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Review Paper

From Colonoscopy to Circulating DNA: Reimagining Colorectal Cancer Screening in the Era of Precision Medicine

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Abstract

Colorectal cancer (CRC) remains a leading cause of cancer-related morbidity and mortality worldwide, largely due to late-stage diagnosis and suboptimal screening adherence. Traditional screening modalities, while effective, face limitations in accessibility, patient compliance, and sensitivity for early lesions. Recent advances have transformed the screening landscape, integrating molecular diagnostics, artificial intelligence, and minimally invasive technologies. This article explores a new paradigm in CRC screening—shifting from invasive, one-size-fits-all strategies to personalized, risk-adapted, and technology-driven approaches. Emphasis is placed on emerging tools such as liquid biopsies, stool DNA testing, AI-assisted colonoscopy, and microbiome profiling. These innovations promise to enhance early detection, improve participation rates, and ultimately reduce disease burden. The future of CRC screening lies in integrating these modalities into cohesive, patient-centered frameworks that prioritize both precision and accessibility.

Introduction

Colorectal cancer (CRC) is among the most preventable yet deadly malignancies when not detected early. Screening plays a pivotal role in reducing both incidence and mortality by identifying precancerous lesions and early-stage cancers. Conventional methods such as colonoscopy and faecal occult blood tests have long been the cornerstone of screening programs. However, barriers such as invasiveness, cost, and patient reluctance necessitate innovative approaches

Limitations of Conventional Screening

Traditional CRC screening methods include

- **Colonoscopy:** Gold standard but invasive, resource-intensive, and associated with low compliance.
- **Fecal Occult Blood Test (FOBT) / Fecal Immunochemical Test (FIT):** Non-invasive but limited sensitivity for advanced adenomas.
- **Flexible Sigmoidoscopy:** Less comprehensive than colonoscopy

Despite their proven effectiveness, these methods face challenges

- Low participation rates due to discomfort or fear
- Limited accessibility in low-resource settings
- Interval cancers due to missed lesions

Emerging Advances in Colorectal Cancer Screening

1. Liquid Biopsy and Circulating Tumor DNA (ctDNA)

Liquid biopsy represents a groundbreaking advancement, enabling detection of CRC through a simple blood test. Circulating tumor DNA (ctDNA) can identify tumor-specific genetic mutations even before clinical symptoms arise

Advantages:

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- Minimally invasive
- High patient acceptance
- Potential for early detection and monitoring recurrence

Recent multi-target blood-based tests are showing promising sensitivity and specificity, potentially revolutionizing population screening.

. Stool DNA Testing (Multitarget Testing)

Stool DNA tests detect abnormal DNA markers shed by cancerous or precancerous lesions.

Key Features:

- Combines molecular markers with hemoglobin detection
- Higher sensitivity than FIT for detecting advanced adenomas
- Non-invasive and home-based

This approach improves screening adherence while maintaining diagnostic accuracy

Artificial Intelligence in Colonoscopy

Artificial Intelligence (AI) is transforming colonoscopy through real-time image analysis.

Applications:

- Detection of polyps missed by human eyes
- Characterization of lesions (benign vs malignant)
- Reduction in operator variability

AI-assisted colonoscopy significantly improves adenoma detection rates (ADR), a key quality indicator

Capsule Endoscopy and Non-Invasive Imaging

Capsule endoscopy involves swallowing a small camera that captures images of the gastrointestinal tract

Advantages:

- Non-invasive and painless
- Useful for patients unwilling or unable to undergo colonoscopy

Although still evolving, improvements in imaging resolution and navigation are enhancing its diagnostic value.

Future Directions

The future of CRC screening lies in a hybrid model combining

- Molecular diagnostics (ctDNA, stool DNA)
- Advanced imaging technologies
- AI-driven analytics
- Personalized risk assessment

Integration into national screening programs will require validation, cost-effectiveness analysis, and infrastructure development.

Conclusion

Colorectal cancer screening is undergoing a transformative shift from conventional invasive procedures to innovative, patient-friendly, and precision-based approaches. Advances such as liquid biopsy, AI-assisted diagnostics, and microbiome analysis are redefining early detection strategies. By improving accessibility, accuracy, and compliance, these technologies hold the potential to significantly reduce the global burden of colorectal cancer. A future-oriented screening paradigm must prioritize personalization, technological integration, and equitable access to maximize public health impact

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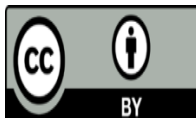
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