A new composite measure of colonoscopy: the Performance Indicator of Colonic Intubation (PICI)

Valori, RM; Damery, Sarah; Gavin, Daniel; Anderson, John; Donnelly, Mark; Williams, Graham; Swarbrick, Edwin

DOI:
10.1055/s-0043-115897

A new composite measure of colonoscopy: the Performance Indicator of Colonic Intubation (PICI)

Dr Roland M. Valori, MB BS MD (Corresponding Author)
Consultant Gastroenterologist
Gloucestershire Hospitals NHS Foundation Trust
Gloucester
GL1 3NN
United Kingdom
roland.valori@nhs.net

Dr Sarah Damery PhD
Department of Primary Care Clinical Sciences
School of Health and Population Sciences
University of Birmingham
West Midlands
B15 2TT

Dr Daniel R. Gavin, MD, MB ChB
Consultant Gastroenterologist
Ipswich Hospital NHS Trust

Dr John T. Anderson, MB ChB MD
Consultant Gastroenterologist
Gloucestershire Hospitals NHS Foundation Trust
Cheltenham
GL53 7AN

Dr Mark T. Donnelly, MB ChB
Consultant Gastroenterologist
Sheffield Teaching Hospitals NHS Foundation Trust
Sheffield S5 7AU

Mr J. Graham Williams, MCh, FRCS
Consultant Surgeon
The Royal Wolverhampton Hospitals NHS Foundation Trust
Wolverhampton
WV10 0QP

Dr Edwin T. Swarbrick, MD
Consultant Gastroenterologist (retired)
The Royal Wolverhampton Hospitals NHS Foundation Trust
Wolverhampton
WV10 0QP

Keywords:

Colonoscopy, Audit, Colorectal Cancer, Adenoma Detection rate, Caecal Intubation Rate, Accreditation, Polyp, Gastrointestinal Endoscopy, Performance Indicator

Abbreviations:

PICI	Performance Indicator of Colonic Intubation
BCSP	National Bowel Cancer Screening Program
CIR	Caecal intubation rate
JAG	Joint Advisory Group on Gastrointestinal Endoscopy
NHS	National Health Service
ADR	Adenoma Detection rate
PDR	Polyp detection rate
UK	United Kingdom

Background

Caecal intubation rate (CIR) is an established performance indicator of colonoscopy. Caecal intubation with acceptable tolerance is only achieved in some patients with more sedation. This study proposes a composite Performance Indicator of Colonic Intubation (PICI) combining CIR, comfort and sedation.

Methods

Data from 20085 colonoscopies reported in the 2011 UK national audit were analysed. PICI was defined as percentage of procedures achieving caecal intubation with median dose (2mgs) of midazolam or less, and nurse-assessed comfort score of 1-3/5. Multivariate logistic regression analysis evaluated possible associations between patient, unit, colonoscopist and diagnostic factors and PICI.

Results

PICI was achieved in 54.1% of procedures. PICI identified factors affecting performance more frequently than single measures such as CIR and polyp detection, or CIR + comfort alone. Older age, male sex, adequate bowel preparation and FOBT screen-positive as indication were associated with a higher PICI. Unit accreditation, the presence of magnetic imagers in the unit, greater annual volume, fewer years' experience and higher training/trainer status were associated with higher PICI rates. Procedures in which PICI was achieved were associated with significantly higher polyp detection rates than when PICI was not achieved.

Conclusions

PICI provides a simpler picture of performance of colonoscopic intubation than separate measures of CIR, comfort and sedation. It is associated with more factors that are amenable to change that might improve performance and with higher likelihood of polyp detection. It is proposed that PICI becomes the key performance indicator for intubation of the colon in colonoscopy quality improvement initiatives.

Study highlights

What is current knowledge?

- There are three components of colonoscopy: safe and comfortable intubation; detection of pathology; and therapy
- Caecal intubation rate (CIR) is the current gold standard performance measure for intubation but a satisfactory CIR does not indicate whether intubation is safe or comfortable
- Sedation is usually required to achieve comfortable and complete colonic intubation and in many jurisdictions propofol has become a popular sedative agent
- Sedation for colonoscopy affects patient satisfaction, safety and costs

What is new here?

- A composite measure of colonic intubation (PICI) provides a broader and more discriminating picture of performance of colonic intubation than CIR alone
- PICI is better able to discern differences in performance in relation to colonoscopists, equipment and units than either CIR alone or polyp detection rates
- Unit accreditation (JAG) is associated with higher PICI
- PICI is associated with higher polyp detection rate

Introduction

Colonoscopy is the gold standard investigation of the colon for patients with symptoms and in many countries it is used for colorectal cancer screening. The quality of colonoscopy is important because poor quality colonoscopy is associated with more frequent adverse outcomes such as missed cancers [1,2] and complications. To monitor and improve performance surrogate performance indicators for colonoscopy are necessary as adverse outcomes are infrequent and difficult to capture reliably.

There are three components to colonoscopy: safe and comfortable intubation to the caecum; identification of polyps and other pathology; and safe and complete removal of polyps. Caecal intubation rate (CIR) is the traditional performance measure of caecal intubation, but it fails to take account of other variables that might reflect safety and experience, such as patient comfort and sedation.

A desire to achieve a high CIR in combination with sub-optimal technique can result in pushing harder to reach the caecum, making the procedure more uncomfortable, and possibly less safe, as colonoscopists push harder to reach the caecum. The increasing popularity of propofol suggests that patient tolerance of colonoscopy is an important barrier to widespread patient acceptance of conscious sedation for colonoscopy. However, propofol increases costs [3] and while some of these will be offset by faster colonoscopy (the colonoscopist is not constrained by patient pain) and quicker recovery (patients spend less time recovering than from benzodiazepine sedation), propofol sedation will remain unaffordable in countries where an anaesthetist is required to administer it.

In response to concerns about the impact on safety, comfort and sedation of using an unadjusted caecal intubation rate as a key performance indicator, the UK Joint Advisory Group on Gastrointestinal Endoscopy (JAG), has required all endoscopy units in the UK to monitor safety, sedation and patient comfort for all colonoscopies [4]. This study proposes a new

measure of colonic intubation, termed Performance Indicator of Colonic Intubation (PICI), which combines three key parameters of colonic intubation: CIR; sedation; and patient comfort. The data from a national audit of colonoscopy [5] performed in the UK in 2011 were used to develop an initial standard and to test the utility of this measure to assess performance. Finally, data from a single hospital endoscopy service were analysed to explore how the PICI might be used in practice and to recommend potential performance targets.

Methods

The methodology and headline results of the 2011 UK national colonoscopy audit were published in 2013 [5]. All National Health Service units performing >100 colonoscopies per year agreed to participate. All colonoscopists in these units and all adult colonoscopies performed during a two-week period in March 2011 were recorded on a web-based database. Patient and case mix variables (age, gender, inpatient/outpatient procedure, primary indication for colonoscopy and quality of bowel preparation), endoscopy unit factors (accreditation status, presence of imaging facilities) and colonoscopist variables (experience and training attainment) were captured. The 'presence/absence of a trainer' was a marker of training occurring: if a trainer was present, then a trainee did all or part of that procedure. The 'trainee/independent' status indicated whether the person doing the procedure was still in a training role or not.

Accreditation, administered by the JAG, occurring on a five-year cycle, involves a peer review process assessing against a predetermined set of standards [6].

Colonoscopy performance indicators included CIR, sedation, polyp detection and nurse-assessed patient comfort using the Gloucester comfort scale [7]. The vast majority of patients received a combination of an opiate and midazolam [5]. It is common practice in the UK and many other countries for the patient to receive an opiate followed by midazolam at the outset

of colonoscopy and if more medication is required midazolam is usually given in preference to more opiate, even though midazolam does not have inherent analgesic properties.

In the absence (at the time) of a validated comfort score for colonoscopy, the Gloucester comfort scale was selected because it was in common use throughout the UK in 2011 and because it correlates well with a simple measure of patient experience [7]. The scale has five levels and assesses three components of discomfort: severity, frequency and impact on the patient (distress):

1. *No discomfort* Talking and comfortable throughout
2. *Minimal discomfort* 1 or 2 episodes of mild discomfort with no distress
3. *Mild discomfort* More than 2 episodes of discomfort without distress
4. *Moderate discomfort* Significant discomfort experienced several times with some distress
5. *Severe discomfort* Frequent discomfort with significant distress

The principal diagnosis was noted. The data were validated for completeness and accuracy [5].

Statistical analysis

Achievement of PICI was defined as the proportion of all of the procedures of the audit that achieved caecal intubation AND less than or equal to the median dose of midazolam (2mg) AND a nurse-assessed comfort score of 1-3 ('comfortable' to 'mild discomfort'). PICI is a binary indicator. Procedures in which PICI was not achieved are those in which one or more of the three components of the indicator were not met. Thus:

$$\text{PICI\%} = \frac{\text{procedures with caecal intubation, AND comfort score 1-3, AND} \leq \text{2mg midazolam}}{\text{all procedures}}$$

PICI was compared to three further indicators of colonoscopy performance: CIR alone; CIR + comfort score 1-3; and polyp detection rate (PDR >1). In all analyses, CIR was adjusted for examinations not completed due to obstructing lesions.

As all predictor variables were categorical, analysis was based on a comparison of the characteristics of procedures in which the PICI was achieved vs. those in which it was not achieved. Multivariate binary logistic regression assessed patient, unit and colonoscopist variables in order to derive Odds Ratios (OR) and 95% confidence intervals (CI) for those that were independently associated with PICI after controlling for the effects of all other model variables. Regression analysis used the forward entry procedure, in which all variables were retained in the model regardless of statistical significance or individual contribution to the model. All OR and CI cited in the analysis are adjusted estimates from multiple logistic regression. To correct for multiple comparisons, a pragmatic reduction in the p value considered to indicate statistical significance was adopted (alpha 0.01).

Sensitivity of PICI as a performance indicator

Sensitivity in this context refers to whether PICI is more likely to find differences in performance for the variables captured in the study compared to the other three indicators (CIR, CIR + comfort and PDR>1). The data comprise four variables related to the patient (age, sex, procedure type, indication) and ten variables related to the unit or the colonoscopist (bowel preparation, country, accreditation, +/- imager, consultant status, professional group, colonoscopy and training experience, and whether training was occurring). Sub-group analysis was carried out for the variables most likely to be modifiable by change in practice (i.e. ten unit and colonoscopist variables comprising 25 sub-groups).

Relationship of PICI to polyp detection

This analysis looks at, on a case-by-case basis, whether PICI was achieved and whether a polyp(s) was found and expresses the relationship in terms of an odds ratio – the relative likelihood of finding polyps if PICI was achieved. There are three analyses: one for one or more polyps and the second for 2 (the median) or more polyps and the third for cancer. All analyses were adjusted for other variables that might independently be associated with PICI, PDR and cancer.

Statistical analysis was undertaken using SPSS version 21 (Armonk NY: IBM Corp).

Single site composite caecal intubation rate

Colonoscopy performance data across four sites in Gloucestershire (population 550,000) is collected on a single sequel-based reporting system [7], which contains two data fields (extent of procedure and midazolam dose) required to create the PICI. Data are entered immediately following procedures and both fields must be completed before a report can be generated. Nurse-assessed comfort is recorded separately on the hospital patient administration system. Data from the two databases are combined into a single database [7], which is updated every night to produce real-time performance outputs for colonoscopists, which included PICI from January 2014.

Data are presented on all colonoscopies occurring between 1st January and 31st December 2013 inclusive. In order to provide an accurate reflection of the relationship of volumes to PICI, only data from colonoscopists performing colonoscopy for the entire one year period are included in the analysis.

Results

Performance data were captured from 20,085 colonoscopies during the two-week audit, representing 94.1% of all NHS procedures performed during this time [5].

The criteria for achieving PICI were met in 54.1% of procedures (n=10,865) (Figure 1). Procedures undertaken with older patients; males; and those where quality of bowel preparation was 'adequate' or 'excellent' were significantly associated with PICI achievement (comparison of proportions tests all significant to the p<0.0001 level, supplementary Table 1). For all unit and endoscopist variables (with the exception of independent/trainee status of the endoscopist, and presence/absence of a trainer during the procedure), there was a statistically significant difference in the proportion of procedures that achieved PICI (supplementary Table 2). 60% of procedures undertaken in JAG accredited endoscopy units achieved PICI, compared to only 45.4% of procedures undertaken in non-accredited units. Procedures undertaken in units with two or more imagers achieved PICI in 57.9% of cases. 62.3% of procedures undertaken by practitioners with course faculty status achieved PICI.

Multivariate modelling of variables associated with achieving PICI

Table 1 outlines the Odds Ratio (OR), 95% Confidence Intervals (CI) and p values for all variables in a multivariate model. Odds ratios indicate the likelihood that a given sub group will be associated with achievement of PICI in comparison to the relevant 'reference' group.

All patient and case mix sub groups were associated with a statistically significant likelihood of achieving PICI with the exception of procedure type. PICI was significantly more likely to be achieved in procedures undertaken with older patients, males, and those undertaken due to FOBt positivity. For the other variables, adequate or excellent bowel preparation, country, unit JAG accreditation, having one or more imagers in the unit, procedures carried out by surgeons or specialist practitioners, fewer years' experience, greater annual volume and course participation (including course faculty status) were associated with a significantly higher likelihood of achieving PICI. There were some important negative findings. There was no statistical difference when independent practitioners were compared to independent trainees.

Likewise trainer presence, indicating that training was occurring did not show a significant difference.

Multivariate modelling of variables associated with achieving the CIR + comfort indicator

Table 2 outlines the multivariate modelling for CIR + comfort level 1-3, excluding the influence of sedation. 86.7% of procedures (n=17417) met the criteria for the CIR + comfort indicator. The direction of the association compared to PICI was reversed for two sub groups: procedures undertaken in Wales were significantly more likely to achieve PICI than those undertaken in England (OR 1.52, 95% CI: 1.27 to 1.81). In contrast, procedures undertaken in Wales were significantly *less* likely to achieve the indicator based on CIR + comfort score 1-3 than those undertaken in England (OR 0.70, 95% CI: 0.56 to 0.88). Similarly, compared to physicians, surgeons were significantly *more* likely to achieve PICI, but significantly *less* likely to achieve the CIR + comfort indicator.

Comparative multivariate modelling of four colonoscopy performance indicators

Table 3 compares multivariate analyses for four different performance indicators (PICI, CIR + comfort, CIR alone and PDR>1). 17 out of 25 sub-groups of the unit/training/colonoscopist variables showed statistically significant OR for the likelihood of achieving PICI. Eight out of 25 categories were statistically significant predictors of CIR alone, compared to eight for CIR + comfort level 1-3, and four for PDR >1. Thus PICI is more sensitive to impact on performance in relation to the sub groups of unit/training/colonoscopist variables than the other three indicators assessed.

Association between PICI and polyp/cancer detection

Achieving PICI was associated with a significantly higher likelihood of detecting one or more polyps, compared to procedures that did not achieve PICI (OR: 1.44, 95% CI: 1.35 to 1.53). The likelihood of detecting two or more polyps was also significantly higher when PICI was

achieved (OR: 1.45, 95% CI: 1.34 to 1.57). Achieving PICI was associated with an increased likelihood of detecting cancer, although this was not statistically significant (OR: 1.14, 95% CI: 0.98 to 1.32).

Single site data

6236 colonoscopies were performed across four endoscopy sites in Gloucestershire during 2013. After removing procedures performed by locums or recent appointees (n=990), there were 5246 colonoscopies, performed by 19 colonoscopists, for analysis. Annual procedure volumes for each colonoscopist ranged from 67-546, unadjusted CIR from 91-99%, level 4/5 comfort scores 3-14% and the average midazolam dosage ranged from 0.8-2.2 mgs for patients aged >70, and 1.1-2.4mgs for those aged <70. 25% of procedures were undertaken without sedation.

Figure 2 illustrates the relationship of volume of procedures to PICI with four broad groupings:

A. High volume – high PICI (80-90%)
B. High volume – low PICI (38%)
C. Low volume – high PICI (63-96%)
D. Low volume – low PICI (36-47%)

The single colonoscopist in group B had an unadjusted CIR of 99% and greater use of midazolam was the predominant reason for the lower PICI. This colonoscopist has an unusual case mix that requires more 'top-up' sedation, including tertiary referrals for resection of large polyps and colonoscopy done during hands-on courses. The three colonoscopists in group D had unadjusted CIR of 91, 94 and 96% respectively.

Discussion

This paper describes a new performance indicator of colonic intubation that provides a simpler picture of colonoscopist expertise than CIR, comfort and sedation measured separately. Moreover, it is better able to identify potentially modifiable colonoscopist and endoscopy unit factors that may affect performance than CIR alone, CIR + comfort or PDR. The PICI may identify individuals in need of additional training more readily than each of its three components. Even though it is principally an indicator of colonic intubation, it complements adenoma detection rate, a surrogate of adequacy of inspection because it is associated with a higher rate of polyp detection.

The association between patient variables and PICI is similar to that found with CIR in other studies [8,9]: older age; male gender and FOBT-screen positive indication are all associated with a significantly higher likelihood of achieving PICI. PICI has also identified factors that influence colonic intubation not previously reported. JAG-accredited endoscopy units [6], units with one or more magnetic imagers, recently certified colonoscopists, and those with higher annual volumes and higher training status had higher PICI.

PICI is an intuitive measure of colonic intubation: it is difficult to intubate the colon to the caecum comfortably with minimal sedation. It may also be safer to intubate the caecum with less pain and less sedation. Detecting significant differences in diagnostic colonic perforation is problematic because perforations are not all immediately apparent and because large sample sizes are required to compare rates. Pain occurs when more force is applied to the colon wall so it seems probable that perforation is less likely to occur if the patient is comfortable and awake. Thus a high PICI may become a proxy for safer colonoscopy.

We examined how PICI compared to established performance indicators such as CIR, PDR and CIR + comfort. PICI was more likely to identify differences in performance related to units and colonoscopists than the other indicators: PICI identified significant differences in 17/25 sub-groups compared to 8/25 for CIR and 8/25 for CIR + comfort alone.

The validity of this study depends on the completeness and accuracy of the dataset. It was estimated that >90% of the activity that occurred in the audit period was captured [5]. Validation of CIR against endoscopy reporting systems showed a good match between audit and reporting system data [5].

Sedation levels and caecal intubation are relatively hard endpoints, while nurse-assessed comfort is not. Assessment of comfort of colonoscopy became mandatory in the UK in 2007[4]. Nurse-assessed comfort is arguably more reliable than patient assessed comfort because of the amnesic effect of sedatives. However, differences between units in their experience of the scale may have led to inconsistent assessments of nurse-assessed comfort but it is difficult to explain how this might have caused systematic bias.

Composite performance indicators have potential limitations. We chose to use the median dose of midazolam and nurse-assessed comfort of <4 as cut-offs, but do not suggest that higher doses of midazolam are inappropriate. It is possible to obtain a high PICI rate (perhaps >80-85%) with low CIR and/or an unacceptable proportion of patients having excessive pain. Thus a high PICI may only be considered acceptable if there is a minimum CIR (perhaps 90%) and maximum level 4/5 pain (perhaps <10% or even lower). Application of the PICI may be inappropriate in some situations: complex procedures and procedures performed in hands-on courses often take longer and may require 'top-up' sedation.

The prospectively acquired colonoscopy performance data from a single organisation illustrates how PICI might be interpreted and utilised in everyday practice. All colonoscopists achieved the required 90% unadjusted CIR, but data showed disparities in performance that can be divided into four groups. The high volume colonoscopists have high PICI with the exception of one colonoscopist with a unique case mix. Reassuringly, some relatively low volume colonoscopists (<200/year) have high a PICI (group C). Thus, according to this measure, an annual volume of 100-200 appears to be adequate. However, a second group of low

volume colonoscopists have a PICI below the average (54%) in the national audit. The practice of these individuals should be subject to further scrutiny. If case mix or other factors cannot explain performance, they should consider increasing their annual volume and/or have further training. Finally, these data suggest a PICI of 80% is a reasonable minimum performance target, and 90% an aspirational one.

This is the first study to demonstrate that endoscopy service accreditation [6] is associated with higher performance of colonoscopy. This may be due to the quality enhancing effect of accreditation and/or that higher performing units are more likely to get accredited. Units with one or more imager had significantly higher numbers of procedures in which PICI was achieved. This association disappeared with CIR and CIR + comfort (Table 3) suggesting that lower sedation levels in these units did not compromise comfort. However, the presence of magnetic imagers might be a marker for another factor that was not captured, such as academic status of the unit. In keeping with studies of volume and CIR [10], high annual volumes are associated with a higher likelihood of achieving PICI.

In the UK, trainees can practice independently after passing a structured competency test [11]. It is reassuring that these 'independent' trainees perform as well as independent colonoscopists and that when a trainee is being trained the PICI is unaffected. These results indicate that the government sponsored colonoscopy-training programme, which began in 2000 has been effective and that patients are not adversely affected by training [12].

Finally, colonoscopists were assigned to four levels of training exposure: no experience of courses; attended one or more course; attended a 'training the colonoscopy trainer' course; and faculty on courses [13]. At each level of training experience, PICI achievement significantly increased. This may indicate that the most able colonoscopists chose to participate in and/or deliver courses, and/or that participation improves skills. The most likely explanation is that both factors are influential.

It was not possible to determine adenoma detection in this study but many studies have found a tight relationship between polyp detection rates (PDR) and adenoma detection rates (ADR) [14,15]; thus PDR is regarded as a good proxy for ADR. The significant association between PICI and polyp detection suggests that PICI is a marker for vigilance. It is also possible that more polyps are found in more comfortable less sedated patients because they are easier easier to turn on withdrawal [16].

The use of propofol for colonoscopy is increasing and now very common in North America, Australia and some European countries. However, while propofol enhances patient experience it is more expensive if an anaesthetist is required to administer it. It is possible that propofol is used by some practitioners to mask poor technique and that with deeper sedation they can use more force [17]. A recent American study has shown an increased risk of complications in patients receiving monitored anaesthesia services [18]. There are anecdotal reports of colonoscopists finding it difficult to colonoscope patients with conscious sedation after being taught to colonoscope patients with propofol sedation, suggesting propofol sedation limits skills acquisition. It is proposed that colonoscopists should, prior to using propofol sedation, demonstrate they are able to achieve a high PICI.

The PICI might be used in two specific circumstances: to identify, support and monitor individuals in need of improvement and second, for benchmarking. For quality improvement purposes an individual endoscopy service might create its own PICI measure, using a local comfort scale and sedation threshold (with minimum levels for CIR and comfort scores). Any unit that routinely captures all three parameters (virtually all units in the UK) should be able to use PICI immediately for quality improvement.

In contrast to using PICI to improve quality, all three components of the PICI would need to be agreed and defined for benchmarking. The principal constraint on this is a reliable performance measure for comfort: one method would have to be used consistently.

A sensible first step would be to use the PICI locally to better identify who might need further skills training. Local jurisdictions, or programme-based screening programmes, might use one method of assessing patient comfort, allowing comparisons of performance between units, as occurs in the English Bowel Cancer Screening Programme. In the UK, the JAG has created a National Endoscopy Database (NED) [19] that draws key indicators from reporting systems. Upload will become compulsory to maintain unit accreditation from 2018. NED uses a single comfort assessment measure so in time it will be possible to compare PICI across the country and explore its relationship to other indicators such as post-colonoscopy colorectal cancer.

In summary, this study has developed a new performance indicator of colonic intubation. This measure provides a more nuanced picture of intubation skill and one that is better able to detect differences in performance. The study confirms previous findings that age, sex and indication affect performance. New findings are that unit accreditation status, availability of imagers and features of the endoscopist (particularly training status) affect performance. PICI is associated with significantly higher polyp detection. It is proposed that PICI becomes the key performance indicator of colonic intubation for quality improvement of colonoscopy and that 80% should be the initial standard for average case mix. In time PICI might also be used to benchmark performance of endoscopy services.

Table 1: Multivariate modelling – sub groups associated with PICI achievement

Variable [a]	Sub-groups	Odds Ratio (95% CI)	P value [b]
Patient age	<50	0.38 (0.35 to 0.41)	**<0.0001**
	50 to 59	0.49 (0.45 to 0.54)	**<0.0001**
	60 to 69	0.61 (0.56 to 0.66)	**<0.0001**
	70+	Reference	
Patient gender	Male	1.40 (1.32 to 1.49)	**<0.0001**
	Female	Reference	
Procedure type	Inpatient	Reference	
	Outpatient	0.98 (0.86 to 1.13)	0.78
Procedure indication	Diagnostic	Reference	
	Surveillance	1.09 (1.00 to 1.18)	0.04
	BCSP [c]	1.88 (1.66 to 2.12)	**<0.0001**
	Screening	1.11 (0.95 to 1.29)	0.19
	Therapeutic	0.87 (0.74 to 1.03)	0.10
Bowel preparation	Poor	Reference	
	Adequate	1.43 (1.30 to 1.58)	**<0.0001**
	Excellent	1.63 (1.48 to 1.80)	**<0.0001**
Country	England	Reference	
	Scotland	0.38 (0.34 to 0.43)	**<0.0001**
	Wales	1.52 (1.27 to 1.81)	**<0.0001**
	Northern Ireland	1.11 (0.95 to 1.30)	0.19
Unit JAG accreditation status	Accredited	1.26 (1.16 to 1.35)	**<0.0001**
	Not accredited	Reference	
Imagers per unit	None	Reference	
	One	1.27 (1.18 to 1.37)	**<0.0001**
	Two or more	1.29 (1.19 to 1.40)	**<0.0001**
Professional group of colonoscopist	Physician	Reference	
	Surgeon	1.10 (1.03 to 1.18)	**0.008**
	Nurse	1.09 (0.98 to 1.22)	0.12
	SAS [d]	1.26 (1.06 to 1.51)	**0.009**
	GP	0.83 (0.63 to 1.10)	0.20
Independent/trainee colonoscopist	Independent	1.12 (0.95 to 1.31)	0.17
	Trainee	Reference	
Number of years independent	0 to 3	Reference	
	3 to 5	1.06 (0.94 to 1.19)	0.36
	5 to 10	0.70 (0.63 to 0.78)	**<0.0001**
	10 to 20	0.72 (0.65 to 0.80)	**<0.0001**
	20+	0.67 (0.58 to 0.76)	**<0.0001**
Annual number of colonoscopies	<100	Reference	
	100 to 199	1.00 (0.91 to 1.10)	0.97
	200 to 299	1.14 (1.03 to 1.26)	**0.01**
	300 to 499	1.28 (1.15 to 1.42)	**<0.0001**
	500+	1.13 (1.00 to 1.29)	0.06
Highest level of training	None	Reference	
	Skills	1.16 (1.04 to 1.28)	**0.005**
	TCT [e]	1.33 (1.21 to 1.47)	**<0.0001**
	Faculty	1.74 (1.57 to 1.92)	**<0.0001**
Presence or absence of trainer	Yes	Reference	
	No	0.99 (0.92 to 1.06)	0.73

[a] 216 procedures excluded from multivariate model due to missing data (model based on data from 19869 procedures), [b] bold p values indicate statistically significant findings at the p=0.01 level, [c] BCSP = Bowel Cancer Screening Programme, [d] SAS = specialist practitioner, [e] TCT = 'Train the colonoscopy trainer' course

Table 2: Multivariate modelling – sub groups associated with achievement of combined CIR + comfort indicator

Variable [a]	Sub-groups	Odds Ratio (95% CI)	P value [b]
Patient age	<50	0.96 (0.85 to 1.08)	0.557
	50 to 59	1.08 (0.95 to 2.23)	0.234
	60 to 69	0.96 (0.86 to 1.08)	0.518
	70+	Reference	
Patient gender	Male	1.99 (1.83 to 2.18)	**<0.0001**
	Female	Reference	
Procedure type	Inpatient	Reference	
	Outpatient	1.38 (1.17 to 1.63)	**<0.0001**
Procedure indication	Diagnostic	Reference	
	Surveillance	1.38 (1.22 to 1.56)	**<0.0001**
	BCSP [c]	1.53 (1.26 to 1.86)	**<0.0001**
	Screening	1.22 (0.97 to 1.55)	0.092
	Therapeutic	1.07 (0.84 to 1.36)	0.609
Bowel preparation	Poor	Reference	
	Adequate	2.86 (2.55 to 3.20)	**<0.0001**
	Excellent	3.41 (3.03 to 3.84)	**<0.0001**
Country	England	Reference	
	Scotland	0.83 (0.71 to 0.96)	0.014
	Wales	0.70 (0.56 to 0.88)	**0.002**
	Northern Ireland	1.46 (1.14 to 1.88)	**0.003**
Unit JAG accreditation status	Accredited	1.07 (0.96 to 1.19)	0.218
	Not accredited	Reference	
Imagers per unit	None	Reference	
	One	1.07 (0.96 to 1.18)	0.226
	Two or more	1.15 (1.02 to 1.29)	0.020
Professional group of colonoscopist	Physician	Reference	
	Surgeon	0.80 (0.72 to 0.88)	**<0.0001**
	Nurse	0.79 (0.67 to 0.93)	**0.004**
	SAS [d]	0.76 (0.60 to 0.97)	0.029
	GP	1.12 (0.73 to 1.73)	0.596
Independent/trainee colonoscopist	Independent	0.94 (0.75 to 1.18)	0.579
	Trainee	Reference	
Number of years independent	0 to 3	Reference	
	3 to 5	1.08 (0.91 to 1.28)	0.359
	5 to 10	0.96 (0.83 to 1.10)	0.536
	10 to 20	1.03 (0.88 to 1.19)	0.742
	20+	0.88 (0.73 to 1.06)	0.179
Annual number of colonoscopies	<100	Reference	
	100 to 199	1.06 (0.93 to 1.20)	0.378
	200 to 299	1.15 (0.99 to 1.31)	0.056
	300 to 499	1.38 (1.19 to 1.60)	**<0.0001**
	500+	1.93 (1.59 to 2.34)	**<0.0001**
Highest level of training	None	Reference	
	Skills	1.04 (0.91 to 1.19)	0.601
	TCT [e]	1.13 (0.99 to 1.29)	0.082
	Faculty	1.19 (1.04 to 1.37)	0.013
Presence or absence of trainer	Yes	Reference	
	No	1.06 (0.96 to 1.16)	0.251

[a] 216 procedures excluded from multivariate model due to missing data (model based on data from 19869 procedures), [b] bold p values indicate statistically significant findings at the p=0.01level, [c] BCSP = Bowel Cancer Screening Programme, [d] SAS = specialist practitioner, [e] TCT = 'Train the colonoscopy trainer' course

Table 3: Comparison between sub groups in multivariate models that were significant predictors of PICI compared to those that predicted CIR, CIR +comfort and polyp detection

Variable [a]	Sub-groups	P value PICI [b]	P value CIR alone	P value CIR + comfort	P value PDR
Patient age	<50	**<0.0001**	**0.001**	0.557	**<0.0001**
	50 to 59	**<0.0001**	0.048	0.234	**<0.0001**
	60 to 69	**<0.0001**	0.042	0.518	0.091
	70+	-	-	-	-
Patient gender	Male	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
	Female	-	-	-	-
Procedure type	Inpatient	-	-	-	-
	Outpatient	0.78	**<0.0001**	**<0.0001**	0.059
Procedure indication	Diagnostic	-	-	-	-
	Surveillance	0.04	**<0.0001**	**<0.0001**	**<0.0001**
	BCSP [c]	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
	Screening	0.19	0.204	0.092	**<0.0001**
	Therapeutic	0.10	0.433	0.609	**<0.0001**
Bowel preparation	Poor	-	-	-	-
	Adequate	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
	Excellent	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
Country	England	-	-	-	-
	Scotland	**<0.0001**	0.688	0.014	0.140
	Wales	**<0.0001**	0.089	**0.002**	0.625
	Northern Ireland	0.19	0.137	**0.003**	0.425
Unit JAG accreditation status	Accredited	**<0.0001**	**0.006**	0.218	0.490
	Not accredited	-	-	-	-
Imagers per unit	None	-	-	-	-
	One	**<0.0001**	0.226	0.226	0.048
	Two or more	**<0.0001**	0.020	0.020	0.109
Professional group of colonoscopist	Physician	-	-	-	-
	Surgeon	**0.008**	**<0.0001**	**<0.0001**	0.089
	Nurse	0.12	**<0.0001**	**0.004**	0.200
	SAS [d]	**0.009**	0.181	0.029	0.149
	GP	0.20	0.175	0.596	0.950
Independent/trainee colonoscopist	Independent	0.17	0.562	0.579	0.916
	Trainee	-	-	-	-
Number of years independent	0 to 3	-	-	-	-
	3 to 5	0.36	0.820	0.359	0.206
	5 to 10	**<0.0001**	0.237	0.536	0.017
	10 to 20	**<0.0001**	0.871	0.742	**<0.0001**
	20+	**<0.0001**	0.017	0.179	**<0.0001**
Annual number of colonoscopies	<100	-	-	-	-
	100 to 199	0.97	0.309	0.378	0.925
	200 to 299	**0.01**	0.107	0.056	0.342
	300 to 499	**<0.0001**	**0.002**	**<0.0001**	0.777
	500+	0.06	<**0.0001**	**<0.0001**	0.264
Highest level of training	None	-	-	-	-
	Skills	**0.005**	0.038	0.601	0.578
	TCT [e]	**<0.0001**	**0.009**	0.082	0.557
	Faculty	**<0.0001**	0.445	0.013	0.085
Presence or absence of trainer	Yes	-	-	-	-
	No	0.73	0.445	0.251	0.162

[a] 216 procedures excluded from multivariate model due to missing data (model based on data from 19869 procedures), [b] bold p values indicate statistically significant findings at the p=0.01 level, [c] BCSP = Bowel Cancer Screening Programme, [d] SAS = specialist practitioner, [e] TCT = 'Train the colonoscopy trainer' course. Reference categories indicated by hyphenated cells

References

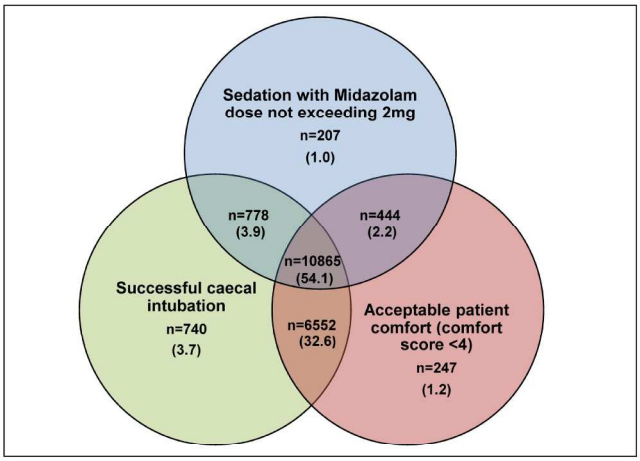
1. Corley D A, Jensen CD, Marks AR et al. Adenoma detection rate and risk of colorectal cancer and death. N Engl J Med 2014;370:1298-1306.
2. Kaminski MF, Regula J, Kraszewska E et al. Quality indicators for colonoscopy and the risk of interval cancer. N Engl J Med 362:1795-1803.
3. LiuH, Waxman DA, Main R, Mattke S. Utilization of anesthesia services during outpatient endoscopies and colonoscopies and associated spending in 2003-2009. JAMA 2012;307:1178-1184.
4. BSG quality and safety indicators for colonoscopy and flexible sigmoidoscopy accessed 14th January 2017 at http://www.thejag.org.uk/downloads/Unit%20Resources/JAG%20Summary%20guide%20to%20quality%20and%20safety%20indicators%20April%202016.pdf
5. Gavin DR, Valori RM, Anderson JT, Donnelly MT, Williams JG, Swarbrick, ET. The national colonoscopy audit: a nationwide assessment of the quality and safety of colonoscopy in the UK. Gut 2013;62:242-249.
6. Guide to the JAG accreditation scheme accessed 14th January 2017 at http://www.thejag.org.uk/downloads/Accreditation/Guide%20to%20the%20JAG%20accreditation%20scheme%20v2.pdf
7. Ekkelenkamp VE, Dowler K, Valori RM, Dunckley P. Patient comfort and quality in colonoscopy.World J.Gastroenterol. 2013;19:2355-2361.
8. Valori RM, Rey J-F, Atkins WA et al. European guidelines for quality assurance in colorectal cancer screening and diagnosis. First Edition. Quality assurance in endoscopy in colorectal cancer screening and diagnosis. Endoscopy 2012; 44: 1–18
9. Rathgaber SW, Wick TM. Colonoscopy completion and complication rates in a community gastroenterology practice. Gastrointest Endosc. 2006;64:556–562
10. Enns R. Quality indicators in colonoscopy. Can J Gastroenterol 2007;21:277–279

11. JAG trainee certification process – colonoscopy accessed 14th January 2017 at http://www.thejag.org.uk/downloads/JAG%20Certification%20for%20trainees/Colonoscopy%20application%20criteria%20and%20process.pdf
12. Valori R. Quality Improvements in Endoscopy in England. In: Techniques in Gastrointestinal Endoscopy. 2012;14:63-72
13. JAG endoscopy training courses accessed 14th January 2017 at http://www.thejag.org.uk/downloads/JAG%20approved%20training%20courses/JETS%20course%20overview%20v3.0.pdf
14. Patel NC, Islam RS, Wu Q et al. Measurement of polypectomy rate by using administrative claims data with validation against the adenoma detection rate. Gastrointest Endosc. 2013;77:390-394.
15. Williams JE, Holub JL, Faigel DO. Polypectomy rate is a valid quality measure for colonoscopy: results from a national endoscopy database. Gastrointest Endosc. 2012;75:576-582.
16. James EE, Bassett P, Arebi N, Thomas-Gibson S, Guenther T, Saunders BP. Dynamic patient position changes during colonoscope withdrawal increase adenoma detection: a randomized, crossover trial. Gastrointestinal Endosc. 2011;73:456–463
17. Korman LY, Haddad NG, Metz DC et al. Effect of propofol anesthesia on force application during colonoscopy. Gastrointest Endosc. 2014;79:657-662.
18. Wernli KJ, Brenner AT, Rutter CM and Inadomi JM. Risks Associated With Anesthesia Services During Colonoscopy. Gastroenterology 2016;150:888–894
19. http://www.thejag.org.uk/downloads/National%20Endoscopy%20Database%20(NED)/NED%20key%20facts%20v1.1.pdf

Figure legends

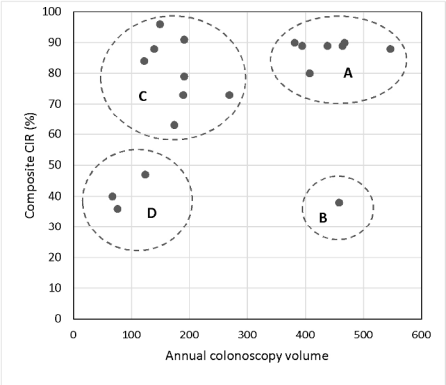
Figure 1: Number and proportion of procedures comprising each facet of PICI (not shown are 252 procedures (1.3%) in which none of the three quality indicators were achieved)

Figure 2: Relationship of volume to PICI for 5246 colonoscopies performed by 19 colonoscopists in a single institution in one year (2013)



Number and proportion of procedures comprising each component of PICI (not shown are 252 procedures (1.3%) in which not all the three quality indicators were achieved)

279x361mm (300 x 300 DPI)



Relationship of volume to PICI for 5246 colonoscopies performed by 19 colonoscopists in a single institution in one year (2013)

215x279mm (300 x 300 DPI)