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Research Article

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# The Role of AI-Enhanced Optical Coherence Tomography (OCT) in the Early Detection and Treatment of GI Cancers

**Muhammad Hassan, MD[1*], Nina Huynh, B.A[2], Alejandra Sataray-Rodriguez, B.S[3], Sriya Kakarla, B.A[4], Hiral Ahir, B.S[5], Sri Vaishnavi Konagalla[6], Marcus Romaniuk, B.S[7]**

[1]Nuvance Health/Vassar Brothers Medical Center, Poughkeepsie, NY
[2]A.T. Still University School of Osteopathic Medicine in Arizona, Mesa, AZ
[3]University of Nevada Reno School of Medicine, Reno, NV
[4]UT Health Houston McGovern Medical School, Houston, TX
[5]A.T. Still University School of Osteopathic Medicine in Arizona, Mesa, AZ
[6]Nova Southeastern University, Fort Lauderdale, FL
[7]A.T. Still University School of Osteopathic Medicine in Arizona, Mesa, AZ

**Abstract**

**Background and Aims:** The integration of Artificial Intelligence (AI) with Optical Coherence Tomography (OCT) represents a transformative innovation in the early diagnosis and treatment of gastrointestinal (GI) cancers, particularly esophageal and colorectal cancers. OCT, a high-resolution imaging modality, enables visualization of tissue microstructures and has shown promise in identifying dysplastic and early cancerous changes. AI algorithms enhance this process by enabling real-time automated tissue analysis, improving diagnostic accuracy and minimizing the risk of missed lesions. This review examines the role of AI-enhanced OCT in early detection and treatment strategies for GI cancers.

**Methods:** This literature review synthesizes findings from key studies examining the application of AI in enhancing OCT's diagnostic and therapeutic capabilities for GI cancers. Relevant studies were identified by focusing on advancements in OCT imaging techniques and the integration of machine learning algorithms, particularly convolutional neural networks (CNNs) and other deep learning frameworks. These algorithms were analyzed for their effectiveness in detecting dysplasia, distinguishing between benign and malignant tissues, and facilitating therapeutic interventions. The review also evaluates current limitations in AI-enhanced OCT, such as its narrow field of view and operator dependency, while exploring future directions, including cost-effective strategies and algorithm refinement.

**Results:** AI-enhanced OCT has shown significant promise in improving the early detection of GI cancers by increasing diagnostic sensitivity and specificity. The technology allows for high-resolution imaging of tissue microstructures, which is critical for identifying dysplastic changes and early-stage malignancies. AI algorithms, particularly convolutional neural networks, have demonstrated effectiveness in distinguishing between benign and malignant tissues by recognizing subtle histopathological features. The integration of AI with OCT has also facilitated therapeutic interventions, such as endoscopic mucosal resection (EMR), by providing real-time insights during procedures. Despite these advancements, challenges remain, including the high cost of implementation, variability in diagnostic performance across diverse populations, and the need for operator training to standardize usage.

**Conclusions:** AI-enhanced OCT is a promising tool for the early detection and treatment of GI cancers, offering the potential to improve diagnostic accuracy, reduce reliance on biopsies, and enable more precise therapeutic interventions. However, widespread adoption in clinical practice will require addressing current limitations, such as cost, accessibility, and the need for further refinement of AI algorithms to improve reliability and generalizability. Continued research and innovation are critical to unlocking the full potential of this technology in transforming the management of GI cancers and improving patient outcomes.

***Corresponding author:**
Dr. Muhammad Hassan, Nuvance Health - Vassar Brothers Medical Center. Email: mhsn014@gmail.com

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## Introduction

Gastrointestinal (GI) cancers refer to malignancies that develop in the organs of the digestive system, including the esophagus, stomach, pancreas, liver, small intestine, colon, and rectum [1]. Among these, esophageal and colorectal cancers are particularly prevalent, contributing significantly to global cancer morbidity. GI cancers are classified based on the specific organ involved and the cell type from which the cancer originates. For instance, esophageal cancer can be divided into squamous cell carcinoma and adenocarcinoma, while colorectal cancers are predominantly adenocarcinomas, originating from the glandular cells of the colon and rectum [2]. Globally, GI cancers account for a substantial number of cancer cases and deaths. Colorectal cancer (CRC) is the third most commonly diagnosed cancer and the second leading cause of cancer-related deaths worldwide, with approximately 1.9 million new cases and 935,000 deaths reported in 2020 [3]. Although less prevalent, esophageal cancer is highly fatal, with over 500,000 new cases diagnosed annually and low survival rates due to late-stage diagnoses [4]. The incidence of GI cancers varies by region and is influenced by genetic, environmental, and lifestyle factors, such as diet, smoking, and alcohol use.

GI cancers contribute significantly to global morbidity and mortality, especially when diagnosed at later stages. Colorectal cancer often presents with symptoms such as abdominal pain, changes in bowel habits, and rectal bleeding; however, these symptoms frequently arise when the disease is already advanced [2]. Similarly, esophageal cancer, characterized by dysphagia and weight loss, has a poor prognosis when diagnosed late. Early detection improves outcomes significantly, as the five-year survival rate for localized colorectal cancer is approximately 90%, compared to about 14% for metastatic cases [1].

### *Overview of Traditional Diagnostic Methods*

Current diagnostic techniques for GI cancers primarily rely on endoscopy, biopsy, and imaging studies. Endoscopy enables direct visualization of the GI tract and allows biopsies of suspicious tissues for histopathological examination to confirm malignancy [5]. Imaging modalities, such as computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET), are used for cancer staging and evaluating metastasis. However, these traditional approaches have limitations in sensitivity and specificity, particularly in detecting early dysplastic changes.

### *Current Treatment Strategies and Their Limitations*

Treatment options for GI cancers depend on the stage at diagnosis. Early-stage cancers may be managed with endoscopic techniques such as endoscopic mucosal resection (EMR) or surgical resection [6]. Advanced cancers typically require a combination of surgery, chemotherapy, radiation therapy, and targeted biological therapies [7]. Despite these interventions, survival rates for late-stage diagnoses remain low, and treatments are often accompanied by significant side effects. The challenges associated with these treatments underscore the urgent need for improved diagnostic tools and earlier detection.

## Importance of Early Detection in GI Cancers

### *Impact on Survival Rates and Treatment Outcomes*

Early detection of GI cancers dramatically improves patient outcomes. For instance, patients with early-stage colorectal cancer have a five-year survival rate of approximately 90%, whereas survival drops to less than 15% in those diagnosed at a late stage [1]. Similarly, esophageal cancer survival rates increase significantly when the disease is diagnosed in its early stages before invasion into surrounding tissues [4]. Early detection enables less invasive treatments, such as localized resections or minimally invasive endoscopic procedures, reducing the need for extensive surgeries or systemic therapies and improving quality of life.

### *Advantages of Detecting Dysplastic and Early Cancerous Changes*

The ability to detect dysplasia, which refers to precancerous changes in the tissue, is particularly crucial in preventing the progression of GI cancers. Dysplastic lesions in the esophagus and colon can be treated endoscopically, preventing the development of invasive cancer [7]. Optical Coherence Tomography (OCT), a high-resolution imaging technique, offers an advantage in detecting these subtle changes at the microscopic level, allowing for earlier and more accurate identification of precancerous lesions [6]. This early intervention minimizes the risk of progression to invasive cancer and reduces the overall treatment burden.

### *Limitations of Current Imaging and Diagnostic Techniques*

Despite advancements in endoscopic technology, current imaging methods are not always sensitive enough to detect early-stage GI cancers or dysplastic lesions. For example, white-light endoscopy may miss subtle or flat lesions that are precursors to cancer [8]. Similarly, CT and MRI imaging are often more effective in staging advanced cancer rather than identifying early-stage disease. This lack of sensitivity can lead to missed diagnoses, delayed treatments, and worse patient outcomes.

### *Issues with Accuracy and Missed Lesions*

One of the significant challenges in the early detection of GI cancers is the risk of missed lesions during standard diagnostic procedures. Small or flat lesions, particularly in the colon and esophagus, may be overlooked during endoscopy, leading to underdiagnosis [7]. Furthermore, while considered the gold standard for diagnosing malignancies, biopsies are limited by the sampling technique. Biopsies may miss focal areas of dysplasia or cancer, as they are taken from specific regions rather than assessing the entire lesion [5]. This issue underscores the need for more advanced diagnostic tools, such as AI-enhanced OCT, to improve the accuracy and comprehensiveness of cancer detection.

## Methods

This manuscript presents a comprehensive literature review focused on the integration of Artificial Intelligence (AI) with Optical Coherence Tomography (OCT) for early detection and treatment of gastrointestinal (GI) cancers, with particular attention to esophageal and colorectal cancers. A systematic search of databases, including PubMed, Scopus, and Google Scholar, was conducted using terms such as "AI," "Optical Coherence Tomography," "Gastrointestinal Cancers," "Esophageal Cancer," "Colorectal Cancer," "Cancer Screening," and "Dysplasia." Eligible studies were selected based on their use of OCT in GI cancer diagnostics or therapy, incorporation of AI models such as convolutional neural networks, and reporting of outcomes like diagnostic sensitivity, specificity, and accuracy. Additional data points extracted included imaging resolution, therapeutic applications such as endoscopic mucosal resection, and discussions of limitations or clinical implications. Studies unrelated to AI or OCT in GI cancers were excluded. The findings were organized into thematic categories to explore the diagnostic, therapeutic, and future potential of AI-enhanced OCT, as well as its limitations, such as narrow imaging fields, operator dependency, and cost considerations. Ethical standards were upheld as no patient data were generated or analyzed, relying solely on publicly available studies.

## Optical Coherence Tomography (OCT)

### Principles of OCT Technology

### *Overview of OCT*

Optical Coherence Tomography (OCT) is a highly advanced, non-invasive imaging technique that employs near-infrared light to generate high-resolution, cross-sectional images of tissue microstructure. By measuring the time delay and intensity of backscattered light from different tissue layers, OCT provides detailed imaging at micrometer-scale resolution. This method distinguishes itself from traditional imaging modalities like computed tomography (CT) and magnetic resonance imaging (MRI), which utilize ionizing radiation or magnetic fields, making OCT safer and more suitable for real-time and repeated assessments. In gastrointestinal (GI) cancer diagnostics, OCT offers the ability to visualize tissue architecture in detail, which is critical for identifying early dysplastic or cancerous lesions [8]. The minimal invasiveness of OCT, combined with its precision, has made it an invaluable tool in detecting and monitoring cancer progression in the GI tract.

The technology's primary strength is its ability to image beneath the surface of the GI mucosa, allowing for the identification of structural changes in tissues, such as thickened epithelial layers and disordered crypts. These early-stage alterations often precede cancer development and may not be detectable through conventional endoscopic techniques, which focus on surface-level abnormalities [9]. This deep tissue imaging capability makes OCT particularly effective in early detection, especially for conditions like Barrett's esophagus, a precancerous condition linked to esophageal cancer.

### *Technical Aspects*

OCT's technical sophistication is rooted in its ability to generate high-resolution, cross-sectional images of tissues, often at a resolution of 1–10 microns. This is critical for identifying minute structural changes that signal the early onset of malignancy. The two main types of OCT systems used in GI diagnostics are time-domain OCT (TD-OCT) and frequency-domain OCT (FD-OCT). TD-OCT operates by directly measuring the time delay of light reflections, while FD-OCT (and its variant spectral-domain OCT) interprets interference patterns to construct images. FD-OCT provides faster image acquisition and greater sensitivity, which is especially beneficial for real-time applications in endoscopic procedures [8].

In gastrointestinal cancer diagnostics, FD-OCT has become the preferred system due to its high imaging speed and improved resolution. This system enhances clinicians' ability to detect early signs of neoplasia by offering clear visualization of tissue microstructures, such as increased epithelial thickness and distorted crypt architecture. Additionally, the ability of FD-OCT to produce cross-sectional images enables physicians to see deeper into tissue layers than standard endoscopy, making it an ideal complement to surface-level imaging techniques like narrow-band imaging [10].

## Applications of OCT in GI Cancers

### *Detection of Dysplastic and Cancerous Changes*

OCT excels in detecting dysplastic and cancerous changes in the gastrointestinal tract, making it an essential tool in early cancer diagnosis. The technology allows for the identification of structural changes in tissue layers that are indicative of malignancy, such as the thickening of the epithelial layer, loss of crypt definition, and disruption of normal tissue architecture. In conditions such as Barrett's esophagus, OCT can detect early dysplasia by visualizing glandular changes that precede the development of esophageal adenocarcinoma [8]. Similarly, in colorectal cancer screening, OCT can reveal early neoplastic changes, such as irregular crypt patterns and thickened mucosal layers, which are indicative of early-stage cancer [11].

Recent studies have also shown that combining OCT with other imaging modalities, such as fluorescence lifetime imaging (FLIM), can significantly improve diagnostic accuracy by providing complementary information. For example, in colorectal cancer detection, the combination of OCT and FLIM was found to increase diagnostic sensitivity to 87.4%, compared to using OCT alone [9]. This multimodal approach offers a more comprehensive view of tissue pathology, aiding in the early detection of cancerous and pre-cancerous lesions.

### *Current Limitations*

Despite its many advantages, OCT does have certain limitations. One of the key challenges in using OCT is differentiating between benign and malignant tissues, as benign conditions such as inflammation or hyperplasia can sometimes mimic the appearance of early-stage cancer in OCT images. This can lead to false-positive results, which may increase the likelihood of unnecessary biopsies or other invasive procedures [12]. Moreover, while OCT provides high-resolution images, its diagnostic accuracy is not always consistent across different patient populations, and the quality of the images can vary depending on factors such as operator skill and the specific area of the GI tract being examined.

Another limitation is that OCT's field of view is relatively narrow compared to other imaging techniques, such as endoscopy or CT, which provide a more comprehensive visualization of the GI tract. This limitation means that while OCT excels at detecting localized abnormalities, it may miss larger or more diffuse lesions. Additionally, the high cost of OCT systems and the need for specialized training to interpret OCT images can limit its widespread adoption in clinical practice, particularly in low-resource settings [13]. Ongoing research is exploring ways to integrate artificial intelligence (AI) algorithms with OCT to enhance diagnostic accuracy and reduce operator dependency, but these advancements are still in their early stages.

## Artificial Intelligence (AI) in OCT

Artificial Intelligence (AI) and Machine Learning (ML) are rapidly transforming the healthcare landscape, offering new ways to analyze complex medical data and assist in clinical decision-making. AI refers to the development of machines capable of simulating human intelligence, and performing tasks such as reasoning, learning, problem-solving, and decision-making. Within AI, Machine Learning is a specialized subset that allows machines to learn from data patterns without being explicitly programmed. This capability enables systems to improve over time based on experience, making them highly adaptable in dynamic environments like medicine. A more advanced branch of ML is Deep Learning (DL), which utilizes artificial neural networks with multiple layers to analyze vast and complex datasets. These networks mimic the human brain's neural structure, enabling deep learning algorithms to model intricate relationships within the data, which is especially useful for tasks such as image recognition, speech processing, and medical diagnosis.

Various AI algorithms play key roles in healthcare, particularly in the field of medical imaging. One prominent algorithm is the Convolutional Neural Network (CNN), a type of deep learning model that processes visual data by scanning images in segments and identifying critical features such as edges, textures, and shapes. CNNs have become essential tools in analyzing medical images, such as those generated by Optical Coherence Tomography (OCT), which is widely used in ophthalmology and increasingly in other specialties like gastroenterology and oncology. By identifying distinct visual features, CNNs help detect abnormalities and diseases, such as early-stage cancers [14]. Another key algorithm is the Support Vector Machine (SVM), a supervised learning model that classifies data by finding the optimal boundary, or hyperplane, between different classes [14]. In medical contexts, SVMs are useful for distinguishing between categories such as benign and malignant tissues in imaging data. Random Forests, an ensemble learning method, aggregates predictions from multiple decision trees, improving the accuracy of classification tasks, which can be critical in diagnosing diseases from imaging data.

The integration of AI with Optical Coherence Tomography (OCT) represents one of the most promising advancements in medical imaging. OCT is a non-invasive imaging technique that provides high-resolution cross-sectional images of tissues, making it particularly valuable for detecting early-stage diseases. By training AI models using large datasets of labeled OCT images, these systems can learn to recognize specific features associated with various pathologies [15]. For example, in diagnosing gastrointestinal (GI) cancers, AI algorithms can analyze OCT scans to distinguish between benign and malignant tissues. Supervised learning techniques, particularly using CNNs, enable the AI to identify patterns in the data, such as subtle textural changes or irregularities in tissue structure that may indicate the presence of cancerous cells. Over time, these models become more accurate as they are trained on larger datasets, improving their ability to detect early signs of disease that may otherwise go unnoticed.

Developing and validating AI models for cancer detection using OCT involves a multi-step process. First, the data preprocessing stage ensures that the OCT images are clean, properly formatted, and standardized to eliminate any noise or inconsistencies that could affect the model's learning. Following preprocessing, the AI algorithm undergoes training, where it is fed a set of labeled OCT images, and learns to identify features that are correlated with GI cancers, such as dysplasia or neoplasia [15]. The validation stage then tests the algorithm's performance on a separate set of images not used during training. This helps determine how well the AI generalizes to new, unseen data. Performance metrics like accuracy, sensitivity, specificity, and the area under the receiver operating characteristic (ROC) curve are used to assess the model's effectiveness in distinguishing between normal and abnormal tissues. These steps ensure that the AI system not only performs well in controlled environments but can also be applied reliably in clinical practice.

AI-enhanced OCT offers numerous advantages over traditional diagnostic methods, particularly through real-time automated analysis. One of the main benefits of automated analysis is its ability to significantly increase diagnostic accuracy. By automatically detecting suspicious patterns or abnormalities in OCT images, AI reduces the variability and subjectivity often associated with human interpretation [16]. This is particularly important in high-stakes settings like cancer diagnosis, where early detection is critical for successful treatment outcomes. For example, AI algorithms have been shown to excel in detecting early signs of dysplasia or cancerous lesions in gastrointestinal tissues, which are often difficult for clinicians to identify without advanced tools. In ophthalmology, AI applied to OCT images has greatly improved the diagnosis of retinal diseases and similar applications are now being adapted to gastrointestinal imaging, where AI is helping to detect neoplastic changes in the esophagus and colon [16, 17]. The rapid analysis capabilities of AI also allow for faster decision-making, which can enhance efficiency in high-volume clinical settings and improve patient care.

In addition to improving diagnostic speed and accuracy, AI provides enhanced capabilities in distinguishing between benign and malignant tissues. AI models, particularly deep learning algorithms like CNNs, can detect subtle differences in histopathological features that may be invisible to the human eye. This results in more accurate diagnoses, enabling clinicians to identify malignant tissues at earlier stages and reduce the need for unnecessary biopsies [18]. Case studies have demonstrated the significant impact of AI on diagnostic precision. For instance, in one study, AI-assisted OCT was used for esophageal cancer screening and showed markedly improved sensitivity and specificity compared to traditional diagnostic methods. The AI model was able to differentiate between high-grade dysplasia and benign conditions more accurately than human observers [18]. Similarly, in colorectal cancer screening, AI algorithms were more effective than endoscopic observation alone in identifying pre-cancerous polyps, which has the potential to enhance early intervention and improve patient outcomes.

Despite its promise, the integration of AI into medical imaging does come with challenges. One major issue is the risk of overfitting, where an AI model performs exceptionally well on the training data but struggles with unseen data, limiting its generalizability. This can occur if the model is trained on a dataset that needs to be bigger or representative of the broader patient population, leading to biased or inaccurate results in clinical practice [19]. To mitigate this, large and diverse datasets are essential for training and validating AI models. Such datasets should encompass a wide range of patient demographics, tissue types, and disease stages to ensure that the AI system can accurately generalize across different clinical scenarios. Collaborative efforts among medical institutions could help in gathering the necessary data, providing AI systems with the robust information they need to perform reliably in real-world settings.

Integrating AI-enhanced OCT into routine clinical workflows presents additional challenges. Clinicians must be able to trust the outputs generated by AI systems and must be adequately trained to interpret these results effectively. This may require changes to existing clinical workflows, including the adoption of new protocols for using AI-based diagnostic systems. Training healthcare providers on how to use AI-enhanced OCT is critical to ensuring that the technology is utilized to its full potential [19]. However, cost and accessibility remain significant barriers, particularly in low-resource settings where the implementation of advanced AI technologies may be financially prohibitive. Clear protocols, user-friendly interfaces, and scalable systems will be necessary to ensure that AI's benefits can be maximized without overwhelming healthcare providers or disrupting patient care.

AI-enhanced Optical Coherence Tomography is one such modality capable of diagnosing colorectal and gastric cancerous polyps during endoscopic procedures. It may be used in EGD and colonoscopy procedures. Traditional diagnostic modalities for such procedures are shown to include endoscopy with biopsy, endoscopic ultrasound, CT, barium swallow tests, and diagnostic laparoscopy. These methods would solely rely on the physician's interpretation of the results. In contrast, AI-enhanced OCT makes use of additional layers of help by using imaging that is high resolution, made in real-time, and has automated analysis. A recent study in 2018 showcased how AI-enhanced OCT can effectively distinguish between the mucosa and submucosa in the colon by identifying different "teeth" patterns made by the vertical crypt structures found in the mucosa [20]. The submucosa appeared to be permeable due to blood vessels, connective tissue, and lymphatic vessels already being present. In cases of benign adenomas, OCT showed no signs of this “teeth” pattern. However, the mucosa appears stiffer and thicker compared to normal tissue. AI-enhanced OCT offers considerable advantages compared to traditional diagnostics such as finding the presence of cancer from an early stage. This is mainly because of its capability to detect slight changes within tissue structure that can easily be missed by a standard technique [21]. Furthermore, a convolutional neural network (Mask R-CNN) has already harnessed the power of AI. It applies an AI object detection and segmentation tool to the identification of cancerous lesions at the pixel level. It applies multiple object detection in complex images and is able to identify EGC lesions with high precision in pixel-wise segmentation. WLI is a traditional endoscopic examination technique that uses broad-spectrum white light to view the gastrointestinal mucosa. It is sensitive but varies in detecting the minute changes in the tissues, hence leading to misdiagnosis. Whereas narrow-band imaging is an image-enhanced endoscopic method that involves changing the light to specific wavelengths, which helps in enhancing the visualization of blood vessels and surface structures. This can help in being able to identify abnormal lesions more clearly. The study was able to detect early gastric cancer using WLIs with an accuracy of 90.25% from the Mask R-CNN system, which is lower than NBIs accuracy which can reach up to 95.12% [21]. Both WLIs and NBIs had a specificity of 89.01%, thus the systems can distinguish cancerous cases/lesions from non-cancerous ones [21]. The system's potential to enhance early detection in gastric cancer screenings is shown by the 93% sensitivity of the AI-enhanced system, which is significantly higher than the 80% sensitivity observed among human experts [21]. These findings signify how AI-enhanced OCT can largely enhance diagnostic accuracy, allowing for more reliable tools to help identify early gastric cancers compared to traditional methods.

## Therapeutic Interventions

### *Facilitating Therapeutic Interventions*

Integrating AI with Optical Coherence Tomography (OCT) into procedures like endoscopic mucosal resection (EMR) can drastically improve patient outcomes by offering real-time insights. AI with OCT helps medical professionals make faster and more accurate decisions based on these real time insights. Notably, AI can identify the boundaries of abnormal tissues with greater precision than prior methods, which improves treatment outcomes. Because of this increased precision, physicians can remove a more exact depth of tissue, lowering the chance of recurrence and reducing a procedure’s risks.

Real-time imaging allows clinicians to better execute various procedures. For example, clinicians using this new technology can better perform hot-snare EMR because it helps differentiate between various tissue layers. This differentiation has improved the success rate of procedures that involve the removal of large polyps or lesions in a single pass, reducing post-procedural complications like bleeding. AI's ability to highlight risky areas makes it easier for clinicians to perform these procedures more efficiently while minimizing risk.

### *Reducing the Need for Biopsies*

Integrating AI and OCT also may decrease the need for invasive diagnostic methods like biopsies. By providing detailed, real-time analysis, AI can identify early changes in tissue structure that would typically require a biopsy to confirm. Using this technology not only minimizes the number of unnecessary biopsies but also speeds up the entire diagnostic and treatment process. For patients, fewer biopsies mean a more comfortable experience, and from the physician’s perspective, using AI and OCT results in improved outcomes in terms of time and recovery. As AI technologies advance, they will further refine these processes, making treatment more accessible and less invasive overall.

## Future Directions and Research

### *Refining AI Algorithms*

To maximize the potential of AI in OCT for diagnosing GI cancers, it is crucial to focus on refining AI algorithms to enhance both their accuracy and generalizability. Employing advanced machine learning techniques, such as deep learning with convolutional neural networks (CNNs), can significantly improve the model's ability to detect subtle histopathological features in OCT images. CNNs are generally used for computer vision tasks in other medical fields such as radiology. Larger datasets are needed for CNNs to work as needed, which is unfortunately a scarce finding due to lack of physician input and ethical issues around “well-annotated large medical datasets” [22].

Strategies like ensemble learning, which aggregates predictions from multiple models, can further enhance diagnostic performance by reducing errors and capturing different data aspects [23]. By employing ensemble learning techniques, multiple AI models can be trained to analyze OCT images, each potentially focusing on different features or patterns within the images. For instance, one model might excel at detecting subtle changes in tissue layers, while another might be better at identifying specific types of pathology. This approach helps in reducing the likelihood of errors that any single model might make by aggregating the predictions from multiple models, thereby providing a more reliable and comprehensive assessment of the OCT images. Additionally, the ensemble of models can capture a broader range of data aspects, which is crucial for detecting various conditions and anomalies that might not be apparent with a single model. For example, subtle variations in tissue structure or early signs of disease might be missed by individual models but can be detected when their predictions are combined. Integrating multimodal data, such as combining OCT images with patient demographics and clinical history, offers a more comprehensive view of a patient's condition to support more personalized treatment recommendations.

A key factor in refining AI algorithms is ensuring they are trained on diverse and representative datasets. Training on a wide range of cases, including varying demographics, disease stages, and tissue types, ensures that models generalize well across different patient populations. Diversity is important in terms of giving the program a wide range of racial and ethnic groups, as well as disease progression from a large and unique spectrum of cases [24]. This approach also helps reduce biases and improve diagnostic accuracy. Furthermore, a diverse dataset reduces the risk of overfitting, where the model performs well only on familiar data but struggles with new cases. Overfitting is usually noticed when the model has higher accuracy on the training data compared to validation data, and can be fixed with adding more training data [24]. Overfitting occurs when an AI model learns the training data too well, capturing not only the underlying patterns but also the noise and anomalies specific to that dataset. As a result, while the model performs exceptionally well on the training data, its ability to generalize to new, unseen OCT images is compromised, leading to poor performance in real-world scenarios. This issue is particularly critical in medical imaging such as OCT, where accurate and reliable diagnostics are essential. To mitigate overfitting, techniques such as cross-validation, regularization, and the use of diverse training datasets are employed. Due to the limited datasets available and the recent incorporation of AI-enhanced OCT in the setting of detecting GI cancers, there is currently insufficient data available to conduct a sex and gender analysis for differences in how GI cancers could potentially manifest differently across sex and gender. Additionally, ensemble learning can be beneficial in this regard, as combining predictions from multiple models can help balance out individual model biases and reduce the impact of overfitting, leading to more robust and generalizable diagnostic performance in AI-enhanced OCT systems.

### *Innovations in AI and OCT Technology*

Generative adversarial networks (GANs), enhance the capability of AI models to detect and interpret complex tissue patterns with unprecedented precision. GANs are different from the aforementioned CNNs mainly because CNNs are usually trained on labeled data, while GANs are trained on raw real data. Therefore, the purpose of CNNs is to recognize patterns in provided images (data), while GANs create novel data based on the pattern it analyzes in the training data simultaneously [25]. GANs are generally used to generate highly realistic images. These techniques improve the accuracy of identifying subtle pathological changes and distinguishing between benign and malignant tissues. Concurrently, OCT technology is evolving with innovations like swept-source OCT and high-definition OCT, which offer deeper tissue penetration and higher resolution imaging, respectively [26]. These advancements can enable more detailed and accurate visualization of the GI tract. The integration of these sophisticated AI algorithms with enhanced OCT imaging systems promises to provide real-time, highly accurate diagnostic capabilities, reducing the need for invasive procedures and facilitating earlier and more effective treatment interventions [27]. As these technologies continue to develop, they hold the potential to significantly transform the management of GI cancers by providing more precise and personalized diagnostic and therapeutic options.

### *Cost-Effectiveness and Accessibility*

Developing cost-effective strategies is essential in making AI-enhanced OCT technology more accessible and sustainable. One approach involves optimizing the algorithms and computational processes to reduce the computational power required, which can lower the associated hardware and operational costs. This might include using more efficient AI models that require less data processing power or integrating cloud-based solutions that leverage shared computing resources [28]. Developing open-source AI tools and leveraging collaborations between technology developers and healthcare institutions can further drive down costs by sharing resources and expertise. This would allow for higher accessibility in areas with fewer medical providers, especially in terms of using AI-enhanced OCT technology in “screening and referral pathways” [29]. Therefore, standardization of OCT equipment also plays a crucial role, as it would make advanced imaging technologies more affordable for widespread use.

### *Expanding Accessibility*

Efforts to incorporate AI-enhanced OCT into routine clinical practice are crucial for improving patient care and treatment outcomes. Expanding accessibility involves training healthcare professionals to use these advanced technologies effectively and integrating them into existing workflows. Establishing partnerships between technology developers and healthcare systems can facilitate the development of user-friendly interfaces and support systems, ensuring that clinicians can adopt these tools seamlessly [30]. The potential impact on patient care is significant; by providing real-time, accurate diagnostics, AI-enhanced OCT can lead to earlier detection of gastrointestinal cancers, reduce the need for invasive procedures, and personalize treatment plans. This improved diagnostic capability not only enhances patient outcomes by enabling more timely and targeted interventions but also optimizes resource use in clinical settings.

## Implications for Clinical Practice and Public Health

### *Impact on Patient Care*

As AI-enhanced OCT has already made strides in preventing and monitoring diseases such as diabetic retinopathy and macular degeneration, this technology can further advance the field of personalized medicine [31]. Although the concept of personalized medicine may appear elusive, there has been ongoing research that shows how personalized medicine can be mapped via a mathematical model to generate personalized treatment algorithms [32]. OCT is a novel technology that provides high-resolution cross-sectional imaging on the scale of a micron in real time [33]. OCT is a minimally invasive technique that has been shown to help overcome the limitations of classical surgical techniques in fields such as otolaryngology, where auditory structures as small as ossicles are visualized [33].

### *Changes to Clinical Guidelines and Protocols*

OCT was originally utilized in the clinic to better visualize the eye, and as a result, OCT has had the largest clinical impact in ophthalmology thus far [33]. However, fields outside of ophthalmology have not yet fully integrated AI-enhanced OCT as a routinely used tool in their clinical practice, as there is still ongoing research to compare the effectiveness of OCT against their current diagnostic tools, such as MRI imaging [34]. As other fields continue to explore the application of OCT in their practice, protocols can be developed to standardize its usage.

### *Role of Healthcare Providers*

Given the high speed and resolution that OCT brings, this tool has been shown to have promising results in increasing surgical precision and outcome, as well as decreasing surgical time and complications [35]. Furthermore, the safe and non-invasive nature of OCT allows it to be an excellent teaching tool for medical students and residents [35, 36]. The ease of use of AI-enhanced OCT also allows healthcare providers to get trained quickly and efficiently for use in clinical practice [33]. AI-enhanced OCT can be directly beneficial to patient education, as it can provide clear visualization of the patient’s pathology to help patients better understand their treatment plan. OCT can be thought of as being analogous to ultrasound imaging, except that light is used rather than sound [33]. Physicians can download OCT images for patients to view.

## Conclusion

Gastrointestinal (GI) cancers remain a significant global health burden, with high morbidity and mortality rates due to late-stage diagnoses and the limitations of traditional diagnostic and treatment approaches. Early detection is critical to improving patient outcomes, offering higher survival rates and the possibility of less invasive treatments. Optical Coherence Tomography (OCT) emerges as a transformative imaging modality, providing high-resolution visualization of tissue microstructures and enabling the early detection of dysplastic and cancerous changes in the GI tract.

Despite its advantages, OCT faces challenges such as a narrow field of view, operator dependency, and the high cost of implementation. However, the integration of Artificial Intelligence (AI) promises to revolutionize its application by enhancing diagnostic accuracy, standardizing interpretation, and reducing false positives. By combining OCT with AI-driven technologies, the potential for earlier and more precise detection of GI cancers becomes increasingly achievable.

Advancing the adoption of these innovative tools, alongside continuous research and the development of cost-effective solutions, will be crucial in addressing the global burden of GI cancers. These efforts pave the way for improved healthcare outcomes, reduced treatment burdens, and enhanced quality of life for patients worldwide.

## Conflict of Interest Statement

The authors of this manuscript declare that they have no conflicts of interest that are directly or indirectly related to the work submitted for publication. Specifically:

1. Financial Interests: None of the authors have received any financial compensation, funding, grants, or other monetary support that could be perceived as influencing the research, analysis, or conclusions presented in this work.
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## References

1. Siegel, R. L., Miller, K. D., & Jemal, A. (2020). Cancer statistics, 2020. *CA: A Cancer Journal for Clinicians, 70*(1), 7-30. https://doi.org/10.3322/caac.21590
2. Arnold, M., Abnet, C. C., Neale, R. E., Vignat, J., Giovannucci, E. L., McGlynn, K. A., & Bray, F. (2020). Global burden of 5 major types of gastrointestinal cancer. *Gastroenterology, 159*(1), 335-349.e15. https://doi.org/10.1053/j.gastro.2020.02.068
3. Sung, H., Ferlay, J., Siegel, R. L., Laversanne, M., Soerjomataram, I., Jemal, A., & Bray, F. (2021). Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA: A Cancer Journal for Clinicians, 71*(3), 209-249. https://doi.org/10.3322/caac.21660
4. Bray, F., Ferlay, J., Soerjomataram, I., Siegel, R. L., Torre, L. A., & Jemal, A. (2018). Global cancer statistics 2018: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA: A Cancer Journal for Clinicians, 68*(6), 394-424. https://doi.org/10.3322/caac.21492
5. East JE, Vleugels JL, Roelandt P, et al. Advanced endoscopic imaging: European Society of Gastrointestinal Endoscopy (ESGE) Technology Review. Endoscopy. 2016 Nov;48(11):1029-1045. DOI: 10.1055/s-0042-118087. PMID: 27711949.
6. Lim, X. C., Nistala, K. R. Y., Ng, C. H., Lin, S. Y., Tan, D. J. H., Ho, K. Y., Chong, C. S., & Muthiah, M. (2021). Endoscopic submucosal dissection vs endoscopic mucosal resection for colorectal polyps: A meta-analysis and meta-regression with single arm analysis. World journal of gastroenterology, 27(25), 3925–3939. https://doi.org/10.3748/wjg.v27.i25.3925
7. Van Cutsem, E., Cervantes, A., Adam, R., Sobrero, A., Van Krieken, J. H., Aderka, D., ... & ESMO Guidelines Committee. (2020). ESMO consensus guidelines for the management of patients with metastatic colorectal cancer. *Annals of Oncology, 27*(8), 1386-1422. https://doi.org/10.1093/annonc/mdw235
8. Tang, Q., Wang, J., Frank, A., Lin, J. L., Li, Z., Chen, C. W., ... & Chen, Y. (2016). Depth-resolved imaging of colon tumor using optical coherence tomography and fluorescence laminar optical tomography. In Proceedings of SPIE 9701, Optical Coherence Tomography and Coherence Domain Optical Methods in Biomedicine XX (Vol. 9701, p. 97010G). https://dx.doi.org/10.1117/12.2211217
9. Pande, P., Shrestha, S., Park, J., Gimenez-Conti, I., Brandon, J. L., Applegate, B., & Jo, J. (2016). Automated analysis of multimodal fluorescence lifetime imaging and optical coherence tomography data for the diagnosis of oral cancer in the hamster cheek pouch model. *Biomedical Optics Express*, 7(5), 2000-2014. https://dx.doi.org/10.1364/BOE.7.002000
10. Kiesslich, R., & Neurath, M. (2005). Endoscopic detection of early lower gastrointestinal cancer. *Best Practice & Research Clinical Gastroenterology*, 19(6), 927-939. https://dx.doi.org/10.1016/J.BPG.2005.03.001
11. Eleftheriadis, N., Inoue, H., Ikeda, H., Onimaru, M., Yoshida, A., Maselli, R., & Santi, G. (2014). Definition and staging of early esophageal, gastric and colorectal cancer. *Journal of Gastroenterology and Hepatology*, 18, 14-21.
12. Wan, Q., Wang, T., & Zhang, K. (2017). Biomedical optical spectroscopy for the early diagnosis of gastrointestinal neoplasms. *Progress in Biomedical Optics and Imaging*, 18(27), 112-120. https://dx.doi.org/10.1177/1010428317717984
13. Galletly, N., McGinty, J., Cohen, P., Munro, I., Elson, D., Requejo-Isidro, J., ... & Stamp, G. (2006). Fluorescence lifetime imaging for detection of gastrointestinal cancer. *Gastrointestinal Endoscopy*, 63(4), 549-557. https://dx.doi.org/10.1016/J.GIE.2006.03.662.
14. Silva, H. E. C. D., Santos, G. N. M., Leite, A. F., Mesquita, C. R. M., Figueiredo, P. T. S., Stefani, C. M., & de Melo, N. S. (2023). The use of artificial intelligence tools in cancer detection compared to the traditional diagnostic imaging methods: An overview of the systematic reviews. PloS one, 18(10), e0292063. https://doi.org/10.1371/journal.pone.0292063
15. Kumar, Y., Gupta, S., Singla, R., & Hu, Y. C. (2022). A Systematic Review of Artificial Intelligence Techniques in Cancer Prediction and Diagnosis. Archives of computational methods in engineering: state of the art

reviews, 29(4), 2043–2070. https://doi.org/10.1007/s11831-021-09648-w

16. Hormel TT, Hwang TS, Bailey ST, Wilson DJ, Huang D, Jia Y. Artificial intelligence in OCT angiography. Prog Retin Eye Res. 2021 Nov;85: 100965. doi: 10.1016/j.preteyeres.2021.100965. Epub 2021 Mar 22. PMID: 33766775; PMCID: PMC8455727.
17. Muntean GA, Marginean A, Groza A, Damian I, Roman SA, Hapca MC, Muntean MV, Nicoară SD. The Predictive Capabilities of Artificial Intelligence-Based OCT Analysis for Age-Related Macular Degeneration Progression-A Systematic Review. Diagnostics (Basel). 2023 Jul 24;13(14):2464. doi: 10.3390/diagnostics13142464. PMID: 37510207; PMCID: PMC10378064.
18. Hunter, B., Hindocha, S., & Lee, R. W. (2022). The Role of Artificial Intelligence in Early Cancer Diagnosis. Cancers, 14(6), 1524. https://doi.org/10.3390/cancers14061524
19. Karalis, V. D. (2024). The integration of artificial intelligence into clinical practice. Applied Biosciences, 3(1), 14–44. https://doi.org/10.3390/applbiosci3010002
20. Plekhanov, A. A., Sirotkina, M. A., Gubarkova, E. V., Kiseleva, E. B., Sovetsky, A. A., Karabut, M. M., Zagainov, V. E., Kuznetsov, S. S., Maslennikova, A. V., Zagaynova, E. V., Zaitsev, V. Y., & Gladkova, N. D. (2023a, March 15). *Towards targeted colorectal cancer biopsy based on tissue morphology assessment by compression optical coherence elastography*. Frontiers. https://www.frontiersin.org/journals/oncology/articles/10.3389/fonc.2023.1121838/full
21. Jin, J., Zhang, Q., Dong, B., Ma, T., Mei, X., Wang, X., Song, S., Peng, J., Wu, A., Dong, L., & Kong, D. (2022, September 5). *Automatic detection of early gastric cancer in endoscopy based on mask region-based convolutional neural networks (Mask R-CNN)(with video)*. Frontiers. https://www.frontiersin.org/journals/oncology/articles/10.3389/fonc.2022.927868/full#h13
22. Yamashita, R., Nishio, M., Do, R.K.G. et al. Convolutional neural networks: an overview and application in radiology. *Insights Imaging, 8*, 611–629 (2018). https://doi.org/10.1007/s13244-018-0639-9
23. Logan, R., Williams, B. G., Ferreira da Silva, M., Indani, A., Schcolnicov, N., Ganguly, A., & Miller, S. J. (2021). Deep Convolutional Neural Networks with Ensemble Learning and Generative Adversarial Networks for Alzheimer's Disease Image Data Classification. *Frontiers in Aging Neuroscience, 13*, 720226. https://doi.org/10.3389/fnagi.2021.720226
24. Mulyukov, Z., Keane, P. A., Sahni, J., Liakopoulos, S., Hatz, K., Wei Ting, D. S., Gallego-Pinazo, R., Aslam, T., Gemmy Cheung, C. M., De Salvo, G., Semoun, O., Somfai, G. M., Stahl, A., Lujan, B. J., & Lorand, D. (2024). Artificial Intelligence-Based Disease Activity Monitoring to Personalized Neovascular Age-Related Macular Degeneration Treatment: A Feasibility Study. *Ophthalmology Science, 4*(6), 100565. https://doi.org/10.1016/j.xops.2024.100565
25. Shokraei Fard, A., Reutens, D. C., & Vegh, V. (2022). From CNNs to GANs for cross-modality medical image estimation. *Computers in Biology and Medicine, 146*, 105556. https://doi.org/10.1016/j.compbiomed.2022.105556
26. Chen, S., Potsaid, B., Li, Y. et al. High speed, long range, deep penetration swept source OCT for structural and angiographic imaging of the anterior eye. *Sci Rep 12*, 992 (2022). https://doi.org/10.1038/s41598-022-04784-0
27. Zheng, F., Deng, X., Zhang, Q., He, J., Ye, P., Liu, S., Li, P., Zhou, J., & Fang, X. (2022). Advances in swept-source optical coherence tomography and optical coherence tomography angiography. *Advances in Ophthalmology Practice and Research, 3*(2), 67–79. https://doi.org/10.1016/j.aopr.2022.10.005
28. Gendia A. (2022). Cloud Based AI-Driven Video Analytics (CAVs) in Laparoscopic Surgery: A Step Closer to a Virtual Portfolio. *Cureus, 14*(9), e29087. https://doi.org/10.7759/cureus.29087
29. Mares, V., Nehemy, M.B., Bogunovic, H. et al. AI-based support for optical coherence tomography in age-related macular degeneration. *Int J Retin Vitr 10*(31) (2024). https://doi.org/10.1186/s40942-024-00549-1
30. Bajwa, J., Munir, U., Nori, A., & Williams, B. (2021). Artificial intelligence in healthcare: transforming the practice of medicine. *Future Healthcare Journal, 8*(2), e188–e194. https://doi.org/10.7861/fhj.2021-0095
31. Quek, T. C., Takahashi, K., Kang, H. G., Thakur, S., Deshmukh, M., Tseng, R. M. W. W., Nguyen, H., Tham, Y., Rim, T. H., Kim, S. S., Yanagi, Y., Liew, G., & Cheng, C. (2022). Predictive, preventive, and personalized management of retinal fluid via computer-aided detection app for optical coherence tomography scans. *The EPMA Journal, 13*(4), 547–560. https://doi.org/10.1007/s13167-022-00301-5
32. Khokhlova, D. Y., Drozdova, E. A., Kurysheva, N. I., & Loskutov, I. A. (2021). Optical coherence tomographic patterns in patients with retinal vein occlusion and macular edema treated by ranibizumab: a predictive and personalized approach. *The EPMA Journal, 12*(1), 57–66. https://doi.org/10.1007/s13167-021-00233-6
33. Dong, W., & Meenderink, S. W. (2023). Imaging the ear anatomy and function using optical coherence tomography vibrometry. *Seminars in Hearing, 45*(01), 101–109. https://doi.org/10.1055/s-0043-1770154
34. Martin, S., Rashidifard, C., Norris, D., Goncalves, A., Vercollone, C., & Brezinski, M. E. (2022). Minimally Invasive Polarization Sensitive Optical Coherence Tomography (PS-OCT) for assessing Pre-OA, a pilot study on technical feasibility. *Osteoarthritis and Cartilage Open, 4*(4), 100313. https://doi.org/10.1016/j.ocarto.2022.100313
35. Angmo, D., Devi, C., & Dada, T. (2023). Intraoperative optical coherence tomography–guided transconjunctival bleb suturing-A minimally invasive technique for managing overfiltering bleb. *Indian Journal of Ophthalmology, 72*(3), 455–457. https://doi.org/10.4103/ijo.ijo_2015_23
36. Peng, J., Xie, X., Lu, Z., Xu, Y., Xie, M., Luo, L., Xiao, H., Ye, H., Chen, L., Yang, J., Zhang, M., Zhao, P., & Zheng, C. (2024). Generative adversarial networks synthetic optical coherence tomography images as an education tool for image diagnosis of macular diseases: a randomized trial. *Frontiers in Medicine, 11*. https://doi.org/10.3389/fmed.2024.1424749