A Novel Fully Contactless Individual Nucleic Acid Sampling Model

Authors: Zhang Lijun, Jiaji Li, Li Ye, Wang Xiao, Tang Ling, Tang Ling

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Abstract

The novel coronavirus (hereinafter referred to as SARS-CoV-2) is a positive-sense single-stranded RNA virus belonging to the Betacoronavirus genus. Compared with other common respiratory pathogens, SARS-CoV-2 has greater transmissibility: (1) The primary routes of human-to-human transmission of SARS-CoV-2 are via respiratory droplets and close contact. Droplets generated during face-to-face conversations, coughing, and sneezing being inhaled by susceptible individuals represent the most common transmission mode 1-2. Additionally, SARS-CoV-2 can also be transmitted through aerosols. (2) Contact with virus contamination refers to droplets depositing on object surfaces, followed by contact with contaminated hands and subsequently with mucous membranes of the mouth, nose, eyes, etc., leading to infection. (3) COVID-19 has a large number of asymptomatic patients and mild cases, which account for a substantial proportion of the infected population and enable silent transmission. It can also spread at any time of the year, particularly causing pandemics during winter and spring seasons, which necessitates routine prevention and control for the COVID-19 pandemic 3.

Full Text

Preamble

A Contact-Free Single-Person Nucleic Acid Self-Collection Innovation Model

Zhang Lijun, Li Jiaji, Li Ye, Wang Xiao, Tang Ling

Beijing University of Chinese Medicine Dongfang Hospital, Beijing, 100078

SARS-CoV-2 (hereinafter referred to as the novel coronavirus) is a positive-sense single-stranded RNA virus belonging to the betacoronavirus genus. Compared with other common respiratory pathogens, the novel coronavirus exhibits greater

transmissibility: (1) The primary routes of human-to-human transmission are respiratory droplets and close contact. Droplets produced during face-to-face conversation, coughing, and sneezing that are inhaled by susceptible individuals represent the most common transmission mode [1-2]. Additionally, COVID-19 can spread through aerosols. (2) Contact transmission occurs when droplets deposit on surfaces and susceptible individuals touch these contaminated surfaces and subsequently touch mucous membranes of the mouth, nose, eyes, etc., resulting in infection. (3) COVID-19 has a large proportion of asymptomatic and mild cases within the infected population, facilitating silent transmission. The virus can spread at any time throughout the year, particularly during winter and spring seasons when it may cause major outbreaks, necessitating sustained prevention and control measures for the COVID-19 epidemic [3].

Keywords: COVID-19, nucleic acid, innovation

1. Cross-Infection Risks in Large-Scale Nucleic Acid Collection

The global COVID-19 pandemic has profoundly impacted global public health, social functioning, and economic operations. With delayed drug development and insufficient validation of vaccine efficacy, large-scale rapid screening of populations to identify potential infected individuals—especially mild and asymptomatic cases—and implement centralized isolation to interrupt transmission chains and protect susceptible populations has become the primary task. Consequently, early diagnosis of SARS-CoV-2 infection is particularly critical [4]. COVID-19 diagnosis initially focuses primarily on viral nucleic acid detection, with PCR-based nucleic acid testing having become the gold standard for SARS-CoV-2 detection [5-6]. During oropharyngeal swab sampling for nucleic acid testing, healthcare workers must maintain close contact with patients who remove their masks. From mask removal through collection completion, patients' coughing, forceful breathing, and other actions generate substantial droplets or aerosols, substantially increasing healthcare workers' risk of cross-infection during sampling. To prevent infection of healthcare workers by the novel coronavirus and improve oropharyngeal swab sampling quality, we propose adopting a contact-free single-person nucleic acid collection model for self-administered sampling. This approach can reduce healthcare workers' workload and mental stress while lowering cross-infection risk, holding considerable importance for novel coronavirus prevention and control.

2. Contact-Free Single-Person Nucleic Acid Self-Collection Process Flow

We developed a contact-free single-person nucleic acid self-collection model wherein collectors and subjects maintain zero contact throughout the collection process. The specific workflow proceeds as follows: (1) Healthcare professionals and paraprofessionals receive training in nucleic acid self-testing through video instruction; (2) Staff distribute nucleic acid testing kits at scheduled times and locations; (3) Each kit contains a self-collection video and instruc-

tional flowchart; (4) [Figure 4: see original paper] After subjects complete self-collection, they place the kits at designated locations per staff instructions; (5) Staff retrieve the kits from designated locations at scheduled times and uniformly notify third-party testing services. The entire process is monitored, with collection progress trackable in real-time via a mobile application, achieving integrated monitoring.

The self-collection procedure involves several steps. First, subjects prepare the materials, including a preservation solution tube and a disposable sterile throat swab. Next, they remove the throat swab and face a mirror with their head slightly tilted back. Subjects then open their mouth wide and say "ah" to expose the posterior pharyngeal wall. Using the swab tip, they rub the exposed posterior pharyngeal wall 3-5 times vertically and horizontally. Finally, they immediately place the swab tip into the tube containing collection solution after sampling.

3.1 Reducing Nucleic Acid Testing Work Pressure

Against the backdrop of the global COVID-19 pandemic, evolving epidemic conditions have created new testing demands. The contact-free single-person nucleic acid collection model can reduce personnel gathering and alleviate pressure on testing staff [7-8]. Compared with antigen testing, which also enables self-testing, nucleic acid testing offers higher accuracy, whereas antigen testing suffers from lower sensitivity, achieving relatively high detection accuracy only when viral load is high, such as in patients within five days of symptom onset during early infection. COVID-19 is transmissible between humans with strong contagiousness [9-10], profoundly affecting public health and posing challenges to medical personnel. Frontline healthcare workers in particular face enormous pressure from direct contact with COVID-19 patients. Surveys of healthcare workers treating Class A infectious diseases or Class B diseases managed as Class A reveal significant negative psychological characteristics, primarily manifested as anxiety, fear, and tension [10-11]. Healthcare workers' mental health directly impacts medical service quality; high psychological pressure leads to poorer service quality, reduced patient satisfaction, compromised patient treatment and recovery, and increased risk of doctor-patient disputes [12]. The contact-free single-person nucleic acid collection model can reduce healthcare workers' psychological burden to some extent, holding significant importance for alleviating pressure and psychological distress among frontline workers, particularly nurses, healthcare workers with children, and support staff from non-infectious disease specialties.

3.2 Reducing Cross-Infection

COVID-19 is a respiratory infectious disease with transmission routes including contact, droplet, and aerosol (airborne) transmission. Contact transmission comprises direct and indirect pathways. Direct contact transmission occurs when pathogenic microorganisms spread directly from carriers to susceptible

hosts; indirect contact transmission occurs when pathogenic microorganisms contaminate surfaces and susceptible hosts become infected through contact with these contaminated surfaces. Droplet and aerosol contamination generally originates from patients' respiratory tracts. Coughing, sneezing, speaking, and even breathing can disperse liquid particles into the air, classified by size as spatter or droplets, with particles larger than 100 m accounting for over 99% of total volume and capable of carrying substantial pathogenic microorganisms [13-15]. During oropharyngeal swab sampling for nucleic acid testing, healthcare workers require close contact with patients who remove their masks. Since the contact-free model eliminates contact among subjects, collectors, and testing companies, it reduces personnel interaction and further decreases transmission risk to collectors during procedures, blocking further risk spread.

3.3 Reducing Medical Costs Including Protective Resources

The model reduces medical costs such as protective resources. Since self-testing kits are uniformly distributed, 1-2 staff members can distribute and collect kits within the same timeframe, requiring protective clothing donning and doffing only 1-2 times, thereby reducing medical costs and shortening work duration. During individual self-testing, subjects download a nucleic acid testing app to synchronize their self-collection progress, enabling staff to conduct centralized retrieval at unified times and improving work efficiency. This reduces medical resource waste, optimizes resource allocation, and maximizes resource utilization. This study provides a new solution to challenges in nucleic acid collection, effectively reducing personnel cross-contact and lowering risk of further epidemic spread. As the epidemic becomes normalized, enabling all medical professionals to conduct self-testing can further support domestic epidemic prevention and control efforts by reducing medical resource waste, optimizing resource allocation, and maximizing resource utilization.

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Note: Figure translations are in progress. See original paper for figures.