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Factors predicting conversion from colon capsule endoscopy to conventional optical endoscopy—findings from the CESCAIL study

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Abstract

Background Colon capsule endoscopy (CCE) has become an alternative to traditional colonoscopy for low-risk patients. However, CCE's low completion rate and inability to take biopsies or remove polyps often result in a CCE-to-conventional colonoscopy conversion (CCC).

Objective(s) The aim is to identify the factors that predict issues with bowel cleansing, capsule excretion rates, pathology detection, and the need for CCC.

Methods This prospective study analysed data from patients who underwent CCE as part of the CESCAIL study from Nov 2021 till June 2024. Predictive factors were examined for their association with CCC, including patient demographics, comorbidities, medications, and laboratory results from symptomatic and surveillance groups. Statistical methods such as LASSO, linear, and logistic regression were applied.

Results Six hundred and three participants were analysed. Elevated f-Hb levels (OR = 1.48, 95% CI:1.18–1.86, p = 0.0002) and smoking (OR = 1.44, 95% CI: 1.01–2.11, p = 0.047) were significantly associated with CCC. The area under the curve (AUC) of elevated f-Hb for predicting CCC was 0.62 after adjusting for confounders. Diabetes was linked to poor bowel preparation (OR = 0.40, 95%CI:0.18–0.87, p = 0.022). Alcohol (p = 0.004), smoking (p = 0.003), psychological conditions (p = 0.001), and haemoglobin levels (p = 0.046) were significantly associated with the number of polyps, whilst antidepressants (p = 0.003) and beta-blockers (p = 0.001) were linked to the size of polyps.

Conclusion Non-smokers with lower f-Hb levels are less likely to need conventional colonoscopy (CCC). Patient selection criteria are key to minimising the colonoscopy conversion rate. Our findings would benefit from validation in different populations to develop a robust CCE Conversion Scoring System (CECS) and ultimately improve the cost-effectiveness.

Keywords Colon capsule endoscopy, Panenteric capsule endoscopy, Colonoscopy, Capsule endoscopy, Histopathology, Completion rate, Bowel preparation

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Introduction

During the COVID- 19 pandemic, colon capsule endoscopy (CCE) was implemented in the UK through the SCOTCAP study [1] and NHS England Pilot [2, 3]. The second-generation colon capsule endoscopy (CCE- 2) is an advanced, non-invasive imaging modality for colon visualisation, offering an alternative to conventional colonoscopy and CT colonography. It features dual cameras with a 344° field of view and an adaptive frame rate (AFR) that adjusts between 4 and 35 frames per second, optimising imaging quality and battery efficiency. These technological advancements contribute to high diagnostic accuracy, with a sensitivity of 0.87 and a specificity of 0.95 for detecting polyps of any size [4]. Additionally, for inflammatory bowel disease (IBD) detection, CCE- 2 demonstrates a sensitivity of 0.90, a specificity of 0.76, and an AUC of 0.92 [5]. Challenges with CCE include suboptimal capsule excretion rates, inadequate bowel cleansing, and the need for additional biopsies and interventions, leading to further endoscopic procedures [5]. This has financial implications as demonstrated in the SCOTCAP study by Innovative Medical Technology Overview under the Healthcare Improvement Scotland [6].

Additionally, patient dissatisfaction has been a concern, with 92% of participants in the Scottish study by Bond et al. reporting a negative experience with bowel cleansing agents [7]. As a result, the need for additional endoscopic procedures requiring repeat bowel preparation remains a key factor contributing to patient dissatisfaction with CCE. Patient selection is crucial to establish CCE as a standard and cost-effective diagnostic tool and avoid these pitfalls. Understanding the factors influencing Conversion rates from CCE to Conventional endoscopy (CCC) will aid the process of pre-procedural patient selection, ultimately enhancing patient satisfaction by ensuring the proper test is administered to the right patient.

The SCOTCAP study found that age and faecal haemoglobin (f-Hb) were associated with a higher CCC. In symptomatic patients from an NHS Scotland health board, a FIT range between 10–399 µg/g was linked to CCC despite the known suboptimal sensitivity of the FIT test for detecting advanced polyps [8]. However, no dedicated studies have examined the association between f-Hb ≤100 µg/g and CCC [2, 3]. Additionally, the predictors that influence the intra-procedural factors, such as bowel cleansing quality, capsule excretion rates, and pathology detection in CCE —each of which ultimately contributes to CCC— remain unexplored. These predictors of the intra-procedural factors can be seen as indirect variables that sequentially impact CCC. Therefore, this sub-analysis of the CESCAIL study aims to identify direct and indirect factors that influence CCC within the symptomatic cohort of f-Hb ≤100 µg/g and post-polypectomy surveillance in the UK.

Methods

Study design and ethics

The sub-analysis reported here uses data from the CESCAIL study: a multicentre diagnostic accuracy study (from November 2021 to Jan 2025) comparing polyp detection using the machine learning algorithm AiSPEED™ against the standard human reader review. All eligible patients underwent CCE, and the accuracy of polyp detection was assessed and compared between the AI-assisted and standard human reader pathways. The CESCAIL study received ethical approval from the Southwest-Central Bristol Research Ethic Committee (IRAS ID: 305,067) and registered at ClinicalTrials.gov (NCT06008847) on 02/09/2022. A full trial protocol is available elsewhere [9]. This sub-analysis is one of the secondary outcomes of the CESCAIL study focused on identifying factors influencing CCE's performance, including CCC.

Participants in the CESCAIL study

Patients were included in this study if they met the NHS England CCE criteria, specifically those referred through the urgent cancer (two-week-wait) pathway within the symptomatic lower GI secondary care service with a f-Hb ≤100 µg/g. The detailed inclusion and exclusion criteria for this study are outlined in Table 1 [10, 11]. 720 participants were recruited, 508 prospectively (71%) and 212 retrospectively (29%), depending on whether they had already undergone their CCE procedure within the study period. Statistical tests, including the Mann–Whitney U test and Chi-square test, were used to evaluate population differences in the main study. The retrospective cohort was slightly older by less than two years ($p = 0.007$) and had a marginally higher FIT value by 6 µg/g ($p = 0.0004$) compared to the prospective cohort. While these differences were statistically significant, their small magnitude suggests they are unlikely to be clinically meaningful. Their CCE videos were analysed through AI-assisted and standard human reader pathways. Each video was reviewed and reported by at least one CCE reader trained for each path. The primary outcome of the CESCAIL study was to assess the diagnostic accuracy of the AI-assisted pathway.

Outcome measures

In this planned sub-analysis, the endpoint was CCC referral or discharge from the CRC pathway as part of participants' standard care following CCE in the standard clinical path. The outcome is to identify pre-procedural

Table 1 Inclusion and exclusion criteria for NHS England Criteria used in the CESCAIL study [3, 10]

Patient type	Inclusion criteria	Exclusion criteria
All	- Over 18 years of age - Able to provide valid consent	- Difficulty swallowing - Indwelling electromedical device - Insulin dependent diabetes - Past medical history of stricture - Pregnancy - Unfit for bowel preparation
Symptomatic	- Referred from the primary care under the lower gastrointestinal two week wait pathway - assessed by a secondary care consultant	- Predominant referral symptom of diarrhoea - F-Hb ≥ 100 μg/g - Microcytic anaemia as the sole investigation reason
Surveillance	- Due post polypectomy surveillance colonoscopy within a month before, during and after the recruitment period - More than 5 polyps in last colonoscopy - Presence of one or more advance polyp (≥ 10 mm in size), serrated polyp with dysplasia, adenoma with high-grade dysplasia [12]	- Family history of colorectal cancer - History of colonic polyposis - Hereditary non-polyposis syndrome

factors (predictors) that are associated with the following (see Fig. 2):

1. Colonic (including rectal) pathology
2. Bowel cleansing/bowel preparation
3. Rate of capsule battery depletion before excretion
4. The ultimate CCC rates

This study defines adequate bowel preparation as when all examined, colonic mucosa receives a Leighton-Rex Score of"Fair"or higher or a CC-Clear score of 6 or above. Conventional endoscopic procedures encompass flexible sigmoidoscopy and colonoscopy. A complete procedure is defined by complete capsule excretion before battery depletion and adequate colorectal cleansing. A large or significant polyp is defined as a polyp measuring ≥10 mm [11]. The polyp reporting standard and classification in this study adhered to established consensus as documented in the literature [13].

Statistical analysis

The target sample size was 672 patients, with the sample size calculations published previously in the study protocol [9]. Patient demographic and clinical characteristics were summarised using descriptive statistics, with continuous variables reported as mean and standard deviation (SD). The Least Absolute Shrinkage and Selection Operator (LASSO) regression was implemented for variable selection due to its ability to shrink the coefficients of non-essential variables to zero. This retained the most relevant factors for predicting significant outcomes [14]. The selected variables were then used in multivariate logistic regression analyses using R software [15]. All the available predictors were analysed using univariate and multivariate logistic regression. Results were expressed as odds ratio (OR) with 95% confidence intervals (CI). Further linear regression was conducted to explore and quantify any associations between predicting factors, polyp size, and number.

The primary analyses were made on a complete case basis: i.e. participants with missing data for factors such as body mass index (BMI), smoking history, alcohol consumption, and creatinine levels were excluded from the multivariate logistic regression analysis. The number of missing data for each variable are shown in Table 2. A sensitivity analysis was performed using logistic regression models, incorporating both Complete Case Analysis (CCA) [16] and Multiple Imputation by Chained Equations (MICE) [17] with Predictive Mean Matching (PMM). To address missing data, five imputed datasets were generated, and the results were pooled using Rubin's rules to obtain unbiased parameter estimates [18]. The R package "MICE" was employed for the imputation process [19].

For analysis purposes, the f-Hb values of < 4 μg/g or < 7 μg/g were replaced with exact values of 4 μg/g and 7 μg/g, respectively. The accuracy of using FIT as a predictor of CCC was demonstrated using the Receiver Operating Characteristic curve (ROC) by calculating the Area Under the ROC (AuROC) with or without controlling for other confounding factors. Due to the skewed distribution of f-Hb, likely a consequence of the FIT range of ≤100 μg/g (NHS England cutoff), natural logarithmic f-Hb level was used as the dependent variable. A significance level of 5% was used for all analyses, and all simulations were performed using the R program version of 3.6.0 [15]. The R code used for the analysis is available upon request.

Table 2 Baseline Participants demographics and characteristics

Number or participants	611
Age	**60.7 ± 13.8**
Sex	
Male	**276 (45.2)**
Female	**335 (54.8)**
Ethnicity	
White British	**561 (91.8)**
Asian	**17 (2.78)**
Afro-Caribbean	**14 (2.3)**
Other Ethnic Group	**8 (13.1)**
BMI	
< 18.5	**7 (1.1)**
18.5–24.9	**151 (24.7)**
25–29.9	**163 (26.7)**
30–39.9	**126 (20.6)**
> 40	**12 (2.0)**
Missing	**146 (23.9)**
Alcohol consumption	
Yes	**328 (53.6)**
No	**171 (28.0)**
Missing data	**112 (18.3)**
Smoking history	
Yes	**221 (36.2)**
No	**286 (46.8)**
Missing data	**104 (17.0)**
Haemoglobin	
> 140	**228 (37.3)**
70–140	**410 (67.1)**
Missing data	**5 (0.8)**
Platelet count	
450	**20 (3.2)**
150–450	**493 (80.7)**
< 150	**21 (34.3)**
Missing data	**5 (0.8)**
Creatinine	
> 130	**4**
< 130	**512 (83.8)**
Missing data	**23 (3.8)**
Antidepressant	
Yes	**35 (5.7)**
No	**576 (94.3)**
Opioid/Opiate	
Yes	**44 (7.2)**
No	**567 (92.8)**
Antihyperlipidaemics	
Yes	**33 (5.4)**
No	**578 (94.6)**
f-Hb (μg/g)	
f-Hb ≤ 7	**134 (21.9)**
7 < f-Hb ≤ 100	**477 (78)**
Bowel preparation	
Adequate	**436 (71.4)**
Poor	**140 (22.9)**
Missing data	**35 (5.7)**
Completion rate	**486 (79.5)**
Proportion requiring further test	**356 (58.3)**
Urgent further tests (< 2 weeks)	**272 (44.5)**
Routine further tests (> 6 weeks)	**84 (13.7)**
Colonoscopy	**206 (33.7)**
Flexible sigmoidoscopy	**132 (21.6)**
OGD	**5 (0.01)**
CT scan	**13 (2.1)**

BMI Body mass index, *CT scan* Computed Tomography scan, *OGD* Oesophaga-Gastro-Duodenoscopy, *FIT* Faecal Immunochemical Test

Age are presented as mean ± SD

Results

Of the 720 participants from the CESCAIL study, 603 had available f-Hb ≤ 100 μg/g (Fig. 1), and the indications were a combination of symptomatic and post-polypectomy surveillance. Table 2 summarises participants'demographics, with a mean age of 60.7 years and 91.8% of the participants being Caucasians. A complete procedure, defined by complete capsule transit (78.9%) and adequate colorectal cleansing (77.2%), was achieved in 71.4% of cases. Only 12 patients (2%) were suspected of inflammatory bowel disease (IBD), and the pathological findings that prompted CCC were predominantly related to polypoid disease.

The CCC cases were 326 (54.1%), within which colonoscopy accounted for 198 (32.9%) of follow-up investigations, followed by flexible sigmoidoscopy at 128 (21.2%). Figure 2 and Fig. 3 summarise the breakdown of CCC based on intraprocedural factors. Among the three intraprocedural factors, pathology detected during CCE alone accounts for 145 cases (24% of all CCE procedures), making it the primary contributor to CCC. Table 3 summarises the statistically significant factors predicting CCC and all intra-procedural outcomes, including capsule battery depletion before excretion, bowel cleansing quality, and pathology detection (polyp size and number). These findings were identified through LASSO selection, and all of them underwent univariate and multivariate analyses. The complete datasets are available in Appendix Table A5 - 8.

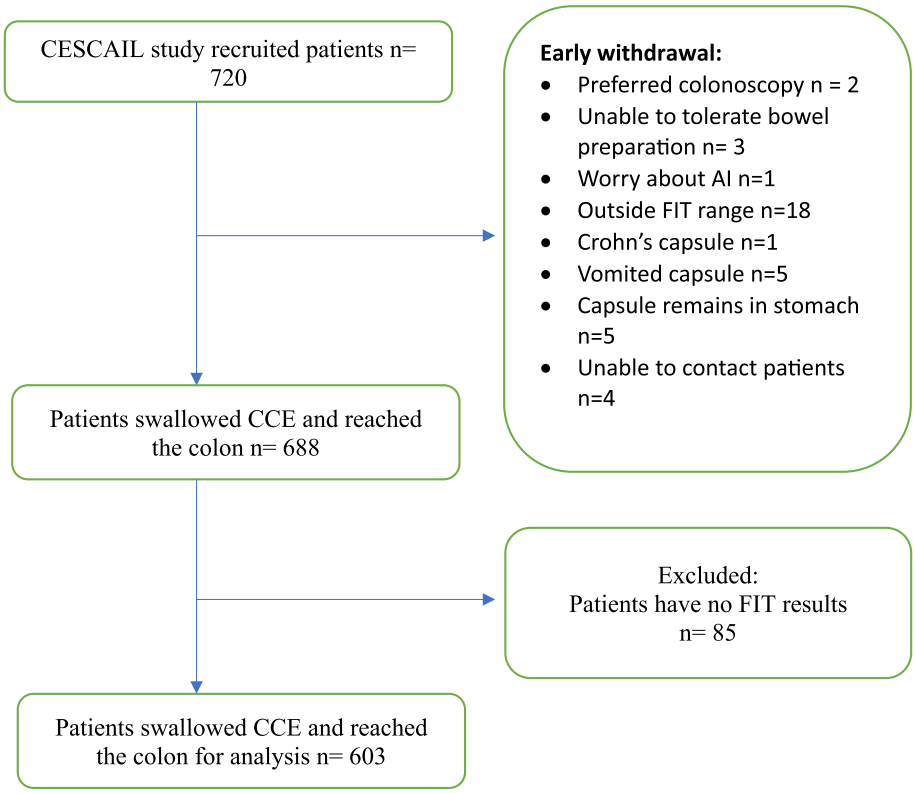

Fig. 1 Study flow chart. CCE, Colon capsule endoscopy; CESCAIL study, capsule endoscopy delivery at scale through enhanced AI analysis study

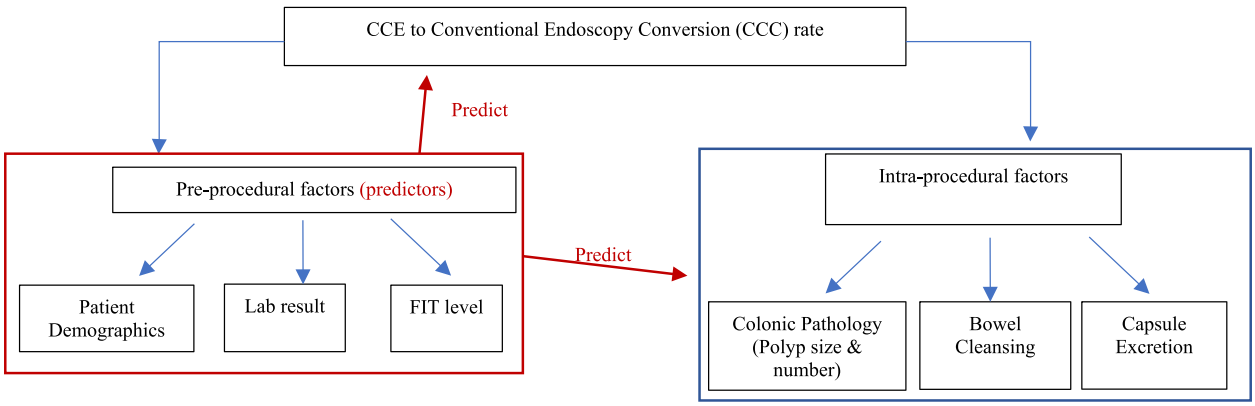

Fig. 2 The Breakdown of different factors that influence the CCC rate

Pre-procedural factors predicting conversion

Following the LASSO model selection (see Appendix Table A4), four selected pre-procedural factors underwent multivariate logistic regression analyses. Log f-Hb level (OR = 1.48, 95% CI: 1.18–1.86, $p < 0.001$) and current smoker (OR = 1.44, 95% CI: 1.01–2.11, $p = 0.047$) were found to be significantly associated with CCC in both univariate and multivariate analyses, as shown in Table 3.

Preprocedural factors predicting complete capsule excretion, bowel cleansing and colonic polyps

Despite no variables being selected by the LASSO analysis for predicting intra-procedural factors, both univariable and multivariable analyses showed male sex (OR = 2.22, 95%CI: 1.10–4.58, $p = 0.024$) remained statistically significant for better complete capsule excretion compared to females. Even though age (OR = 0.99, 95%CI: 0.97–1.00, $p = 0.010$) and creatinine (OR = 1.01,

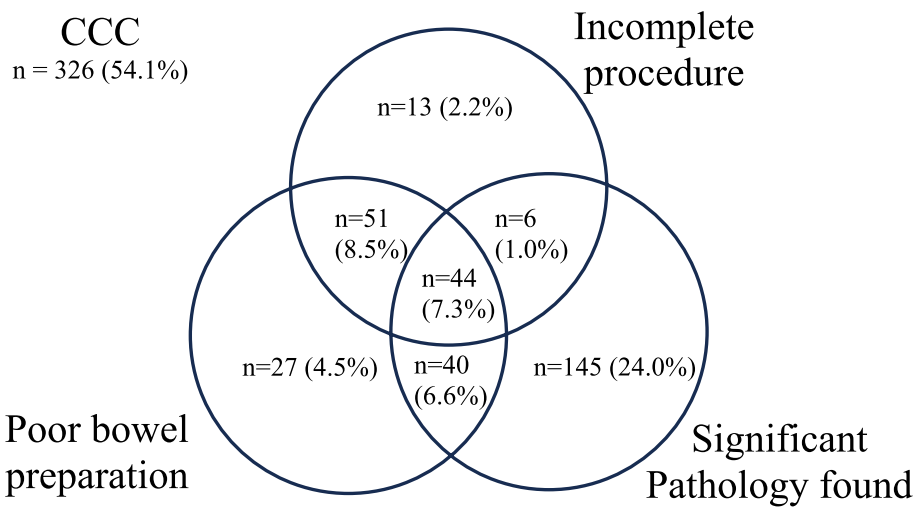

Fig. 3 The Breakdown of total CCC based on intraprocedural factors

Table 3 LASSO, Univariate and Multivariate analysis of factors predicting CCC and Intra-procedural Factors

Factors associated with CCE to further endoscopy procedure conversion							
Factors (n = 247)	LASSO coefficient	Univariate analysis			Multivariate analysis with LASSO variables		
		Odd ratio	95% CI	p-value	Odd ratio	95% CI	p-value
Log(f-Hb)	0.0081	1.47	1.20–1.81	< 0.001***	1.48	1.18–1.86	< 0.001***
Smoking	– 0.2925	1.5	1.05–2.17	0.034*	1.44	1.01–2.11	0.047*
Factors associated with Incomplete Capsule Excretion							
Factors (n = 385)	LASSO coefficient	Univariate analysis			Multivariate analysis		
		Odd ratio	95% CI	p-value	Odd ratio	95% CI	p-value
Age	-	0.99	0.97–1.00	0.010**	0.99	0.96–1.01	0.209
Sex—Male	-	2.13	1.36–3.38	0.001**	2.22	1.10–4.58	0.024*
Creatinine	-	1.01	1.00–1.03	0.035*	1.00	0.98–1.02	0.796
Factors associated with Bowel Cleansing							
Factors (n = 338)	LASSO coefficient	Univariate analysis			Multivariate analysis		
		Odd ratio	95% CI	p-value	Odd ratio	95% CI	p-value
Age	-	0.99	0.97–1.00	0.020*	0.99	0.97–1.01	0.272
Sex—Male	-	1.46	1.05–2.04	0.023*	1.72	0.93–3.22	0.084
Diabetes	-	0.54	0.31–0.93	0.028*	0.40	0.18–0.87	0.022*
Factors associated with Significant Pathology (Polyp > = 10 mm or > = 5 polyps)							
Factors (n = 221)		Linear regression Polyp Size			Linear regression Polyp Number		
		Regression coefficient	95% CI	p-value	Regression coefficient	95% CI	p-value
Alcohol		0.27	– 0.58 to 1.11	0.628	0.79	0.41 to 1.16	0.023*
Smoking		0.88	0.13 to 1.64	0.301	0.76	0.42 to 1.09	0.025*
Psychological conditions		0.57	– 0.37 to 1.51	0.632	1.05	0.63 to 1.47	0.013*
Antidepressant (Yes)		2.16	1.18 to 3.13	0.028*	– 0.47	– 0.90 to – 0.04	0.278
Beta Blocker		– 4.55	– 6.22 to – 2.88	0.008**	– 0.72	– 1.46 to 0.02	0.339
Haemoglobin		0.02	– 0.01 to 0.04	0.460	– 0.02	– 0.04 to – 0.01	0.046*

CI Confident Interval, *f-Hb* Faecal haemoglobin, *FIT* Faecal immunochemical test, *LASSO* Least absolute shrinkage and selection operator

95%CI: 1.00–1.03, $p = 0.035$) were statistically significant for capsule excretion in the univariate analysis, their odds ratios were clinically insignificant.

Diabetes (Type 2 only) consistently predicted poor bowel preparation (OR = 0.40, 95%CI: 0.18–0.87, $p = 0.022$) in both analyses. Although male sex was

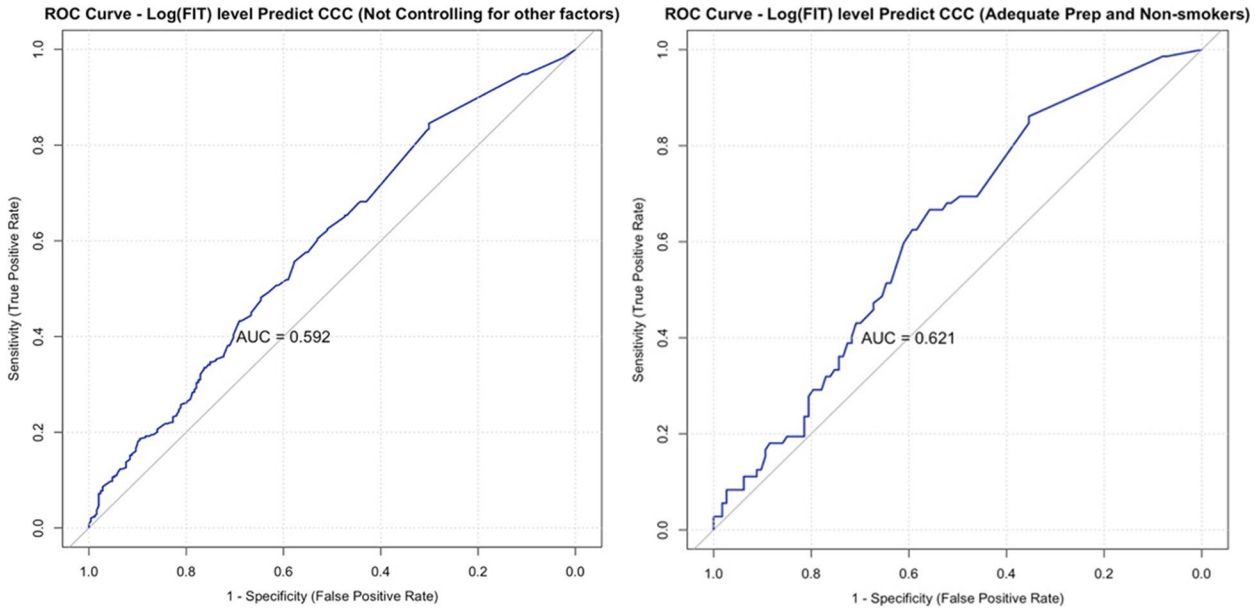

Fig. 4 Receiver Operating Characteristic (ROC) curves for Log(FIT) level in predicting conversion rates. The left graph shows the ROC curve without adjustment for confounding factors, while the right graph presents the ROC curve adjusted for adequate bowel cleansing and non-smoking status

significantly associated with improved bowel cleansing (OR = 1.46, $p = 0.023$) in the univariate analysis, the multivariable analysis ($p = 0.084$) did not achieve statistical significance. In the linear regression analysis of polyp number, alcohol ($p = 0.023$), smoking ($p = 0.025$), psychological conditions ($p = 0.013$), and haemoglobin ($p = 0.046$) were significantly associated with CCE polyp numbers. Conversely, antidepressant ($p = 0.028$) and beta-blocker use ($p = 0.008$) were significantly associated with CCE polyp size.

The sensitivity analysis using both CCA and MICE confirmed that the key significant predictors remained generally unchanged after imputation. This consistency suggests that missing data did not introduce significant bias in the primary analysis. While some minor variations in estimates were observed, the overall reliability of the findings are supported (see Appendix Table A8).

Discussion

In this study, using log(f-Hb) and smoking were directly associated with CCC. Although f-Hb has previously been identified as a predictor for CCC, the Receiver Operating Characteristic (ROC) curve demonstrated suboptimal predictive ability. Without adjusting for confounding factors, the accuracy of f-Hb test achieved an AuROC (Area Under the ROC) was 0.59 (95%CI 0.55–0.64). However, after controlling for two key factors —adequate bowel cleansing and non-smoking status— the accuracy improved to 0.62 (95%CI 0.54–0.70) (see Fig. 4). However, the preselection of the CESCAIL study (based on NHS England criteria) of f-Hb threshold ≤100 μg/g indicates that our cohort represents a low-risk population, which limits the predictive accuracy of the f-Hb test in this context (Fig. 5).

Smoking is linked to a higher risk of CCC, CRC, and advanced adenomas, with a relative risk of up to 1.26 [20]. This emphasises the likelihood of significant findings and the need for subsequent CCE. Given this level of risk, it may be more appropriate to directly refer smokers for a colonoscopy, providing timely access to both diagnostic and therapeutic interventions.

Intraprocedural factors occurring during the procedure were also closely examined. Regarding complete transit, males were found to have twice the pre-battery exhaustion excretion rate (OR = 2.2) compared to females. This may be due to the longer colonic length in women, especially in the transverse colon [21], which increases the risk of colonic loop formation. Additionally, the deeper and more rounded female pelvis can result in sharper angulations, potentially slowing the passage and increasing the capsule rocking motion within the colon, thus complicating the analysis of the video. Similar challenges have been reported in the literature during colonoscopy in females [21]. Remarkably, while capsule excretion rates appeared to be higher in males, they did not ultimately impact the overall CCC rate. One possible explanation is the higher likelihood of detecting advanced polyps in males compared to females [22], which may have offset

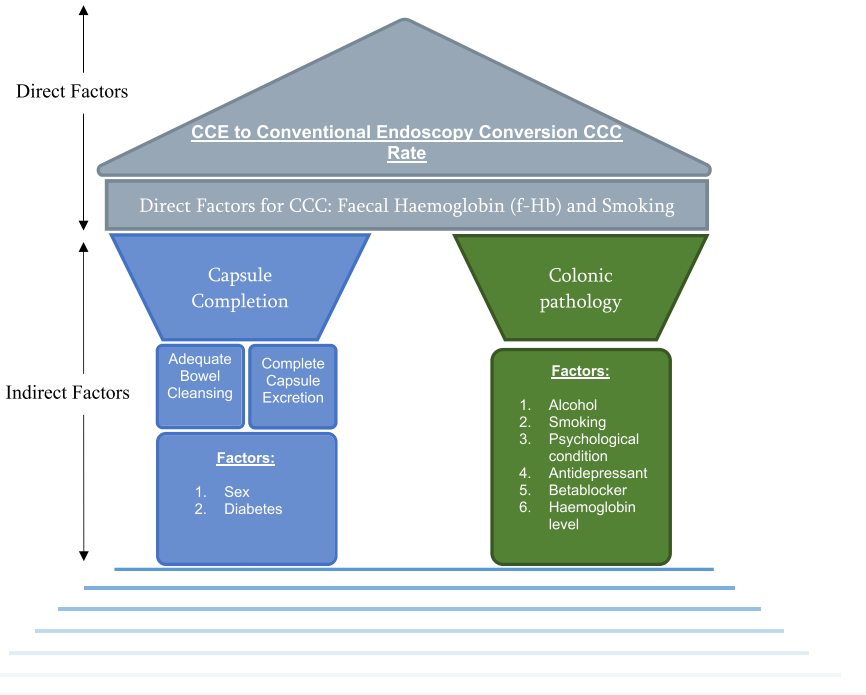

Fig. 5 Summary of all the factors associated with different pillars that support the overall CCC

the potential benefits of an improved completion rate. Given these differences, future research could explore sex-specific optimisation of booster regimens, such as using a higher dose of laxatives in females to enhance colonic motility and completion rates.

Diabetes was the only consistent factor significantly associated with inadequate bowel preparation (OR = 0.40, 95%CI: 0.18–0.87, $p = 0.022$). This finding is consistent with colonoscopy studies, where a meta-analysis reported an OR of 0.58, indicating that diabetes is a risk factor for poor bowel prep [23, 24]. While this association is well established, the underlying pathophysiology remains poorly understood. It is thought to be linked to decreased intestinal transit and delayed gastric emptying, likely caused by the impact of diabetes on both the autonomic and enteric nervous systems [25]. Conversely, although male sex was also associated with better bowel preparation in the univariate analysis, this relationship did not achieve statistical significance in the multivariate analysis ($p = 0.08$). As discussed earlier, the improved bowel cleansing observed in men may be explained by the same factors contributing to higher procedure completion rates in males.

Finally, linear regression analysis identified alcohol consumption, smoking, psychological conditions, and haemoglobin levels as factors associated with polyp number. Both alcohol consumption and smoking are well-established risk factors for advanced colorectal neoplasia. A recent large-scale study further confirmed this association, showing that alcohol use is linked to an increased prevalence of left-sided and rectal neoplasia [26]. The positive association between psychological conditions and polyp number is less clear. While correlation does not imply causation, one study found that patients previously diagnosed with polyps were significantly more anxious and depressed. This increased association may reflect the inclusion of a more anxious cohort under post-polypectomy surveillance rather than psychological conditions being a direct cause of polyp development [27]. While serum haemoglobin showed a borderline negative association with polyp number ($p = 0.046$), the very low coefficient of − 0.02 renders this finding clinically insignificant.

Among the factors associated with polyp size, a significant positive association was observed between larger polyp size and antidepressant use. The underlying cause remains unclear, but some studies suggest that depressive symptoms in women undergoing colonoscopy may be linked to an increased likelihood of CRC diagnosis. However, this does not imply an increased risk of cancer onset, as correlation does not equate to causation, as previously mentioned [28]. Controversially, one study showed that depressive symptoms have not been directly linked to colorectal adenomas. Further, it should be noted that the primary focus of the referenced study was on the number

of advanced adenomas rather than their sizes [28, 29]. Therefore, the reason for the observed association between polyp size and antidepressant use remains largely unknown.

Interestingly, beta-blockers were significantly associated with smaller polyp sizes in our study. Smaller polyps are generally believed to lower the likelihood of CCC. Macleod et al. also reported a reduced rate of further investigations in patients using beta-blockers, though the underlying reason remains unclear [8]. While evidence on the relationship between beta-blockers and colorectal cancer or advanced neoplasia remains inconclusive in the literature, there have been some suggestions that beta-blockers may limit tumour growth and replication [30, 31].

Other intra-procedural factors, such as capsule retention in the stomach or small bowel or vomiting of the capsule, occurred in 1.4% of cases (10/720) in our study. Fortunately, there were no instances of capsule technical failure in this study. However, Wang et al. reported a capsule technical failure rate of 0.94% (95% CI: 0.65–1.28%) [32], suggesting that while rare, such failures can occur leading to CCC. Patient tolerance during the prolonged CCE procedure may also influence conversion rates to colonoscopy. Notably, in our study, no patients discontinued the procedure midway or opted for a repeat colonoscopy due to discomfort or technical issues. This is likely due to the non-invasive nature of CCE and the significant commitment patients had already made by adhering to a low-residue diet and bowel preparation regimen. A meta-analysis comparing patient preference between CCE and colonoscopy found that 52% preferred CCE, while 45% preferred colonoscopy, with no significant difference [33]. This further supports the good tolerability of CCE despite its prolonged fasting requirements and stringent bowel preparation regimens.

In addition, there is an assumption that incomplete CCEs were predominantly converted to conventional endoscopy rather than repeat CCE or proceed to CT colonography. This is mainly because of the concern of poor bowel preparation. When bowel preparation is poor, subsequent conventional procedures with more rigorous preparation are generally preferred over repeating CCE, as conventional procedures allow for mucosal washing, reducing the risk of inadequate preparation occurring again. Our study observed insufficient bowel preparation in 22.9% of cases, often necessitating CCC unless the clinical questions had already been sufficiently addressed. This factor alone accounted for nearly 40% of CCC cases. Therefore, repeat CCE or CT colonography should also be considered, particularly considering patient preferences.

Limitations

The study protocol (based on the NHS England Pilot project's FIT threshold), combined with inexperience and lack of confidence in the new CCE technology, led to potential selection bias toward the lower-risk patients. The FIT threshold of ≤ 100 μg/g was an empirically derived cutoff based on extensive research in colorectal cancer screening using colonoscopy. However, this threshold may have limited FIT's impact on CCC, potentially underestimating its AUC in our study, given the broad range of FIT values (0 to >400 μg/g). This contrasts with the SCOTCAP study [34], where a higher rate of further investigation was observed, suggesting a broader FIT range may have yielded different predictors of CCC.

While the multi-centre nature of the data enhances the generalisability of the findings, one-third of the data were collected retrospectively, which introduces the risk of reduced data quality and completeness. This resulted in significant missing data for some variables, as shown in Table 2, and limited our ability to conduct a comprehensive multivariate analysis. Additionally, factors such as the subject's education level, the inclusion of patients from private healthcare settings, and previous history of poor bowel cleansing in previous colonic investigations were not accounted for despite their potential influence on bowel preparation compliance and overall cleansing quality. As these variables were not considered as primary factors affecting the study's primary focus on AI-assisted reading, they were consequently not included.

Moreover, the predefined study population excluded high-risk cohorts, such as individuals with hereditary polyposis or non-polyposis syndromes and those with a family history of colorectal cancer. Additionally, there was a tendency to enrol younger and fitter patients in clinical practice, which may have introduced selection bias affecting the reported conversion rate. Further studies are warranted to explore the extent and impact of these factors on conversion rates. Given the limited number of clinically and statistically significant factors identified in this study, we could not develop a risk stratification scoring system to predict the likelihood of CCC.

A recent study on CCE utilisation in Europe indicates that most European countries currently use CCE primarily for patients who decline or cannot tolerate colonoscopy rather than for symptomatic or surveillance cohorts [35]. In contrast, the NHS England criteria incorporate CCE more broadly, including in symptomatic patients and colorectal cancer (CRC) surveillance pathways. As a result, the findings of this study may not yet be directly applicable to other countries where CCE is used in a more limited capacity. However, as CCE adoption expands and clinical guidelines evolve internationally, the applicability of these results is expected to improve.

Conclusion

This study found that non-smokers with lower f-Hb levels are less likely to require conversion to conventional endoscopy (CCC). Additionally, male, non-diabetic, non-smokers and non-alcohol consumers were indirectly associated with a reduced likelihood of CCC by lowering the risk of incomplete capsule excretion, poor bowel preparation, and fewer significant polyp findings. These findings align with the previous results of the SCOTCAP study. However, further research on larger datasets with additional predictors, including the emerging serum markers for colorectal cancer, is needed to develop a robust CCE Conversion Scoring System. These insights could help optimise patient selection and improve the cost-effectiveness of CCE services in clinical practice.

Abbreviations

AI	Artificial Intelligence
CCE	Colon Capsule Endoscopy
CD	Crohn's disease
COVID- 19	Coronavirus Disease 2019
CR	Completion rate
CRC	Colorectal Cancer
CT	Computed Tomography
CTC	CT Colonography
ESGE	European Society of Gastrointestinal Endoscopy
GI	Gastrointestinal
HP	Histopathology
IBD	Inflammatory bowel disease
IC	Ileocolonoscopy
MRI	Magnetic Resonance Imaging
MRE	Magnetic Resonance Enterography
NHS	National Health Service
NPV	Negative Predicted Value
OE	Optical Endoscopy *(includes colonoscopy and flexible sigmoidoscopy)*
PCE	Panenteric Capsule Endoscopy
PEG	Polyethylene glycol

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12876-025-03828-9.

Supplementary Material 1

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Authors'contributions

Conceptualization, I.I.L.; validation, I.P., A.B., F.P.P., T.L., C.S., M.M., S.A., A.W., A.C., R.B., K.M., J.J., A.D., J.B., N.P., A.K. and R.P.A.; literature review, I.I.L.; resources, H.W., E.W., I.P., A.B., F.P.P., T.L., C.S., M.M., S.A., A.W., A.C., R.B., K.M., J.J., A.D., J.B., N.P., A.K. and R.P.A.; writing—original draft preparation, I.I.L.; writing—review and editing, I.I.L., S.A., N.P., A.K. and R.P.A.; visualisation, I.I.L., A.K. and R.P.A., All authors have read and agreed to the published version of the manuscript.

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Data availability

The datasets used and analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

The CESCAIL study was approved by the South West – Central Bristol Research Ethics Committee (21/SW/0169) and registered at ClinicalTrials.gov (NCT06008847) on 02/09/2022. All participants were informed about the study and provided their consent to participate, as detailed in our published protocol [9]. This study was performed in accordance with relevant guidelines and regulations. All procedures were conducted in accordance with the ethical principles of the Declaration of Helsinki, as revised in 2013 and updated by the World Medical Association in 2024 [36].

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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