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Research article

ASSESSMENT OF BACTERIAL FILTRATION AND AIR PERMEABILITY OF FACE MASKS USED BY PEOPLE DURING THE COVID-19 PANDEMIC

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The pandemic caused by SARS-CoV-2 remains a serious threat to human health. Non-specific protection measures including face masks are an effective way to reduce risks of the infection spread. Face masks have different protective capacities and their effectiveness depends on an extent to which a material a mask is made of can retain droplets and aerosol particles containing the virus. Bacterial filtration can be used an as indicator showing how effectively a mask protects from contagion and air permeability can be used to estimate how comfortable it is to wear it.

Our research aim was to comparatively assess effectiveness and comfort in wearing provided by masks which were most frequently used by people during the pandemic.

We examined medical, cotton, and neoprene masks. Bacterial filtration was determined in accordance with the procedure stipulated in the State Standard GOST 12.4.136-84. Air permeability was estimated by determining how thin air was with VTPM-2 device produced by "Metroteks" LLC. All the data were statistically analyzed with StatTech v. 2.4.1 software package. We calculated quantitative indicators (M ± SD, 95 % CI for normal distribution), Fischer's test (comparison between groups as per quantitative indicators) and Spearman's rank correlation coefficient (directions and intensity of correlations). We developed our predictive model using linear regression.

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The research results indicate that the neoprene mask tends to have the highest bacterial filtration; the cotton mask, the highest air permeability. We detected a correlation between bacterial filtration and air permeability.

All masks are quite comparable to a medical one as per all their combined examined characteristics and can be used as a barrier for mitigating risks of droplet infections spread. It is advisable to further investigate face masks with concentrating on more characteristics of their effectiveness, comfort in wearing and safety.

Key words: *face mask, COVID-19, bacterial filtration, air permeability, cotton mask, neoprene mask, medical mask, statistical analysis.*

The COVID-19 pandemic caused by SARS-CoV-2 virus which started in December 2019 still remains a threat to human health all over the world [1]. Despite newly developed and quite effective immunobiological medications and wide-scale vaccination the COVID-19 incidence is growing at the moment due to new occurring SARS-CoV-2 virus strains. Therefore, non-drug approaches to COVID-19 prevention, face masks included, are still considered a simple and effective way to reduce risks of the infection spread [2–5].

In different countries there are different approaches to regulation of mask wearing during the COVID-19 pandemic. Primarily, all these approaches take into account epidemiological significance and barrier functions of a mask but they are not usually based on its hygienic assessment. The WHO recommends people in general and those who work in closed spaces or in close proximity from each other (or clients) to use non-medical (woven) masks consisting of 3 layers[1]. The US Centers for Disease Control and Prevention recommend using woven masks made of at least 2 layers of materials with good air permeability[2] whereas the European Center for Disease Prevention and Control recommends both medical and non-medical masks which meet the requirements on effective filtration and air permeability[3]. In China it is recommended to wear non-reusable medical masks in places where contagion risks are relatively low and non-medical masks in places where these risks are low[4]. In the Russian Federation, just as in some other countries, administrative, organizational, technical, sanitary and hygienic measures were introduced step by step. All these measures were aimed at preventing COVID-19 spread [6]. At present, it is mandatory to wear hygienic masks in public places and public transport[5]; employers are obliged to provide their workers with non-reusable masks to be worn at workplaces[6].

Effectiveness of protection provided by a mask depends on a material it is made of; to be

[1] Mask use in the context of COVID-19: interim guidance. Geneva, Switzerland, World health organization, December 1, 2020, 22 p.; Preventing and mitigating transmission of COVID-19 at work: policy brief, 19 May 2021. *WHO, ILO*, 2021, 23 p.

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[5] O dopolnitel'nykh merakh po snizheniyu riskov rasprostraneniya COVID-19 v period sezonnogo pod"ema zabolevaemosti ostrymi respiratornymi virusnymi infektsiyami i grippom: Postanovlenie glavnogo gosudarstvennogo sanitarnogo vracha RF ot 16.10.2020 № 31 [On additional activities aimed at reducing risks of COVID-19 spread during a seasonal rise in morbidity with acute respiratory virus infections and flu: The Order by the RF Chief Sanitary Inspector issued on October 16, 2020 No. 31]. *The official Internet portal of legal information*. Available at: http://publication.pravo.gov.ru/Document/View/0001202010270001 (November 09, 2021) (in Russian).

[6] O merakh po profilaktike novoi koronavirusnoi infektsii (COVID-19): Pis'mo Rospotrebnadzora ot 10.03.2020 № 02/3853-2020-27 [On prevention measures against the new coronavirus infection (COVID-19): The Letter by Rospotrebnadzor issued on March 10, 2020 No. 02/3853-2020-27]. *The Federal Service for Surveillance over Consumer Rights protection and Human Wellbeing*. Available at: https://www.rospotrebnadzor.ru/deyatelnost/epidemiological-surveillance/?ELEMENT_ID=13955 (November 09, 2021) (in Russian).

more exact, it depends on how well this material retains droplets and aerosol particles which contain viruses. Although the size of SARS-CoV-2 virus is about 1 μm, virus particles attach to water droplets which are released into the air by sick people when they she breathe, sneeze, cough, or talk. Therefore, the total size of a single infecting virus particle together with water becomes larger and varies from 5 to 15 μm [7, 8]. According to some other data, when a person breathes, water particles which are released in the process vary from 0.1 to 1000 μm [9]. Pore size in a medical mask varies from 0.3 to 10 μm and is quite comparable to sizes of various bacteria. For example, *Staphylococcus aureaus* is 0.8–1 μm in diameter; this bacterial culture is often used to determine bacterial permeability of personal protective equipment (GOST 12.4.136-84[7]). Therefore, masks which are recommended to be worn by people for protection make contagion with coronaviruses less probable and bacterial filtration can be used as an indirect indicator showing how effectively a mask protects from respiratory viral infections, COVID-19 included.

Comfort in wearing is primarily determined by air permeability of a material a mask it made from [10–14]. This property determines how easy it is for a person to breathe through a mask; it also determines if there is a probability of various adverse effects produced by wearing it such as breathing discomfort, headache, and local skin reactions.

Our research aim was to comparatively assess effectiveness and comfort in wearing provided by masks which were used by population during the pandemic.

To achieve it, it was necessary to solve the following tasks:

1. To determine effectiveness of bacterial filtration provided by the most frequently used types of masks as an indicator showing effectiveness.

2. To determine air permeability of the most frequently used masks as an indicator showing comfort in wearing.

3. To comparatively assess effectiveness and comfort provided by different types of masks.

Materials and methods. We selected 3 types of masks to be examined bearing in mind our accomplished market analysis which focused on sales of respiratory protective equipment applied during this pandemic [15] as well as recommendations on mask wearing developed in different countries (Table 1).

Examined masks of each type were bought from the same manufacturer.

Bacterial filtration was determined as per the conventional procedure stipulated in the State Standard GOST 12.4.136-84 "Personal protective means. Method for determination of microorganism permeability"[7]. The procedure involves comparing a number of grown *Staphylococcus aureus* colonies which penetrated through a tested mask with a number of colonies grown on control plates. We calculated the bacterial filtration coefficient as $1 - (M \div M_1) \cdot 100$ where M was a simple mean of a number of colonies for each sample and M1 was a simple mean of a number of colonies

Table 1

Examined types of masks

Type	Description
Medical	Disposable medical non-woven 3-layer (spunbond / metlblown) mask with noise clip and ear straps
Cotton	Reusable non-medical cotton 2-layer mask with behind-the-ear loops, without nose clip and exhalation valve
Neoprene	Reusable non-medical neoprene one-layer mask with behind-the-ear loops, without nose clip and exhalation valve

[7] The State Standard GOST 12.4.136-84. System of safety standards. Personal protective means. Method for determination of microorganism permeability: approved and validated by the Order of the USSR State Committee on standards issued on March 23, 1984 No. 896. *KODEKS: an electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200012741 (November 09, 2021) (in Russian).

in control. All the tests were conducted by an accredited testing laboratory.

Air permeability was determined as per how thin the air was using VTPM-2 device manufactured by "Metroteks" LLC (Russia). Pressure difference at air passage through a sample was kept at the same level equal to 49 Pa. We estimated air output in l/sec through the preset cross-sectional area of a mask. Ten measurements were accomplished for each sample. The results were checked with Q-test to identify and reject outliers.

We statistically analyzed all the data using StatTech v. 2.4.1 software package ("StatTech" LLC, Russia). Quantitative indicators were checked to determine whether they were distributed normally using Shapiro – Wilk test. Quantitative indicators which were distributed normally were described with simple means (*M*) and standard deviations (*SD*) as well as boundaries of the 95 % confidence interval (95 % CI). Fischer's test was applied to compare the analyzed groups as per quantitative indicators. We applied Spearman's rank correlation coefficient to determine direction and intensity of correlations between two quantitative indicators. We developed our predictive model which characterized dependence between a quantitative variable and various factors by using linear regression.

Results and discussion. Table 2 provides results produced by examining bacterial filtration.

All the examined masks had comparable bacterial filtration. Bacterial filtration of the examined medical masks didn't conform to the standard value. We established that the cotton mask had the lowest bacterial filtration out of all three examined types. The neoprene mask turned out to be less permeable for bacteria than the medical mask made of spunbond / meltblown.

There are multiple research works with its basic focus being on aerosol filtration effectiveness of masks. The authors established that medical masks protected from the COVID-19 agent better than cotton ones and were inferior only to respirators [14, 16–19]. According to Brazilian researchers, neoprene masks provide as good filtration as medical ones do [20].

We compared air permeability of different masks (Table 3 and Figure).

Having analyzed air permeability depending on a type of a mask, we revealed that there were statistically significant differences ($p < 0.001$, the applied procedure was Fischer's test).

According to the requirements[10] materials which contact human skin directly should have air permeability being not lower than 100 dm^3/m^2sec. Air permeability of all the examined masks conformed to these requirements. The cotton mask was established to have the highest air permeability.

Our results produced by estimating air permeability are similar to those described by other authors. For example, cotton masks were established to have air permeability which was approximately by 2 times higher than that of medical masks made from spunbond / meltblown [13]. However, Brazilian experts also showed that neoprene masks had extremely

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Table 2

Bacterial filtration provided by different types of masks

Type	Bacterial filtration coefficient, %	
	Research results	Standard value
Medical	85.00	$\geq 95^{8}$
Cotton	62.50	$\geq 50^{9}$
Neoprene	93.75	$\geq 70^{5}$

Table 3

Analysis of air permeability depending on a type of a mask

Type	Air permeability (dm^3/m^2sec)			p
	$M \pm SD$	95 % CI	n	
Medical	209.28 ± 8.75	198.42–220.14	10	$p_{medical-cotton} = 0.001$ $p_{neoprene-cotton} = 0.001$
Cotton	397.85 ± 22.99	369.31–426.39	10	
Neoprene	248.69 ± 52.73	183.22–314.17	10	

Note: n is a number of samples.

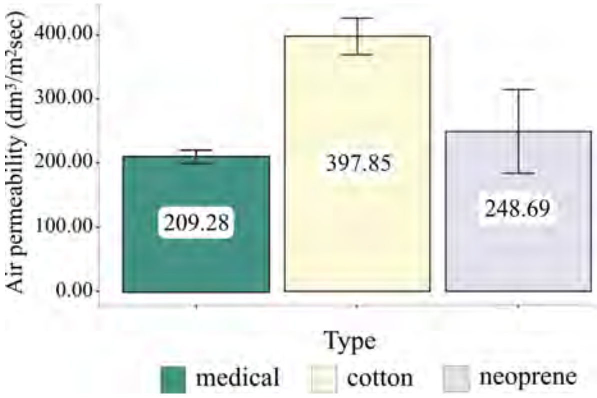

Figure. Analysis of air permeability depending on a type of a mask

Table 4

Analysis of the correlation between bacterial filtration and air permeability

Indicator	Correlation characteristics		
	r_{xy}	Correlation intensity as per Chaddock scale	p
Bacterial filtration – Air permeability	–0.889	High	0.303

low air permeability and didn't conform to safety standards [20].

We analyzed the correlation between bacterial filtration and air permeability (Table 4).

The expected dependence of bacterial filtration from air permeability is given by the following pair linear regression equation:

$$y = -0.144x + 121.491,$$

where y is bacterial filtration and x is air permeability.

When air permeability goes down by 1 dm^3/m^2sec, we should expect a rise in bacterial filtration by 0.144. This model explains 79.0 % of the observed dispersion of bacterial filtration.

Our research results prove there is dependence between air permeability of a material a mask is made from and its bacterial filtration coefficient. Thus, the neoprene mask had the highest bacterial filtration but its air permeability was average. This can be due to neoprene being more hydrophobic that cotton and this prevents microorganisms which spread in the air together with water droplets from penetrating through the mask.

Research limitations. We didn't examine respirators since the WHO recommends them only for medical personnel who work with patients in an environment where virus aerosol can occur in the air and not for the general public. Besides, qualitative respirators which conform to all international standards and are registered in the Russian State Medical Equipment and Organizations Register are rather expensive and therefore rather rarely used by population.

In future it is necessary to examine each type of masks produced by different manufacturers. It is also advisable to examine other properties of face masks influencing their effectiveness, comfort in wearing and safe everyday use. These properties are absorbability, chemical structure, changes in skin temperature and humidity behind a mask etc.

Conclusions. The neoprene mask turned out to have the highest bacterial filtration (93.75 %); the cotton mask, the highest air permeability (397.85 ± 22.99 dm^3/m^2sec).

We established and described the correlation between bacterial filtration and air permeability ($r = 0.889$, $p = 0.3$).

All the examined masks were comparable with a medical one as per all their combined examined characteristics and can be used as a barrier for mitigating risks of droplet infections spread.

It is necessary to conduct further research focusing on more properties of face masks which allow estimating their effectiveness, comfort, and safety.

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Conflict of interests. The authors declare there is no any conflict of interests.

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