The Laryngoscope

Improving Nasopharyngeal Swab Technique via Simulation for Frontline Workers

Ryan S. Instrum, MD; Robert W. Koch, MSc; Taciano Rocha, PhD; Seyed Alizera Rohani, PhD; Hanif Ladak, PhD; Sumit K. Agrawal, MD, FRCSC; Leigh J Sowerby, MD, MHM, FRCSC

Objectives/Hypothesis: Nasopharyngeal swabs currently remain the gold standard for COVID-19 sample collection. A surge in testing volume has resulted in a large number of health care workers who are unfamiliar with nasal anatomy performing this test, which can lead to improper collection practices culminating in false-negative results and complications. Therefore, we aimed to assess the accuracy and educational potential of a realistic 3D-printed nasal swab simulator to expedite health care workers' skill acquisition.

Study Design: Prospective pre-post interventional study.

Methods: A nasal swab task trainer (NSTT) was developed to scale from computed tomography data with a deviated septum. Frontline workers at COVID-19 testing sites in Ontario, Canada, were recruited to use the NSTT for nasopharyngeal swab training. Integrated video recording capability allowed participants to self-evaluate procedure accuracy. A five-point Likert scale was collected regarding the NSTT's educational value and procedural fidelity.

Results: Sixty-two frontline workers included in the study were primarily registered nurses (52%) or paramedics (16%). Following simulator use, self-assessed accuracy improved in 77% of all participants and 100% of participants who expressed low confidence before training. Ninety-four percent reported that the NSTT provided a complete educational experience, and 82% regarded the system as a more effective training approach than what is currently available. Eighty-one indicated that the simulator should be used at all COVID-19 testing sites, with 77% stating province-wide implementation was warranted.

Conclusions: The nasal swab task trainer is an effective educational tool that appears well-suited for improved skill acquisition in COVID-19 testing and may be useful for training other nasal swab applications.

Key Words: SARS-CoV-2, Nasopharyngeal swab test, Simulation training, COVID-19, Education.

Level of Evidence: 3

***Laryngoscope*, 00:1–5, 2022**

INTRODUCTION

Clinical and public health measures aimed at mitigating the spread of COVID-19 (coronavirus disease 2019) are contingent on the ability to diagnose the disease accurately.[1,2] Diagnostic testing for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) involves collecting upper respiratory specimens with subsequent nucleic acid amplification tests, and nasopharyngeal (NP) swabs are the preferred sampling method.[3–6] Test reliability is constrained by sample quality and directly related to collection practices; improperly obtained specimens may yield inconclusive or false-negative results.[1,3]

False-negative COVID-19 test results range from 2% to 40% and have significant public health implications insofar as they provide a false sense of security, contributing to super-spreader events.[1,2,4,7–12] With polymerase chain reaction (PCR) approaching a sensitivity and specificity of 100% against the reference standard, it appears that suboptimal sampling may introduce error in the chain of diagnostics.[1,6] Unfortunately, considerable heterogeneity exists within NP swab guidelines as well as in training protocols.[13] Procedural education is typically provided in text or videos, and physical skills are trained on-the-job, with no verifiable means of ensuring technique accuracy.[14]

The global response to COVID 19 pandemic has shed light on the need for large-scale training resources to effectively boost health care workers training on specific medical procedures such as NP swabs, granting worldwide pandemic diseases preparedness. In response to the need for more reliable training methods for COVID-19 sample collection, we developed a nasal swab task trainer (NSTT). The device is a realistic 3D-printed simulator representing the nasal passages, made of a translucent polymer and equipped with an integrated video capture.

From the Department of Otolaryngology–Head and Neck Surgery, Schulich School of Medicine and Dentistry (R.S.I., T.R., S.A.R., S.K.A., L.J.S.), Western University, London, Ontario, Canada; School of Biomedical Engineering (R.W.K.), Western University, London, Ontario, Canada; and the Department of Electrical and Computer Engineering (H.L.), Western University, London, Ontario, Canada.

Additional supporting information may be found in the online version of this article.

Editor's Note: This Manuscript was accepted for publication on January 18, 2022.

Funding was received from the Peter Cheski Innovative Research Fund (non-profit).

R.W.K. is President and CEO of Ahead Simulations. His involvement included the development and provision of simulators free of charge, aiding in study design, and providing final approval of the manuscript to be published. He was not involved with data collection or analysis to limit the potential for bias.

The authors have no other funding, financial relationships, or conflicts of interest to disclose.

Send correspondence to Leigh J Sowerby, MD, MHM, FRCSC, Department of Otolaryngology – Head & Neck Surgery, Western University, St. Joseph's Hospital, 268 Grosvenor St, London, ON N6A 4V2, Canada. Email: leigh.sowerby@sjhc.london.on.ca

DOI: 10.1002/lary.30034

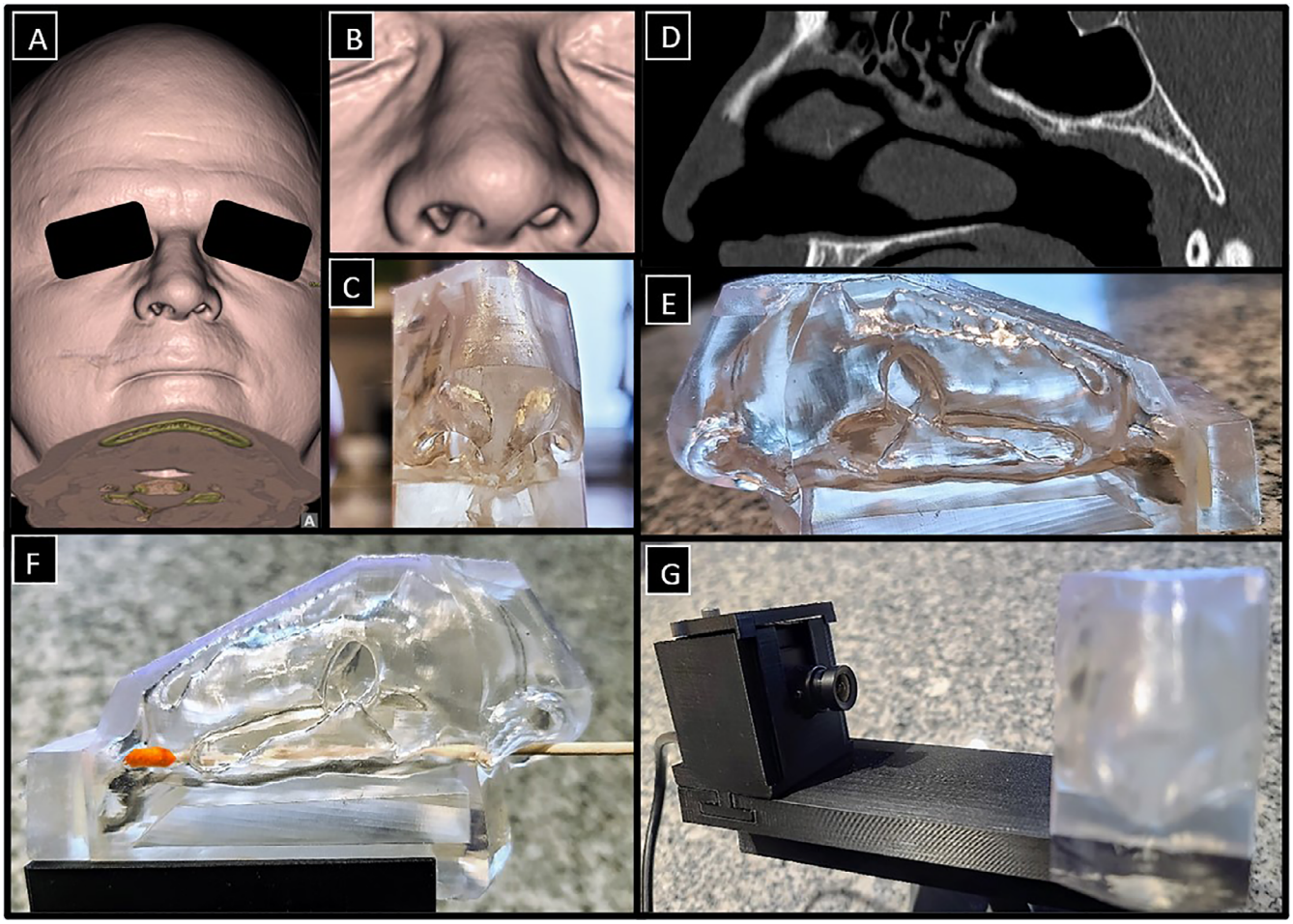

Fig. 1. Nasal swab simulator and radiographic correlates. A-C) External nasal anatomy. D, E): Internal nasal anatomy. F) Translucent polymer allows for direct visualization of swab accuracy. G) Integrated video capture device enables retrospective review of swab attempts. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

This study aimed to assess the realism and educational potential of the NSTT in real-world scenarios by gathering feedback on usability and learning potential from COVID-19 frontline workers performing NP swabs.

MATERIALS AND METHODS

Nasal Swab Task Trainer (NSTT)

Radiographic human data allowed for the accurate representation of nasal passages, including a septal deviation for an added degree of difficulty (present in over one-third of the population).[15] The NSTT included integrated video recording capability allowing participants to review each swab attempt and evaluate their procedural accuracy before and after use of the trainer.

Likert scale data and feedback were generated regarding the educational value and procedural fidelity of the NSTT itself as well as the associated training modules. Figure 1 depicts the nasal swab simulator and its anatomical correlates.

Study Design

Ethics approval was obtained through the Western University Research Ethics Board (REB—116400) and Lawson Health Research

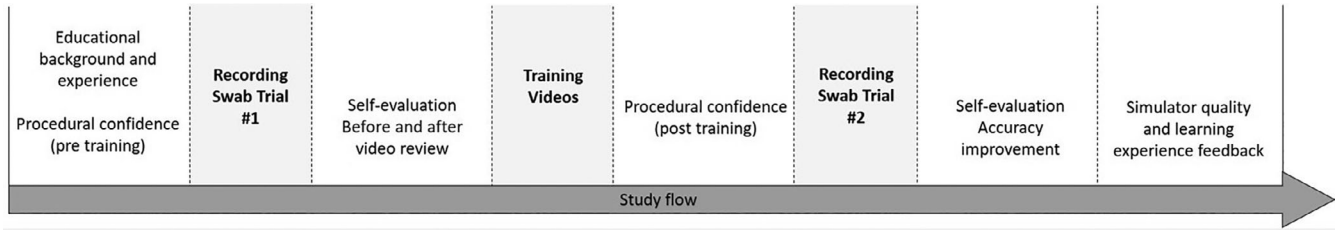

Fig. 2. Schematic flow diagram depicting study design and chronology.

TABLE I.
Demographic Data.

Education	n	%
Registered nurse	32	51.6
EMS paramedic	10	16.1
Other	20	32.3
Total	62	100

Procedural Experience	Mean	SD
Nasal swab experience (years)	1.40	3.09
Average # swabs performed (per day)	29	38
NP swabs performed (% of overall daily swabs)	79	39

EMS = Emergency Medical Services; N = number of participants; NP = Nasopharyngeal; SD = Standard Deviation.

Institute (ReDA ID—10268). Study execution (training and data collection) took place between October and December 2020. Nasopharyngeal swab training and data collection was conducted remotely at six COVID-19 testing sites across Ontario, Canada, involving frontline workers who were performing diagnostic NP swabs. Identical task training simulators were provided at each site.

First, participants were invited to complete an online-based demographic questionnaire (see Supporting Information, Appendix 1, in the online version of this article). The demographics questionnaire asked for participants' swab experience, daily swab rate, and self-rated procedural confidence in swab performance on a five-point Likert scale, where 1 represented "not confident" and 5 represented "extremely confident." All participants then completed a video-recorded NP swab on the model (Swab Trial #1). Participants were asked to self-evaluate their swab performance before and after review of the recorded video on a five-point Likert scale. Standardized instructional videos (training module) based on the instructions provided by the Centers for Disease Control and Prevention (CDC) and New England Journal of Medicine[14] were then reviewed by participants (Supporting Video 1 and Supporting Video 2, in the online version of this article). Next, participants were asked to score their procedural confidence once again. A second swab was then performed (Swab Trial #2) and recorded once again. After review of the second trial, participants were asked to grade their performance again and provide feedback on overall experience with the NSTT (Figure 2).

RESULTS

A total of 62 frontline workers were included in the study (Table I). Participants were primarily registered

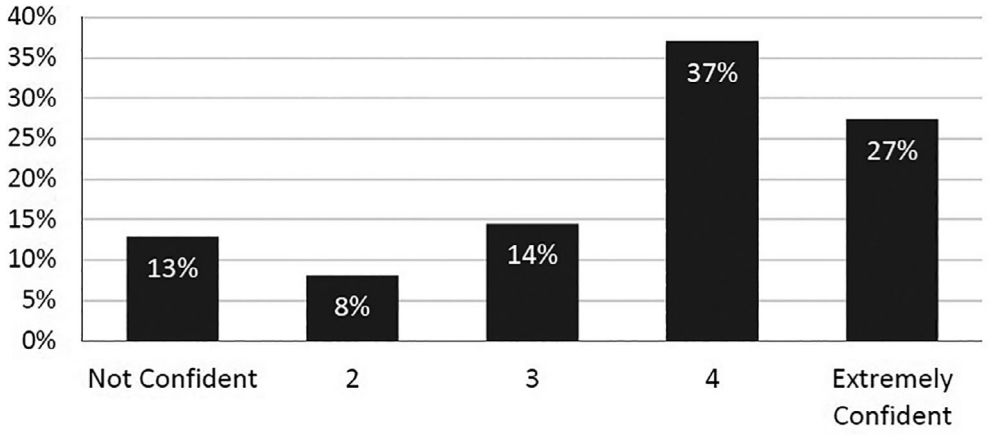

Fig. 3. Pretraining: How confident are you that you are collecting a proper specimen for your COVID-19 tests? Overall data with percentages indicated.

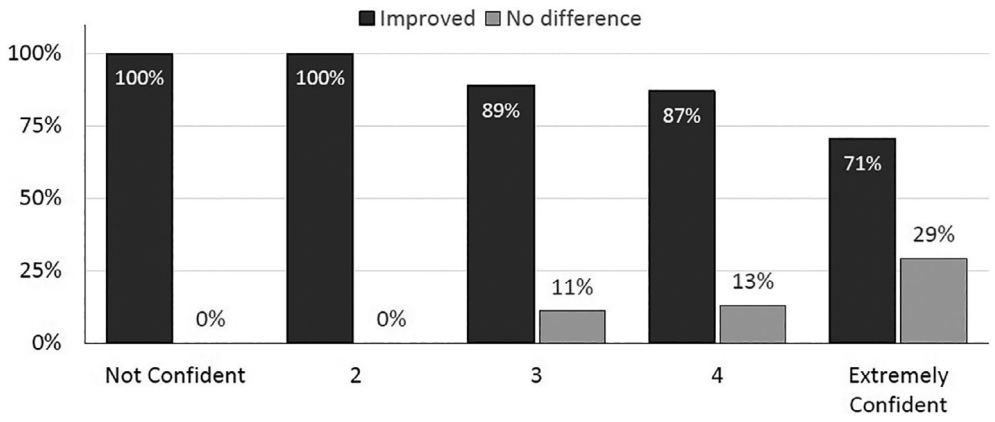

Fig. 4. Post-training: Do you feel more confident in best practices to perform a nasopharyngeal sample collection now? Overall data grouped by baseline (pretraining) confidence level with percentages indicated.

TABLE II.
Survey Results Regarding Simulator Quality and Educational Experience.

Simulator Feedback	% High or Very High
Appearance realism	82.3%
Tactile feedback realism	58.1%
Anatomical quality + septal deviation value	87.1%
Swab depth + angle realism	79.8%
Overall quality	83.9%
Educational Experience Feedback	**% Agree or Strongly Agree**
High-quality practice opportunity for nasal swab administrators	87.1%
Provides a more effective approach to training than what is currently available	82.3%
Should be used at all COVID-19 testing sites to ensure consistent and high-quality testing	80.6%
Province-wide implementation would result in high-quality testing across the province	77.4%

nurses (52%) or EMS paramedics (16%). The reported mean NP swab experience was 1.4 years (SD 3.09), and individuals performed an average of 29 NP swabs per day (SD 38).

Before starting the study, participants demonstrated high baseline confidence on proper specimen collection as 64% indicated a confidence level ≥4 on the Likert scale. After the first swab attempt on the simulator, 74% reported that they were happy with their first swab's results, representing that confidence remained high on procedural accuracy, before reviewing the footage. However, after reviewing the video of their first attempt, 42% considered that they could have done a more accurate NP swab. (Figure 3) After task trainer usage and training module completion, 77% of the health care workers considered that they had performed a more accurate swab on their second attempt. Under a subgroup analysis by pre-training confidence levels, robust improvements were seen in all subgroups. Eighty percent of participants with high baseline confidence (≥4 on the Likert scale) displayed improvement, as did 100% of participants with low baseline confidence (≤2 on the Likert scale). (Figure 4).

Survey results regarding usability and educational value of the NSTT system are presented in Table II. Feedback related to anatomical realism and procedural fidelity in the domains of appearance, anatomy, and swab depth/angle were rated high (4) or very high (5) by 82%, 87%, and 80% of participants, respectively.

For 94% of participants, the videos and NSTT usage were considered a complete educational experience for health care workers new to swabbing. Furthermore, 82% of participants regarded the use of the NSTT as a more effective training approach than what is currently available. Eighty-one percent of individuals indicated that the NSTT should be used at all COVID-19 testing sites to ensure consistent proper testing procedures, with 77% feeling as though province-wide implementation was warranted.

DISCUSSION

The COVID-19 pandemic has created an unprecedented demand for health care workers able to perform an NP swab. However, many of these providers are unfamiliar with nasal anatomy, and received only rapid on-the-job training, culminating with a trial swab on another trainee or directly on patients being screened. Unfortunately, this approach to training often reinforces improper procedural technique and hinders objective confirmation of successful skill acquisition.

Our study aimed to develop an intuitive method of training over a user-friendly platform that would not rely on the presence of a tutor (ie, facilitator), to allow accelerated and flexible training of health care workers on NP swab procedures. Mark et al. developed a training protocol on NP technique involving teaching sessions in which an otolaryngology resident provided informational handout, anatomy lessons, proper NP technique demonstrations, and real-time feedback on swab technique high-fidelity airway model to health care workers.[16] Their 62 participants were requested to answer a five-point Likert scale self-assessment for competence performing an NP swab for COVID-19 before and after the training sessions. The competency scores presented a significant increase of 1.41 points (3.13–4.54), which placed most of them near the self-assessed score of 5, considered "highly knowledgeable and confident, independent." Despite their positive results, such a training method may not be adaptable to time and geographic constraints of a global pandemic.

Among the study participants, the majority deemed themselves as very confident and extremely confident in the proper NP technique before the visual feedback of their first swab attempt. Nonetheless, after reviewing the footage, nearly half of the participants considered that they could have performed it more accurately. In the real-world scenario, when confidence is not accompanied by proper training or reliable accuracy confirmation, negative consequences can occur. For instance, Sullivan et al.[17] reported a case of iatrogenic cerebrospinal fluid leak after a nasal swab for a COVID-19 patient with preexisting encephalocele, whereas Koskinen et al.[18] reported COVID 19 swab test complications that included broken swabs and epistaxis, requiring medication, nasal packing, and surgical procedures. Although the frequency of these events is low, all complications were preventable with correct NP swab technique.

Improper NP technique also deserves attention because it can lead to false-negative COVID-19 test results.[14] Failing to reach the target site of the nasopharynx can lead instead to the swab being performed in the mid-air of the nasopharynx or as a mid-turbinate swab, which reduces the chance of accurate viral detection.[19] This becomes particularly important when case prevalence is high, as false-negative results can lead to super-spreader events. The lack of anatomical knowledge in the nasal cavity area of health care workers redirected to COVID 19 test centers can cause hesitancy and lead to incomplete insertion. After reviewing the video of their first attempt, only 42% of the study participants felt confident that an accurate sample had been obtained (out of 74% before reviewing the footage). Participants who judged their swab favorably based on gestalt alone (as one would in a real diagnostic setting) later discovered that their accuracy

was suboptimal upon direct visualization. This seems to illustrate that an individual's subjective perception of swab accuracy is a poor indicator of success and underscores the need for a paradigm shift in procedural training. Despite the availability of literature depicting proper NP procedures, NP procedure guidelines are heterogeneous and may not work as a proper training tool on NP swab technique.[13,20] Hands-on training with visual feedback can increase accuracy and comfort with nasal anatomy.

Simulation is the new standard for surgical training, resuscitation, or trauma, and it seems logical that it can and should be adapted to other health care domains, especially when the public health impact is so consequential.[21] In a systematic review, Cook et al.[22] showed that technology-enhanced simulation is related to better learning outcomes, especially with knowledge and procedural skills of health care professionals. In our study, the vast majority of participants expressed that the video and task trainer used were a superior educational experience that boosted confidence in procedural accuracy. Although the rate of accuracy improvement was greater in the low confidence group, considerable accuracy refinement was appreciable in the high baseline confidence group as well (100% vs 75%, respectively). These findings suggest that standardized training curricula in conjunction with simulation is of substantial value, irrespective of experience or perceived confidence levels before training.

Three-dimensional printing technology has played an important role in fighting the SARS-CoV-2 pandemic in several aspects. It was used to overcome material shortage to produce 3D printed nasal swabs and face shields, as well as to fill training gaps caused by a large inflow of health care workers to COVID-19 frontline centers.[23,24] Sananès et al.[25] presented a realistic 3D printed nasal swab simulator based on CT and MRI scans of the nasal and pharyngeal cavities as a potential educational tool on NP swab technique. Nonetheless, despite the similarities with the NP swab simulator used in the current study in respect to realism in design and potential for procedural feedback, no pilot data have been published yet concerning its usability in a real-world scenario such as the COVID-19 testing centers.

This study has generated user satisfaction data from six different COVID-19 testing sites using an NSTT. The feedback on NSTT educational value and procedural fidelity was largely positive. Most responses indicated that the potential of the task trainer as a learning tool is substantial, with 77% in favor of wide implementation. Furthermore, given that the simulator represents the anatomy of the entire nasal passage to scale, the platform can be adapted to other intranasal applications, and its potential as a learning tool may not be limited to NP swab task training.

CONCLUSIONS

The nasal swab task trainer represents a relevant educational tool on NP swab education, and it appears well-suited as a training system for those performing diagnostic swabs on the frontlines of COVID-19 care. The model can help improve technique even in seasoned providers by presenting some anatomical challenge and allowing for immediate review and feedback.

Acknowledgments

The authors would like to express their gratitude to the staff of all COVID 19 testing sites involved in this study.

BIBLIOGRAPHY

1. Kinloch NN, Ritchie G, Brumme CJ, et al. Suboptimal biological sampling as a probable cause of false-negative COVID-19 diagnostic test results. *J Infect Dis* 2020;222:899–902. https://doi.org/10.1093/infdis/jiaa370.
2. Afzal A. Molecular diagnostic technologies for COVID-19: limitations and challenges. *J Adv Res* 2020;26:149–159. https://doi.org/10.1016/j.jare.2020.08.002.
3. WHO. Diagnostic testing for SARS-CoV-2. https://www.who.int/publications/i/item/diagnostic-testing-for-sars-cov-2. 2020. Accessed December 20, 2020.
4. Kevadiya BD, Machhi J, Herskovitz J, et al. Diagnostics for SARS-CoV-2 infections. *Nat Mater* 2021;20:593–605. https://doi.org/10.1038/s41563-020-00906-z.
5. Wang H, Li X, Li T, et al. The genetic sequence, origin, and diagnosis of SARS-CoV-2. *Eur J Clin Microbiol Infect Dis* 2020;39:1629–1635. https://doi.org/10.1007/s10096-020-03899-4.
6. Public Health Ontario. COVID-19 Laboratory Testing Q & As. https://www.publichealthontario.ca/-/media/documents/lab/covid-19-lab-testing-faq.pdf?la=en. 2020. Accessed December 2020.
7. Woloshin S, Patel N, Kesselheim AS. False negative tests for SARS-CoV-2 infection - challenges and implications. *N Engl J Med* 2020;383:e38. https://doi.org/10.1056/NEJMp2015897.
8. Arevalo-Rodriguez I, Buitrago-Garcia D, Simancas-Racines D, et al. False-negative results of initial RT-PCR assays for COVID-19: a systematic review. *PLoS One* 2020;15:1–19. https://doi.org/10.1371/journal.pone.0242958.
9. Watson J, Whiting PF, Brush JE. Interpreting a covid-19 test result. *BMJ* 2020;369:m1808. https://doi.org/10.1136/bmj.m1808.
10. Mina MJ, Parker R, Larremore DB. Rethinking Covid-19 test sensitivity - a strategy for containment. *N Engl J Med* 2020;383:e120. https://doi.org/10.1056/NEJMp2025631.
11. Kanji JN, Zelyas N, MacDonald C, et al. False negative rate of COVID-19 PCR testing: a discordant testing analysis. *Virol J* 2021;18:1–6. https://doi.org/10.1186/s12985-021-01489-0.
12. Shuren J, Stenzel T. Covid-19 molecular diagnostic testing - lessons learned. *N Engl J Med* 2020;383:e97. https://doi.org/10.1056/NEJMp2023830.
13. Hiebert NM, Chen BA, Sowerby LJ. Variability in instructions for performance of nasopharyngeal swabs across Canada in the era of COVID-19 – what type of swab is actually being performed? *J Otolaryngol Head Neck Surg* 2021;50:4–9. https://doi.org/10.1186/s40463-020-00490-x.
14. Marty FM, Chen K, Verrill KA. How to obtain a nasopharyngeal swab specimen. *N Engl J Med* 2020;382:e76. https://doi.org/10.1056/nejmvcm2010260.
15. Gray LP. Deviated nasal septum. Incidence and etiology. *Ann Otol Rhinol Laryngol* 1978;87:3–20. https://doi.org/10.1177/00034894780873s201.
16. Mark ME, LoSavio P, Husain I, Papagiannopoulos P, Batra PS, Tajudeen BA. Effect of implementing simulation education on health care worker comfort with nasopharyngeal swabbing for COVID-19. *Otolaryngol Head Neck Surg* 2020;163:271–274. https://doi.org/10.1177/0194599820933168.
17. Sullivan CB, Schwalje AT, Jensen M, et al. Cerebrospinal fluid leak after nasal swab testing for coronavirus disease 2019. *JAMA Otolaryngol Head Neck Surg* 2020;146:1179–1181. https://doi.org/10.1001/jamaoto.2020.3579.
18. Koskinen A, Tolvi M, Jauhiainen M, Kekäläinen E, Laulajainen-Hongisto A, Lamminmäki S. Complications of COVID-19 nasopharyngeal swab test. *JAMA Otolaryngol Head Neck Surg* 2021;147:672–674. https://doi.org/10.1001/jamaoto.2021.0715.
19. Higgins TS, Wu AW, Ting JY. SARS-CoV-2 nasopharyngeal swab testing—false-negative results from a pervasive anatomical misconception. *JAMA Otolaryngol Head Neck Surg* 2020;146:993–994. https://doi.org/10.1001/jamaoto.2020.2946.
20. Pruidze P, Mincheva P, Weninger JT, Reissig LF, Hainfellner A, Weninger WJ. Performing nasopharyngeal swabs-guidelines based on an anatomical study. *Clin Anat* 2021;34:969–975. https://doi.org/10.1002/ca.23762.
21. Aimar A, Palermo A, Innocenti B. The role of 3D printing in medical applications: a state of the art. *J Healthcare Eng* 2019;2019:5340616. https://doi.org/10.1155/2019/5340616.
22. Cook DA, Hatala R, Brydges R, et al. Technology-enhanced simulation for health professions education: a systematic review and meta-analysis. *JAMA* 2011;306:978–988. https://doi.org/10.1001/jama.2011.1234.
23. Tay JK, Cross GB, Toh ST, et al. Design and multicenter clinical validation of a 3-dimensionally printed nasopharyngeal swab for SARS-CoV-2 testing. *JAMA Otolaryngol Head Neck Surg* 2021;147:418–425. https://doi.org/10.1001/jamaoto.2020.5680.
24. Flanagan ST, Ballard DH. 3D printed face shields: a community response to the COVID-19 global pandemic. *Acad Radiol* 2020;27:905–906. https://doi.org/10.1016/j.acra.2020.04.020.
25. Sananès N, Lodi M, Koch A, et al. 3D-printed simulator for nasopharyngeal swab collection for COVID-19. *Eur Arch Otorhinolaryngol* 2021;278:2649–2651. https://doi.org/10.1007/s00405-020-06454-1.