Innovative Design of 3D-Printed Nasopharyngeal Pediatric Swab for COVID-19 Detection

Ameerah Alazemi

Kuwait University Faculty of Medicine <https://orcid.org/0000-0002-7419-4923>

Ghadeer AbdulHussain

Kuwait University

Abdullah Alawwam

Kuwait University

Ali Al-Shatti

Kuwait Oil Company

Mohammad alghounaim

: Kuwait Ministry of Health

Sulaiman Almazeedi

: Kuwait Ministry of Health

Sarah Al Youha

Kuwait Ministry of Health

Salman alsabah (✉ salman.k.alsabah@gmail.com)

Jaber Al-Ahmad Hospital

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Abstract

3-dimensional (3D) printing technology provides a solution to meet the high demand for producing adult nasal swabs. A smaller, more flexible nasopharyngeal swab needs to be developed for children and infants suspected of having coronavirus. The information shared here presents a novel 3D-printed pediatric swab for the purpose of collecting upper respiratory clinical specimens.

Introduction

On January 30 2020, the World Health Organization declared severe acute respiratory syndrome-related coronavirus 2 (SARS-CoV-2), a novel Betacoronavirus responsible for causing coronavirus disease 2019 (COVID-19) to be a global pandemic [1]. The rapid escalation and spread of the virus with more than 100 million confirmed cases and more than two million confirmed deaths worldwide, has emphasized the importance of employing accurate diagnostic tests and results to hinder the transmission of the virus [2]. Consequently, shortages in crucial medical supplies such as ventilators, masks, face shields, nasopharyngeal (NP) swabs, and others have impacted all countries [3].

Epidemiologic studies have demonstrated that the elderly population is more prone to infection by coronavirus [4]. The prevalence of COVID-19 in the pediatric population is low [5]; infants [6] and children affected with SARS-CoV-2 exhibit milder symptoms, lower hospitalization, and mortality rates [7,8]. However, patients with comorbidities are inclined to develop severe acute disease [9-11].

Detection of SARS-CoV-2 on respiratory specimens collected by nasopharyngeal (NP) swabs is the common modality for sample collection and subsequent SARS-CoV-2 detection by reverse transcription polymerase chain reaction (RT-PCR) [12]. To combat the global deficit of commercial (NP) swabs, 3-dimensionally (3D)-printed NP swabs have been created and clinically validated as an alternative to the standard NP swab [13,14]. However, the majority of 3D-printed NP swabs are designed for adults, which can be too rigid and large for safe pediatric use [15]. The main basis for the diagnosis of COVID-19 in children is the RT-PCR detection of SARS-CoV-2 in nasopharyngeal samples [12]. This issue accentuated the need to design a pediatric NP swab with qualities such as efficient collection of viral particles from the posterior nasopharynx and flexibility to maneuver inside the nasopharynx.

For the target age of 2 years was printed using a fused deposition modeling 3D printer (FDM), a relatively inexpensive equipment (approximately US\$ 500) that can be readily purchased [16].

Polylactic acid (PLA) is the chosen material to create swabs because of its safety, biocompatibility, low cost, and resistance to breakage [17-19]. To facilitate production without using adhesive material, the tip of the PLA swab featured small nubs to tightly intertwine the polyester threads and decrease the possibility of it becoming unwound. A swab applicator was used (<https://www.thingiverse.com/thing:4373981>) to intertwine the polyester fibers on the tip of the swab. By inserting the PLA swab and some polyester in the applicator, the swab was rotated like a pencil sharpener, ensuring that the polyester was securely wrapped on the tip without the concern of it becoming dislodged, enforced uniformity in the

production, and created a brush-like texture. Polyester was chosen because it is chemically safe, does not interfere with PCR reagents, has a high absorption capacity, and elutes into the viral transport media (VTM) [20,21].

The final 3D printed pediatric swab (Fig. 1) was approximately 120 mm in length with a 58 mm break point (Fig. 2) from the tip. The tip of the swab was 9 mm long and had a diameter of 2 mm. The tip of the shaft has three pins per side to adhere the polyester fibers (less than 0.01 g) to the swab, eliminating the need for adhesive substrates. The neck was 12 mm in length and 2 mm in diameter. The shaft is 1 mm in diameter and the base is 74 mm long with a 2.5 mm diameter. Plastinated nasopharyngeal models at the dissection room in the Anatomy Department, Faculty of Medicine, Kuwait University, were used as a simulation to demonstrate the flexibility of both adult and pediatric swabs in reaching the posterior nasopharynx (Fig. 3). The same swab design with variant measurements was validated for the adults [14].

The swabs were sterilized at the Central Sterilization Service Department (CSSD) in Kuwait's Ministry of Health via low-temperature (45°C) hydrogen peroxide plasma. To confirm adequate sterilization, ten swabs were randomly selected and cultured on blood agar (BAP) plus chocolate agar and incubated at 35°C ± 2°C for 48 hours. The sterility of the prepared VTM was validated by randomly selecting three tubes from the beginning, middle, and end of each batch, and 100 µL was inoculated on BAP and incubated at 35 ± 2°C for 48 hours. The VTM was concocted at Jaber Al Ahmad Al Sabah Hospital laboratory, Kuwait, according to the protocol published by the Centers for Diseases Control and Prevention (CDC) [22]. Along with the prepared VTM, the 3D printed swab was packed and labeled as a pediatric COVID-19 testing kit.

In comparison to the adult version (Fig. 4), the 3D printed pediatric swabs are shorter in length and more flexible, ultimately providing comfort to the patients. The altered dimensions of the pediatric swab and its flexibility will reduce the number of attempts required to reach the posterior nasopharynx and decrease the duration needed to obtain a sample from pediatric patients.

The production of pediatric prototype NP swabs using 3D-FDM printers has several advantages. Inexpensive readily available materials were used to create pediatric NP swabs (costs less than US\$0.05), making it a reasonable option for countries suffering from a shortage of commercial pediatric swabs. The universal availability of 3D printers and the simplicity of iterating and testing various designs of swabs are attractive factors for producing novel 3D-printed swabs. Nonetheless, for large-scale production, 3D printers are quite slow, requiring approximately one hour to produce only 20 swabs.

Abbreviations

3D; 3-dimension, SARS-CoV-2; severe acute respiratory syndrome-related coronavirus 2, NP; nasopharyngeal, COVID-19; coronavirus disease 2019, RT-PCR; reverse transcription polymerase chain reaction, FDM; fused deposition modeling 3D printer, US\$; United States dollar (currency), PLA; Polylactic acid, VTM ; viral transport media, mm; millimeter (unit of length in the metric system), °C; temperatures in

Celsius degree, CSSD; Central Sterilization Service Department, BAP; blood agar, CDC; Centers for Diseases Control and Prevention.

Declarations

Ethical approve and consent of participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

A swab applicator 3D design is available on (<https://www.thingiverse.com/thing:4373981>)

The swab design blueprint and production standard operating procedures (SOPs) are available online (<https://projectjaber.com/>).

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

All authors contributed equally to this paper. The author(s) read and approved the final manuscript.

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Figures

Figure 1

(A) The complete three dimensionally printed pediatric swab. (B) Design of the 3D printed pediatric swab.

Figure 2

(A) Pediatric swab inserted in VTM tube. (B) Holding the breakpoint near the rim of the tube, break the applicator from the break point indicator line. (C) The swab tip submerged in the VTM tube

Figure 3

(A) Plastinated nasopharyngeal model with the pediatric swab inside the nasopharynx. (B) Plastinated nasopharyngeal model with the adult swab inside the nasopharynx. Pediatric (C) and adult swab (D) 180° bending test for the swab

Figure 4

(A) The complete three dimensionally printed adult swab. (B) Design of the 3D adult swab.