European Review for Medical and Pharmacological Sciences 2023; 27: 3552-3564

Significance of photodocumentation-associated factors in colonoscopy on the detection rate of colorectal neoplasms

K.-J. LEE[1,3], D.K. YON[2], J.H. KIM[3], D.H. KIM[3], Y.-S. KIM[4], J.H. YOO[3]

[1]Department of Internal Medicine, CHA Gumi Medical Center, CHA University, Gyeongsangbuk-do, South Korea
[2]Center for Digital Health, Medical Science Research Institute, Kyung Hee University College of Medicine, Seoul, South Korea
[3]Digestive Disease Center, CHA Bundang Medical Center, CHA University, Seongnam, South Korea
[4]Department of Family Medicine, CHA Bundang Medical Center, CHA University, Seongnam, South Korea

Young-Sang Kim and Jun Hwan Yoo both contributed equally and are corresponding authors

Abstract. – OBJECTIVE: It is unclear whether photodocumentation is associated with colorectal neoplasm (CRN) detection at colonoscopy, despite its ability to take more images with the development of affordable digital imaging systems. This study aimed to investigate whether photodocumentation-related factors could affect the detection rate of CRNs in healthy subjects.

PATIENTS AND METHODS: A total of 2,637 subjects undergoing screening colonoscopy in routine health check-ups at CHA Bundang Medical from January to September 2016 were enrolled in this study. Only the endoscopic image data for observation purposes during colonoscopy withdrawal was used in this analysis. The number of observation images, observation time and the speed of photodocumentation (SPD) defined as the number of observation images per minute were used as quantity measures of photodocumentation. The presence of documented anatomical landmarks such as appendix orifice (AO), ileocecal valve (ICV), anorectal junction was used as quality measures of photodocumentation.

RESULTS: Among subject-related factors, the independent factors for CRN detection in the multivariate analysis were age, male sex, waist circumference, and family history of colorectal cancer. In photo-documentation-related factors, SPD [Odds ratio (OR) 0.800; 95% confidence interval (CI), 0.740 to 0.864], observation time over 6 min (OR 1.671; 95% CI, 1.145 to 2.439), clear documentation of appendix orifice (AO) (OR 5.976; 95% CI, 4.548 to 7.852) and ileocecal valve (ICV) (OR 3.826; 95% CI, 2.985 to 4.904), and endoscopists (*p* < 0.001) were independently significant factors. However, the number of observation images was not associated with the detection of CRNs.

CONCLUSIONS: Lower SPD and clear documentation of cecal landmarks might be associated with an increased detection rate of CRNs.

Key Words:
Colonoscopy, Endoscopy, Colorectal neoplasms.

Introduction

Post-colonoscopy colorectal cancers (PCCRCs), which are defined as CRCs diagnosed months or years after a colonoscopy that are negative for CRC or premalignant lesions, may arise from missed cancers and missed or incompletely resected benign lesions[1]. In a previous study[2], the rate of PCCRCs within 3 years was 7.4%. A total of 85% of PCCRCs are caused by missed lesions[3]. A recent meta-analysis and review article[4,5] reported that the colorectal neoplasm (CRN) miss rate at a single colonoscopy was approximately 26%. Previous studies[4,6-8] have shown that inadequate bowel preparation, incomplete colonoscopy, and a short withdrawal time may be predictive of missed CRNs. However, a significant CRN miss rate is still observed[9] with adequate bowel preparation and withdrawal time. Therefore, additional studies on other factors associated

Corresponding Author: Young-Sang Kim, MD, Ph.D; e-mail: zeroup@cha.ac.kr; Jun Hwan Yoo, MD, Ph.D; e-mail: jhyoo@cha.ac.kr

with CRN detection are required. The factors associated with CRN detection can be divided into subject-related factors (e.g., age, male sex, metabolic syndrome, smoking, family history, and bowel preparation)[10-13] and procedure-related factors (e.g., observation time during withdrawal, insertion time, repeat exploration or retroflexion of the right colon, video recording, and position change)[14-17]. In contrast to subject-related factors, procedure-related factors can be modified by endoscopists. However, studies of procedure-related factors are limited.

With the development of affordable digital imaging systems, the quality and quantity of photodocumentation among endoscopic procedures are growing rapidly[18]. However, studies on photodocumentation-related factors associated with CRN detection are lacking and virtual chromoendoscopy, such as narrow band images, has not yet had a significant impact on CRN detection[19]. Among photodocumentation-related factors, observation time (withdrawal time) is associated with increased CRN detection[17,20-23]. The observation time is divided into the time consumed for real-time observation during endoscopic movement and the time consumed for photodocumentation (freezing/capturing images) during the pause of endoscopic movement.

Although the photodocumentation process takes up a significant part of the observation time, few studies in literature have investigated whether photodocumentation is related to CRN detection. Unlike the real-time observation process during endoscopic movement, the main purpose of photodocumentation is to record rather than to observe, which could have a negative effect on CRN detection. On the other hand, photodocumentation could play a positive role in CRN detection by inducing mucosal cleansing, meticulous inspection, and longer withdrawal time[15,24,25]. In addition, freezing an image can play a positive role in CRN detection by providing an opportunity to observe the area of interest without artifacts caused by patient movement[24]. A recent study[26] showed that meticulous cecal documentation is related to improved polyp detection. However, another study[27] reported that cecal documentation was not significantly associated with adenoma and polyp detection rates. In upper gastrointestinal endoscopy, documentation of anatomical landmarks and the number of images are related to abnormal mucosal lesion detection[24,28-30]. However, studies investigating the association between photodocumentation and CRN detection are still limited.

Therefore, this study aimed to define several factors related to photodocumentation (number of observation images, observation time, speed of photodocumentation, and clear documentation of landmarks) and investigated the association between these factors and CRN detection.

Patients and Methods

Ethical Approval and Informed Consent

This study was approved by the Institutional Review Board (IRB) of CHA Bundang Medical Center (approval number: CHAMC 2022-04-067). All methods were performed in accordance with the relevant guidelines and regulations of the IRB. All participants provided written informed consent for participation in the study.

Study Population

This cross-sectional, retrospective study reviewed the medical records of subjects who underwent colonoscopy as part of routine health check-ups from January to September 2016 at the CHA Bundang Medical Center, Korea. A total of 2,637 subjects who underwent colonoscopy were enrolled. We excluded subjects who had any of the following: (1) colonoscopy for any reason in the previous 5 years; (2) history of colorectal cancer; (3) history of colorectal surgery or polypectomy; (4) history of inflammatory bowel disease or intestinal tuberculosis; (5) cecal intubation failure; (6) Boston bowel preparation scale (BBPS) under 7; (7) failure of an adequate biopsy; (8) image transfer error to Picture Archiving and Communication Systems (PACS); and (9) examination by an unregistered endoscopist (Figure 1).

Colonoscopic Photodocumentation-Related Factors

All images and times were based on data uploaded to the PACS. In the observation image, only images for observational purposes during withdrawal were included, excluding images taken at the time of insertion, images of anal red-out, images with blurred focus, images recorded for treatment purposes, and images of the terminal ileum. In the case of the appendix orifice (AO) image, only a close-up shot with the endoscope entering the cecal base was accepted (Figure 2A), and a distantly captured image with the ICV was not accepted (Figure 2C). In addition, if a turbid

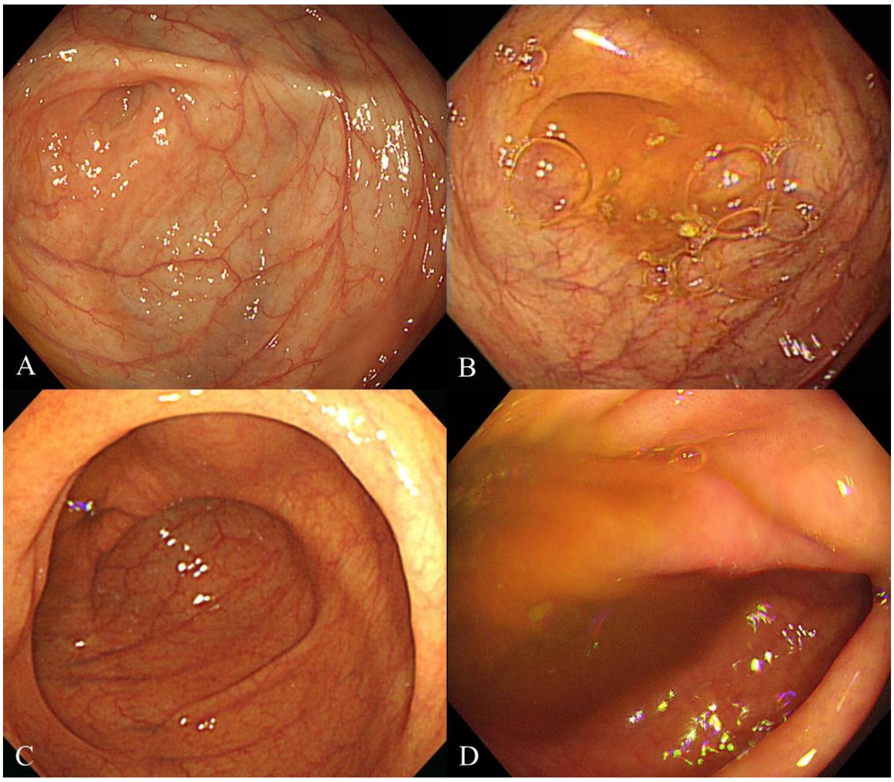

Figure 1. Cases accepted as appendix orifice images (**A-B**) and not accepted (**C-D**).

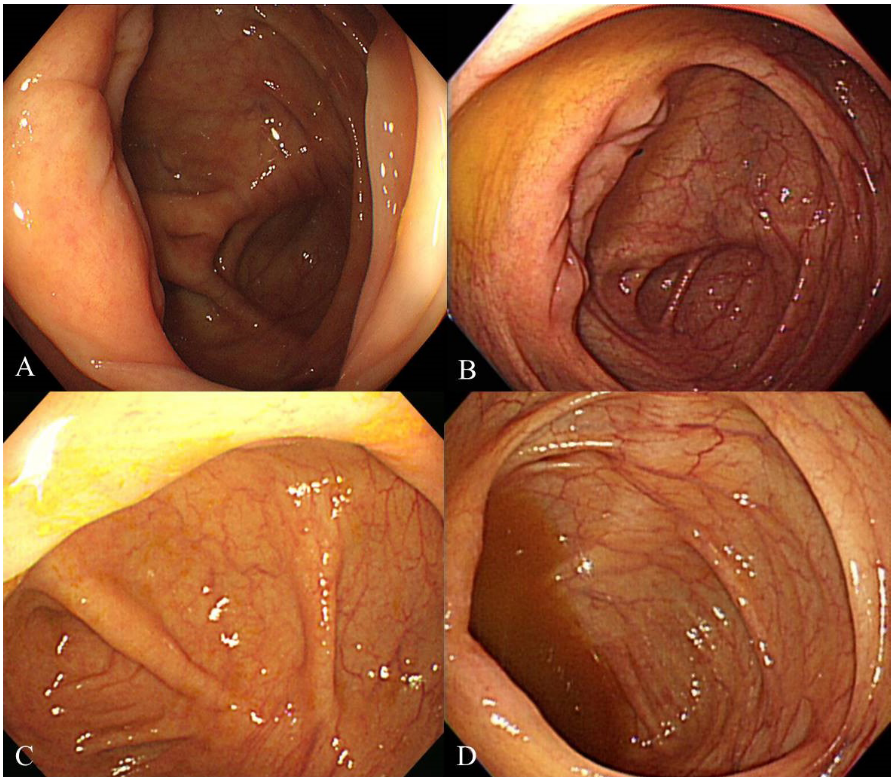

Figure 2. Cases accepted as ileocecal valve images (**A-B**) and not accepted (**C-D**).

liquid (Figure 2D) or a solid material other than the transparent serous fluid (Figure 2B) covers the orifice, it is not acknowledged as an accurate AO image. For ICV images, only close-up images showing more than half of the opening lip were accepted (Figure 3A-B). Moreover, even a close-up image was not approved if the opening lip was less than half visible (Figure 3C-D). An anorectal junction retroflexion image was defined as a case in which the inserted endoscope was visible with anorectal junction.

The observation time was calculated using PACS, because the present time is simultaneously stored when endoscopists perform image capture. The observation time was calculated by subtracting the time between the first image of the cecum and the last image of the rectum. When endoscopic procedures such as biopsy or polypectomy were performed during withdrawal, in agreement with the literature, we subtracted the procedure time calculated *via* PACS[22,31]. Since the current guidelines and literature suggest that 6 min is the minimum adequate mean withdrawal time for screening colonoscopy in which no polyps are removed, we divided the observation time into two groups (≥ 6 min *vs.* < 6 min)[23,31,32]. The SPD is a new concept created in this study based on other studies[33] and is defined as the number of observation images in observation time (min). This study was designed to investigate whether the simple number of colonoscopically captured images and the number of images per unit time are related to the quality of colonoscopy.

Detection of Colorectal Neoplasms

All colonoscopies were conducted by one of four endoscopists with specialty certificates in gastroenterology and endoscopy. For bowel preparation, 2 L of polyethylene glycol with ascorbate (CM Light Power®; CMG Pharmaceuticals, Seoul, South Korea) was prescribed prior to colonoscopy. The number, size, and location of CRN were obtained from a colonoscopy report. Polyp size was measured using biopsy forceps. The location of CRN was classified into the following four sections: (1) cecum, (2) ascending colon containing hepatic flexure, (3) transverse colon containing splenic flexure, and (4) descending colon to the rectum. Histological findings of CRN were classified as tubular adenoma (TA), tubulovillous adenoma or villous adenoma (TVA or VA), high-grade dysplasia (HGD), sessile serrated

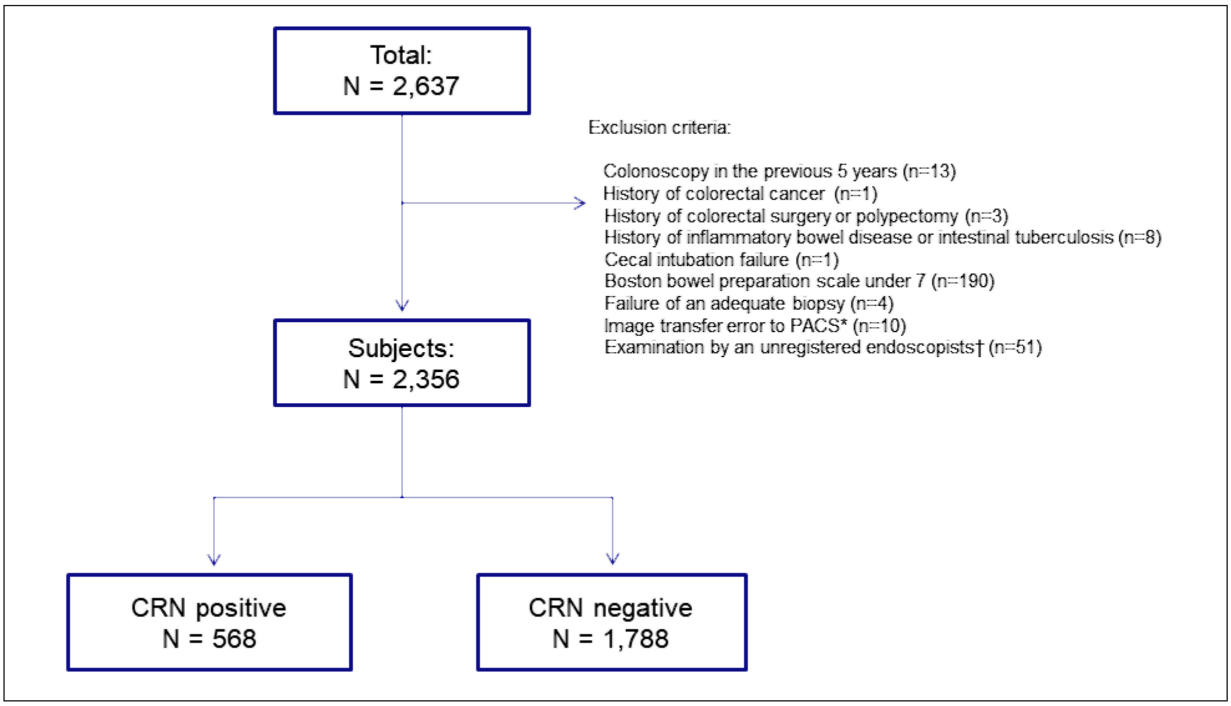

Figure 3. Flow diagram illustrating the exclusion of the study subjects from this analysis for the reasons indicated. *The wrong person's image is uploaded, there is no image in PACS, or only an image captured incorrectly is uploaded.
†Endoscopists who are not registered full-time at the center where the subjects received colonoscopy. CRN, colorectal neoplasm; PACS, Picture Archiving and Communication Systems.

adenoma (SSA), and cancer. Advanced CRN was defined as cancer or adenoma that satisfied any of the following criteria: (1) at least 10 mm in diameter, (2) high-grade dysplasia, and (3) a villous or tubulovillous component. If three or more adenomas were found in a single examination, it was defined as multiple CRNs and separated into groups with and without multiple CRNs. For subjects with two or more CRNs, the size and pathology of neoplasms with the largest size or advanced pathology were recorded.

Measurements, Definitions, and Laboratory Assays

All body measurements (height, weight, and waist circumference) of the subjects were performed by well-trained nurses. Metabolic syndrome was defined based on the updated National Cholesterol Education Program/Adult Treatment Panel III criteria[34]. Laboratory tests, including serum glucose and lipid profiles, were measured after a fasting period of at least 12 h on the day of endoscopy. The presence of fatty liver was determined using abdominal ultrasonography.

Questionnaire

All subjects responded to the following items on the questionnaire: smoking status (ever, never), alcohol consumption, physical activity, family history (FH) of CRC in first-degree relatives, aspirin use (confirmed prescription in the medical record), and current medications (diabetes and hypertension). Subjects receiving antihypertensive medications were included in the hypertension group. Subjects receiving diabetes treatment or with a fasting blood glucose level of 110 mg/dL or more were included in the high fasting glucose group[34].

Statistical Analysis

All statistical analyses were performed using SPSS version 27 for Windows (IBM Corp., Armonk, NY, USA). Differences in categorical variables between the groups were analyzed using the Chi-square test or Fisher's exact test. Continuous variables were compared using Student's *t*-test. All risk factors with a significant difference, as determined by univariate analysis, were included in the multivariate analysis using forward stepwise logistic regression. OR and 95% CIs were calculated for each variable in the multivariate analysis. Statistical significance was set at $p < 0.05$[35,36].

Results

Subject-Related Factors Associated with Colorectal Neoplasm Detection

After the exclusions were complete, 2,356 subjects were included in the analysis (Figure 1). Table I presents the baseline characteristics of the subjects and the univariate analysis of subject-re-

Table I. Univariate analysis of subject-related factors associated with CRN detection.

Subject-related factors	CRN positive (n = 568)	CRN negative (n = 1,788)	*p*-value
Male sex	388 (68.3%)	942 (52.7%)	< 0.001
Age, years	52.0 ± 11.0	44.7 ± 10.6	< 0.001
Body mass index, kg/m^2	24.5 ± 3.1	23.6 ± 3.5	< 0.001
Metabolic syndrome	73/532 (13.7%)	165/1,732 (9.5%)	0.006
Waist circumference, cm	86.6 ± 8.9	83.8 ± 9.5	< 0.001
Hypertension	216/532 (40.6%)	465/1,732 (26.8%)	< 0.001
High fasting glucose	115/532 (21.6%)	185/1,732 (10.7%)	< 0.001
Triglycerides, mg/dL	122.9 ± 87.7	109.8 ± 72.7	0.002
HDL, mg/dL	55.8 ± 14.8	59.0 ± 15.9	< 0.001
LDL, mg/dL	131.5 ± 36.1	131.3 ± 33.7	0.904
Total cholesterol, mg/dL	201.8 ± 39.1	202.7 ± 35.4	0.642
Smoking (ever)	304/531 (57.3%)	719/1,730 (41.6%)	< 0.001
Alcohol consumption	301/531 (56.7%)	906/1,730 (52.4%)	0.081
Aspirin use	26/532 (4.9%)	44/1,732 (2.5%)	0.006
Fatty liver	216/532 (40.6%)	526/1,732 (30.4%)	< 0.001
Physical activity	303/532 (57.0%)	1,019/1,732 (58.8%)	0.442
FH of CRC	45/532 (8.5%)	86/1,732 (5.0%)	0.003

Variables shown are numbers (percentages) or expressed as the mean ± standard deviation. Some data are missing. Differences in categorical variables between groups were analyzed using the Chi-square test or Fisher's exact test. Continuous variables were compared by Student's *t*-test. CRN, colorectal neoplasm; HDL, high-density lipoprotein; LDL, low-density lipoprotein; FH of CRC, family history of colorectal cancer.

lated factors associated with the detection of CRNs. The overall prevalence of colorectal neoplasms was 24.1% (568/2,356). Compared to the CRN-negative (control) group, the CRN-positive group was more likely made up of men, older, who had a family history of colorectal cancer, higher body mass index (BMI), higher waist circumference, higher triglyceride and lower HDL levels, and had a higher prevalence of metabolic syndrome, fatty liver, hypertension, high fasting glucose, smoking (ever), and aspirin use.

The clinicopathological characteristics (location, pathology, and numerical features) of the detected CRNs are shown in **Supplementary Table I**. There were 41 cases of advanced CRNs, accounting for 7.2% of the total CRN-positive group. The average number of CRNs in CRN-positive subjects was 1.56, and the proportion of subjects with multiple CRNs (≥ 3) was 32.6%.

Photodocumentation-Related Factors Associated with CRN Detection

The univariate analysis of the photodocumentation-related factors that are associated with the detection of CRNs is shown in Table II. When comparing the results of the quantitative measurements, the mean number of observation images did not differ between the two groups. However, the observation time of the CRN-positive group was longer than that of the control group (309.3 s *vs.* 274.1 s; $p < 0.001$). The CRN-positive group also had a higher prevalence of long observation time (≥ 6 min) compared to the control group (24.1% *vs.* 7.2%, $p < 0.001$). On the other hand, the speed of photodocumentation (SPD) was significantly lower in the CRN positive group (6.9 ± 2.6 in CRN positive group *vs.* 7.6 ± 2.4 in the control group, $p < 0.001$).

Regarding quality measurements, the CRN-positive group showed a higher proportion of documentation of the appendix orifice (AO) than the CRN-negative group (75.2% *vs.* 40.1%, $p < 0.001$). The proportion of documentation of the ileocecal valve (ICV) was also higher in the CRN-positive group (58.1% *vs.* 24.9%, $p < 0.001$). However, there were no significant differences in the proportion of documented anorectal junction retroflexion views between the two groups. The endoscopists themselves were also a significant factor in CRN detection ($p < 0.001$).

Multivariate Analysis of The Factors Associated with CRN Detection

A total of 18 factors (13 subject-related and five photodocumentation-related) with a significant difference, as determined by univariate analyses, were included in the multivariate analysis for the factors associated with CRN detection. Among the five photodocumentation-related factors, an observation time ≥ 6 min, SPD, AO, ICV, and endoscopists were included in the analysis.

Forward stepwise logistic regression was used for multivariate analysis and the results are shown in Table III. Among the subject-related factors, age (OR, 1.055; 95% CI, 1.043-1.066), male sex (OR 2.095; 95% CI, 1.596-2.748), waist circumference (OR, 1.018; 95% CI, 1.004-1.032),

Table II. Univariate analysis of photodocumentation-related factors associated with CRN detection.

Photodocumentation-related factors	CRN positive (n = 568)	CRN negative (n = 1,788)	*p*-value
Number of observation images (N)	32.8 ± 9.5	33.6 ± 9.5	0.078
Observation time (T)*	309.3 ± 102.5	274.1 ± 60.4	< 0.001
Observation time (≥ 6 min)	137 (24.1%)	129 (7.2%)	< 0.001
Speed of photodocumentation (SPD, N/T)†	6.9 ± 2.6	7.6 ± 2.4	< 0.001
Clear photodocumentation of Appendix orifice	427 (75.2%)	717 (40.1%)	< 0.001
Ileocecal valve	330 (58.1%)	445 (24.9%)	< 0.001
Anorectal junction retroflexion view	563 (99.1%)	1,775 (99.3%)	0.715
Endoscopists			< 0.001
A	122 (21.0%)	458 (79.0%)	
B	130 (20.9%)	492 (79.1%)	
C	135 (25.2%)	400 (74.8%)	
D	181 (29.2%)	438 (71.8%)	

Variables shown are numbers (percentages) or expressed as the mean ± standard deviation. Differences in the categorical variables between the groups were analyzed using Chi-square test or Fisher's exact test. Continuous variables were compared by Student's *t*-test. *The unit of observation time (T) is s. †The unit of photodocumentation speed (N/T) is the number per min.

Table III. Multivariate analysis of the factors associated with CRN detection.

Variable	*p*-value	Odds ratio	95% confidence Interval	
			Lower	Upper
Subject-related factors				
Age	< 0.001	1.055	1.043	1.066
Male sex	< 0.001	2.095	1.596	2.748
Waist circumference	0.013	1.018	1.004	1.032
FH of CRC	0.048	1.585	1.004	2.504
Photodocumentation-related factors				
SPD	< 0.001	0.800	0.740	0.864
Observation time (≥ 6 min)	0.008	1.671	1.145	2.439
Appendix orifice	< 0.001	5.976	4.548	7.852
Ileocecal valve	< 0.001	3.826	2.985	4.904
Endoscopist	< 0.001			
A		1.000		
B	< 0.001	3.219	2.191	4.728
C	0.986	1.003	0.706	1.426
D	0.004	1.966	1.233	3.134

SPD, speed of photodocumentation (per minute).

and family history of colorectal cancer (OR, 1.585; 95% CI, 1.004-2.504) were significant independent risk factors for CRN detection. Among photodocumentation-related factors, SPD (OR, 0.800; 95% CI, 0.740-0.864), observation time ≥ 6 min (OR 1.671; 95% CI, 1.145-2.439), AO (OR 5.976; 95% CI, 4.548-7.852), and ICV (OR 3.826; 95% CI 2.985-4.904) were independently significant factors. Endoscopists ($p < 0.001$) remained significant independent factors influencing CRN detection.

Multivariate Analysis of the Factors Associated with CRN Detection Stratified by Individual Endoscopists

An additional stratified analysis was performed to determine whether similar results were obtained when the same analysis was performed by each endoscopist. Stratified analysis by individual endoscopists showed that four factors (age, SPD, AO, and ICV) were common factors associated with CRN detection in all endoscopists (Table IV-VII).

Multivariate Analysis of the Factors Associated with Advanced CRN or Multiple CRN Detection

Additional multivariate analysis was performed for factors associated with the detection of advanced CRNs (adCRNs) or multiple CRNs (mCRNs, ≥ 3). In the case of adCRN (**Supplementary Table II**) detection, a total of four subject-related factors, such as age (OR, 1.059; 95% CI, 1.042-1.076), smoking (OR, 1.944; 95% CI, 1.338-2.824), waist circumference (OR, 1.033; 95% CI, 1.012-1.054), and FH of CRC (OR, 2.209;

Table IV. Endoscopist A.

Variable	*p*-value	Odds ratio	95% confidence Interval	
			Lower	Upper
Subject-related factors				
Age	0.005	1.033	1.010	1.058
Male sex	< 0.001	3.008	1.718	5.268
Photodocumentation-related factors				
SPD	< 0.001	0.684	0.550	0.852
Appendix orifice	< 0.001	8.993	5.103	15.848
Ileocecal valve	< 0.001	5.262	3.030	9.138

Table V. Endoscopist B.

Variable	*p*-value	Odds ratio	95% confidence Interval	
			Lower	Upper
Subject-related factors				
Age	< 0.001	1.058	1.036	1.080
Body mass index, kg/m^2	0.001	1.119	1.045	1.198
Photodocumentation-related factors				
SPD	0.005	0.839	0.741	0.950
Appendix orifice	< 0.001	3.421	2.140	5.470
Ileocecal valve	< 0.001	3.767	2.296	6.180

Table VI. Endoscopist C.

Variable	*p*-value	Odds ratio	95% confidence Interval	
			Lower	Upper
Subject-related factors				
Age	< 0.001	1.075	1.050	1.100
Male sex	< 0.001	2.067	1.111	3.844
Metabolic syndrome	0.001	0.189	0.073	0.495
Waist circumference	0.006	1.044	1.012	1.076
Triglycerides, mg/dL	0.004	1.006	1.002	1.009
HDL, mg/dL	0.029	1.023	1.002	1.043
Photodocumentation-related factors				
SPD	< 0.001	0.737	0.637	0.852
Appendix orifice	< 0.001	6.645	3.772	11.707
Ileocecal valve	< 0.001	3.004	1.809	4.990

Table VII. Endoscopist D.

Variable	*p*-value	Odds ratio	95% confidence Interval	
			Lower	Upper
Subject-related factors				
Age	< 0.001	1.063	1.041	1.086
Male sex	< 0.001	3.104	1.901	5.068
Photodocumentation-related factors				
SPD	0.022	0.851	0.741	0.977
Observation time (≥ 6 min)	< 0.001	4.943	2.021	12.088
Appendix orifice	< 0.001	11.976	5.006	28.652
Ileocecal valve	< 0.001	4.609	2.821	7.532

Multivariate analysis of the factors associated with CRN detection stratified by individual endoscopists.

95% CI, 1.240-3.938) were independently significant. In terms of photodocumentation-related factors, four factors, SPD (OR, 0.700; 95% CI, 0.631-0.776), AO (OR, 2.331; 95% CI, 1.556-3.492), ICV (OR, 3.629; 95% CI, 2.491-5.288), and endoscopists ($p < 0.001$) were significant. In terms of mCRN detection (**Supplementary Table III**), two factors, including the presence of fatty liver (OR, 2.210; 95% CI, 1.158-4.217) and FH of CRC (OR, 2.684; 95% CI, 1.045-6.896) were significant among subject-related factors. Among photodocumentation-related factors, SPD (OR 0.682; 95% CI, 0.531-0.876), observation time ≥ 6 min (OR, 2.393; 95% CI, 1.023-5.597), and AO (OR, 6.153; 95% CI, 2.443-15.493) were significant.

Discussion

This cross-sectional study assessed photodocumentation-related factors associated with the detection rate of CRNs. We found that five photodocumentation-related factors, including SPD, observation time of ≥ 6 min, clear photodocumentation of AO and ICV, and endoscopists, were independently associated with CRN detection. Among them, SPD and clear photodocumentation of AO and ICV were commonly significant factors in the stratified analysis performed to compensate for the influence of the relatively limited number (four) of endoscopists. In the additional multivariate analysis of the factors associated with the detection of adCRNs, four factors (SPD, AO, ICV, and endoscopists) were significant, whereas, in mCRNs, three factors (SPD, observation time ≥ 6 min, and AO documentation) were significant.

In our hypothesis, we expected the number of observation images to be a significant factor associated with CRN detection because photodocumentation might be closely correlated with meticulous observation behavior. Interestingly, not the number of observation images, but the SPD was an independent factor commonly associated with CRN, adCRN, and mCRN detection. SPD was a common significant factor for CRN detection in all endoscopists in the stratified analysis. The lower the SPD value, the significantly increased the CRN detection rate. Because the SPD value is the number of images taken during the unit observation time (1 min), the lower the SPD value, the fewer images are taken per unit observation time, which means that the proportion of time spent on photodocumentation decreases, and inversely, the proportion of time spent on real-time observation increases. The observation time during withdrawal consists of the time spent on real-time observation during endoscopic movement and the time spent on photodocumentation (freezing and capturing) during the pause of endoscopic movement. Therefore, as the time required for photodocumentation increases, the time spent on real-time observation decreases, which may interfere with CRN detection. Therefore, our results suggest that photodocumentation may play a negative role in CRN detection by reducing the time spent on real-time observation. In contrast, photodocumentation might provide an opportunity to observe the area of interest without artifacts caused by patient movement, and this frozen image observation might play a positive role in CRN detection[24]; however, this has not been proven. Furthermore, our results suggest that frozen image observations during photodocumentation may not play a positive role in CRN detection. Assuming that the observation time is constant, frozen image observations and real-time observations have a quantitative inverse relationship. Therefore, an excessive level of frozen image observation (or image documentation) may not be advantageous, but even disadvantageous, for CRN detection by inhibiting real-time observation. Further studies are needed to determine which of the two processes is more advantageous for CRN detection and the optimal range of SPD values.

In this study, clear documentation of AO and ICV was a significant factor associated with CRN detection. AO documentation was an independently significant factor in the detection of CRNs, advanced CRNs, and multiple CRNs. ICV documentation was an independently significant factor in the detection of both CRNs and advanced CRNs. Photodocumentation of cecal landmarks (AO, ICV) has been considered an indicator of complete colonoscopy, cecal intubation, and meticulous observation behavior and is included in guidelines[32,37] as a quality indicator of colonoscopy. A previous study[3] reported that the absence of cecal image documentation was related to the risk of PCCRC. Another study[26] found that clear documentation of the cecum was associated with improved polyp detection, suggesting that it could reflect the meticulous inspection behavior of colonoscopists. In addition, a recent study[27] showed that the adenoma detection rate (ADR) was higher in the group with adequate cecal documentation than in the group with inadequate cecal image documentation, although the difference was not statistically significant owing to the small sample size (colonoscopies = 286). In the present study, cecal image documentation was significantly associated with increased CRN detection. This result may be attributed to larger sample size (colonoscopies = 2,356) and a stricter definition of cecal image documentation (AO image: close-up shot, clear image without fecal material; ICV image: close-up shot with more than half of the opening lip). However, the reason why cecal image documentation is associated with increased CRN detection remains controversial. A few studies[38,39] have stated that cecal documentation does not necessarily guarantee complete colonoscopy because cecal intubation is not correlated with the withdrawal technique associated with ADR. Therefore, we hypothesized that the clear documentation of AO and ICV could increase total CRN detection by improving regional CRN detection around AO and ICV. In our further analysis, the proportion of clear AO documentation was approximately twice (86.1% *vs.* 48%, $p < 0.001$) higher in CRN in the cecum (CRN-C)-positive group than in the CRN-C-negative group, which means that clear documentation of AO is associated with increased detection of cecal CRNs (**Supplementary Table IV**). Similarly, clear documentation of ICV was significantly associated with increased detection of CRN in the ascending colon (**Supplementary Table V**). These results suggest that clear documentation of cecal landmarks may reflect meticulous inspection behavior, which can improve the detection rate of regional CRNs around the cecum and ascending colon where flat lesions were more common[40].

Because the total number of observation images can reflect the colonoscopist's meticulous inspection behavior, it was expected to be a significant factor in CRN detection. However, the total number of observation images in this study did not correlate with CRN detection. Contrary to our results, a previous study[26] reported that colonoscopists who were more meticulous in cecal image documentation had a higher polyp detection rate and took significantly more observation images during colonoscopy than non-meticulous endoscopists. This result indicates that a meticulous endoscopist could make extra effort to obtain clearer and more images, which leads to an increase in CRN detection. In addition, another study[28] found that endoscopists taking more images in gastroscopy showed a higher detection rate of clinically significant gastric lesions (CSGLs). Moreover, endoscopists taking more photo images tended to have longer observation times and more biopsies than endoscopists taking fewer images. Thus, the authors suggested that enthusiasm and interest of endoscopists are closely related to taking more images, more observation time, and a higher biopsy rate, which may lead to a higher detection rate of CSGLs. To our knowledge, our study is the first to investigate the relationship between the number of observation images and CRN detection. The number of observation images may reflect the operator's meticulous inspection behavior, which could affect CRN detection during colonoscopy. However, our data showed that the total number of observation images was not associated with CRN detection, but the number of observation images per unit time (speed of photodocumentation) was associated with a lower detection rate of CRNs. This suggests that taking an excessive number of observation images per unit time can interfere with real-time observations and negatively affect CRN detection. Thus, further studies are necessary to determine the adequate number of observation images or the optimal speed of photodocumentation during colonoscopy.

In this study, an observation time of over 6 min was associated with increased detection of CRNs and mCRNs but not with that of adCRNs. This finding is consistent with the results of previous studies[20,21]. This finding may be related to the larger size or distinct morphology of adCRNs, which are usually more detectable once visualized. A previous study[41] found that the miss rate for large-size CRNs was significantly lower than that for small-size CRNs (6% in CRNs ≥ 10 mm *vs.* 27% in CRNs ≤ 5 mm) in back-to-back colonoscopy performed on the same day, and another study[42] showed that an observation time of over 6 min was not a significant predictor for the detection of polyps (≥ 5 mm). This result suggests that a longer observation time may play a significant role in increasing the detection rate of small CRNs, which may play a small or no role in detecting adCRNs or large CRNs. Therefore, it is necessary to identify other procedure-related factors that can increase the detection rate of adCRNs, in addition to a longer observation time. In this study, we found SPD to be a novel predictive factor for the detection rate of adCRNs. In our stratified analysis, according to endoscopists, an observation time of over 6 min was significant in only one of four endoscopists as an independent factor for CRN detection, but the SPD value was significant in all endoscopists. Although a longer observation time has been validated to some extent as a predictive factor for CRN detection in previous studies in literature, it has significant limitations. For instance, an inefficient endoscopist may spend more than 6 min without complete visualization of the mucosa proximal to folds and flexures, appropriate colonic distension, and washing of debris. Thus, other factors that reflect meticulous inspection behavior or complete visualization should be investigated[43]. The results of the stratified analysis in this study showed that reducing the photodocumentation speed can be more effective in improving the detection of CRNs than a longer observation time, according to the individual endoscopist. Therefore, SPD can be considered a novel colonoscopy quality indicator that can supplement observation time.

Limitations

This study has some limitations. First, this is a retrospective cross-sectional study, and the antecedent relationship is unknown. Second, only a limited number of endoscopists from a single institution were included in the study. A single-institutional study is disadvantageous for the generalization of the results, but it has the advantage of ensuring good quality control. To mitigate the influence of the limited number of endoscopists, an additional stratified analysis was performed for each endoscopist. Third, data on time variables related to photodocumentation (observation time, procedure time, and SPD) were collected and analyzed through a retrospective analysis of time information recorded in Picture Archiving and Communication Systems (PACS) images. Therefore, there may be differences in the real-time data. Fourth, bowel preparation score, a key predictive factor for CRN detection, was not included as an analysis variable. However, only subjects satisfying adequate bowel preparation (BBPS score ≥ 7) were enrolled in this study, and it is known that an additional supra-optimal level of bowel preparation is not necessary for CRN detection once adequate bowel preparation is secured[44]. In addition, bowel preparation is a subject-related factor, which is not the main concern of this study because it is associated with compliance with bowel cleansing, socioeconomic status, constipation, diabetes, and chronic narcotics. Fifth, we did not suggest an optimal SPD range for CRN detection. Finally, we analyzed only SPD values for the total colon (cecum to rectum). Because there are many limitations in accurately differentiating individual colonic segments by retrospectively analyzing the PACS images, we did not analyze the SPD value for each colonic segment. Optimal SPD may have a different optimal range for individual colonic segments, similar to the observation time[45]. Therefore, further prospective studies with SPD measured by endoscopists could clarify the relationship between SPD and CRN detection according to the individual colonic segments.

Conclusions

A lower speed of photodocumentation and clear documentation of cecal landmarks (AO and ICV) during colonoscopy might improve the detection rate of CRNs. Photodocumentation of overspeed can negatively affect CRN detection; therefore, further research on appropriate photodocumentation is needed.

Conflict of Interest

The Authors declare that they have no conflict of interests.

Acknowledgements

None.

Funding

This research was supported by National Research Foundation of Korea (NRF) grant from the Korean government [The Ministry of Science and ICT; NRF-2020R1F1A1066323].

Availability of Data and Materials

The datasets generated and/or analyzed during the current study are not publicly available due this was data from a private screening center and contains sensitive personal information but are available from the corresponding author on reasonable request.

Informed Consent

All participants provided written informed consent for participation in the study.

Ethics Approval

This study was approved by the Institutional Review Board of CHA Bundang Medical Center (approval number: CHAMC 2022-04-067).

Authors' Contribution

Y.-S. Kim and J.H. Yoo conceived and planned the project. K.-J. Lee, J.H. Kim, and D.H. Kim performed data entry. K.-J. Lee and J.H. Yoo drafted the main manuscript. K.-J. Lee, D.K. Yon and J.H. Yoo conducted statistical analysis. D.K. Yon, J.H. Kim, D.H. Kim, and J.H. Yoo edited and revised the manuscript. Y.-S. Kim and J.H. Yoo organized and supervised this study. All authors read and approved the final manuscript.

ORCID ID

Kwanjoo Lee: 0000-0002-6178-2400.
Young Sang Kim: 0000-0002-7397-5410.
Jun Hwan Yoo: 0000-0002-5810-4019.

References

1) Rutter MD, Beintaris I, Valori R, Chiu HM, Corley DA, Cuatrecasas M, Dekker E, Forsberg A, Gore-Booth J, Haug U, Kaminski MF, Matsuda T, Meijer GA, Morris E, Plumb AA, Rabeneck L, Robertson DJ, Schoen RE, Singh H, Tinmouth J,

Young GP, Sanduleanu S. World Endoscopy Organization Consensus Statements on Post-Colonoscopy and Post-Imaging Colorectal Cancer. Gastroenterology 2018; 155: 909-925.e03.

2) Burr NE, Derbyshire E, Taylor J, Whalley S, Subramanian V, Finan PJ, Rutter MD, Valori R, Morris EJA. Variation in post-colonoscopy colorectal cancer across colonoscopy providers in English National Health Service: population based cohort study. BMJ 2019; 367: l6090.

3) Anderson R, Burr NE, Valori R. Causes of Post-Colonoscopy Colorectal Cancers Based on World Endoscopy Organization System of Analysis. Gastroenterology 2020; 158: 1287-1299.e82.

4) Zhao S, Wang S, Pan P, Xia T, Chang X, Yang X, Guo L, Meng Q, Yang F, Qian W, Xu Z, Wang Y, Wang Z, Gu L, Wang R, Jia F, Yao J, Li Z, Bai Y. Magnitude, Risk Factors, and Factors Associated With Adenoma Miss Rate of Tandem Colonoscopy: A Systematic Review and Meta-analysis. Gastroenterology 2019; 156: 1661-1674.e11.

5) Lee JY, Lee JH. Post-colonoscopy Colorectal Cancer: Causes and Prevention of Interval Colorectal Cancer. Korean J Gastroenterol 2020; 75: 314-321.

6) Rabeneck L, Paszat LF. Circumstances in which colonoscopy misses cancer. Frontline Gastroenterol 2010; 1: 52-58.

7) Baxter NN, Sutradhar R, Forbes SS, Paszat LF, Saskin R, Rabeneck L. Analysis of administrative data finds endoscopist quality measures associated with postcolonoscopy colorectal cancer. Gastroenterology 2011; 140: 65-72.

8) Kaminski MF, Regula J, Kraszewska E, Polkowski M, Wojciechowska U, Didkowska J, Zwierko M, Rupinski M, Nowacki MP, Butruk E. Quality indicators for colonoscopy and the risk of interval cancer. N Engl J Med 2010; 362: 1795-1803.

9) Ahn SB, Han DS, Bae JH, Byun TJ, Kim JP, Eun CS. The Miss Rate for Colorectal Adenoma Determined by Quality-Adjusted, Back-to-Back Colonoscopies. Gut Liver 2012; 6: 64-70.

10) Strum WB. Colorectal Adenomas. N Engl J Med 2016; 374: 1065-1075.

11) Kim NH, Park JH, Park DI, Sohn CI, Choi K, Jung YS. Metabolic syndrome is a risk factor for adenoma occurrence at surveillance colonoscopy: A single-center experience in Korea. Medicine (Baltimore) 2016; 95: e4454.

12) Fu Z, Shrubsole MJ, Smalley WE, Wu H, Chen Z, Shyr Y, Ness RM, Zheng W. Lifestyle factors and their combined impact on the risk of colorectal polyps. Am J Epidemiol 2012; 176: 766-776.

13) Lee SE, Jo HB, Kwack WG, Jeong YJ, Yoon YJ, Kang HW. Characteristics of and risk factors for colorectal neoplasms in young adults in a screening population. World J Gastroenterol 2016; 22: 2981-2992.

14) Aranda-Hernandez J, Hwang J, Kandel G. Seeing better--Evidence based recommendations on optimizing colonoscopy adenoma detection rate. World J Gastroenterol 2016; 22: 1767-1778.

15) Madhoun MF, Tierney WM. The impact of video recording colonoscopy on adenoma detection rates. Gastrointest Endosc 2012; 75: 127-133.

16) von Renteln D, Robertson DJ, Bensen S, Pohl H. Prolonged cecal insertion time is associated with decreased adenoma detection. Gastrointest Endosc 2017; 85: 574-580.

17) Vavricka SR, Sulz MC, Degen L, Rechner R, Manz M, Biedermann L, Beglinger C, Peter S, Safroneeva E, Rogler G, Schoepfer AM. Monitoring colonoscopy withdrawal time significantly improves the adenoma detection rate and the performance of endoscopists. Endoscopy 2016; 48: 256-262.

18) Achord JL, Muthusamy VR. The history of gastrointestinal endoscopy. Clinical gastrointestinal endoscopy: Elsevier 2019; 2-11.e11.

19) Sabbagh LC, Reveiz L, Aponte D, de Aguiar SJBg. Narrow-band imaging does not improve detection of colorectal polyps when compared to conventional colonoscopy: a randomized controlled trial and meta-analysis of published studies. BMC Gastroenterol 2011; 11: 1-13.

20) Lee TJ, Blanks RG, Rees CJ, Wright KC, Nickerson C, Moss SM, Chilton A, Goddard AF, Patnick J, McNally RJ, Rutter MD. Longer mean colonoscopy withdrawal time is associated with increased adenoma detection: evidence from the Bowel Cancer Screening Programme in England. Endoscopy 2013; 45: 20-26.

21) Overholt BF, Brooks-Belli L, Grace M, Rankin K, Harrell R, Turyk M, Rosenberg FB, Barish RW, Gilinsky NH. Withdrawal times and associated factors in colonoscopy: a quality assurance multicenter assessment. J Clin Gastroenterol 2010; 44: e80-e86.

22) Yun GY, Eun HS, Kim JS, Joo JS, Kang SH, Moon HS, Lee ES, Kim SH, Sung JK, Lee BS, Jeong HY. Colonoscopic withdrawal time and adenoma detection in the right colon. Medicine (Baltimore) 2018; 97: e12113.

23) Barclay RL, Vicari JJ, Doughty AS, Johanson JF, Greenlaw RL. Colonoscopic withdrawal times and adenoma detection during screening colonoscopy. N Engl J Med 2006; 355: 2533-2541.

24) Beg S, Ragunath K, Wyman A, Banks M, Trudgill N, Pritchard DM, Riley S, Anderson J, Griffiths H, Bhandari P, Kaye P, Veitch A. Quality standards in upper gastrointestinal endoscopy: a position statement of the British Society of Gastroenterology (BSG) and Association of Upper Gastrointestinal Surgeons of Great Britain and Ireland (AUGIS). Gut 2017; 66: 1886-1899.

25) Rex DK, Hewett DG, Raghavendra M, Chalasani N. The Impact of Videorecording on the Quality of Colonoscopy Performance: A Pilot Study. Am J Gastroenterol 2010; 105: 2312-2317.

26) Thoufeeq MH, Rembacken BJ. Meticulous cecal image documentation at colonoscopy is associated with improved polyp detection. Endosc Int Open 2015; 3: E629-E633.

27) Moran B, Sehgal R, O'Morain N, Slattery E, Collins C. Impact of photodocumentation of caecal

intubation on colonoscopy outcomes. Ir J Med Sci 2021; 190: 1397-1402.

28) Lee JI, Kim JS, Kim BW, Huh CW. Taking More Gastroscopy Images Increases the Detection Rate of Clinically Significant Gastric Lesions: Validation of a Systematic Screening Protocol for the Stomach. Korean J Helicobacter Up Gastrointest Res 2020; 20: 225-232.

29) Park JM, Lim CH, Cho YK, Lee BI, Cho YS, Song HJ, Choi MG. The effect of photo-documentation of the ampulla on neoplasm detection rate during esophagogastroduodenoscopy. Endoscopy 2019; 51: 115-124.

30) Emura F, Sharma P, Arantes V, Cerisoli C, Parra-Blanco A, Sumiyama K, Araya R, Sobrino S, Chiu P, Matsuda K, Gonzalez R, Fujishiro M, Tajiri H. Principles and practice to facilitate complete photodocumentation of the upper gastrointestinal tract: World Endoscopy Organization position statement. Dig Endosc 2020; 32: 168-179.

31) Kumar S, Thosani N, Ladabaum U, Friedland S, Chen AM, Kochar R, Banerjee S. Adenoma miss rates associated with a 3-minute versus 6-minute colonoscopy withdrawal time: a prospective, randomized trial. Gastrointest Endosc 2017; 85: 1273-1280.

32) Rees CJ, Gibson ST, Rutter MD, Baragwanath P, Pullan R, Feeney M, Haslam N. UK key performance indicators and quality assurance standards for colonoscopy. Gut 2016; 65: 1923-1929.

33) Kehe K, Girgensohn R, Swoboda W, Bieler D, Franke A, Helm M, Kulla M, Luepke K, Morwinsky T, Blatzinger M, Rossmann K. Analysis of Digital Documentation Speed and Sequence Using Digital Paper and Pen Technology During the Refugee Crisis in Europe: Content Analysis. JMIR Mhealth Uhealth 2019; 7: e13516.

34) Expert Panel on Detection E, Treatment of High Blood Cholesterol in A. Executive Summary of The Third Report of The National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, And Treatment of High Blood Cholesterol In Adults (Adult Treatment Panel III). JAMA 2001; 285: 2486-2497.

35) Lee SW. Methods for testing statistical differences between groups in medical research: statistical standard and guideline of Life Cycle Committee. Life Cycle 2022; 2: e1.

36) Lee SW. Regression analysis for continuous independent variables in medical research: statistical standard and guideline of Life Cycle Committee. Life Cycle 2022; 2: e3.

37) Ahmad A, Saunders BP. Photodocumentation in colonoscopy: the need to do better? Frontline Gastroenterol 2021; 13: 337-341.

38) Thuraisingam AI, Brown JL, Anderson JT. What are the sensitivity and specificity of endoscopic photographs in determining completion of colonoscopy? Results from an online questionnaire. Eur J Gastroenterol Hepatol 2008; 20: 567-571.

39) Thomas-Gibson S. The caecum or not the caecum? Eur J Gastroenterol Hepatol 2008; 20: 500-502.

40) Rex DK. Polyp detection at colonoscopy: Endoscopist and technical factors. Best Pract Res Clin Gastroenterol 2017; 31: 425-433.

41) Rex DK, Cutler CS, Lemmel GT, Rahmani EY, Clark DW, Helper DJ, Lehman GA, Mark DG. Colonoscopic miss rates of adenomas determined by back-to-back colonoscopies. Gastroenterology 1997; 112: 24-28.

42) Moritz V, Bretthauer M, Ruud HK, Glomsaker T, de Lange T, Sandvei P, Huppertz-Hauss G, Kjellevold O, Hoff G. Withdrawal time as a quality indicator for colonoscopy - a nationwide analysis. Endoscopy 2012; 44: 476-481.

43) Atia MA, Ramirez FC, Gurudu SR. Quality monitoring in colonoscopy: Time to act. World J Gastrointest Endosc 2015; 7: 328-335.

44) Choi JM, Seo JY, Lee J, Han YM, Jin EH, Bae JH, Lim JH. Longer withdrawal time is more important than excellent bowel preparation in colonoscopy of adequate bowel preparation. Dig Dis Sci 2021; 66: 1168-1174.

45) Jung Y, Joo YE, Kim HG, Jeon SR, Cha JM, Yang HJ, Kim JW, Lee J, Kim KO, Song HK, Hwangbo Y, Shin JE. Relationship between the endoscopic withdrawal time and adenoma/polyp detection rate in individual colonic segments: a KASID multicenter study. Gastrointest Endosc 2019; 89: 523-530.