Artificial intelligence for the detection of polyps or cancer with colon capsule endoscopy

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Abstract: Colorectal cancer is common and can be devastating, with long-term survival rates vastly improved by early diagnosis. Colon capsule endoscopy (CCE) is increasingly recognised as a reliable option for colonic surveillance, but widespread adoption has been slow for several reasons, including the time-consuming reading process of the CCE recording. Automated image recognition and artificial intelligence (AI) are appealing solutions in CCE. Through a review of the currently available and developmental technologies, we discuss how AI is poised to deliver at the forefront of CCE in the coming years. Current practice for CCE reporting often involves a two-step approach, with a 'pre-reader' and 'validator'. This requires skilled and experienced readers with a significant time commitment. Therefore, CCE is well-positioned to reap the benefits of the ongoing digital innovation. This is likely to initially involve an automated AI check of finished CCE evaluations as a quality control measure. Once felt reliable, AI could be used in conjunction with a 'pre-reader', before adopting more of this role by sending provisional results and abnormal frames to the validator. With time, AI would be able to evaluate the findings more thoroughly and reduce the input required from human readers and ultimately autogenerate a highly accurate report and recommendation of therapy, if required, for any pathology identified. As with many medical fields reliant on image recognition, AI will be a welcome aid in CCE. Initially, this will be as an adjunct to 'double-check' that nothing has been missed, but with time will hopefully lead to a faster, more convenient diagnostic service for the screening population.

Keywords: artificial intelligence, cancer, capsule endoscopy, colon, polyp, software, innovation

Background

Colorectal cancer (CRC) is a common and potentially devastating diagnosis. Within the UK population, the lifetime risk of a CRC diagnosis is 7% for men and 6% for women,[1] with the suggestion that the disease is increasingly affecting younger adults within the UK, Europe and the USA.[2,3] Early detection of malignant or pre-malignant changes of the colonic mucosa dramatically increases the chances of cancer-free survival, with the prompt identification and removal of pre-cancerous polyps shown to prevent deaths.[4]

Screening for these changes is accepted in many countries at a population level but is costly and hard to accurately target those who would gain the most benefit. Screening capacity varies between countries and continents due to the local healthcare systems, the infrastructure and funding available, with most nationally coordinated services using as first-line, non-invasive stool tests, such as the faecal immunochemical test (FIT) or guaiac faecal occult blood test (gFOBT). Opportunistic programmes more frequently rely on colonoscopy.[5] To reflect the higher rates in

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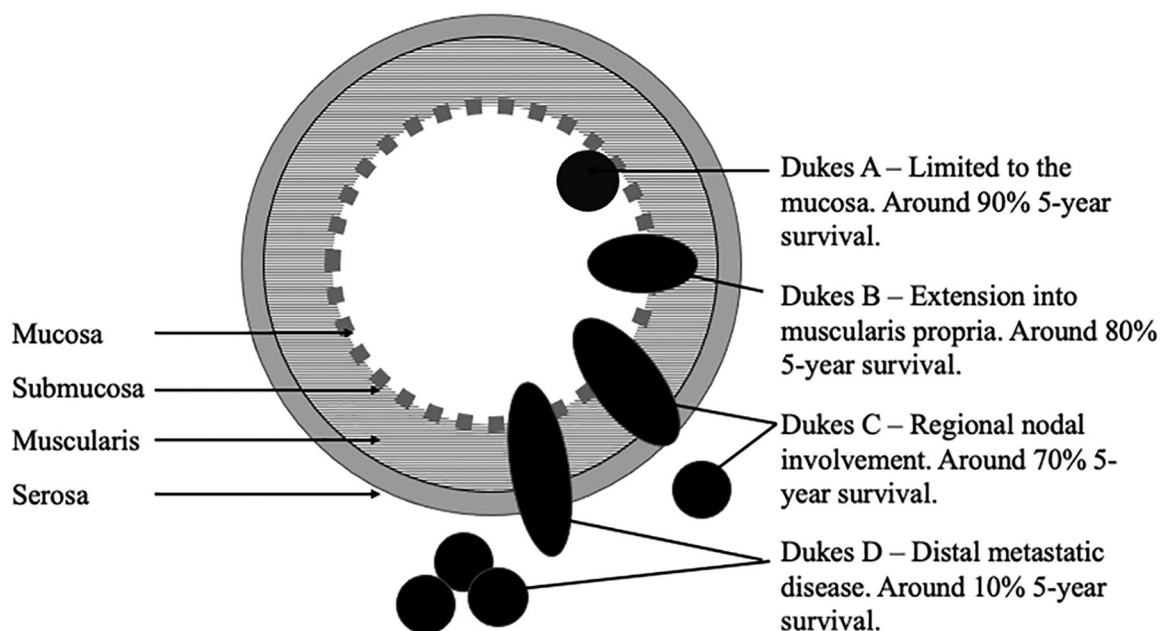
Figure 1. Dukes classification summary. Survival approximations from Cancer Research UK.[8]

younger patients, the American Cancer Society is now recommending CRC surveillance, in those at average risk, from the age of 45. This will only further enlarge the population requiring investigation.[6] Despite an accepted and increasing need for CRC screening, this comes at a time when services are buckling under the pressure of global events and conventional invasive endoscopy is struggling to meet demands, resulting in cancers being missed (Figure 1).[7,8]

When considering less-invasive alternatives to conventional colonoscopy (CC), there are several options available and recommended in recent guidance.[9] Among these, colon capsule endoscopy (CCE) provides an evidence-based solution, with favourable polyp detection when compared with CT colonography (CTC) in recent comparison study, meta-analysis, and systematic review.[10–12] Along with the increased capacity offered by CCE, the coronavirus pandemic has highlighted several previously under-appreciated positive aspects of CCE, such as the possibility to allow individuals to remain in their own homes, which would provide patients with important choices.[13] A limiting factor for this, however, is its availability and reliance on bowel preparation for complete and accurate imaging, when compared with longer-standing technologies, despite it being safe, more comfortable and acceptable to patients.[14,15]

At present, reading a CCE recording is time-consuming and requires skilled and experienced readers.[16] Devices such as the PillCam COLON2 system from Medtronic record at a variable rate between 4 and 35 frames per second (fps) for a minimum of up to 10 hours,[17] thus providing hundreds of thousands of frames for review. Given the burden to CCE readers, various approaches have been adopted. But with improvements in the image recognition capabilities of artificial intelligence (AI) platforms, there seems a natural coupling of the two technologies.[18] The real-world implementation of AI however is complex and produces several key ethical and regulatory issues.[19,20]

What do we have now in routine CCE reading?
Often, for evaluation and reporting of CCE, a two-step method with a nurse pre-reader and consultant validator workflow system is employed. This results in a check, and double-check, to safeguard against missed pathology, ensure high-quality reporting and minimise the time spent by the consultant. To help the human readers focus on important frames, there are software aids available, some examples of these are included below.

Duplicate frame recognition and removal in small bowel (SB) capsule procedures have been seen to reduce the number of frames by almost 10%.[21]

Given the relative stasis of the colon, in comparison to the SB, this is likely to lead to a much more significant reduction in the data load in CCE. Variations on this allow greater reductions and although exclusive use of modes, such as QuickView (PillCam), similar picture elimination (OMOM) or Express or Omni modes (EndoCapsule), clearly cut the time taken for manual review of SB CE videos, this is at the sacrifice of sensitivity, with more than half of pathology being missed in some studies.[22] Although a helpful tool when used appropriately, reliance on these would be ill-advised.

Improving battery life has allowed devices such as the PillCam COLON 2 to function for 10–14 hours. This has been achieved through various technological improvements such as variable frame rate, which includes cutting the recording rate to 4 fps during periods of stasis, or early in the recording while in the stomach in a 'sleep mode'. As the battery life continues to improve, one of the major drawbacks of CCE, the completion rate, is likely to continue to rise. A recent meta-analysis seeing completion rates between 65% and 93% (pooled 76%).[11]

Colour cue software, such as the suspected blood indicator (SBI) mode has been shown to be extremely sensitive for active bleeding but less reliable for discrete lesions or ulceration, with physician review required for isolation of the cause of the bleeding once seen on SBI.[23,24] SBI software works by recognising clusters of red-coloured pixels,[25] and so the sensitivity can be changed, at the cost of specificity, by increasing the range of colour shades and the number of pixels accepted.

There are several virtual chromoendoscopy systems available, including narrow-band imaging (NBI) (Olympus), flexible spectral imaging colour enhancement (FICE) (FujiFilm) and i-scan (Pentax Medical). These use software to filter and restrict the light wavelengths included in the presented image with the aim of enhancing detection, delineation, and characterisation of abnormalities. FICE is available in capsule endoscopy. However, on meta-analysis, when compared to white light (WL), did not show improved detection of lesions, although FICE setting 1 was felt to show improved delineation and detection of pigmented lesions in the SB.[26] When applied to CCE images to detect polyps it does however seem to result in a higher detection, particularly those that are large, flat or sessile when compared to WL.[27]

Blue mode (BM) filters for short wavelengths of light and superimposes this onto WL images. There are conflicting results on whether this enhances detection beyond WL alone in the SB.[28,29] On CCE examination of polyps, however, retrospective review of images using FICE and BM has been shown to predict, with a high degree of accuracy, whether a polyp is adenomatous or hyperplastic.[30] This very useful when deciding on whether resection and invasive colonoscopy will be required.

Integrating AI into the CCE process

As new technology emerges, healthcare providers will be slow to trust the safety of their patients to it. Integrating AI into routine practice will require an evolutionary change, with developments that provide practical improvement being kept and adopted by the professional community. Regulatory and ethical hurdles will need overcoming to establish the infrastructure necessary to data share with appropriate patient confidentiality and information governance.[20] This introduction of AI into CCE reading may take a stepwise introduction to improve the diagnostic process in a predetermined, controlled, and evolutionary way of five stages:

Stage 1—Quality improvement: AI is used to spot-check finished CCE evaluations and reports after a diagnosis.
Stage 2—Productivity improvement: Workflows are used to prepare new recordings with the aim of 'pre-processing' videos with the pre-reader. AI could be used to suggest potential findings to be reviewed and mark parts of the video that can be disregarded where there are no atypical features.
Stage 3—Performance improvement: As pre-processing becomes more established and trusted, the AI system could begin to replace pre-reading and send provisional results to a validator for interpretation of the findings and other abnormal frames.
Stage 4—Evaluation: AI would replace human analysis, sending results to the gastroenterologist for review and reporting.
Stage 5—Diagnostic: AI replaces the diagnostician for simple pathology and send the high-level result to the patient, with details, if needed, coming from the gastroenterologist.
At present, this seems far from routine practice, although some innovations are already appearing.

What exists but not yet in routine use?

Although AI is expected to impact huge areas of medical practice and everyday life, the earliest targets are likely to be those based on pattern recognition. Image-based diagnostics, such as dermatology, radiology, and pathology have received attention in this regard. In the field of gastroenterology, AI has an enormous potential to boost efficiency and provide rapid and high-quality diagnostics. AI can also help compensate for fatigue-induced human error and brings accuracy and consistency. Several methods have shown promising results in both standard colonoscopy and CCE to differentiate between normal and abnormal mucosa of the SB or colon. With the development of convolutional neural networks (CNNs), the performance and number of solutions have increased enormously.

During CC, the use of computer-aided diagnostic (CADx) systems allows for near real-time assessment of polyps before resection. To date, diminutive polyps can be differentiated into adenomatous or hyperplastic type with an accuracy of 94% from unaltered videos.[31] Although this is suboptimal, it should be borne in mind that this is more reliable than the recognition of many human endoscopists, with CADx systems already outperforming non-expert endoscopists.[32]

Real-time AI to aid with polyp detection has also been shown to increase adenoma detection, when compared to control groups, across several studies in a recent systematic review and meta-analysis. Commercially available examples of real-time AI to aid polyp detection, such as the GI Genius from Medtronic, have been shown to increase adenoma detection without increasing withdrawal time.[33,34] These are powerful tools in aiding with 'pre-processing' and recommendation for the endoscopist but are far from replacing human experience.

When applied to CCE, several methods have been proposed to reduce the inherent drawbacks. We can see methods designed to enhance the video visualisation[35,36] or to automatically detect pathologies such as angiectasia,[37] bleeding,[38] ulcers,[39] polyps,[40,41] or tumours.[42] The detection of polyps, because of their clinical importance, is perhaps one of the areas that have attracted the most attention from researchers. Recently published methods utilising CNN have shown impressive results.[40,41] Laiz and colleagues[40] argue that the detection rate could be higher than 90%, reducing the total number of frames to be reviewed by up to 95%. These methods have the potential to automatically detect several diseases and reduce CCE reading time. There are limited clinical studies, however, validated with data sets from one, or only a few, centres and without the interaction of medical experts. Most of these studies present a high risk of bias, which limits the generalisation of their findings into clinical practice.[33]

As these technologies become more integrated into routine care, they will likely be employed within CCE for pre-reading and the superficial analysis of abnormalities. This adoption will not only improve performance but also the trust of the clinicians involved in the diagnostic workflow. The first step for the adoption of AI into clinical practice will require systems that interact with the human pre-readers in their tasks. The interaction between practitioners and AI requires accurate models but also models that provide an uncertainty measure and explanations of the output.[43,44] An example is shown in Figures 2 and 3. Figure 2 shows a
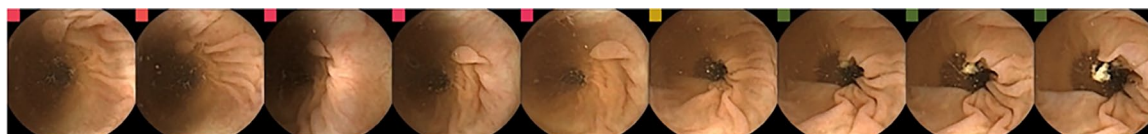
Figure 2. Sequence of nine frames with a polyp observed.
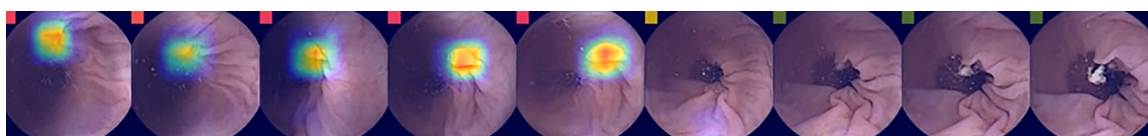
Figure 3. CNN model output detecting the polyp with heatmaps providing confidence and location of the finding.

sequence of nine frames with a visible polyp in its first five frames while Figure 3 shows the output of a CNN for each of those images. The output is not just a binary image classification, but the confidence of the system with the finding and where it has been detected. This type of information helps to focus attention on the important areas, thus reducing the cognitive load of the reviewer. It also increases the confidence and trust of the reviewers. With time and increased 'learning' using the largest data sets, networks will become more reliable and trusted than even the most thorough human reviewer.

Challenges

Medical applications of CADx systems for pathology recognition have been in development for over 50 years.[45] Since then, there have been massive advances, but AI is yet to emerge into routine clinical practice.

Instituting new technology into established healthcare systems faces many challenges. At a time of financial pressure, introducing AI systems would be expensive and require updated hardware. Lobbying for funding for technology, without proven clinical efficacy and costings is seldom successful in this situation. Will an increased polyp detection result in costly further procedures, or will allow patients to undergo colonic investigation with CCE and AI at home result in cost-savings and compliance improvements offsetting any additional follow-ups? Until AI for polyp recognition is in clinical use, predicting costings will be difficult.

The use of AI and advanced computing systems are typically beyond the established skillset of most gastroenterologists and endoscopists. Although the details of how the programming works are not required for the effective use of these systems, further training will be required. The 'hub and spoke' structure of many healthcare systems, with the centralisation of specialists supporting district activity is potentially more aligned with CCE than CC, as the images do not require interpretation in real-time. Reviewing the CCE data can be done remotely via regional networks, allowing specialist input to come from anywhere to support local teams.

The more images and pathology are available to train AI systems, the more accurate and 'experienced' they become. To succeed in this, large image stores and collaboration would be required. Sharing patient data across trusts and healthcare systems raises issues of governance and data protection which will require policy changes.

Future and developments

As AI matures and becomes more 'trusted', it will take over more of the manual and time-consuming works, which will leave the human experts available to train, supervise, and diagnose. This would hopefully ultimately lead to more time and a better experience for the patient.

Due to anatomical variation along the gastrointestinal tract, specialised capsules have been developed to image each area. Such capsules include those for the oesophagus, which requires a very high frame rate to account for the rapid transit; the larger cavity of the stomach results in poor views of the fundus and cardia and so magnetically controllable gastric capsules (MACEs) are increasingly able to resolve this issue; higher definition within the SB is adding capabilities in the capsules' traditional 'home ground'; and finally, CCE is becoming more established. The prospect of these specialities combined into one device is an appealing prospect, to provide a minimally invasive and thorough pan-enteric diagnostic test. Once coupled with AI, this could conceivably be rapid and reliable, giving a diagnosis shortly following the excretion of the device. With adequate community support administration of the capsule could be managed via primary care, or by mail, with the entirety of the procedure carried out at home.[13,46]

With the growth of telemedicine in gastroenterology, brought forward by the COVID-19 pandemic, a large part of specialist care will continue to be performed remotely.[47–49] This, when used correctly with appropriate patient selection, is a positive experience. One of the issues preventing successful national screening in resource-poor countries is the lack of appropriate infrastructure. Commercial partnerships to aid distribution of CCE devices and the use of smartphone apps to make the process more accessible to the service user are underway.[46] Innovations such as these will be required to 'move with the times' and engage patients who are currently being missed.

Beyond the diagnostic, the world of capsule endoscopy continues to expand into therapeutics with new possibilities, such as the release of drugs or direct haemostatic therapy within the GI tract being suggested. For this, a real-time reaction to

pathology would be required, making automated pathology recognition software an appealing prospect to facilitate reactive drug release or therapy.

Conclusion

Early detection of CRC or pre-malignant polyps through screening programmes improves the chances of long-term cancer-free survival. CCE is a powerful tool in this but is underutilised in many counties for several reasons. Given the large numbers of images produced reading a CCE recording is time-consuming and therefore expensive, but with image recognition software becoming increasingly sophisticated, AI could help streamline this process.

Existing technologies include high-performance, reliable capsule devices providing colonic views. The use of virtual chromoendoscopy increases detection and characterisation of the lesions seen, and real-time CADx programmes in use for colonoscopy provide a highly accurate prediction on the nature of the polyp or lesion seen. It seems very likely that these will be incorporated into use in the near future for CCE.

We believe, at first, AI system needs to be used as a compliment, but not a replacement of validators or pre-readers. As AI systems become more accurate and trusted, they will replace re-reading (stage 3) and validators (stage 4). In the last stage (stage 5), AI will replace the diagnostician for simple pathology and send high-level results to the patient. Given recent trends, this is likely to be delivered remotely, allowing the patient to remain in their own home, if they so wished. Should pathology requiring intervention or endoscopic therapy be identified, a procedure with an appropriate interventional endoscopist can then be pre-planned. This pathway will ultimately translate into a better experience for the patient.

Conflict of interest statement
The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: AK is consultant for Jinshan. He is director of iCERV Ltd and cofounder of AJM Medicaps Ltd. He has received a GivenImaging Ltd-ESGE grant, and material support for clinical research from SynMed/Intromedic. In the last ten years, he has received honoraria & lecture fees from Jinshan, Dr FalkPharma UK and Ferring. He has also received educational travel support from Aquilant, Jinshan, Dr FalkPharma, Almirall, Ferring, and has been in advisory board meetings for Tillots, Ankon, Dr FalkPharma UK.

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