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Commentary

Next Generation Diagnostics for Rapid Detection of Viruses and Fungi

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DESCRIPTION

Rapid and accurate diagnosis of viral and fungal infections is essential to initiate timely treatment, prevent disease spread, and reduce healthcare burden, especially in critical care and immunocompromised settings. Traditional diagnostic methods such as culture, microscopy, and serology, though still in use, often suffer from limitations including low sensitivity, long turnaround time, and operator dependency. As pathogens evolve and new infectious diseases emerge, there is a growing demand for next-generation diagnostic (NGDx) technologies that offer high-speed, high-precision, and point-of-care capabilities. These innovations are particularly important in low- and middle-income countries, such as Vietnam, where infectious diseases are prevalent, and rapid detection could mean the difference between containment and an outbreak.

Molecular diagnostic platforms, particularly those based on nucleic acid amplification such as Polymerase Chain Reaction (PCR), real-time PCR, and digital PCR, have revolutionized pathogen detection. These tools can detect extremely low levels of viral or fungal DNA/RNA with high specificity and sensitivity. Multiplex PCR assays, capable of identifying multiple pathogens in a single test, are especially useful in cases where co-infections or unclear symptomatology make differential diagnosis difficult. Viral pathogens like SARS-CoV-2, dengue virus, and hepatitis viruses, as well as fungi such as Candida and Aspergillus, can now be rapidly identified using these systems. Furthermore, advances in sample processing and microfluidics have enhanced the ability to conduct these tests at the point-of-care, reducing the need for centralized labs.

Another transformative technology is next-generation sequencing (NGS), which allows for unbiased detection of known and novel pathogens directly from clinical samples. NGS can detect viral mutations and drug resistance genes, offering vital insights into epidemiology and treatment planning. While its current application is limited by cost and processing time, efforts to miniaturize sequencing platforms and automate analysis are expanding its clinical utility. In fungal diagnostics, NGS has enabled the identification of rare or emerging species that do not grow well in culture, thus reducing diagnostic delays and inappropriate treatments.

CRISPR-based diagnostics represent a breakthrough in rapid detection. Platforms like SHERLOCK and DETECTR harness the gene-editing capabilities of CRISPR systems to identify pathogen-specific nucleic acid sequences in minutes. These systems can be adapted to lateral-flow devices or paper-based diagnostics, enabling low-cost, field-deployable solutions ideal for outbreaks and rural health settings. CRISPR-based assays for viruses such as SARS-CoV-2 and dengue have already demonstrated high sensitivity, and similar developments are underway for fungal pathogens, especially those associated with invasive infections.

Biosensor technologies are also making significant strides in infectious disease diagnostics. These sensors detect biological interactions using optical, electrochemical, or piezoelectric signals, offering rapid results without the need for complex equipment. For instance, graphene-based biosensors have been developed for influenza and HIV detection with high accuracy. Fungal biosensors are being designed to detect fungal cell wall components like β-glucans or galactomannan, aiding early diagnosis of invasive fungal infections. These methods provide a promising avenue for real-time monitoring in high-risk patients, such as those in intensive care units.

Point of care (POC) testing has gained momentum, especially in the wake of the COVID-19 pandemic. Isothermal amplification techniques such as loop-mediated isothermal amplification (LAMP) and Recombinase Polymerase Amplification (RPA) have emerged as alternatives to PCR that can be performed at lower temperatures and without expensive thermal cyclers. Combined with smartphone-based readers or colorimetric indicators, these tests are becoming accessible even in resource-limited settings. Vietnam's growing biotech sector is already contributing to the development of such diagnostics, aiming to strengthen its national disease surveillance systems.

Despite the advancements, several challenges remain. Many NGDx technologies still require validation, regulatory approval, and robust quality control systems before widespread clinical

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adoption. There is also the risk of over-reliance on rapid tests without clinical correlation, leading to misdiagnosis or overtreatment. Furthermore, integration of these diagnostics into existing healthcare systems requires training of personnel, infrastructure upgrades, and sustainable funding models. Interoperability with electronic health records and real-time data sharing for public health monitoring are also essential but underdeveloped aspects in many settings.

In conclusion, next-generation diagnostics are redefining the landscape of viral and fungal disease detection by enabling faster, more accurate, and decentralized testing. These innovations are not only enhancing individual patient care but are also pivotal in outbreak preparedness and global health security. In countries like Vietnam, where emerging infections pose a continuous threat, the adoption and scaling up of these technologies can significantly improve public health outcomes. Future efforts should focus on making NGDx tools more affordable, accessible, and adaptable to diverse clinical environments, thus ensuring their benefits reach even the most underserved populations. Collaborative partnerships between governments, academia, and industry will be key to realizing the full potential of next-generation diagnostics in the fight against infectious diseases.