Modern high-tech approaches to the diagnosis of gastrointestinal diseases

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Abstract

The article discusses modern high-tech approaches to the diagnosis of gastrointestinal diseases. Revealing the relevance of the problem and the importance of accurate and timely diagnosis for the successful treatment of patients, the authors draw attention to the latest methods and technologies used in this field of medicine. The article discusses various diagnostic methods, including endoscopy, ultrasound, computed tomography, magnetic resonance imaging, molecular genetic analyses, as well as the use of artificial intelligence and machine learning to analyze medical data. The advantages and limitations of each method, their effectiveness and development prospects are discussed. The question is also raised about the need for an integrated approach to diagnosis, including a combination of various methods to improve the accuracy and reliability of the results. It is concluded that low-frequency imaging technologies provide a promising strategy for diagnosing diseases of the gastrointestinal tract. These technologies provide more complete information about the disease by integrating multiple contrast agents for imaging.

Keywords

Gastrointestinal tract, Diagnostics, Technologies, Innovations, Accuracy and reliability of results

INTRODUCTION

Diseases of the gastrointestinal tract (GI tract) remain one of the most common and serious medical problems worldwide [1]. They have a significant impact on the quality of life of patients and require a high level of attention from the medical community. However, accurate diagnosis of gastrointestinal diseases remains a difficult task that requires innovative approaches and modern technologies.

In recent years, significant progress has been made in the field of medical diagnostics, in particular in the context of gastrointestinal diseases. New technologies and diagnostic methods make it possible to more accurately and effectively identify pathologies, which contributes to an earlier start of treatment and an improved prognosis of the disease [2].

This review examines modern technological approaches to the diagnosis of gastrointestinal diseases, describes their advantages, limitations and development prospects. Understanding and mastering these modern approaches to the diagnosis of gastrointestinal tract play a key role in improving the quality of medical care and improving patient treatment outcomes.

MATERIALS AND METHODS

To conduct this study, a literature review was carried out, including scientific articles, reviews, clinical recommendations and publications in the field of medicine and diagnosis of gastrointestinal diseases. Data on various diagnostic methods, their advantages and limitations, as well as current trends in this area were analyzed. The data obtained were analyzed taking into account their clinical significance, effectiveness and development prospects in the context of diagnosis and treatment of gastrointestinal diseases.

RESULTS

Diseases of the gastrointestinal tract (GI tract) include various benign and malignant pathologies, as well
as liver, biliary tract and pancreas. These diseases are divided into two main groups: functional and structural [3]. With functional pathology, the structure of the digestive tract looks normal, but medical studies reveal motor disorders. There are various problems and signs, including bloating, constipation, diarrhea, gas, irritable bowel syndrome (IBS), nausea, as well as uncomplicated gastroesophageal reflux disease [4]. In the case of structural pathologies, both abnormal appearance and mobility occur. These include acute and chronic pancreatitis, peptic ulcer of the stomach and duodenum, gallstone disease, as well as benign and malignant neoplasms, inflammatory bowel diseases (IBD), including Crohn's disease (CD) and ulcerative colitis (UC) [5].

Diagnosis and treatment of gastrointestinal diseases are usually very complex and require the participation of a multidisciplinary team including gastroenterologists, radiologists, oncologists and surgeons [6]. Laboratory, imaging, endoscopic, non-invasive and invasive studies are used in the diagnosis of this group of diseases. In addition, the treatment of gastrointestinal diseases has a wide range: from observation and conservative treatment to invasive radiological, endoscopic and surgical procedures [7].

There are many studies that statistically analyze the diagnoses of specialists and artificial intelligence related to gastroenterology, and prove that an artificial intelligence application can diagnose as well as an endoscopist [8]. The experts found the following: when comparing the results of standard colonoscopy and the computer diagnostics system (CDS) based on deep learning used in the diagnosis of polyps, it was determined that more small adenomas (p <0.001) were detected by CDS compared with standard colonoscopy, whereas there was no statistical difference in larger adenomas (p = 0.075) [9]. The results of this study confirm the conclusion that artificial intelligence applications can be more effective than the results of the work of endoscopic diagnostics specialists. An endoscopic specialist for the diagnosis of diseases of the gastrointestinal tract makes a decision by examining the spatial differences between the surface and tissues of the mucous membrane [10]. During the review and decision-making, the specialist may miss small polyps or lesions. Diagnosis using a hybrid artificial intelligence model with high accuracy and sensitive measurements can offer many opportunities to help a specialist, such as saving money, time, workload, early diagnosis and the objectivity of endoscopic diagnosis [11].

Recently, both the diagnosis and treatment of this group of diseases have been improved, including, in particular, molecular laboratory studies, gastrointestinal endoscopy with artificial intelligence, targeted and immunological oncological therapy, as well as robotic surgery [12].

Many studies of the human microbiome have been published recently. Clinical and population-based studies have revealed the diversity of the healthy microbiome, as well as its changes in disease [13]. Changes in the human gut microbiome are associated with various diseases of the gastrointestinal tract and liver, including inflammatory bowel disease, colorectal cancer (CRC), alcohol-associated liver disease and non-alcoholic fatty liver disease. Bacteriophages used against pathogenic bacterial infections can also precisely modulate the gut microbiome and provide promising therapeutic effects in numerous gastrointestinal diseases [14].

With regard to the diagnosis of IBD, non-invasive, affordable and cost-effective biomarkers are needed to diagnose the disease. In recent years, more and more new serum and fecal biomarkers have been discovered, including serum glycoprotein rich in leucine, antibodies against Saccharomyces cerevisiae (ASCA), perinuclear antineutrophil cytoplasmic antibodies (pANCA) (with high specificity for IBD), cytokines such as granulocyte colony stimulating factor associated with endoscopically active disease, interleukins (IL) IL-6 and IL-2, circulating non-coding RNAs, cathelicidin, trefoil factor 3, 25-hydroxyvitamin D3, extracellular matrix components (EMC) and growth factors, as well as fecal myeloperoxidase [15].

In addition, new concepts of pathophysiology, diagnosis and treatment of acute pancreatitis (OP) and chronic pancreatitis (CP) have recently been developed. The most important discoveries include new serum biomarkers – ethyl esters of fatty acids (FAEE) – for the diagnosis of alcoholic OP, new concepts of the participation of monocytes/macrophages in the immune response [16].

Pancreatic cancer (pancreatic cancer) is a very aggressive neoplasm characterized by a very poor prognosis (5-year survival rate of 5-8% and a median survival rate of 5 months). The most common type of this cancer is pancreatic ductal adenocarcinoma (PDAC), which is noted in 95% of patients [17]. Diagnosis is often delayed due to its aggressive biology and late onset. This fact is associated with a poor prognosis. Recently,
the first unicellular and spatial transcriptomic PDAC atlases have been published, the role of Schwann cells in the tumor microenvironment in perineural invasion through JUN activation has been reported, as well as the role of aerobic exercise in reducing PDAC growth through activation. CD8+ T lymphocytes mediated by cytokines (IL-15–IL-15RA) have been described. Due to the poor prognosis and the late stage at the time of diagnosis, early detection of PDAC is an important problem [18]. Progress in the genetic and molecular analysis of various samples, including blood, as well as pancreatic tissue, pancreatic juice and pancreatic cystic fluid, creates the possibility of early diagnosis of PDAC using molecular approaches [19]. Noninvasive assessment of genetic changes in human blood allows early diagnosis of PDAC and precancerous lesions, including mucinous cystic neoplasms (MCN) and intracurrent papillary mucinous neoplasms (IPMN).

Molecular, genetic and epigenetic diagnostic tools, new biomarkers and promising therapeutic targets are promising in PDAC therapy [20]. The introduction of microchip technology and the use of large data warehouses are important for the diagnosis and treatment of PDAC. Numerous molecular analyses based on RNA interference can be used in new therapeutic targets for PDAC patients.

DISCUSSION
At the present stage, standard methods for diagnosing diseases of the gastrointestinal tract include endoscopy, ultrasound (ultrasound), computed tomography (CT), magnetic resonance imaging (MRI) and positron emission tomography (PET). Although endoscopy improves diagnostic accuracy by allowing direct visualization of lesions, it is associated with various procedural complications such as functional disorders, pain reactions, respiratory distress and bacterial infections, both during and after the invasive procedure. In addition, ultrasound, CT, MRI, and PET scans are commonly used to compare the stages and surgical assessment of gastrointestinal diseases. However, due to involuntary movements of the gastrointestinal tract and the overlap of abdominal tissues, their overall sensitivity in detecting diseases of the gastrointestinal tract remains relatively low. Moreover, the contrast agents corresponding to them do not have target specificity, which leads to a non-specific distribution, which can lead to side effects, including allergic reactions, toxicity and nausea. These limitations limit their widespread clinical use. Therefore, in order to overcome these problems, there is an urgent need to develop innovative methods, such as diagnostics based on nanoparticles (NP), which have high sensitivity and specificity [21].

Nanotechnology includes the study of materials with structure sizes from 1 to 100 nm, the study of their properties and potential applications. Woofers have a wide range of unique properties such as optical, electrical, magnetic, thermal and mechanical properties. In addition, they have advantages such as a high surface-to-volume ratio, excellent biocompatibility, minimal toxicity, targeted capabilities and the effect of increased permeability and retention (EPR) [22]. These characteristics make the LF very promising for improving the diagnosis of diseases.

The combination of NP with modern imaging techniques has been widely studied in various diseases, including tumors, cardiovascular diseases, neurological disorders, liver, kidney diseases, etc. In recent years, NP-based imaging techniques have attracted considerable attention in the diagnosis of diseases of the gastrointestinal tract due to their unique advantages [23].

NP used to visualize diseases of the gastrointestinal tract can be divided into two categories depending on their internal properties: inorganic NP and organic NP. These NP serve as imaging agents and nanocarriers, offering various functionality in diagnostic applications. These NP vary in size, shape and properties, which therefore affects their specific application in the diagnosis of diseases, so it is extremely important to have a complete understanding of the various types of NP and the corresponding imaging mechanisms. This knowledge allows flexible integration of modern imaging technologies, facilitating the creation of high-resolution images for the diagnosis of diseases of the gastrointestinal tract [24].

One of the developments in this field is nanowire (NW), which is a one–dimensional structure with a nanoscale cross section (<100 nm) and unlimited longitudinal length. They can be divided into different types depending on their composition, including metallic NW (such as Ni, Ag and Au), semiconductor NW (such as InP, Si and GaN), and insulator NW (such as SiO2 and ZnO) [25]. Metallic NW with their exceptional electrical, optical, thermal and mechanical properties have significantly influenced the field of bio-imaging. For example, copper NW have been
used in the visualization of surface-enhanced raman scattering (SERS), providing signal amplification with a surprisingly high signal-to-noise ratio (SNR). Magnetic NW, which serve as contrast agents for MRI, are increasingly being used in the diagnosis of various diseases due to their tunable magnetic properties and favorable biocompatibility [26]. For example, iron oxide core-shell NW have demonstrated high efficiency in cell detection, acting as T2 contrast agents for MRI, which promises to provide tracking of tumor cells of the digestive system. Silicon NW sensors offer numerous advantages in the early diagnosis of diseases by providing rapid analysis of nanoscale sample volumes by measuring resistance. Therefore, by combining various types of NW with appropriate diagnostic technologies, significant progress can be made in visualizing diseases of the gastrointestinal tract, which will lead to improved diagnostic results [27].

Iron oxide nanoparticles (IONP) have aroused considerable interest in bioimaging due to their exceptional magnetic properties and biocompatibility. They serve as attractive contrast agents, effectively reducing the time of longitudinal and transverse relaxation (T1 and T2), creating a strong contrast in MRI. In addition, by integrating specific ligands, such as antibodies to the epithelial growth factor receptor (EGFR), onto the IONP surface, a molecular target MRI was achieved for the early detection of gastrointestinal tumors, including gastric, pancreatic, colon and hepatocellular carcinoma. In addition to the diagnosis of tumors, IONP have significant potential in the diagnosis of other diseases of the digestive system [28]. For example, single-nanometer IONP in combination with type I collagen-binding peptides were used as T1-weighted contrast agents to improve liver imaging, which allows for rapid and non-invasive diagnosis of liver fibrosis.

Superparamagnetic iron oxide nanoparticles (SMIONP) are quite promising as contrast agents for MRI for diagnostic purposes, providing valuable information about various diseases of the gastrointestinal tract.

Quantum dots (QD) are nanoscale spherical or sphere-like segments of semiconductor crystalline materials with tunable optical properties, typically ranging in size from 2 to 10 nm. Over the years, QD scans have attracted significant attention in the field of biomedicine due to their exceptional capabilities, including increased stability and fluorescence intensity (almost 100 times brighter), high quantum yield, improved resistance to photobleaching and high attenuation coefficient. QD scans have been successfully used to label cells and proteins, which makes it possible to dynamically track biological processes [29].

The researchers used the fluorescent properties of QD to develop innovative diagnostic approaches. For example, one group of specialists linked the fluorescent QD signal to the concentration of biomarkers of the disease by conjugation of tyrosinase with detecting antibodies. This fluorescent immunoassay makes it possible to quickly detect a biomarker of hepatocellular carcinoma (HCC) AFP in concentrations of only 10 pM, opening up new opportunities for early diagnosis and monitoring of HCC in real time. In addition, another group of authors combined fluorescent and radioisotope QD with dextrose for targeting, tracking and multimodal imaging of macrophages using PET/CT and fluorescence imaging. This approach contributes to the monitoring of immune responses in gastrointestinal and IBD tumors [30]. Moreover, QD scans are promising as contrast agents in medical imaging due to their small size, rapid elimination ability and good biocompatibility. Thus, QD scans have great potential in the development of diagnostic methods for diseases of the digestive system, using their fluorescence characteristics and X-ray attenuation capabilities to detect single cells and molecules, as well as to visualize deep tissues.

Nanowells are ultrathin metal shells containing nanoscale nuclei of certain semiconductor complexes. They have highly configurable optical characteristics that depend on the thickness of the shell. Due to their plasmonic, optical and thermal properties, nanowells have found wide application in various biomedical imaging methods, including optical coherence tomography, diffuse optical tomography, ultrasound, PET, MRI [31]. One of the notable advantages of nanowells is their ability to absorb or scatter near-infrared waves (NIW). By adjusting the thickness and size of the shells, their localized surface plasmon resonance can be adjusted. This allows NIW radiation to easily and deeply penetrate into human tissues and blood, reaching a depth of several centimeters. In addition, nanowells can reduce unwanted autofluorescence caused by substances such as hemoglobin, lipids and water. For example, silver nanowells can be transformed into nanopores with high bi-activity by controlling the morphology of their surface. These nanopores exhibit strong and uniform near-infrared scattering signals and are successfully used for the detection of carcinomas.
Another advantage of nanowells is their high load capacity, especially for hollow nanowells. This function allows precise control of the delivery of drugs, nucleic acids, contrast agents and other biomolecules. Accordingly, the unique properties of nanowells improve the functionality of nuclear NP and have great potential as nanoprobes for early detection of tumors of the gastrointestinal tract [32].

Dendrimers are non-polymer compounds with a three-dimensional tree-like globular structure. They are synthesized by adding highly branched layers to the central core. These unique structures make dendrimers versatile platforms for various biomedical applications due to their cavities and easily modifiable surfaces [33]. Polyamidoamine (PAMAM) dendrimers have been widely studied and characterized among dendrimers. One of the notable applications of PAMAM dendrimers is their use as carriers for the delivery of gadolinium ions in MRI.

Unlike other NP, dendrimers have a tunable molecular structure, a narrow polydispersity index, a large number of terminal functional groups and accessible internal cavities and branchings. These features allow specific molecular targets associated with diseases to bind to terminal functional groups, which makes dendrimers “smart” and able to accurately target malignant tumors or other diseases [34]. For example, specialists have developed a dual-mode nanoprobe aimed at the urokinase-type plasminogen activator receptor (uPAR) using dendritically grafted polylysine (DG-P)-U11. This nanoprobe is loaded with contrast agent for Gd 3+ MRI and fluorescent cyanine dye NIR Cy5.5 for the early detection of pancreatic cancer. The targeted nanoprobe improves the sensitivity and spatial resolution of near-infrared waves (NIW) MRI/fluorescence imaging, offering a promising nanoprobe for early detection of pancreatic cancer. The specific capabilities of dendrimers allow them to serve as carriers of contrast agents, contributing to the use of MRI, CT, PET and optical imaging in the diagnosis of diseases of the digestive system.

Polyelectrolyte complex nanoparticles (PCCNP) are formed by mixing polymers with opposite charges in aqueous solutions and can represent any charged substances, such as surfactants, proteins and colloids. PCCNP have been extensively researched for biomedical imaging purposes. For example, they have been used to protect, deliver and visualize therapeutic proteins by loading them with nanoparticles with increased conversion. PCCNP has also been used as contrast media carriers in imaging applications. These nanoparticles offer a universal platform for delivering contrast agents to specific locations, providing accurate and targeted visualization of diseases of the gastrointestinal tract [36].

Liposomes are spherical vesicles consisting of a lipophilic bilayer surrounding an aqueous core. They offer unique advantages as drug delivery systems, including biocompatibility, biodegradability, ease of surface modification and high load capacity. By developing their composition, size, and surface charge, liposomes can be adapted for biomedical imaging applications. Radioactively labeled liposomes have also been used in PET imaging. Liposomes as nanocarriers of imaging tools have great potential for the diagnosis of diseases of the gastrointestinal tract.

Micelles are self-organizing agglomerates with a hydrophobic core and a hydrophilic shell formed in an aqueous medium. They have several key properties, in-
Including high stability, excellent biocompatibility. In addition, their ability to effectively solubilize poorly soluble drugs and affect certain areas makes them highly desirable for biomedical applications. The amphiphilic nature of micelles makes them attractive as carriers of contrast agents in biomedical imaging. For example, frozen phophytin micelles purified from surfactants have been successfully obtained and used for multimodal imaging of the intestine using fluorescence, photoacoustics and PET methods. Loading various contrast agents into micelles offers a promising imaging method for diagnosing diseases of the digestive system [37].

Together, low-frequency imaging technologies provide a promising strategy for diagnosing gastrointestinal diseases. These technologies provide more complete information about the disease by integrating multiple contrast agents for imaging.

CONCLUSIONS

The human gastrointestinal tract is prone to several abnormal consequences: from minor discomfort to life-threatening diseases. Diseases of the gastrointestinal tract, such as ulcers, bleeding, polyps, Crohn’s disease, colorectal cancer, various malignant tumors and other related diseases, are well known all over the world today. According to the International Agency for Research on Cancer, the number of new cases of gastrointestinal cancer and the number of related deaths worldwide in 2018 is estimated at 4.8 million and is responsible for 26% of cancer cases worldwide and 35% of all cancer deaths. Early diagnosis of various gastrointestinal diseases can lead to effective treatment and reduce the risk of mortality. Unfortunately, various gastrointestinal diseases are not detected or create confusion during the examination by medical experts due to noise in the images, which suppresses important details. Visual evaluation of endoscopic images is subjective, often time-consuming and minimally repetitive, which can lead to an inaccurate diagnosis. The use of artificial intelligence (AI) in various endoscopic studies of the gastrointestinal tract can potentially improve clinical practice and increase the effectiveness and accuracy of modern diagnostic methods.

Deep learning techniques are another form of machine learning techniques that are used in several areas of gastrointestinal endoscopy, including the detection and classification of colorectal polyps, analysis of endoscopic images for the diagnosis of Helicobacter pylori infection, infection detection and assessment of the depth of early gastric cancer, as well as the detection of various anomalies in wireless capsule endoscopy images. Taking into account possible errors arising under the influence of the human factor, an automated computer system will be useful for the accurate diagnosis of gastrointestinal polyps in the early stages of cancer.

Low-frequency imaging technologies provide a promising strategy for diagnosing diseases of the gastrointestinal tract. These technologies provide more complete information about the disease by integrating multiple contrast agents for imaging.

LIST OF LITERATURE

11. Chao WL, Manikavasagan H, Krishna SG. The use of artificial intelligence for the detection and differen-


14. Dutta A, Bhattacharji RK, Barbuya FA. Effective detection of lesions during endoscopy. In international seminars and ICPR tasks; Lecture notes on Computer Science; Springer: Cham, Switzerland, 2021; Volume 12668, pp. 315-322.


