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ORIGINAL ARTICLE

Evaluation of face masks as a valuable forensic DNA evidence in the post-COVID era

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Abstract
After the onset of COVID-19 pandemic, a sharp surge in the usage of the face-masks throughout the globe has been observed. Pre-experiment survey of 252 individuals indicated a higher use of cotton-make masks (41%), followed by N-95 make (31%), and surgical disposable masks (26%). It was also further revealed that a higher fraction of individuals wear a face-mask more than 3 times (37%) before its disposal. In order to assess the potential usability of different mask types as forensic DNA evidence, a study was conducted on 50 healthy individuals. DNA content of different fractions such as the portion of mask covering the mouth region and the ear-piece showed a good source of host DNA. Though no statistically significant difference ($P < 0.05$) was found in the DNA quantity obtained from different face mask types, an increasing trend was obtained in the order: cloth make type (7.031 ± 0.31 ng), N-95 make (4.711 ± 0.15 ng), and surgical disposable type (2.17 ± 0.13 ng). The time of wearing of a face-mask showed a positive correlation with the yield of DNA irrespective of the face-mask type used. Samples retrieved from both the portions covering the mouth area and the ear-piece showed a good source of genomic DNA yielding an average of 4.82 ± 0.11 ng and 4.44 ± 0.10 ng of DNA, respectively. Irrespective of the face-mask types, number of reuse, and the portion of the mask, 66.66–96.11% of samples showed a complete autosomal STR DNA profile. This suggests that if a face-mask is found at the crime scene, it should be collected and preserved as a potential source of DNA evidence for routine forensic DNA analysis.

Keywords COVID-19 · Face-masks · Genomic DNA · Forensic DNA analysis

Introduction

The COVID-19 pandemic has revolutionized the life-style of the human beings. Nowadays, hand sanitizers and face masks have become an integral part of the survivors of this virus. Hand sanitizers kill microorganisms and have been recommended by the World Health Organization (WHO) as a useful controlling agent in spreading the virus [1]. Similarly, a face mask is recommended as a necessary tool to handle the outbreak as it protects against many respiratory infections that can spread through the droplet route including coronavirus and other flu [2]. Face masks prevent the exposure of a person from droplets which are originated from someone whose nose and mouth are uncovered; hence, the transmission of the virus is minimized.

Face masks exist as an established habit since the SARS epidemic in 2003 in many Asian countries. In countries like China and South Korea, face masks are routinely used to protect the citizens from air pollutants as well. However, in western countries, face masks present a rare social setting [3]. With the onset of the COVID-19 pandemic, many countries have urged for mandatory use of face masks in public places [4]. It has been reported that mask usage has increased gradually post-COVID-19 which is dependent on socio-demographic factors, risky social behaviors, and mask policies [5]. Though vaccination provides a solution to minimize the risk of COVID-19 infection, a recent simulation study showed that maintaining face mask use until or after a short time of achieving final vaccination coverage levels is cost-effective as well as cost-saving. Besides, with the emergence of the omicron variant and the prospect of future variants which may reduce the vaccine effectiveness, the use of face masks must be continued among the individuals [6].

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With the increased awareness among the public and global policy making of wearing masks compulsorily, a variety of alternative masks other than N95/FFP2 respirators such as the surgical masks and simple cloth masks are regarded as a pragmatic solution for public use [7]. Out of all the masks used globally, the N95 mask type has been reported to provide more safety and security than any other available mask type [8].

Currently, forensic DNA analysis relies on the repeatability of Short Tandem Repeat (STR) markers from routine biological exhibits. Advanced molecular techniques with high specificity and sensitivity are being explored now-a-days for their use in forensic DNA analysis. A recent observation by Aparna et al. [9] highlighted the use of certain uncommon body fluids such as tears to be used for generating a DNA profile. The routine biological exhibits include the stains of various body fluids, bones, teeth, and other trace evidences. With the increased use of face masks globally, it can be envisioned as a suitable source for forensic DNA analysis. Face masks worn by the individuals for a prolonged period of time disseminate their saliva in the inner portion of the mask which can be explored as a suitable DNA source. With the advent of touch DNA analysis and requirement of trace quantity of DNA, transfer of body's cells around the ear piece segment of face masks can also serve as a source of DNA for forensic analysis. Though the use of face masks has increased in the post-COVID era, the saliva traces on the perpetrator's mask have been attributed to a particular criminal long back in 1996 by DNA analysis [10]. Increased breathing through the open mouth under the mask has been reported [11] which increases the chance of transfer of body fluid from mouth to the mask. As the use of face masks has increased manifold in the post-COVID era, the chance of getting any such evidentiary materials from a crime scene is highly likely. Analysis of DNA from these body fluids found on the face mask can provide a huge clue regarding the identification of a perpetrator of a crime. Hence, a novel attempt has been made to assess the usefulness of face masks as a source of DNA for forensic analysis. With the availability of different varieties of face masks used by common people and the variation of wearing time, both the parameters, i.e., face mask type and duration of wearing, were also taken into consideration in this study.

Materials and methods

Pre-experiment survey

A survey was conducted on 252 individuals representing various parts of the globe including South Asia, Middle East Region, and the USA regarding the types of face masks they use, the duration of wearing a mask in a day, and the reuse criteria of the face masks. Based on the responses received from the participants, the experiments were designed to assess the usability of various face mask types for forensic DNA analysis.

Types of face masks, volunteers, and sampling

The study was conducted on 50 healthy volunteers after obtaining their informed written consent. COVID-19 positive patients were excluded from this study. The study was approved by the Ethical committee of National Forensic Sciences University, Delhi Campus no. NFSU_DC/1101/FS-Biology/IHEC-2022–23-6. Three types of face masks were used in this study, i.e., surgical disposable mask, N-95 mask type, and cloth mask. Each individual was allowed to wear these three types of face masks for a period of 1 day, 2 days, and more than 2 days. Samples were collected from two portions of the face mask, i.e., the inner layer of the mask which covers the mouth region, and from the ear piece area. An area of 2 cm × 2 cm was cut from the inner layer of the face mask near to the mouth portion and 2 cm each from both the ear pieces of the mask. Both the samples were processed separately for subsequent experimentations.

DNA extraction and quantification

Genomic DNA was extracted from the samples by manual methods using the phenol–chloroform extraction technique [12] as well as using automated DNA extraction system, i.e., DNA IQ™ System (Promega Corp., US) following the manufacturer's recommendations. Manual process was employed for the extraction of DNA from the mouth-piece region, whereas an automated extraction technique was used to extract DNA from the ear-piece region. The extracted DNA was assessed quantitatively as well as qualitatively using NanoDrop Spectrophotometer (ThermoScientific, USA) and using PowerQuant® System (Promega Corporation) in a real-time PCR (Gene Studio S5, Thermo Scientific, USA) following recommended protocol.

Amplification of autosomal STR markers

Multiplex system PowerPlex® Fusion 6C System (Promega, Madison, WI) was used to amplify the 23 autosomal STR markers including CSF1PO, FGA, TH01, TPOX, vWA, D1S1656, D2S1338, D2S441, D3S1358, D5S818, D7S820, D8S1179, D10S1248, D12S391, D13S317, D16S539, D18S51, D19S433, D21S11, D22S1045, Penta D, Penta E, and SE33. Amplification was carried out in a Veriti thermal cycler (Thermo Scientific, USA) using a total of 25 µl of reaction volume containing 5 µl of 5 × Master Mix, 5 µl of 5 × Primer Pair Mix, and 0.5 ng/µl of control DNA. The protocol used for the amplification of STR markers includes

96 °C for 1 min followed by 29 cycles of 96 °C for 5 s and 60 °C for 1 min followed by 60 °C for 1 min and 4 °C for ∞. The PCR products were stored at − 20 °C till further use.

Capillary electrophoresis

The separation of amplified fragments was carried out in a 3500 Genetic Analyzer (Thermo Scientific, USA) using a 36-cm capillary array, POP™-4 polymer, and respective size standard and allelic ladder. Finally, the alleles were designated by GeneMapper ID-X v.1.5 software (Thermo Scientific, US) using data obtained from size standard, allelic ladder, and the provided beans and panels. 50 relative fluorescence unit (RFU) was maintained as an analytical detection threshold for the generation of DNA profiles.

Data analysis and statistical calculations

Statistical parameters such as 2-way ANOVA with replications and Student's *t* test were carried out using Microsoft Excel® 2010.

Results and discussions

The pre-experiment survey included a total of 252 individuals globally consisting of 125 males and 127 females. The participants of the survey included three age groups, i.e., 18 to 30 (174 individuals), 31 to 45 (63 individuals), and more than 46 (15 individuals). A large fraction of the individuals opined to wear the face mask for 2–8 h a day, i.e., 140 individuals, whereas 112 individuals informed that they wear the face mask for less than 2 h a day. The fraction of individuals wearing the face masks 2–8 h a day may be attributed to the working professionals with an average shift of 8 h a day. Non-working people may not find it necessary to put on a face mask for 8 h and wear it occasionally throughout the day for a limited period of time. Regarding the type of face mask, most of the participants wear a mask of cotton make (41%), followed by N-95 mask (31%), and surgical disposable mask (26%). To our surprise, a higher fraction of participants opined that they wear a mask more than 3 times (37%), followed by single use (26%), 2 times (24%), and 3 times (14%) before dispose (Fig. 1). The higher re-use of a mask is deemed to accumulate more number of host cells

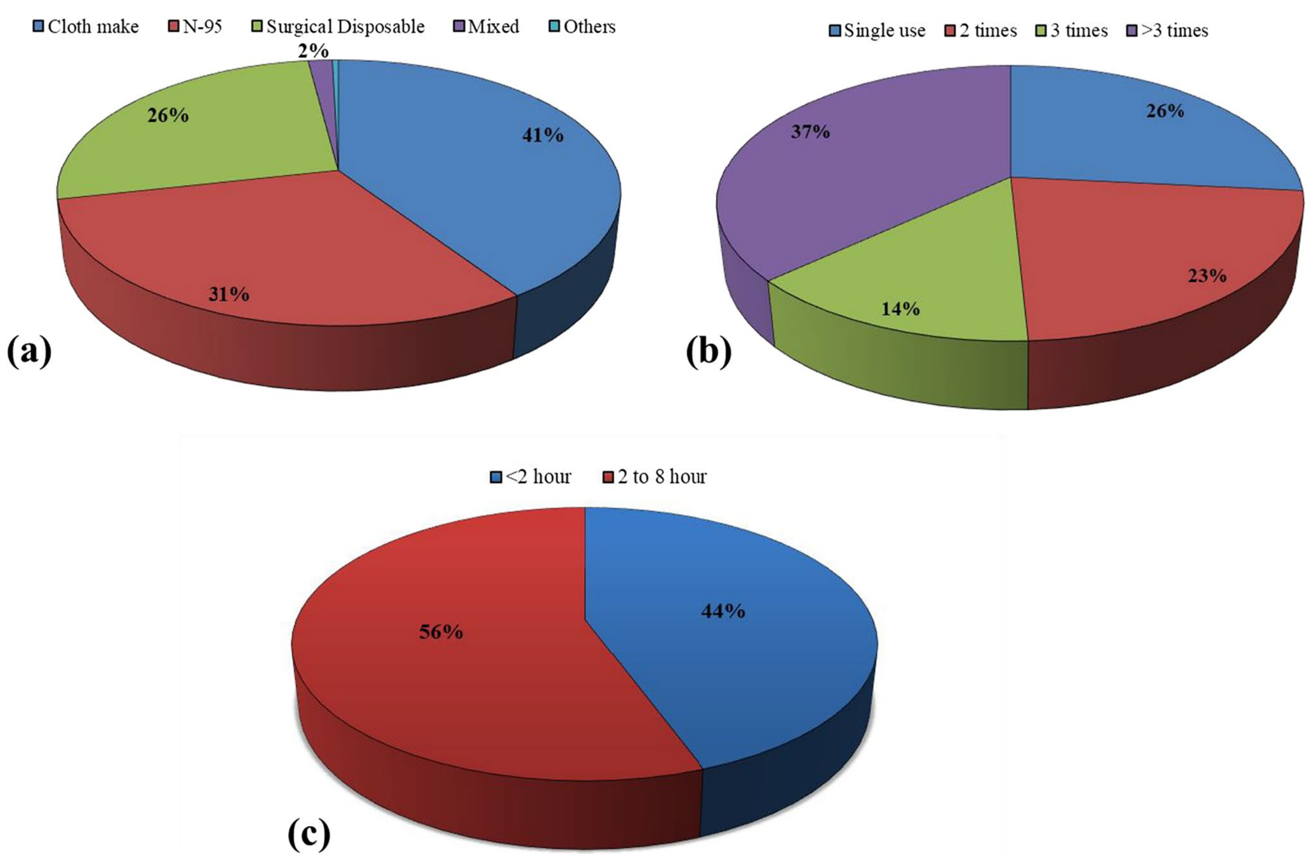

Fig. 1 Response received from the participants regarding **a** the types of face mask used, and **b** no. of times the mask is worn before its disposal **c** duration of wearing masks per day

in the mask surfaces and can be a valuable source of host's DNA for forensic analysis. Based on the pre-survey report, the experiments were designed to include both the face mask types and no. of re-use of the mask as two independent variables to analyze the source of DNA evidences on the masks.

Assessment of DNA quantity from the samples

The average quantity of genomic DNA extracted from different samples ranged from 12.036 ± 0.35 ng to 0.748 ± 0.12 ng (Fig. 2). Out of three face mask types used in this study, cloth make type showed the highest source of DNA (7.031 ± 0.31 ng), followed by N-95 type (4.711 ± 0.15 ng), and surgical disposable type (2.17 ± 0.13 ng). Electrostatic non-woven polypropylene fiber is used to prepare N-95 face masks [13], whereas polymeric materials are widely used for the manufacturing of surgical disposable face masks [14]. The cloth make face masks are mostly manufactured from cotton or its variants. The conducted study depicted that cotton has a higher rate of retention capability of the host cells on its surface in comparison to electrostatic non-woven materials or polymeric materials. To support this finding, the high retention capability of cells of cotton swabs has also been established in many studies [15, 16].

Irrespective of the nature of the face-mask and the source of sampling, the average DNA quantity was found to be the highest in the samples which were used for more than 2 days (5.74 ± 0.14 ng), followed by 1-day use (4.65 ± 0.11 ng), and 2-day use (3.51 ± 0.13 ng). As some non-ambiguous results were detected in some of the face mask types, the yielded DNA quantity was segregated by the number of hours worn by the volunteer. As per the obtained result as represented in Fig. 2, irrespective of the face-mask type, the DNA yield increased with the increase in wearing time of the masks. Though the increase in DNA yield was not found to be linear with the increase in time, different studies have found no correlation between wearing time of an object with the amount of wearer's DNA recovery from the samples [17, 18]. This non-linear relationship between the amount of DNA obtained due to the touch may be attributed to an individual's specific characteristic which depends on the individual's shedder status [19]. The propensity to leave DNA on different parts of a face-mask can also be due to an individual's specific characteristics [20]. This might be the reason for not generating a uniform pattern of the quantity of extracted DNA within different intervals of time.

In a similar fashion, irrespective of the nature of the face-mask and no. of re-use by the host, samples recovered from both mouth-piece (4.82 ± 0.11 ng) and ear-piece (4.44 ± 0.10 ng) showed a significant source of genomic DNA. As expected, the samples recovered from the mouth-piece showed a higher amount of DNA in comparison with the ear piece. The most significant cause of finding a high genomic DNA content from the mouth-piece region may be attributed to the secretion of saliva and nasal secretions during normal speaking activities. Crime scene investigators mostly use face masks to prevent contamination of the crime scene due to mere talking, sneezing or coughing [21]. In general practice, such routine biological activities continuously shed cells on the inner portion of the mask covering the mouth and nose area, which can act as a useful source of host DNA. In comparison to that, the ear piece of mask has a lesser surface area available for friction with the retro-auricular area. Frictional transfer of cells becomes the only source of host DNA around the ear-piece portion of the mask. In a similar line, a study showed that pre-adolescent children have undeveloped auricular cartilage which might cause deformation due to prolonged pressure from the elastic loops of the mask [22]. Such pressure is also generated in the adult hosts as well, which may not be visible in the form of

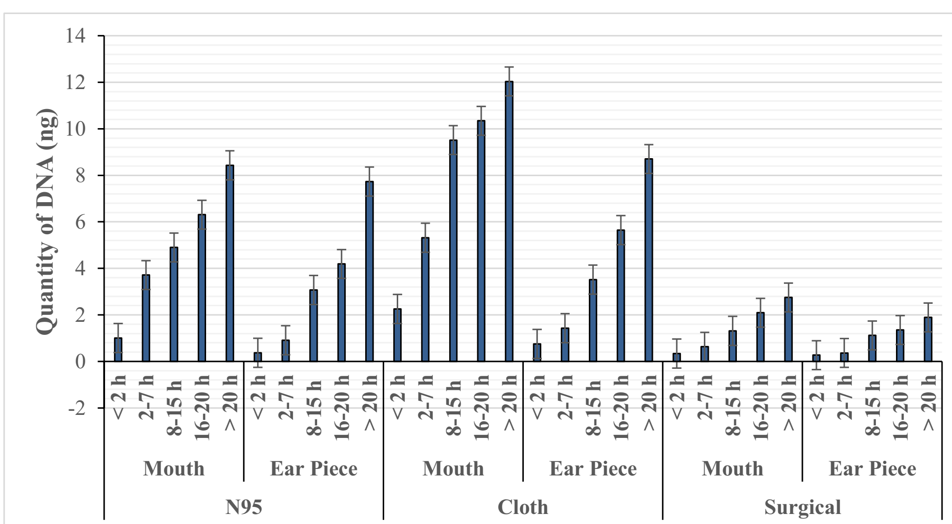

Fig. 2 Amount of DNA extracted from different types of face masks with respect to different portions of masks and duration of wearing of the face-masks ($n = 50$)

any deformities. Due to this pressure and friction between ear piece and skin, the possibility of finding DNA from shed cells increases.

2-way ANOVA with replication showed a statistically significant variation ($P > 0.05$) in the amount of DNA extracted from different individuals included in this study (Table 1). As discussed earlier, this might be due to the shedder status of the volunteers included in this study, which is an individual-specific characteristic. The propensity to leave DNA behind or the shedder status of an individual has shown its correlation with the DNA accumulated in the active hand and skin of the face [23], whereas we did not find any literature to correlate the shedder status of an individual in the oral region of the individual to the best of our knowledge. However, no statistically significant variation ($P < 0.05$) was found among the DNA obtained from different mask-types, portion of mask selected for DNA sampling, and number of days the mask is reused by the host before its disposal. This suggests that any type of mask routinely used by the common public can act as a valuable source of DNA with deemed forensic application.

Quality of STR profiles from the extracted DNA

In corroboration with the obtained DNA quantity, full DNA profiles were obtained from the different sources of cloth make mask type followed by N-95 make and surgical disposable type (Fig. 3). The occurrence of null DNA profile was observed to be of highest occurrence in samples obtained from surgical disposable mask types, mostly when

Table 1 2-way ANOVA with replications of various parameters analyzed in this study. (a) Among different mask types, (b) among different days on host's face, and (c) between different portions of sampling

Source of variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
(a)						
Between individuals	4.91E+10	113	4.35E+08	1.078312	0.314893	1.299465
Between different mask types	1.28E+10	2	6.4E+09	15.87878	3.53E-07	3.035795
Error	9.11E+10	226	4.03E+08			
Total	1.53E+11	341				
(b)						
Between individuals	5.44E+10	113	4.81E+08	1.142913	0.199751	1.299465
Between days on host	3.46E+09	2	1.73E+09	4.108893	0.017669	3.035795
Error	9.51E+10	226	4.21E+08			
Total	1.53E+11	341				
(c)						
Between individuals	7.5E+10	170	4.41E+08	1.014223	0.463375	1.287904
Between different portions of mask	3.99E+09	1	3.99E+09	9.175237	0.002836	3.896742
Error	7.4E+10	170	4.35E+08			
Total	1.53E+11	341				

SS sum of squares, *df* degree of freedom, *MS* mean sum of squares

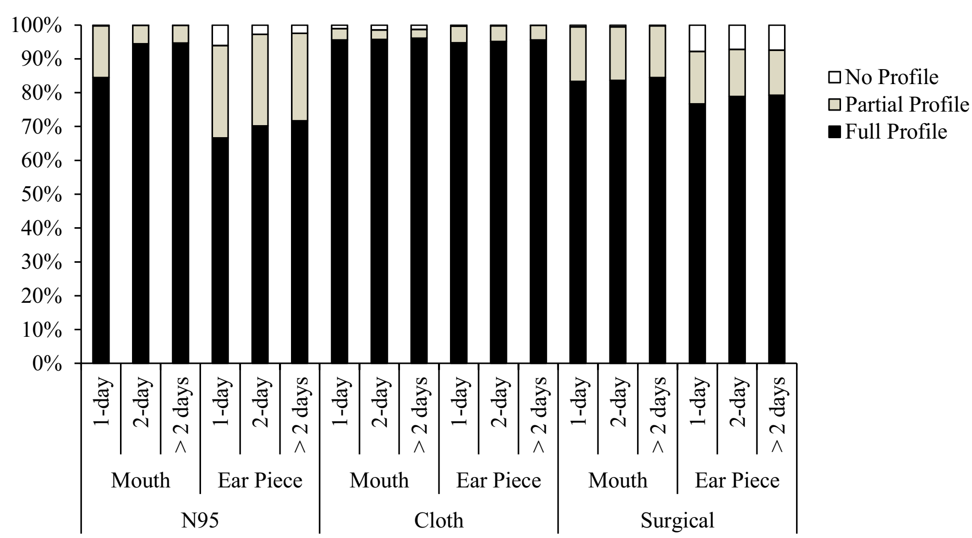

Fig. 3 Quality of STR profiles obtained from the DNA yield from different face mask types

the samples are collected from the ear-piece region. The ear piece region of any mask tends to contain the least number of the host's cells due to minimal transfer and is devoid of direct transfer of any body fluids. Hence, obtaining the highest number of null DNA profiles in samples collected from the ear piece region is deemed obvious. Besides, partial DNA profiles commonly occur in routine forensic DNA analysis [24]. The routine cause of obtaining a partial DNA profile is when the sample is degraded and/or a sufficient quantity of DNA is not obtained. In such cases, peaks of a few loci fall below the predetermined threshold level to give rise to a partial DNA profile. In this scenario, a range of 2.55% (> 2-days use of cloth-make masks from mouth region) to 27.22% (1-day use of N-95 masks from ear-piece sample) of the DNA profiles showed amplification of partial STR markers. Though the occurrence of partial DNA profiles is found in large numbers in different face-mask sources, such DNA profiles can also be useful in forensic DNA analysis either by increasing the sample size or analyzing the alternative markers such as single-nucleotide polymorphism (SNP) markers [25]. Due to its smaller size, mitochondrial DNA analysis can also be performed in such low copy number and/or degraded samples for forensic DNA analysis [26].

Conclusion

After the occurrence of the COVID-19 pandemic, there has been a sharp surge in the usage of face-masks throughout the globe. A survey conducted in this study showed the primary use of cotton-make, N-95, and surgical disposable type of face-masks as the routinely used face-mask types in different global populations. Quantification of genomic DNA from different portions of the face-masks showed that face-masks are a huge source of DNA for further down-stream processing. Out of the routinely used face-mask types, cotton-make masks provided the highest source of host DNA followed by N-95 make and surgical disposable types. The portion of the mask covering the host's face yielded a higher quantity of DNA in comparison to the ear-piece portion of the mask. Irrespective of the types of face masks, when they are reused for more than 2 days, it provided a huge source of DNA compared to the single- or 2-day use of the masks. Amplification of autosomal STR markers also showed a promising result with the generation of a complete DNA profile in 66.66% to 96.11% of samples. This showed a huge promise in exploring the face-masks, if found at the crime scene, as a forensic DNA evidence. Besides, this study showed that the mouth covering area and the ear piece area of a face mask provides a potential source of host DNA and the former portion yields a higher quantity of genomic DNA.

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Author contribution HRD designed the experiment; MA and SK carried out the experiments and analyzed the results. HRD prepared the manuscript. All authors reviewed and agreed to the manuscript.

Declarations

Ethical approval The study was approved by the Ethical Committee of National Forensic Sciences University. All samples were collected with full informed consent.

Competing interests The authors declare no competing interests.

References

1. Francis J (2020) Awareness on the use of hand sanitizer and face mask in disease spread-a survey among college students. Indian J Forensic Med Toxicol 14:5786–5793
2. Humphreys J (2020) The importance of wearing masks in curtailing the COVID-19 pandemic. J Fam Med Prim Care 9:2606–2607. https://doi.org/10.4103/jfmpc.jfmpc_578_20
3. Martinelli L, Kopilaš V, Vidmar M, Heavin C, Machado H, Todorović Z, Buzas N, Pot M, Prainsack B, Gajović S (2021) Face masks during the COVID-19 pandemic: a simple protection tool with many meanings. Front Pub Health. https://doi.org/10.3389/fpubh.2020.606635
4. Flaskerud JH (2020) Masks, politics, culture and health. Issues Ment Health Nurs 41:846–849. https://doi.org/10.1080/01612840.2020.1779883
5. Badillo-Goicoechea E, Chang TH, Kim E, LaRocca S, Morris K, Deng X, Chiu S, Bradford A, Garcia A, Kern C, Cobb C, Kreuter F, Stuart EA (2021) Global trends and predictors of face mask usage during the COVID-19 pandemic. BMC Public Health 21:2099. https://doi.org/10.1186/s12889-021-12175-9
6. Bartsch SM, O'Shea KJ, Chin KL, Strych U, Ferguson MC, Bottazzi ME, Wedlock PT, Cox SN, Siegmund SS, Hotez PJ, Lee BY (2022) Maintaining face mask use before and after achieving different COVID-19 vaccination coverage levels: a modelling study. Lancet Publ Health 7:e356–e365. https://doi.org/10.1016/S2468-2667(22)00040-8
7. Howard J, Huang A, Lid Z, Tufekci Z, Zdimal V, van der Westhuizen HM, von Delft A, Price A, Fridman L, Tang LH, Tang V, Watson GL, Bax CE, Shaikh R, Questier F, Hernandez D, Chu LF, Ramirez CM, Rimoin AW (2020) An evidence review of face masks againstCOVID-19. 118:e2014564118. https://doi.org/10.1073/pnas.2014564118
8. Ahmad MDF, Wahab S, Ahmad FA, Alam MI, Ather H, Siddiqua A, Ashraf SA, Shaphe MA, Khan MI, Beg RA (2021) A novel perspective approach to explore pros and cons of face mask in prevention the spread of SARS-CoV-2 and other pathogens. Saudi Pharm J 29:121–133. https://doi.org/10.1016/j.jsps.2020.12.014
9. Aparna R, Iyer RS, Kumar N, Sharma A (2021) Forensic DNA profiling of tears stains from commonly encountered substrates. Forensic Sci Int 328:111006. https://doi.org/10.1016/j.forsciint.2021.111006
10. Schneider H, Neuhuber F (1996) Detection of saliva traces on perpetrator masks and their attribution to a particular criminal. Arch Kriminol 198:31–37

11. Kisielinski K, Giboni P, Prescher A, Klosterhalfen B, Graessel D, Funken S, Kempski O, Hirsch O (2021) Is a mask that covers the mouth and nose free from undesirable side effects in everyday use and free of potential hazards? Int J Environ Res Pub Health 18:4344. https://doi.org/10.3390/ijerph18084344
12. Köchl S, Niederstätter H, Parson W (2005) DNA extraction and quantitation of forensic samples using the phenol-chloroform method and real-time PCR. Met Mol Biol 297:13–30. https://doi.org/10.1385/1-59259-867-6:013
13. Juang PSC, Tsai P (2020) N95 respirator cleaning and reuse methods proposed by the inventor of the N95 mask material. J Emerg Med 58:817–820. https://doi.org/10.1016/j.jemermed.2020.04.036
14 Aragaw TA (2020) Surgical face masks as a potential source for microplastic pollution in the COVID-19 scenario. Mar Pollut Bullet 159:111517. https://doi.org/10.1016/j.marpolbul.2020.111517
15. Adamowich MS, Stasulli DM, Sobestanovich EM, Bille TW (2014) Evaluation of methods to improve the extraction and recovery of DNA from cotton swabs for forensic analysis. PLoS One 9:e116351. https://doi.org/10.1371/journal.pone.0116351
16. Jansson L, Hedman J (2020) Impact of swab material on microbial surface sampling. J Microbiol Met 176:106006. https://doi.org/10.1016/j.mimet.2020.106006
17. Poetsch M, Pfeifer M, Konrad H, Bajanowski T, Helmus J (2018) Impact of several wearers on the persistence of DNA on clothes-a study with experimental scenarios. Int J Leg Med 132:117–123. https://doi.org/10.1007/s00414-017-1742-z
18. Sessa F, Salerno M, Bertozzi G, Messina G, Ricci P, Ledda C, Rapisarda V, Cantatore S, Turillazzi E, Pomara C (2019) Touch DNA: impact of handling time on touch deposit and evaluation of different recovery techniques: an experimental study. Sci Rep 9:9542. https://doi.org/10.1038/s41598-019-46051-9
19. Farmen RK, Jaghø R, Cortez P, Frøyland ES (2008) Assessment of individual shedder status and implication for secondary DNA transfer. Forensic Sci Int Genet Suppl Ser 1:P415–P417. https://doi.org/10.1016/j.fsigss.2007.08.015
20. Jansson L, Swensson M, Gifvars E, Hedell R, Forsberg C, Ansell R, Hedman J (2022) Individual shedder status and the origin of touch DNA. Forensic Sci Int Genet 56:102626. https://doi.org/10.1016/j.fsigen.2021.102626
21. Rutty GN, Hopwood A, Tucker V (2003) The effectiveness of protective clothing in the reduction of potential DNA contamination of the scene of crime. Int J Leg Med 117:170–174. https://doi.org/10.1007/s00414-002-0348-1
22. Zanotti B, Parodi PC, Riccio M, De Francesco F, Zingaretti N (2020) Can the elastic of surgical face masks stimulate ear protrusion in children? Aesthetic Plast Surg 44:1947–1950
23. Jansson L, Swensson M, Gifvars E, Heddel R, Forsberg C, Ansell R, Hedman J (2022) Individual shedder status and the origin of touch DNA. Forensic Sci Int Genet 56:102626. https://doi.org/10.1016/j.fsigen.2021.102626
24. Weir BS (2004) Matching and partially-matching DNA profiles. J Forensic Sci 49:1009–1014
25. Tillmar A, Grandell I, Montelius K (2019) DNA identification of compromised samples with massive parallel sequencing. Forensic Sci Res 4:331–336. https://doi.org/10.1080/20961790.2018.1509186
26. Court DS (2021) Mitochondrial DNA in forensic use. Emerg Top Life Sci 5:415–426. https://doi.org/10.1042/ETLS20210204

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