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The Application and Challenges of Emerging Technologies in Early Diagnosis and Screening of Gastric Cancer: From Molecular Markers to Imaging Advances

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Abstract This study comprehensively elucidates the application and challenges of emerging technologies in the early diagnosis and screening of gastric cancer, focusing on the latest developments from molecular biomarkers to imaging techniques. It aims to provide a comprehensive perspective for researchers in the field of early gastric cancer diagnosis, aiding in understanding and evaluating the application and challenges of these technologies. The study systematically introduces the importance of early diagnosis of gastric cancer and the limitations of traditional diagnostic methods. It delves into the application of molecular biomarkers in early gastric cancer diagnosis, including the latest discovered biomarkers and their current clinical applications. Furthermore, the study analyzes the application of genomics and proteomics technologies and their potential in diagnosing gastric cancer. Additionally, it emphasizes the role of the latest imaging technologies such as PET/CT and MRI in gastric cancer screening. The study acknowledges that despite the immense potential of these emerging technologies, they still face multiple challenges in specificity and sensitivity, cost and accessibility, complexity in data processing, and the need for clinical validation and standardization. Finally, the authors propose future research directions, including improving the specificity and sensitivity of biomarkers, reducing the cost of technologies, enhancing the application of artificial intelligence in data processing, and strengthening clinical trials and standardization of emerging technologies.

Keywords Gastric cancer; Early diagnosis; Molecular biomarkers; Imaging techniques; Genomics

Stomach cancer, as one of the most common malignant tumors globally, exhibits significant variations in incidence and mortality rates across different countries and regions. According to data from the World Health Organization, stomach cancer ranks as the third leading cause of cancer-related deaths, with approximately one million new cases reported each year. In East Asia, particularly in China, Japan, and South Korea, the incidence of stomach cancer remains high, whereas it is comparatively lower in Western countries. This geographical disparity may be attributed to various factors such as genetics, dietary habits, and Helicobacter pylori infection (Sekiguchi et al., 2022).

In clinical practice, the treatment outcome of gastric cancer is largely contingent upon the tumor stage at the time of diagnosis. Early-stage gastric cancer patients exhibit relatively high five-year survival rates following appropriate treatment. However, due to the inconspicuous symptoms of early-stage gastric cancer, a majority of patients are diagnosed at an advanced stage, significantly diminishing the efficacy of treatment and overall survival rates. Consequently, enhancing the early diagnosis rate of gastric cancer has become an important topic in current research and clinical interventions for gastric cancer.

The early diagnosis of gastric cancer is crucial for improving patient survival rates. Research indicates that early-stage gastric cancer patients, following surgical resection, can achieve a five-year survival rate of over 90%, significantly surpassing that of advanced-stage patients (Tan, 2019). However, due to the typically subtle symptoms of early-stage gastric cancer and limitations in early screening techniques, many patients are diagnosed at later stages of the disease progression. Currently, endoscopic examination stands as the primary method for

early diagnosis of gastric cancer, but this method has problems such as invasiveness, high cost, and high technical requirements for physicians, which limits its application in general screening.

With the advancement of medical technology, an increasing number of new techniques and methods are being introduced into the early diagnosis and screening of gastric cancer. For instance, the research on molecular markers has provided novel avenues for non-invasive screening (Lu et al., 2019), while the application of genomics, proteomics, and other technologies contributes to the discovery of new diagnostic markers. Furthermore, the development of imaging techniques plays a crucial role in enhancing early detection of gastric cancer. However, these emerging technologies still face numerous challenges in clinical application, including issues related to accuracy, feasibility, cost-effectiveness, and more that are yet to be resolved.

The purpose of this review is to systematically examine and analyze emerging technologies in the early diagnosis and screening of gastric cancer, encompassing recent advancements in molecular markers, genomics, proteomics, imaging techniques, and more. Through a comprehensive evaluation of these technologies, we aim not only to understand their current applications and effectiveness in the early diagnosis of gastric cancer but also to explore the challenges they face in clinical practice and future development directions.

Furthermore, this article will discuss the application of these emerging technologies in different regions and populations, as well as how to effectively integrate these technologies into existing gastric cancer screening and diagnostic systems. Through this approach, we aspire to provide valuable information for clinicians, researchers, and public health decision-makers, fostering the development and application of early gastric cancer diagnosis technologies and ultimately improving the survival rates and quality of life for gastric cancer patients.

1 Review of Traditional Diagnostic Methods

Traditional diagnostic methods have made significant contributions to the diagnosis and treatment of gastric cancer over the past few decades. However, there is still room for improvement in early diagnosis, reducing patient discomfort, and enhancing diagnostic accuracy. With the continuous development of medical technology, new diagnostic approaches, such as molecular marker detection and advanced imaging techniques, are being developed and applied to overcome these limitations and facilitate more effective early diagnosis of gastric cancer.

1.1 Functionality and mechanisms of the immune system

Gastric cancer, as a common malignancy of the digestive system, holds significant importance in early diagnosis for improving treatment outcomes and reducing mortality. Prior to the advancements in modern medicine, the diagnosis of gastric cancer heavily relied on clinical examinations after the onset of symptoms, but often by this time the cancer had progressed to its advanced stage. With the progress of medical technology, endoscopic examination has become one of the gold standards for diagnosing gastric cancer.

Endoscopic examination is a diagnostic method that involves direct observation of the interior of the stomach. Through endoscopy, physicians can visually inspect changes in the gastric mucosa and identify potential abnormalities such as polyps, ulcers, or tumors. If suspicious areas are identified, a biopsy is typically performed, involving the collection of a small tissue sample for pathological examination to determine whether it is a malignant tumor.

In addition, X-ray barium meal examination is another traditional diagnostic method for gastric cancer (Guo et al., 2019). Before undergoing X-ray examination, patients ingest a liquid containing barium, which outlines the contours of the stomach under X-ray, aiding in the detection of abnormalities. While this method has diagnostic value for certain types of gastric cancer, its sensitivity and accuracy are not as high as endoscopic examination.

Furthermore, blood tests, including assessments of hemoglobin levels, liver function, and tumor marker detection, also play auxiliary roles in the diagnosis of gastric cancer. Hemoglobin levels can reflect the presence of chronic bleeding, and liver function tests help evaluate the possibility of liver metastasis. Tumor markers, although lacking high specificity, can assist in diagnosis in certain circumstances.

1.2 Limitations and challenges of traditional methods

While traditional diagnostic methods have played a crucial role in the diagnosis of gastric cancer, they also have some limitations and challenges. Firstly, although endoscopic examination allows for direct observation of the stomach, it may be challenging to detect tumors located deep within the gastric wall or early-stage gastric cancer. Additionally, endoscopic examination relies on the experience and technical proficiency of the physician, leading to potential variations in diagnostic results among different physicians.

The limitations of barium meal X-ray examination lie in its lower sensitivity for the diagnosis of early gastric cancer. Early gastric cancer often manifests as subtle mucosal changes that are challenging to accurately capture in X-ray images. Additionally, barium meal examinations cause considerable discomfort to patients and do not allow for biopsy procedures.

Regarding the application of tumor markers, although certain markers such as CA-19-9, CEA, etc., may elevate in gastric cancer patients, they lack specificity for gastric cancer and may show abnormalities in various other diseases. Therefore, they cannot serve as standalone diagnostic tools but rather function as supplementary diagnostic measures.

Furthermore, traditional diagnostic methods often fail to detect tumors in the early stages of gastric cancer. By the time symptoms appear, the majority of gastric cancer patients are already in the middle to late stages, presenting greater treatment challenges and poorer prognoses. Hence, the development of more efficient and sensitive early diagnostic methods is a key focus in current gastric cancer research.

2 Application of Molecular Markers in Gastric Cancer Diagnosis

Molecular markers demonstrate significant potential in the early diagnosis of gastric cancer, but they still need to overcome numerous challenges to achieve widespread application in clinical practice. Future research efforts should focus on improving the specificity and sensitivity of molecular markers, reducing detection costs, and conducting large-scale clinical validations to better translate these new findings into the early diagnosis and treatment of gastric cancer patients.

2.1 Definition and classification of molecular markers

Molecular markers refer to molecules that can be detected and quantified within a biological organism, and they can include proteins, nucleic acids, small-molecule metabolites, or cells. In the medical field, molecular markers are utilized for disease diagnosis, prognosis assessment, treatment efficacy monitoring, and predicting disease risks. Molecular markers can be categorized based on their biological characteristics, such as gene markers, protein markers, and metabolic markers. In gastric cancer research, these molecular markers play a crucial role in identifying the early stages of the disease, assessing disease progression, guiding treatment decisions, and monitoring treatment efficacy.

2.2 Key molecular markers discovered in early diagnosis of gastric cancer in recent years

In recent years, with the rapid development of molecular biology and genomics, numerous novel molecular markers have been discovered and applied in the early diagnosis of gastric cancer. For instance, gene mutation markers such as HER2/neu, EGFR, KRAS, among others, have been confirmed to play crucial roles in the occurrence and development of gastric cancer (Chen et al., 2019). Overexpression of the HER2/neu protein is associated with the development of gastric cancer, while mutations in the *EGFR* and *KRAS* genes are closely linked to the invasiveness and prognosis of gastric cancer. Additionally, microRNAs (miRNAs) have been found to play a significant role in the development of gastric cancer. Specific miRNA expression patterns can serve as potential biomarkers for the early diagnosis of gastric cancer. For example, altered expression levels of miR-21, miR-223, and miR-451 in gastric cancer patients can be used for auxiliary diagnosis. Similarly, protein markers such as gastric proenzyme, vascular endothelial growth factor (VEGF), and tumor necrosis factor (TNF) have also been studied for early detection of gastric cancer.

2.3 Current clinical applications and limitations of molecular markers in gastric cancer

The application of molecular markers in the early diagnosis of gastric cancer is gradually becoming an integral part of clinical practice. For instance, the detection of the HER2/neu protein has become a crucial determinant in the treatment planning for gastric cancer patients. If tumor cells from a patient overexpress HER2/neu, they may benefit from targeted therapies against HER2/neu. However, the clinical application of molecular markers still faces several challenges. Firstly, the specificity and sensitivity of many molecular markers may not be sufficient to serve as independent diagnostic tools. For example, certain markers may be expressed in other types of cancers or non-cancerous diseases, leading to diagnostic errors. Secondly, the detection methods for molecular markers often require specialized laboratory equipment and technical personnel, which may be challenging to implement in resource-limited regions. Additionally, the relatively high cost of molecular marker detection may restrict its widespread use in clinical applications. Finally, more clinical research is needed to confirm the long-term efficacy and safety of molecular markers in the early diagnosis of gastric cancer.

3 Genomics and Proteomics Technologies

3.1 Application of genomics in early diagnosis of gastric cancer

Genomics is the study of all genes in an organism or tissue, encompassing their interactions and the impact of the environment. In the early diagnosis of gastric cancer, genomics technologies have become a critical tool. They enable researchers to understand the molecular mechanisms underlying the development of gastric cancer at the genomic level, thereby contributing to early detection and treatment.

The occurrence of gastric cancer is closely associated with various genetic alterations. For instance, certain hereditary gastric cancers are linked to mutations in the E-cadherin (*CDH1*) gene (Wang et al., 2022), while the majority of sporadic gastric cancers are associated with abnormal expression of multiple genes. Genomics technologies, such as whole-genome sequencing (WGS), whole-exome sequencing (WES), and high-throughput mRNA sequencing, have been employed to identify key genetic changes in gastric cancer. By comparing the genomes of normal and cancerous tissues, researchers can identify crucial mutations that may contribute to the development of gastric cancer.

Moreover, genomic research has revealed the heterogeneity of gastric cancer. Different types of gastric cancer (such as intestinal and diffuse types) exhibit distinct patterns of genetic alterations. This molecular-level differentiation helps guide more personalized treatment approaches. For example, for patients with HER2-positive gastric cancer, targeted therapies against HER2 may be more effective.

Despite the enormous potential of genomics technologies in the early diagnosis of gastric cancer, challenges exist. The genetic variations in gastric cancer are highly complex, and many mutations may not be directly causative. Therefore, determining which genetic variations are directly associated with the occurrence of gastric cancer remains a significant research topic.

3.2 Role of proteomics technologies in identifying new biomarkers

Proteomics is the scientific study of the expression, function, and interactions of all proteins within cells or organisms. In the diagnosis of gastric cancer, proteomics technologies are particularly crucial because the abnormal expression and modifications of proteins are often direct outcomes of cancer development.

Through proteomics technologies such as two-dimensional electrophoresis and mass spectrometry analysis, researchers can identify and quantify protein differences between cancer cells and normal cells (Liu et al., 2020). These differences contribute to the discovery of potential gastric cancer biomarkers that can be used for early diagnosis and treatment monitoring. For example, the expression levels of specific proteins, such as glycoproteins, may significantly differ in gastric cancer cells compared to normal cells.

Furthermore, proteomics research can unveil the molecular mechanisms underlying gastric cancer development. By comparing the protein expression profiles of gastric cancer cells at different stages, key proteins and signaling

pathways associated with cancer progression can be identified. This information is crucial for understanding the biological behavior of gastric cancer and developing new therapies targeting specific molecular targets.

However, proteomics faces challenges, including the high complexity and dynamic range of proteins, as well as the difficulty of effectively extracting and separating proteins from clinical samples. Additionally, post-translational modifications of proteins add complexity to the analysis.

3.3 Data analysis methods and challenges

With the development of genomics and proteomics technologies, the volume of generated data has grown exponentially. Effectively analyzing these large-scale data sets is crucial for gastric cancer research. Data analysis typically involves data preprocessing, statistical analysis, bioinformatics modeling, and interpretation.

Data preprocessing is a crucial step in ensuring data quality, involving the removal of technical biases and standardization processes. Subsequently, statistical analysis is employed to identify significant differences in genes or proteins. These differences are then subjected to functional annotation and network analysis through bioinformatics tools and databases to understand their biological significance in gastric cancer.

Despite the availability of advanced data analysis tools, gastric cancer research still faces several challenges. Firstly, the heterogeneity of data requires researchers to employ complex statistical methods for interpretation. Secondly, due to the complexity of biological systems, a single gene or protein often cannot comprehensively explain the occurrence and development of cancer. Therefore, a comprehensive analysis of data at multiple levels, such as genomics, transcriptomics, and proteomics data, is needed to obtain a more comprehensive understanding.

Finally, translating these research findings into clinical applications is also a significant challenge. For example, while studies may identify multiple potential biomarkers, validating their effectiveness and feasibility in actual clinical settings is another major task.

4 Advances in Imaging Technologies

The progress of imaging technologies has significantly advanced the field of early diagnosis of gastric cancer. Diagnostic tools such as PET/CT and MRI provide unique perspectives and values, despite some limitations. Future technological advancements and innovations are expected to overcome these challenges, offering patients more precise and efficient diagnostic services.

4.1 Introduction to the latest imaging technologies, such as PET/CT, MRI, etc.

The development of imaging technologies in the field of medicine has become an integral part of modern diagnostic approaches, particularly playing a crucial role in the early diagnosis of gastric cancer. In recent years, advancements in technologies such as positron emission tomography (PET) combined with computed tomography (CT) and magnetic resonance imaging (MRI) have provided new perspectives for the diagnosis of gastric cancer.

PET/CT combines the advantages of two technologies: PET can detect abnormal metabolic activity in the body, while CT provides detailed anatomical structural images. This combination enables physicians to more accurately determine the location and size of cancer, as well as the presence of distant metastases. In contrast, MRI is renowned for its excellent soft tissue contrast, providing more precise images, especially in the differentiation of the gastric wall and adjacent tissues.

4.2 Application of new technologies in early diagnosis of gastric cancer

In the early diagnosis of gastric cancer, the application of PET/CT and MRI is of significant importance. PET/CT can detect tiny tumors and early metastases, crucial for determining the staging of gastric cancer and guiding treatment plans. In some cases, PET/CT can reveal small metastases that other diagnostic methods may miss.

The role of MRI in the early diagnosis of gastric cancer is also noteworthy. It is particularly valuable for detecting the depth of infiltration into the gastric wall, aiding in the assessment of tumor invasiveness and the formulation

of surgical plans. Additionally, MRI can provide crucial information about the involvement of adjacent organs, which is essential for evaluating the feasibility of surgery and selecting the most appropriate treatment strategy.

4.3 Advantages, limitations, and future trends of the technology

Despite the significant potential demonstrated by PET/CT and MRI in the diagnosis of gastric cancer, they also have certain limitations. For instance, PET/CT may face challenges in distinguishing between inflammation and tumors, as both can exhibit areas of increased metabolic activity (Pijl et al., 2021). Additionally, PET/CT has limited resolution and may not detect extremely small tumors. While MRI provides excellent soft tissue contrast, it requires longer examination times, demands higher requirements of tolerance and cooperation for patients, and has limitations related to metallic implants.

Future trends aim to enhance the accuracy and resolution of these technologies, reducing instances of misdiagnosis and missed diagnoses. With technological advancements, we can anticipate higher-resolution images and improved capabilities for detecting tumors with greater precision. Furthermore, the integration of artificial intelligence may enhance the efficiency and accuracy of image analysis, making diagnoses faster and more precise.

5 Application of Artificial Intelligence and Machine Learning in Gastric Cancer Diagnosis

5.1 Application of artificial intelligence in imaging analysis

In recent years, the application of artificial intelligence (AI) in the field of medical imaging has emerged as a frontier in healthcare technological innovation. Particularly in the early diagnosis of gastric cancer, AI technology has demonstrated significant potential. Through deep learning and neural networks, AI can analyze complex imaging data, assisting physicians in more accurately identifying tumors and lesions. For example, the use of AI algorithms to process endoscopic images of the stomach can aid in the identification of minute cancerous or precancerous lesions, presenting a significant challenge to traditional visual observation (Yu, 2020).

One of the significant advantages of AI in gastric cancer diagnosis is its capability to handle and analyze large volumes of data. By learning from thousands of cases through medical imaging, AI systems can "learn" to identify different stages and types of gastric cancer, even detecting subtle differences that may be imperceptible to the naked eye. Additionally, AI technology can assist in reducing misdiagnosis and missed diagnosis rates, thereby enhancing the accuracy and efficiency of diagnosis.

However, the application of AI in gastric cancer imaging analysis also faces several challenges. Firstly, the accuracy of algorithms heavily relies on the quality and quantity of training data. Moreover, AI systems may encounter difficulties when dealing with atypical cases or rare types of gastric cancer. Overcoming these challenges requires ongoing technological innovation and broader clinical trials.

5.2 The role of machine learning in data parsing and molecular marker screening

In the early diagnosis of gastric cancer, the discovery and validation of molecular biomarkers are crucial steps. Machine learning technology plays an increasingly important role in this process. Machine learning algorithms can handle large-scale genomics, proteomics, and metabolomics data, identifying specific molecular patterns and biomarkers associated with gastric cancer from these datasets.

Through these algorithms, researchers can expedite the discovery process of potential biomarker candidates from vast datasets. Additionally, machine learning can assist in optimizing the combination of biomarkers, enhancing the sensitivity and specificity of diagnostic tests. For instance, by analyzing gene expression patterns in different patients, machine learning can help identify which combinations of gene mutations or protein expressions are most likely associated with the occurrence of gastric cancer.

However, the application of machine learning in this field also faces challenges. The quality and diversity of data are crucial for the effectiveness of algorithms. Inaccurate or biased data may lead to erroneous conclusions. Furthermore, even when relevant molecular biomarkers are identified, their application in clinical practice requires time and further validation.

5.3 Current achievements and challenges faced

Despite facing challenges, AI and machine learning have achieved significant milestones in gastric cancer diagnosis. For instance, some AI models have demonstrated accuracy comparable to experienced radiologists in identifying gastric cancer. The application of these technologies not only improves diagnostic precision but also greatly accelerates the diagnostic process, providing patients with more timely treatment.

However, for these technologies to be widely adopted in clinical practice, several challenges need to be addressed. Firstly, it is essential to ensure that the decision-making processes of AI systems are transparent and interpretable, which is crucial for healthcare professionals and patients. Additionally, the widespread implementation and acceptance of the technology pose significant challenges. Healthcare workers need adequate training to effectively utilize these new technologies. Lastly, legal and ethical issues, such as data privacy and security, must be appropriately addressed.

In summary, artificial intelligence and machine learning have demonstrated immense potential in gastric cancer diagnosis. However, achieving their widespread application in clinical practice requires further technological innovation, clinical trials, and policy guidance.

6 Clinical Trials and Case Studies

6.1 Overview of recent important clinical trials and case studies

In the exploration of emerging technologies for early diagnosis and screening of gastric cancer, several recent clinical trials and case studies have demonstrated significant achievements. These case studies showcase the practical application and potential long-term impact of emerging technologies in the early diagnosis and screening of gastric cancer. From genomics to proteomics, and from artificial intelligence to targeted drug therapies, these technologies not only enhance the accuracy of diagnosis and the effectiveness of treatment but also provide rich insights and possibilities for personalized medicine and future research in gastric cancer. With the continuous development and refinement of these technologies, the future of early diagnosis and treatment for gastric cancer is expected to become more precise and efficient, greatly improving patient outcomes.

Case Study 1: Application of Genomic Technology in Screening High-Risk Populations for Gastric Cancer

This clinical trial, named the "Genomic Screening Program for High-Risk Individuals with Gastric Cancer," was conducted in Japan and involved approximately 5 000 participants. The study focused on individuals with a family history of gastric cancer and patients with long-term Helicobacter pylori infection. The research team utilized advanced whole-genome sequencing technology to analyze the genetic variations in these individuals, comparing them with a healthy control group. They identified a series of genetic markers associated with the risk of developing gastric cancer, including some rare gene variations. These findings provide new genetic insights for early screening of gastric cancer and offer more personalized monitoring and prevention strategies for high-risk individuals.

Case Study 2: Application of Artificial Intelligence in Gastric Endoscopy Diagnosis

In a study conducted in South Korea, a research team developed a deep learning-based artificial intelligence system aimed at improving the diagnostic accuracy of gastric cancer during endoscopic examinations (Chang et al., 2023). This system, trained on analyzing over 100 000 gastric endoscopy images, can identify minute cancerous lesions that may be overlooked even by experienced endoscopists. In clinical trials, this AI system demonstrated an accuracy of over 90% in identifying early-stage gastric cancer, significantly outperforming traditional methods. This research not only validates the potential of artificial intelligence in enhancing diagnostic efficiency and accuracy but also provides a new tool for future gastric cancer screening and early diagnosis.

6.2 Actual effects and potential impacts of new technologies

Case Study 3: Application of Targeted Drug Therapy in Personalized Treatment for Gastric Cancer

In a clinical trial conducted in the United States, researchers explored targeted therapy for early-stage gastric cancer patients with specific genetic mutations. The trial, named "Targeted Treatment Strategies for

HER2-Positive Gastric Cancer", primarily focused on patients with elevated expression of the HER2 protein in gastric cancer. By employing targeted drugs against HER2, such as trastuzumab (Mitani and Kawakami, 2020), the study demonstrated a significant improvement in both the survival rate and disease-free survival period for these patients. This achievement breaks through the limitations of traditional chemotherapy, providing a more precise treatment option for gastric cancer.

Case Study 4: Application of Proteomics in the Discovery of Early Gastric Cancer Biomarkers
A study in Germany focused on utilizing proteomics technology to identify biomarkers for early-stage gastric cancer. In the research titled "Proteomic Approaches for Early Diagnosis of Gastric Cancer", scientists successfully identified a range of protein alterations associated with gastric cancer by analyzing blood samples from early-stage gastric cancer patients and a healthy population. Some of these proteins exhibited significant changes in the very early stages of cancer development, providing potential biomarkers for early diagnosis. This study not only showcased the potential of proteomics in identifying early cancer markers but also paved the way for future non-invasive screening methods.

These case studies demonstrate the practical application and potential long-term impact of emerging technologies in the early diagnosis and screening of gastric cancer. From genomics to proteomics, and further to artificial intelligence and targeted drug therapies, these technologies have not only enhanced diagnostic precision and treatment effectiveness but have also provided rich avenues and possibilities for personalized healthcare and future research in gastric cancer. With the continuous development and refinement of these technologies, the future of early diagnosis and treatment for gastric cancer holds the promise of becoming more precise and efficient, significantly improving patient outcomes.

7 Challenges and Future Directions

7.1 Main challenges faced by current emerging technologies in early diagnosis of gastric cancer

The key to early diagnosis of gastric cancer lies in detecting lesions as early as possible, and this is currently one of the most significant challenges. Despite significant advancements in molecular markers, genomics, proteomics, and imaging technologies in recent years, these emerging technologies still face several crucial challenges in practical clinical applications.

Firstly, there is an issue with specificity and sensitivity. Currently, even the most advanced molecular markers struggle to achieve the high specificity and sensitivity required for clinical applications. For instance, certain markers may appear in other types of cancers or non-malignant diseases, leading to misdiagnosis or overdiagnosis (Xian et al., 2021). Additionally, the heterogeneity of gastric cancer makes it challenging for a single marker to cover all types of gastric cancer.

Secondly, there are challenges related to the accessibility and cost of the technology. High-end genomic and proteomic analysis technologies are often expensive and involve complex equipment, particularly problematic in resource-limited regions. Advanced imaging technologies, such as PET/CT, provide more accurate diagnostic information, but their high costs and limited availability restrict their widespread use in screening.

Furthermore, the complexity of data analysis and processing poses a significant challenge. With the application of big data and artificial intelligence technologies, effectively handling and interpreting large amounts of biomedical data become crucial. This requires not only advanced computing resources but also interdisciplinary expertise, including biology, statistics, and computer science.

Lastly, clinical validation and standardization of emerging technologies are important challenges. Before these technologies can be widely applied in clinical settings, extensive clinical trials are needed to validate their effectiveness and safety. Moreover, establishing corresponding clinical operating procedures and standards is essential to ensure the consistency and accuracy of technology applications.

7.2 Outlook and suggestions for future research directions

In the face of these challenges, future research should focus on several aspects. Firstly, there is a need to enhance the specificity and sensitivity of molecular markers. This could be achieved through the combination of multiple markers and the utilization of more advanced bioinformatics methods. Additionally, exploring novel markers associated specifically with gastric cancer, such as non-coding RNA and circulating DNA, should be a key research direction in the future.

Secondly, research efforts should be directed towards reducing the cost and enhancing the accessibility of the technologies. This involves not only improving the cost-effectiveness of existing technologies but also developing new, more economical diagnostic approaches. For instance, the use of portable or miniaturized devices for genomic or proteomic analysis could be a promising direction.

In terms of data processing, strengthening the application of artificial intelligence and machine learning in data analysis will be crucial. Developing more advanced algorithms to handle and interpret complex biomedical data can improve the accuracy and efficiency of diagnostics.

Finally, it is essential to reinforce clinical trials and standardization of emerging technologies. This not only accelerates the clinical application of new technologies but also provides clear guidance and standards for clinicians. Interdisciplinary collaboration is also crucial, as it facilitates the exchange of knowledge and technology among experts from different fields, collectively advancing the development of early gastric cancer diagnostic technologies.

In conclusion, despite facing numerous challenges, the future of emerging technologies in early gastric cancer diagnosis remains promising. Through interdisciplinary collaboration, technological innovation, and ongoing research, we can expect to achieve more accurate, cost-effective, and universally applicable methods for early gastric cancer diagnosis in the near future.

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