Gaze patterns hold key to unlocking successful search strategies and increasing polyp detection rate in colonoscopy

Journal:	<i>Endoscopy</i>
Manuscript ID	ENDOS-2017-16035.R1
Manuscript Type:	Innovations and Brief Communications
Date Submitted by the Author:	31-Oct-2017
Complete List of Authors:	Lami, Mariam; Imperial College London, Department of Surgery and Cancer Singh, Harsimrat; Imperial College London, Department of Surgery and Cancer; Imperial College London Dilley, James; Imperial College London, Department of Surgery and Cancer Ashraf, Hajra; Imperial College London, Department of Surgery and Cancer Edmondson, Matthew ; Imperial College London, Department of Interventional Endoscopy Hoare, Jonathan; Imperial NHS Trust, Gastroenterology Darzi, Ara; Imperial College London, Department of Surgery and Cancer Sodergren, Mikael; Imperial College, Biosurgery & Surgical Technology
Keyword:	Statistics < 10 Other focus, Image and data processing, documentatiton < 09 Quality and logistical aspects, Colorectal cancer < 02 Endoscopy Lower GI Tract, Polyps / adenomas / ... < 02 Endoscopy Lower GI Tract, Neoplasia < 03 Endoscopy Small Bowel, Endoscopic resection (polypectomy, ESD, EMRC, ...) < 02 Endoscopy Lower GI Tract, Training < 09 Quality and logistical aspects
Abstract:	<p>Background: The Adenoma Detection Rate (ADR) is an important quality indicator in colonoscopy. The aim of this study is to evaluate the changes in Visual Gaze Patterns (VGPs) with increasing Polyp Detection Rate (PDR), a surrogate marker of ADR.</p> <p>Methods: Eighteen endoscopists participated in the study. VGPs were measured using eye tracking technology during the withdrawal phase of a colonoscopy. VGPs were characterized using two analyses- screen and anatomical based. Eye tracking parameters were used to characterize performance, further substantiated using Hidden Markov Model (HMM) analysis.</p> <p>Results: Subjects with higher PDRs spent more time in the outer ring of the 3 by 3 grid for both analyses (screen-based: $r=0.556$, $p=0.017$; anatomical: $r=0.624$, $p<0.01$). Fixation distribution to the 'bottom U' of the screen in screen-based analysis was positively correlated with PDR ($r=0.622$, $p=0.006$). HMM demarcated the VGPs into 3 PDR groups.</p> <p>Conclusion: This study has defined distinct VGPs that are associated with expert behavior. These data may allow introduction of visual gaze training within structured training programs, and has implications for adoption in higher-level assessment.</p>

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Gaze patterns hold key to unlocking successful search strategies and increasing polyp detection rate in colonoscopy

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There are no conflicts of interest.

Word counts

Abstract (max 175) : 174

Manuscript (max 1500): 1469

References (max 15): 13

Number of tables/figures

Tables: 1

Figures: 6

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- Data collection
- Data analysis and interpretation
- Drafting the article
- Critical revision of the article
- Addressing the Reviewer's comments

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- Final approval of the version to be published

Funding

There are no funders to report for this manuscript.

Competing interests

There are no competing interests.

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Abstract

Background: The Adenoma Detection Rate (ADR) is an important quality indicator in colonoscopy. The aim of this study is to evaluate the changes in Visual Gaze Patterns (VGPs) with increasing Polyp Detection Rate (PDR), a surrogate marker of ADR.

Methods: Eighteen endoscopists participated in the study. VGPs were measured using eye tracking technology during the withdrawal phase of a colonoscopy. VGPs were characterized using two analyses- screen and anatomical based. Eye tracking parameters were used to characterize performance, further substantiated using Hidden Markov Model (HMM) analysis.

Results: Subjects with higher PDRs spent more time in the outer ring of the 3 by 3 grid for both analyses (screen-based: $r=0.556$, $p=0.017$; anatomical: $r=0.624$, $p<0.01$). Fixation distribution to the 'bottom U' of the screen in screen-based analysis was positively correlated with PDR ($r=0.622$, $p=0.006$). HMM demarcated the VGPs into 3 PDR groups.

Conclusion: This study has defined distinct VGPs that are associated with expert behavior. These data may allow introduction of visual gaze training within structured training programs, and has implications for adoption in higher-level assessment.

Introduction

Excision of adenomatous polyps during colonoscopy has been shown to result in a 53% reduction in risk of colorectal cancer mortality when compared with the general population ⁽¹⁾. On this basis, the Adenoma Detection Rate (ADR) is a validated quality indicator in colonoscopy ⁽²⁾. The Polyp Detection Rate (PDR) has become an acceptable alternative ⁽³⁾ and has been reported to significantly correlate with the ADR with a conversion factor of 0.68 between PDR to ADR ⁽⁴⁾.

PDR is likely related to the manual skill of the endoscopists in manipulating the endoscope to achieve the desired visual view and visual search strategy employed to detect polyps. In a colonoscopy, the endoscopist tends to adopt certain eye movement patterns, known as Visual Gaze Patterns (VGPs) to examine the colon. Eye-tracking technology may provide some insight into any differences in PDR of endoscopists observed in clinical practice.

Eye-tracking has recently come to the fore in defining VGPs in other areas of medicine ^{(5) (6) (7)}. In endoscopy, a study by Almansa et al ⁽⁸⁾ recorded VGPs of endoscopists when viewing a pre-recorded video of a colonoscopy. Recently, a pilot study ⁽⁹⁾ analysed eye-tracking during live colonoscopies, improving upon using a pre-recorded colonoscopy that dissociates the element of endoscopic manipulation from the endoscopists with the bowel lumen used as a reference for mapping eye movements.

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The aim of this study is to evaluate visual gaze patterns of endoscopists in clinical practice and to determine differences in visual search strategies in relation to PDR .

Methods and Materials

This study was conducted at St Mary’s Hospital, London. Ethical approval was granted by the North West London NRES committee.

Participants

20 endoscopists were enlisted for this study. Two subjects were excluded due to poor quality eye tracking data, caused by interference of data registration by prescription glasses. Colonoscopies carried out on patients with suspected/confirmed inflammatory disease were excluded.

Data Recording

Eye-tracking glasses were fitted and calibrated before the procedure began (Figure 1). The number of colonoscopies and level of training were recorded as surrogate markers of experience. PDRs were obtained from reporting software (Egton Medical Information Systems Limited, UK) between 1st January 2010 to 8th May 2015. Procedures performed as part of the National Bowel Cancer Screening Programme were not included.

Evaluation of bowel preparation

A senior endoscopist, clinical lead at St Mary’s Hospital, assessed bowel preparation of each colonoscopy to ascertain the influence of bowel

preparation on the quality of search. Scores were assigned per colonoscopy using the Boston Bowel Preparation Score (10). This served to reduce bias where poor preparation may contribute to reduced or different search strategies. All colonoscopies were rated BBPS of either 2 or 3, inferring that visualization of bowel mucosa was adequate in all cases.

Data Analysis

Fixation count and duration were measured per Area Of Interest (AOI) in the 2-minute segments of each recording. Both fixation count and duration were normalized per AOI and presented as a percentage of total fixation count and duration of each video.

Areas of Interest Identification

Screen based (SB): The monitor was split into a 3×3 grid, with each square representing an AOI.

Anatomical based (AB): In this analysis, the lumen of the bowel seen on the monitor represented the centre of the 3×3 grid, with each fixation position mapped relative to the lumen. The lumen was defined as the area on the screen where it was not possible to identify the bowel mucosa.

For AOI generation, heat maps obtained using this grid were inspected for trends in fixation (Figure 2). Sets of shape AOIs were investigated for both analyses (Figure 3).

Figure 4 illustrates the methodology of both analyses.

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For each data recording, fixations were mapped for 2 minutes from the caecum during withdrawal. Only fixations captured during polyp search were mapped with exclusion of segments during flushing, polyp biopsy and removal. All data recordings were calibrated before mapping and offset corrections were made throughout the mapping process where necessary.

Gaze behaviour characterisation using Hidden Markov Modelling (HMM)

Our group have previously validated the use of HMM to allow classification of eye tracking data in clinical practice^{(11) (12) (13)}. Briefly, for each subject and analysis type (SB or AB), the sequences of AOI-tagged fixations were fed to a probabilistic hidden Markov Model. Pairwise differences among AOI-tagged fixations sequences i.e. among its associated models, were subsequently established using the log probability of a certain sequence being generated by the descriptive model of another sequence, permitting behavioural analysis of gaze patterns. The analysis was akin to that carried out previously by Sodergren et al⁽¹²⁾ and executed using bespoke software on MATLAB (Mathworks, UK).

Statistical Analysis

Correlations between AOI metrics and PDR/endoscopy experience were calculated using Pearson's coefficient and Spearman's rank as appropriate. All statistical analyses were performed using SPSS (Version 22.0.0, IBM, USA), with significance level fixed at $p < 0.05$.

Results

Experience and Polyp Detection Rate (PDR)

Table 1 shows markers of experience and PDR of registrars and consultants.

The number of years of endoscopic experience correlated well with the total number of colonoscopies performed ($r=0.876$, $p<0.01$). There was no significant correlation between PDR and number of colonoscopies; however, there was a significant correlation between PDR and years of experience ($r=0.497$, $p=0.036$).

Anatomical Based (AB) Analysis

Endoscopists with higher PDRs fixated more and for longer in the outer ring compared to the centre (fixation count $r=0.564$, $p=0.015$; fixation time $r=0.624$, $p<0.01$) and on the monitor versus the surrounding environment (fixation count $r=0.649$, $p<0.01$; fixation time $r=0.550$, $p=0.018$) as illustrated in the scatter plots for Outer Ring AOI Count and Monitor AOI Time in Figure 5. No significant correlations were seen with level of training or number of colonoscopies.

Screen Based (SB) Analysis

Significant correlations with PDR were observed. With higher PDRs, endoscopists spent greater attention and time in the outer ring (fixation count $r=0.550$, $p=0.018$; fixation time $r=0.556$, $p=0.017$) than the centre (fixation count $r=-0.553$, $p=0.017$; $r=-0.560$, $p=0.016$). Endoscopists with higher PDRs also had higher fixation count and time at the 'bottom U' of the screen (see

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Figure 3 for reference; fixation count $r= 0.627$, $p=0.005$ and fixation time $r=0.622$, $p=0.006$).

Gaze behaviour patterns

The endoscopists were classified into three groups based on PDR:

- A) Less than 20%,
- B) Between 20 and 25% and,
- C) Greater than 25%.

Figure 6 shows the planar (2D) embedding of gaze patterns whereby the spatial location is characteristic of each gaze pattern similarity with regards to others. The three group clusters and their centroids are shown. In case of AB, there is visible separability between group (a) and the other two groups. In the case of SB, clusters exhibit high variance, but centroids remain close indicative of small effect sizes (Figure 6).

Discussion

This study affirms the use of eye-tracking technology to describe the VGPs of endoscopists in clinical practice. Further to the pilot work reported by Dik et al⁽⁹⁾, clinical applicability has been established by relating VGPs to PDRs. The results illustrate that there is an increase in proportion of fixation count and time in the outer ring framing the centre of the 3x3 grid with increasing PDR. For AB analysis, this suggests that endoscopists with higher PDRs have a systematic pattern to cover all areas of bowel mucosa while those with lower PDR may look centrally for polyps. However when analysed with SB approach, it appears that endoscopists prefer to manipulate the endoscope so

that this segment of the bowel is completely in view. The idea of 'endoscope manipulation' is justified by this overlap in results between analyses, also seen by Dik et al⁽⁹⁾ where gaze time was strongly correlated between endoscopy monitor and area of colonic surface. However, this study has shown that AB analysis allows for easier interpretation of results, with understanding of search patterns in relation to the anatomy of the bowel. A machine learning approach confirms this result, where AB analysis exhibit sufficient separability between group clusters based on PDR.

There are some limitations to this study. Firstly, lack of standardisation of the endoscopist's environment may have led to potential bias. Nevertheless by controlling the endoscopist's environment, although reducing bias, would reduce applicability to clinical practice. Furthermore, the sample size may limit interpretation; a larger sample of endoscopists may be needed to confirm specific VGPs associated with PDR. Also to consider is an element of subjectivity of defining 'the lumen' during analysis which could result in low inter-reliability between videos. However, clear rules and procedures to identify markers for AOIs in AB analysis were agreed by authors to limit this. Finally, loss of subjects for eye tracking analysis due to technical reasons may introduce inevitable bias, which will hopefully be eliminated with evolution in eye tracking technology.

Conclusions

This study has identified specific visual gaze patterns associated with higher PDRs that have important potential applications in training. Further research

should focus on corroborating these findings and evaluating their use in formal training curricula.

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	Consultant Versus Registrars	
	Registrars	Consultants
Age	35	45
Number of Colonoscopies	600	1500
PDR (%)	21.52	32.46

Table 1- medians of age, number of colonoscopies and PDR of consultants and registrars.

The study group was split into 9 consultants and 9 registrars for comparison. Consultants were significantly older ($p<0.01$) and had performed more colonoscopies ($p<0.01$) than registrars.

Figure 1- Eye-tracking glasses worn by an endoscopist. The glasses contain a front camera, located on the bridge of the glasses in the midline, and two infrared cameras, located inferiorly on the inside ridge of both lens. The front camera records the user's environment, i.e. the endoscopist's view. The two inner cameras channel infrared (IR) beams into the eye and capture the corneal reflection, recorded as an eye movement. A Portable Digital Assistant (PDA) monitor is attached to the glasses using a USB connection to collect the data.

61x83mm (300 x 300 DPI)

Figure 2- heat maps of endoscopists with low PDR (15.75%) and high PDR (40.07%) using screen based analysis. + Colour represents fixation count, with red being high fixation and green being low fixations. The diameter represents the fixation time, where greater diameter represents longer fixation duration. There is a transition in fixation count and time from the upper corner to the bottom rows of the screen with increasing PDR.

38x16mm (300 x 300 DPI)

Figure 3- Sets of AOIs used for both analyses. From top left to bottom right: left, middle and right; top, middle and bottom; all corners; 4 L shapes consisting of bottom left and right and top left and right; each part of the grid; 4 boxes; central and outer ring; bottom U shape.

35x31mm (300 x 300 DPI)

Figure 4- 2D interface used by endoscopists to visualise the bowel during endoscopy. A 3x3 grid was placed according to screen in screen-based analysis (left image). In anatomical based analysis (right image), the centre of the 3x3 grid was placed over the bowel lumen shown on the screen.

62x22mm (300 x 300 DPI)

Figure 5- Left scatter plot: Correlation between Standardised Outer Ring AOI fixation count and the Polyp Detection Rate (%); Right scatter plot: Correlation between the Standardised Monitor AOI fixation time and the Polyp Detection Rate (%).

57x22mm (300 x 300 DPI)

Figure 6- 2D Illustration of subject's performance. Subject's numbers are represented within shapes. Groups centroids are illustrated by colour coded crosses, with the average distance of each group to its group centroid is represented by the surrounding circle. Left image- Fixations assigned using Anatomical based (AB) approach; Right image- Fixations assigned using Screen based (SB) approach.

250x95mm (300 x 300 DPI)