0.95; $P = .035$) (Table 2). When compared with no improvement, reaching or maintaining the highest annual category of adenoma detection rate ($>24.56\%$) was associated with an adjusted hazard ratio for interval colorectal cancer of 0.27 (95% CI, 0.12–0.63; $P = .003$), and 0.18 (95% CI, 0.06–0.56; $P = .003$), respectively (Figure 3). In absolute numbers, this translates to a reduction in the rate of interval cancer from 25.3 cases per 100,000 patient-years of follow-up evaluation, to 7.1 (at which an adenoma detection rate 5 category is reached) or 4.5 (at which a category 5 score is maintained) cases per 100,000 patient-years of follow-up evaluation, respectively. Similar results were found in the sensitivity analyses. In the case of follow-up evaluation censored uniformly at 3 or 5 years, adjusted hazard ratios were 0.49 (95% CI, 0.29–0.80; $P = .005$) and 0.64 (95% CI, 0.47–0.88; $P = .006$) for interval colorectal cancer, and 0.32 (95% CI, 0.12–0.87; $P = .026$) and 0.50 (95% CI, 0.26–0.94; $P = .032$) for colorectal cancer death, respectively. When, the model was adjusted additionally for baseline adenoma detection rate category, the improvement in the annual adenoma detection rate was associated with an adjusted hazard ratio for interval colorectal cancer of 0.66 (95% CI, 0.48–0.91; $P = .012$). Sensitivity analysis in which all the endoscopists in the highest quintile at baseline were excluded showed no meaningful difference from the results presented earlier (data not shown). Another sensitivity analysis in which endoscopists' adenoma detection rates were standardized for age, sex, and family history also showed no meaningful difference from the results presented earlier (data not shown). Finally, a detailed analysis of all possible changes between baseline and current adenoma detection rate category suggests that the latter determines the risk of interval colorectal cancer independently of the baseline category (Supplementary Figure 3).

Discussion

Previous studies have shown that an endoscopist's adenoma detection rate is a powerful indicator of their skill in performing colonoscopy, with a proven inverse association with interval colorectal cancer,³ and subsequently dying from colorectal cancer.⁴ Consequently, adenoma detection rate has become the key quality indicator for colonoscopy, as endorsed by multiple professional societies.^{15,16} Improved education and awareness of the need for quality control in screening,^{6,7,17} together with feedback, benchmarking,⁵ and upgraded endoscopic equipment, all have helped to improve adenoma detection rates.⁸ However, to close the audit cycle and encourage quality control and practice improvement we needed to show that an improved adenoma detection rate could translate to clinically meaningful outcomes for the patient.¹⁸ This study showed a significant inverse association between improved adenoma detection rate and the risk of interval colorectal cancer, or colorectal cancer death after screening colonoscopy. These results corroborate the findings of a recently published microsimulation modeling study¹⁹ and prove the causal relationship between endoscopists' adenoma detection rates and the likelihood of being diagnosed with, or dying from, interval colorectal cancer.

In our study, reaching or maintaining an annual adenoma detection rate in excess of 24.6% was a prerequisite to achieving a profound and statistically significant reduction in the risk of interval colorectal cancer. This is in line with the currently recommended adenoma detection rate performance target for a mixed male/female population of at least 25%.¹⁵ Although a less pronounced improvement in adenoma detection rates showed a numeric reduction in interval cancer risk, this reduction failed to reach statistical significance, likely owing to insufficient power. It presently is uncertain as to whether further improvements in adenoma detection rate beyond the minimum benchmark value of 24.6% would result in any further incremental reduction in the rate of interval colorectal cancer. However, given observation of a linear inverse association between the 2 criteria,⁴ we would suggest that this very likely would be the case.

Two previously published modeling studies showed that the costs of policies to improve adenoma detection rates are marginal compared with the expected increase in the cost effectiveness for screening.^{19,20} Therefore, it is timely to consider the best policies with which to achieve a national improvement in endoscopists' adenoma detection rates. In Germany, increased awareness of quality control, and an ongoing upgrade in endoscopy equipment, were sufficient to maintain a steady national improvement in adenoma detection rates.⁸ However, even with this policy in place, variation in the ranking of individual endoscopists by adenoma detection rates remained relatively stable, with only 39.6% of endoscopists improving their adenoma detection rate quintile over a 10-year period. In Poland, feedback with benchmarking using colonoscopy quality indicators resulted in a sustained 1.5% point annual improvement in the overall adenoma detection rate,⁵ with 74.5% of endoscopists improving their adenoma detection rate quintile during the

Table 2. Effect of Adenoma Detection Rate Improvement on Adjusted Hazard Ratios for Interval Colorectal Cancer and Colorectal Cancer Death

	Interval colorectal cancer		Colorectal cancer death	
	Adjusted hazard ratio (95% CI)	P value	Adjusted hazard ratio (95% CI)	P value
Age, y	1.08 (1.04–1.11)	<.001	1.10 (1.03–1.17)	.005
Male sex	1.20 (0.88–1.64)	.25	1.77 (0.98–3.20)	.058
Family history of colorectal cancer	1.15 (0.72–1.84)	.56	0.33 (0.08–1.40)	.13
Adenoma detection rate improvement	0.63 (0.45–0.88)	.006	0.50 (0.27–0.95)	.035

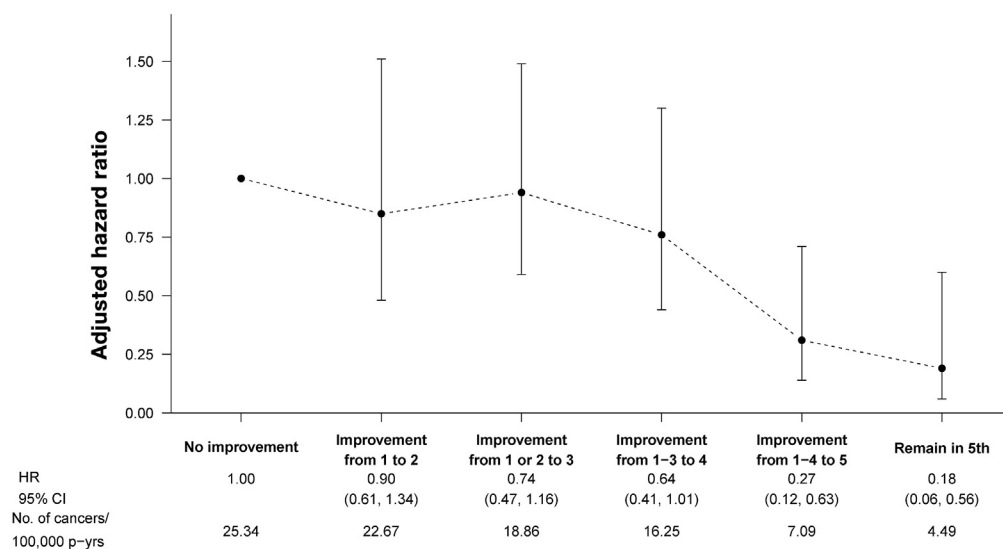
course of our study. However, many poorly performing endoscopists failed to improve their adenoma detection rates, indicating the need for additional training.⁵ In the United Kingdom and United States, efforts in colonoscopy quality control have focused on improved training and establishing a colonoscopy culture change.²¹ The United Kingdom's methodology has been tested in a countrywide randomized trial in Poland and showed the significant impact of leadership training on adenoma detection rates achieved for entire endoscopy units.⁶ Therefore, combining feedback, benchmarking, and training are by far the most effective strategies with which to improve the adenoma detection rate.

There are also potential downsides to adenoma detection rate improvement, such as the concomitant increase in complication rate, and the increased burden of surveillance colonoscopies after adenoma removal. In our study, the rate of reported perforations remained stable throughout the enrollment period and was well below the recommended target of less than 0.05%.¹⁵ Furthermore, the perforation rate was identical for endoscopists who improved their adenoma detection rate, and for those who did not (0.02% for both groups). In a study by Brenner et al,⁸ age-adjusted bleeding and perforation rates were stable over the 10-year observation period despite increased adenoma detection

rates. Therefore, both studies would appear to agree that increased adenoma detection did not result in a proportionately higher complication rate.

The knock-on effect of improved adenoma detection is that more patients will be offered surveillance colonoscopy, with a greater proportion categorized as high risk and offered more intensive surveillance. During our study, the increased rate of adenoma detection between 2004 and 2008 resulted in the shift of an additional 4.9% of screenees into the low-risk adenoma group (from 7.4% to 12.3%, respectively), and 1% into the high-risk adenoma group (from 6.4% to 7.4%, respectively). According to current surveillance recommendations, in 10 years' time, this displacement likely will translate into 6.9 additional colonoscopies per 100 screenees. This estimate is derived from the instigation of 3- (high-risk) and 5- (low-risk) year screens, instead of the customary 10-year screen. By applying a similar simulation to the Brenner et al⁸ study we would predict an increased colonoscopy workload of 12.2 per 100 screened men, and 8.1 per 100 screened women, respectively. Therefore, the provision of higher-quality colonoscopy services paradoxically will result in more intensive surveillance than less. This paradox needs to be addressed in the upcoming surveillance recommendations and through the results of ongoing surveillance trials.

Figure 3. Adjusted hazard rates for interval colorectal cancer according to ADR improvement category. Endoscopists in the no improvement category scored a mean ADR of 10.8%, those reaching categories 2, 3, 4, or 5, or those consistently in category 5, scored a mean ADR of 13.1% (at least 11.22%), 17.1% (at least 15.11%), 21.6% (at least 19.18%), 28.8% (at least 24.57%), and 31.3% (at least 24.57%), respectively. Vertical lines indicate 95% CIs. HR, hazard ratio; p-yrs, patient-years.



Our study had limitations. First, the data on interval colorectal cancers were derived from the National Cancer Registry, with only 90% of cases thought to be registered.¹¹ This estimate of accuracy was confirmed by our cross-referencing of registration frequency for screen-detected colorectal cancers during our project. Nevertheless, this parameter remained stable over the entire follow-up period and should have little effect on the observed reduction in interval cancer rates. Second, we had no data for colonoscopy withdrawal time, which is known to be associated with adenoma detection rate²² and interval cancer rate.²³ It is likely that colonoscopy withdrawal times increased over time in our study, but this should be seen as a trade-off for the improved efficacy of colonoscopy. Third, the relationship between feedback with benchmarking and adenoma detection rate improvement in our study is plausible, however, no definitive conclusions can be drawn owing to the lack of a control group. Other potential causes of the observed improvement might have been an upgrade in endoscopy equipment, better bowel cleansing, or better colonoscopy training, and so forth. No matter what the cause of improvement was, however, the observed associations with interval cancer rates and deaths likely are valid. Fourth, because of the relatively small annual number of colonoscopies performed by endoscopists, the precision of adenoma detection rate calculation was limited. We alleviated this limitation by restricting the analysis to endoscopists who contributed at least 30 colonoscopies per annum, assigning endoscopists to broader adenoma detection rate quintile categories and using frailty models that account for background hazard within endoscopists. We also performed a sensitivity analysis in which endoscopists' adenoma detection rates were standardized for age, sex, and family history to take into account potential unbalanced distribution of these confounders among screenees. The sensitivity analysis showed no meaningful difference compared with the primary analysis.

In summary, we now show that an improvement in adenoma detection rate at screening colonoscopy, achieved by a comprehensive quality-assurance program, translates into reduced risks of interval colorectal cancer and colorectal cancer death.

Supplementary Material

Note: To access the supplementary material accompanying this article, visit the online version of *Gastroenterology* at www.gastrojournal.org, and at <http://dx.doi.org/10.1053/j.gastro.2017.04.006>.

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Conflicts of interest

The authors disclose no conflicts.

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