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Artificial Intelligence in Gastrointestinal Endoscopy

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The primary aim of *Artificial Intelligence in Gastrointestinal Endoscopy* (AIGE, *Artif Intell Gastrointest Endosc*) is to provide scholars and readers from various fields of artificial intelligence in gastrointestinal endoscopy with a platform to publish high-quality basic and clinical research articles and communicate their research findings online.

AIGE mainly publishes articles reporting research results obtained in the field of artificial intelligence in gastrointestinal endoscopy and covering a wide range of topics, including artificial intelligence in capsule endoscopy, colonoscopy, double-balloon enteroscopy, duodenoscopy, endoscopic retrograde cholangiopancreatography, endosonography, esophagoscopy, gastrointestinal endoscopy, gastroscopy, laparoscopy, natural orifice endoscopic surgery, proctoscopy, and sigmoidoscopy.

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Artificial intelligence as a means to improve recognition of gastrointestinal angiodysplasia in video capsule endoscopy

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Abstract

Gastrointestinal angiodysplasia (GIAD) is defined as the pathological process where blood vessels, typically venules and capillaries, become engorged, tortuous and thin walled – which then form arteriovenous connections within the mucosal and submucosal layers of the gastrointestinal tract. GIADs are a significant cause of gastrointestinal bleeding and are the main cause for suspected small bowel bleeding. To make the diagnosis, gastroenterologists rely on the use of video capsule endoscopy (VCE) to “target” GIAD. However, the use of VCE can be cumbersome secondary to reader fatigue, suboptimal preparation, and difficulty in distinguishing images. The human eye is imperfect. The same capsule study read by two different readers are noted to have miss rates like other forms of endoscopy. Artificial intelligence (AI) has been a means to bridge the gap between human imperfection and recognition of GIAD. The use of AI in VCE have shown that detection has improved, however the other burdens and limitations still need to be addressed. The use of AI for the diagnosis of GIAD shows promise and the changes needed to enhance the current practice of VCE are near.

Key Words: Artificial intelligence; Video capsule endoscopy; Gastrointestinal angiodysplasia; Detection; Bleeding; Small bowel

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Core Tip: Video capsule endoscopy (VCE) is the primary modality to diagnose gastrointestinal angiodysplasias (GIADs). Typically, gastroenterologists rely on VCE to make a diagnosis of GIAD prior to referral for deep enteroscopy. However, VCE analysis can be cumbersome secondary to reader fatigue, suboptimal preparation, and difficulty in distinguishing images. Use of artificial intelligence in VCE has shown improved GIAD detection, however limitations exist that still need to be addressed. The use of artificial intelligence for GIAD diagnosis shows promise and changes needed to enhance current VCE practices are near.

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INTRODUCTION

Gastrointestinal angiodysplasia (GIAD) is defined as the pathological process where blood vessels, typically venules and capillaries, become engorged, tortuous and thin walled - which then form arteriovenous connections within the mucosal and submucosal layers of the gastrointestinal (GI) tract[1]. GIADs are found throughout the GI tract, but they most often occur in the small intestine (80% jejunum, 57% duodenum), stomach (22.8%) and less frequently the ascending colon (11.4%)[2]. The gold standard in diagnosis of GIAD has been endoscopy, with the addition of video capsule endoscopy (VCE) in 2001. The technology of VCE radically improved the diagnostic yield of GIADs as well as other small bowel diseases. VCE provided a means to target lesions in the small bowel and has played a role in the development of balloon enteroscopy for advanced diagnoses and treatment options. Although, VCE improved the diagnostic yield of GIADs, as well other as small bowel diseases, there are several challenges which a reader continues to face. First, review of these images has been an arduous process, which can last from 30-40 min to over an hour. The abnormalities that are of interest may only present in a couple of frames that last a minute or less. Second, the long reading time may lead to reader fatigue and a reduction in diagnostic accuracy. To address these issues, there have been several advances made to VCE technology such as a Quick-view algorithm, suspected blood indicator and adaptive frame rate technology. None of these technologic advances have improved diagnostic accuracy[3-5]. Despite these limitations, VCE is still the widely used technology to diagnose GIAD and has become a growing focus for the use of artificial intelligence (AI) to improve the identification of GIAD. We discuss the implementation of computer software known as AI, machine programs capable of learning and simulating patterns like the human brain.

TYPES OF AI

Several layers exist within AI and have been utilized throughout the field of gastroenterology, especially endoscopy. One aspect is machine learning (ML), a discipline where large, complex data sets are used to predict outcomes and identify patterns using various algorithms[6]. These algorithms are often trained to differentiate data sets or characteristics such as color, size and shape, which help to distinguish between lesions within the GI tract. Beyond ML, two other types of AI exist, artificial neural networks (ANNs) and convolutional neural networks (CNNs). ANNs utilize the patterns observed within data sets to perform complex task of cross comparison at various points of calculation. Therefore, numerous computed data sets can be collected at any stage and compared to provide one outcome. This simulates the intelligence and neurobiological processes of the human brain, as the computer continues to learn to perform new task through automated analysis. CNNs use real time or still images to distinguish between normal and abnormal, then further investigate abnormal objects to identify a diagnosis with relatively highly accuracy and efficacy (Table 1).

Table 1 Artificial intelligence methods for gastrointestinal angiodysplasia detection[17]

Artificial intelligence	Description	Function	Advantages	Disadvantages
Machine learning	Ability of a computer program to learn	Discern logic-based rules from input and output data	Automation of tasks	Requires high-quality data likely to have some causal link
	Algorithm workflow improves performance		Detect patterns between input and output data	
Artificial neural network	Use of weighted/graded signals to perceive data	Adaptive learning	Mapping performance between input and output data	Requires labeled data
	Use of computational communication		Adaptive learning capability	Requires large volumes of data
Convolutional neural network	Image detection	Computer vision	Highly accurate image recognition and classification	Highly dependent on a training model or models
	Interpretation through three-dimensional convolutional layers		Limited by image rotation or orientation	

CNNs have become one of the most commonly used AI modalities, particularly in VCE, which has significantly aided in the detection of GIADs. The use of AI, particularly CNNs, has created a new era in capsule endoscopy (CE) capable of improving lesion detection rates, reducing capsule reading time, as well as reducing reviewer fatigue. This shift towards computer-aided diagnostic tools in clinical practice may represent a future of common practice. Further investigation with AI in computer-aided diagnosis of GIAD leans heavily towards CE. Three of the most popular areas of CNN implementation include newly developed algorithms, single-shot multibox detection (SSD) and region of interest (ROI) color contrast analysis.

MODALITIES WHERE AI CAN BE USED WHEN DETECTING GIAD

In 2019, Leenhardt *et al*[7] analyzed 2946 still frames with vascular lesions utilizing CNN, where two data sets were used to create a trained algorithm for GIAD detection. The first dataset, also termed the “training and learning phase,” consisted of a CNN analysis of 2946 still frame images containing vascular lesions for characteristic analysis of abnormal lesions based on size, shape, color, pattern, and contour. This helped the CNN distinguish GIADs within a still frame. The second data set utilized the learned features from the previous data set, which were applied to new images to detect and locate GIAD within a still frame. The primary and secondary endpoints were the sensitivity and specificity of the computer aided diagnosis (CADx) algorithm. These values were 100% and 96% respectively[7].

Similarly, Hwang *et al*[8] developed their own CNN-based AI model based on a collection of still images later classified as ulcerative or hemorrhagic, which were augmented by rotating each image by 90 degrees 3 times and flipping each rotated image horizontally. As a result, a collection of 30224 abnormal images (11776 hemorrhagic lesions and 18,448 ulcerative lesions) and 30224 normal images were used to train their CNN model by observing similar outcomes in the Leenhardt *et al*[7] study. However, Hwang *et al*[8] went a step further in developing their own CNN based on VGGnet, a CNN that incorporates more convolution filters or layers when screening an image to improve its accuracy of image recognition[9]. Using two training protocols, Hwang *et al*[8] developed a binary model, trained to detect any pathological images as abnormal without distinguishing the types of lesions, and a combined model, trained to detect distinctive hemorrhage or ulcerative lesions.

Another type of CNN is called SSD which is very similar to CNNs described above. However, in this instance, an expert endoscopist will demarcate a rectangular box around a lesion within an image making it much faster to provide a unifying framework for both training and interpretation[10]. Tsuboi *et al*[11] incorporated this technique with 2237 still images of small-bowel GIAD captured by VCE and placed a bounding box where GIAD were found. Through this method, Tsuboi *et al*[11] were able to test their ability to detect GIAD using an area under the receiver operating characteristic (ROC) curve for the probability score, as well as sensitivity, specificity, PPV and NPV of their CNN’s detection rate for GIAD and accurately distinguish their

location within an image. Lin *et al*[12] delved deeper into this approach by combining SSD with RetinaNet, a CNN that mimics VGGnet described above, with the enhanced ability to find shortcuts when comparing images in order to limit the number of layers used when training. Otani *et al*[13] was able to analyze and characterize images of erosions and ulcers, GIAD and tumors, then compared the ROC, sensitivity, specificity, and accuracy of their AI detection system for each lesion image.

Another prevalent area of CNN performance is color contrast analysis. Since color is one of the most relevant features in diagnosing GIAD, Noya *et al*[14] used color to detect potential regions of GIAE within an image. This is done in 4 categorized steps: Image preprocessing (contrast enhancement), selection of potential ROI (geometric outline of colored pixels making up the angiodysplastic lesion), feature extraction and selection (labeling a ROI based on color, texture and geometric pattern) and classification of a ROI (recognizing patterns of potential angiodysplasia lesions as pathological vs. non-pathological). Comparably, Iakovidis and Koulaouzidis[15] use color-based pattern recognition to separate pathological vs. normal lesions from 137 still images, which they placed into four categories: vascular, inflammatory, lymphangiectatic, and polypoid. Iakovidis and Koulaouzidis[15] used a 4-step categorization process, like Noya *et al*[14] above, however, they differ with the introduction of salient point saturation (SPS), an automated extraction algorithm which selects salient points in a digital image based on changes in observed color intensity[16].

OUTCOMES OF AI IN DETECTING GIAD

The effects of AI computer-aided diagnosis in GIAD are producing promising results that individual practitioners may hope to incorporate into their practices. The diagnostic yield of GIADs using AI leans heavily on VCE with the use of CNNs. Newly developed algorithms, such as SSD and ROI color contrast analysis have been areas of particular focus in medical literature. Each modality of these CNN implementing tools stands on their own, as very limited research compares these techniques by using the same data set or still images for a head-to-head comparison.

The diagnostic performance of a CADx algorithm for the detection of GIAD using VCE, assess its diagnostic precision as a means for a segmental approach in localizing lesions. Leenhardt *et al*[7] found a sensitivity of 100% [95% confidence interval (CI), 100%-100%]. Secondary endpoints revealed a specificity of 96.0% (95%CI: 93.78%-98.22%), a positive predictive value of 96.15% (95%CI: 93.97%-98.33%), a negative predictive value of 100.0% (95%CI: 100%-100%) and a kappa coefficient of reproducibility at 1.0[7]. Only "clean" images were used in their data set, which meant that images with poor preparation quality or the presence of bubbles would not be included. This is a limitation to the study, which the authors point to. In comparison, the algorithm of Hwang *et al*[8] combined (all images trained separately as hemorrhagic or ulcerative) *vs* binary training (all images trained without segregation) approach in the development of an automated CNN, demonstrated that combined training revealed higher sensitivity (97.61% *vs* 95.07%, $P < 0.001$). Although, accuracy classifying GIADs as small bowel lesions was 100% in both the combined and binary training models.

The use of SSD by Tsuboi *et al*[11] to automatically detect GIAD in VCE images focuses on diagnostic accuracy utilizing t-test analysis. The study reported a ROC curve for CNN detection of GIAD at 0.999. The cut-off value for the probability score was 0.36, exhibiting a sensitivity, specificity, positive predictive value, and negative predictive value of their CNN at 98.8%, 98.4%, 75.4%, and 99.9% respectively at this value[11]. Otani *et al*[13] enhanced CNN by combination of SSD with RetinaNet detection of vascular lesions displayed an AUC 0.950 (95%CI: 0.923-0.978) among the internal cohort (images obtained for training) and 0.884 (95%CI: 0.874-0.893) among the external cohort (randomly obtained imaged for cross-validation). This is an observable difference compared to Tsuboi *et al*[11] study, although still relatively high in automated lesion detection.

Color contrast has been used as well. Iakovidis and Koulaouzidis[15] assessed the validity of color-based pattern recognition in the classification of pathologic lesions with the addition of SPS, including p0 GIAD (low probability of bleeding), p1 GIAD (intermediate probability of bleeding) and p2 GIAD (high probability of bleeding). Classification per type of GIAD revealed an AUC of 69.9 ± 15.8 (P0 GIAD), 97.5 ± 2.4 (P1 GIAD), and 79.6 ± 13.1 (P3 GIAD) respectively[15]. Noya *et al*[14] used the combination of a color-based, texture, statistical and morphological features analysis for GIAD detection. Utilization of this method led to a sensitivity of 89.51% and a

specificity of 96.8%, as well as an AUC 82.33% \pm 10.43% detection of GIAD[14].

CONCLUSION

GIADs are a significant cause of GI bleeding and are the main cause for suspected small bowel bleeding. To make the diagnosis, gastroenterologists rely on the use of VCE to “target” GIAD. However, the use of VCE can be cumbersome secondary to reader fatigue, suboptimal preparation, and difficulty in distinguishing images. Humans are imperfect. The human eye is imperfect. The same capsule read by two different readers are noted to have miss rates like other forms of endoscopy. The use of AI in VCE have shown that detection has improved, however the other burdens and limitations still need to be addressed. AI used for the diagnosis of GIAD shows promise and the changes needed to enhance the current practice of VCE are near.

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