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Development of tissue and cellulose masks for emergency response to the SARS-CoV-2 pandemic

Desenvolvimento de máscaras de tecido e celulose para resposta emergencial à pandemia provocada pelo SARS-CoV-2

Desarrollo de máscaras de tejido y celulosa para la respuesta de emergencia a la pandemia de SARS-CoV-2

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ABSTRACT
Objective: to develop a model of fabric mask, with the application of a cellulose filter element, for use as a safe physical barrier for aerosols, as an emergency response strategy for the SARS-CoV-2 pandemic. **Method:** laboratory research carried out by means of prototypes, empirical tests and analyses, and discussions with experts. **Results:** the research demonstrated that aerosols are retained by the physical cellulose barrier introduced into the structure of the masks, which motivated the second phase of the study into the effectiveness of these materials at a unit of the Brazilian Analytical Health Laboratories Network. **Conclusion:** the making of fabric masks is an important and urgent worldwide phenomenon in tackling the COVID-19 pandemic. In view of the supply crisis and the parameters highlighted in this study, it is believed that the use of this equipment can be extended to non-critical sectors of health units, as well as to the general population.
Descriptors: Disasters; Coronavirus Infections; Personal Protective Equipment; Masks.

RESUMO
Objetivo: desenvolver um modelo de máscara de tecido, com aplicação do elemento filtrante em celulose, para fins de utilização como barreira física segura para aerossóis, como estratégia de resposta emergencial à pandemia provocada pelo SARS-CoV-2. **Método:** pesquisa laboratorial realizada por meio de protótipos, testagens empíricas e análises e discussões junto a expertises. **Resultados:** a condução da pesquisa demonstrou que os aerossóis são retidos pela barreira física de celulose introduzida à estrutura das máscaras, o que motivou a segunda fase do estudo em unidade da Rede Brasileira de Laboratórios Analíticos de Saúde sobre a eficácia desses materiais. **Conclusão:** a confecção de máscaras de tecido é um fenômeno mundial importante e urgente frente à pandemia da COVID-19. Em função da crise de abastecimento e dos parâmetros ressaltados neste estudo, acredita-se que o uso desse equipamento possa ser estendido a setores não críticos de unidades de saúde, além da população em geral.
Descritores: Desastres; Infecções por Coronavírus; Equipamento de Proteção Individual; Máscaras.

RESUMEN
Objetivo: desarrollar un modelo de mascarilla de tela, con la aplicación de un elemento filtrante de celulosa, para su uso como barrera física segura para aerosoles, como estrategia de respuesta de emergencia para la pandemia SARS-CoV-2. **Método:** investigación de laboratorio realizada mediante prototipos, pruebas y análisis empíricos y discusiones con expertos. **Resultados:** la investigación demostró que los aerosoles son retenidos por la barrera física de celulosa introducida en la estructura de las máscaras, lo que motivó la segunda fase del estudio sobre la efectividad de estos materiales en una unidad de la Red Brasileña de Laboratorios Analíticos de Salud. **Conclusión:** la fabricación de máscaras de tela es un fenómeno mundial importante y urgente para hacer frente a la pandemia de COVID-19. Ante la crisis de oferta y los parámetros resaltados en este estudio, se cree que el uso de este equipamiento puede extenderse a sectores no críticos de las unidades de salud, así como a la población en general.
Descriptores: Desastres; Infecciones por Coronavirus; Equipo de Protección Personal; Máscaras.

INTRODUCTION

The pandemic caused by the Coronavirus Disease 2019 (COVID-19), an infectious disease that has indiscriminately victimized thousands of people, has led the world health authorities to develop guidelines for its non-pharmacological prevention, among which hand hygiene, the use of 70% alcohol gel solution, and the use of masks are highlighted[1].

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Since the pandemic outbreak of the new coronavirus (2019-nCoV), direct and indirect impacts were felt in the social, political, economic, cultural and, above all, health fields. In fact, there is great concern about the progress of this still unknown disease, with high transmissibility and clinical severity, which is accentuated by the social determinants of health, especially in the most vulnerable countries with poor governance[2].

On January 30th, 2020, the World Health Organization (WHO) declared the outbreak as a '*public health emergency of international concern*' (PHEIC) due to the spread of the coronavirus 2 (SARS-CoV-2) in several countries[3]. In view of this situation and of the need for a coordinated response among the municipal, state, and federal management spheres of the Unified Health System (*Sistema Único de Saúde*, SUS), several measures for the prevention, control and containment of risks, problems and harms to public health started to be strategically developed. On February 3rd, 2020, the Brazilian Ministry of Health declared the situation as a '*public health emergency of national concern*' (PHENC), through Ordinance no. 188[4].

The first case of COVID-19 in Brazil was officially confirmed on February 26th, 2020. At that time, it was still possible to identify cases individually and to monitor the contacts[3]. On March 11th, the WHO characterized COVID-19 as a pandemic disease. On August 8th, Brazil started to account for more than 100,000 deaths of citizens due to this biological disaster[5,6].

The accelerated spread of infection by coronavirus 2 (SARS-CoV-2) has been impacting the global supply chain of Personal Protective Equipment (PPE). The demand generated by the extraordinary increase in the number of cases associated with misinformation, fear, and panic led to the irrational purchase and storage of these products. This widespread and inappropriate use of PPE, as well as the lack of provision of these materials for emergency situations, led to shortages in many countries, given the limited capacity to expand global production[7].

Faced with this situation of imminent risk of PPE shortage, especially of N95/PFF2 masks, the Brazilian Ministry of Health (MoH) approved Collegiate Board Resolution (*Resolução de Diretoria Colegiada*, RDC) No. 356 on March 23rd, 2020[8], which addresses requirements for manufacturing, importing, and acquiring medical devices identified as priorities for use in health services, due to the international public health emergency related to COVID-19. Furthermore, the publication of this RDC involved the need to develop products similar to the standard ones, with the operational purpose of minimizing the impacts caused by shortages, in an extraordinary and temporary way[8].

Due to this problem of PPE shortage, and its potential implications for the quality and safety of care in Brazilian health institutions, at a scientific meeting on April 9th, 2020, members of the Education, Research and Health Extension Group in Emergency and Disasters from the Federal University of Rio de Janeiro (*Grupo de Ensino, Pesquisa e Extensão de Saúde em Emergências e Desastres/Universidade Federal do Rio de Janeiro*, GEPESED/UFRJ) discussed the pressing need to develop studies on possible technologies and emergency response strategies in the face of to this situation of PPE shortage. Thus, this perspective was framed within the scope of the doctoral thesis of the first author of this article, which deals with the development of health technologies focused on logistics in emergencies and disasters.

With the legal protection of Law No. 13,969 of February 6th, 2020 and of Ordinance No. 327 of March 24th, 2020, which establish measures for prevention, caution, and reduction of transmission risks for confronting COVID-19, which refer to the use of PPE, attention has been paid to the development of masks that, in a safe and effective manner, could better meet the barrier criteria and prevent the spread of droplets by the airways, in order to guarantee a physical barrier and prevent new cases of the disease[9,10].

Thus, the development process of this study began with the production of prototypes and with testings of individual protection masks, made of cotton fabric and with an extra protection barrier using cellulose, regarding safety, quality, and effectiveness standards against contamination by coronavirus 2 (SARS-CoV-2).

In addition to the concern with such standards, this study also involves potential contributions to ecological protection, since the masks made of fabric and the cellulose filter element can fulfill two socio-environmental purposes: reuse (masks made of fabric) and recycling (filter element). It is therefore a counterpoint regarding the use of disposable medical hospital materials, which usually have the final destination of incineration or even contamination of the environment through inappropriate disposal.

In view of this scenario, the objective was to develop a template for masks made of fabric, adding the cellulose filter element, for use as a safe physical barrier for aerosols, as an emergency response strategy to the COVID-19 pandemic.

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METHOD

This is a laboratory research study, which was determined by the development of a template for masks made of fabric with the insertion of a cellulose filter element. For the analysis of this object of study, variables capable of influencing it were selected, and ways of controlling and observing the effects that each variable could produce on the object were defined[11].

The team had the participation of members from different research and health institutions from the State University of Rio de Janeiro, the Federal University of Rio de Janeiro, the War College, the Military Institute of Engineering, the National Cancer Institute, in the city of Rio de Janeiro, and the Ministry of Health, in Brasília (Federal District), including volunteer artisans who made the prototypes.

The research was divided into two distinct phases. One focused on preliminary studies, analysis of official documents, actual production of the masks, empirical testings and public disclosure; and another for laboratory testings and validation of the masks. It should be noted that this article refers to the results of the first phase of the research.

The masks were created in accordance with the guidelines for the production of masks made of cotton, which were made available by the Ministry of Health through Information Note No. 3/2020-CGGAP/DESF/SAPS/MS and Technical Note GVIMS/GGTES/ANVISA No. 4/2020 with guidelines for the general population and health services, which converge in prevention and control measures that must be adopted when assisting suspected or confirmed cases of infection by the new coronavirus (SARS-CoV- 2)[12].

The researchers developed three empirical Tests, the results of which were publicly disclosed through social networks, which motivated the second phase of this study. The video is available in the following electronic address: https://youtu.be/vhoRRwB7pHA.

After the prototypes were produced and the empirical Tests were conducted, analyses and discussions were carried out with experts in the area of technological production at the Military Institute of Engineering of the Army, a unit linked to the Ministry of Defense. Afterwards, it was ensured that the masks were in compliance with the standards of the Brazilian Technical Standards Association (*Associação Brasileira de Normas Técnicas*, ABNT) through the recommended practice published on April 17th, 2020 (ABNT PR1002:2020), with regard to the guidelines and standards recommended for the making and composition of this type of PPE[13].

After making the prototypes, samples of the masks were sent to a laboratory of the Brazilian Network of Health Analytical Laboratories (*Rede Brasileira de Laboratórios Analíticos em Saúde*, REBLAS), in accordance with what is established by the Brazilian Health Surveillance Agency (*Agência Nacional de Vigilância Sanitária*, ANVISA), through RDC 12 of February 16th, 2012[14].

For this phase, tests were requested and budgeted to assess air permeability in the masks made of cotton with and without the cellulose filter element in the Physics laboratory linked to the REBLAS® network, which is accredited by the ANVISA and by the National Institute of Metrology, Standardization and Industrial Quality (*Instituto Nacional de Metrologia, Qualidade e Tecnologia*, INMETRO), the latter being a federal independent agency linked to the Special Secretariat for Productivity, Employment and Competitiveness of the Ministry of Economy.

For the permeability trials, the researchers provided the laboratory with 10 (ten) units of each mask, being made of double layer cotton fabric and with a nose clip with a slit. Industrialized masks were also sent in the same number: disposable surgical masks, model N95/PFF2, and masks in double cotton fabric, totaling 5 (five) trials. The mask prototypes developed by the researchers (double-layer masks made of cotton with a nose clip with a slit) were analyzed in two stages, by measuring the air permeability with and without the cellulose filter element.

Materials and raw materials used

100% cotton fabric was the material used to make the masks, which is the most indicated fabric due to its wefts and calendaring, adapting to washing processes with more abrasive sanitizing products. This type of material has the following grammages: 90 to 110, 120 to 130, and 160 to 210. In general, the following mixtures are tolerated in their composition: 90% cotton with 10% spandex, 92% cotton with 8% spandex, and 96% cotton with 4% spandex[16]. The use of other types of fabrics, such as pure polyester and other synthetic fabrics, are not recommended for the production of masks with PPE quality.

The component that differentiates the prototype model advocated by this study is the insertion of the filtering and biodegradable barrier composed of cellulose, which enhances the safety of users of this protective equipment. It is known that breathing eliminates droplets, heat and moisture, which go into the environment, where the virus may (or may not) exist. In this sense, the applicability of the cellulose barrier, which is inserted in the center of the double layer mask, has the potential to contribute to the retention of particles.

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This raw material is composed of 100% cellulosic fiber (known as crepe paper), with double pressing in its manufacture. Cellulose is an organic material extracted mainly from wood or corn straw, biodegradable/sustainable, which does not cause damage to human and environmental health. A number of studies indicate that cellulose can be obtained from any plant, and processes for obtaining cellulose and producing bleached paper from brachiaria grass (*Brachiaria decumbens*), a grass species very common in Brazil, are also evidenced[15,16].

The flowchart with the stages for producing the mask made of cotton and with a slit is shown in Figure 1.

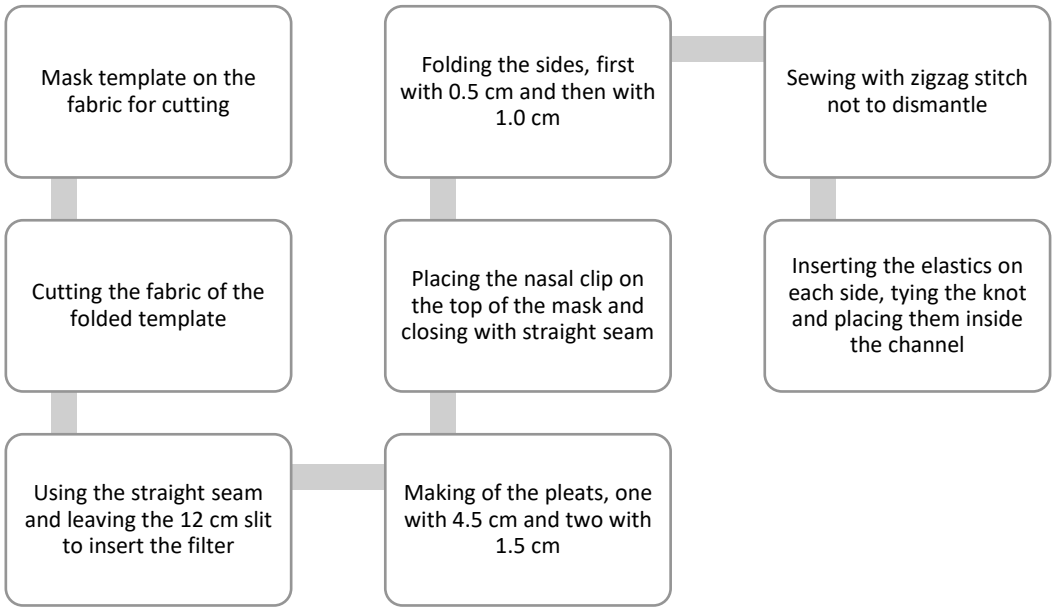

FIGURE 1: Flowchart with the stages for producing the mask made of cotton, with a slit. Rio de Janeiro, Brazil, 2020.

The developed prototypes of masks made of cotton were designated by the researchers as "LisLu20". It should be noted that, in the light of the Berne Convention, this study was registered on April 23rd, 2020, for purposes of protection of literary and artistic works, under Registration no. 712144782[17].

RESULTS AND DISCUSSION

In this study, it was considered that the insertion of the cellulose filter element in the masks produced and tested is a positive aspect for safety. In general, this element is easily accessible and of low cost, which can have potential repercussions for reducing the import dependence of this type of equipment. In fact, the problem of self-sufficiency in the production of PPE is one of the major challenges faced by several countries in the emergency response to the COVID-19 pandemic, including in Brazil.

It is relevant that Brazil is the fourth largest pulp producer in the world. In 2016, Brazil produced 17.1 million tons of cellulose and 9.5 million tons of paper. The pulp produced in Brazil is usually derived from planted forests of eucalyptus and pine[17].

It is also considered that pulp, with its biodegradable and moist fibrous structure, has the ability to retain liquids and particles due to the multiple hydrogen bonds, which makes them insolvable (impenetrable to water)[18].

Another aspect has to do with the appropriate ecological disposal of the infected material, as the incorrect disposal tends to harm the environment. After using the mask herein indicated, it must be washed together with the cellulose filter, using soap and water. Thus, the mask is reused, and the biodegradable filter is disposed of more safely.

It should be noted that the document prepared by the WHO and translated into Portuguese by the PAHO discusses the use of masks for the general population, in environments where physical distancing is not possible and there is a greater risk of infection and/or negative outcomes, mainly for vulnerable populations (individuals aged ≥ 60 years old,

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individuals with underlying comorbidities such as cardiovascular disease or diabetes, chronic lung disease, cancer, cerebrovascular disease, immunosuppression) who should wear a surgical mask and not a mask made of fabric[19].

Results of the preliminary Tests of the masks

Figure 2 describes the development of the three empirical Tests and their respective results.

Testing	Description	Actions developed	Results of the empirical tests
1st testing	Analysis of the physical barrier provided by prototypes WITHOUT cellulose filter	**a)** positioning the mask on the face, following technical recommendations of RDC 356/2020; **b)** ignition of a small flame; **c)** positioning the flame at a distance of 15 cm from the face of the mask user; **d)** blows of low, moderate, and strong intensity by the user; **e)** spraying from the inside of the mask, with strong intensity.	**a-d)** the flame of the match or the lighter GOES OFF easily; **e)** aerosols PASS easily through the mask, visibly without the filter element (cellulose).
2nd testing	Analysis of the physical barrier provided by the prototypes WITH cellulose filter	**a)** positioning the cellulose inside the mask made of fabric; **b)** positioning the mask on the face, following technical recommendations of RDC 356/2020; **c)** ignition of a small flame; **d)** positioning the flame at a distance of 15 cm from the face of the mask user; **e)** blows of low, moderate, and strong intensity by the user.	**a-e)** the flame of the match or the lighter DOES NOT go off
3rd testing	Analysis of the physical barrier provided by the prototypes WITH cellulose filter	**a)** positioning the mask on the user's face according to technical recommendations of RDC 356/2020; **b)** spraying from the inside of the mask, with strong intensity.	**a-b)** aerosols DO NOT pass through the mask, visibly WITH the filter element (cellulose)

FIGURE 2: Preliminary testings. Rio de Janeiro, Brazil, 2020.

Test 1, which analyzed the physical barrier provided by the prototypes without a cellulose filter, evidenced that, in a clear and recurrent way, the flame was extinguished, demonstrating that the aerosols expelled by the users of the mask were not retained. Subsequently, in Tests 2 and 3, cellulose sheets were added. In Test 2, the aerosols sprayed on the mask, with strong intensity, did not pass through. And, in Test 3, the users' blows, with strong intensity, were not able to extinguish the flame at a distance of 15 cm from the face. Thus, these Tests proved empirically that the exhaled aerosols were retained by the physical barrier introduced.

Through such preliminary results, it is assumed that the individual protection measures contained in this proposal have a potential positive impact on controlling the progress of the COVID-19 pandemic. Such use must necessarily be combined with the preventive measures recommended by the WHO and by the Pan American Health Organization (PAHO)[18,19], such as hand hygiene with soap and water or 70% alcohol solution, safety and respiratory hygiene measures for coughing, such as covering the nose and mouth with the elbow flexed, using a disposable handkerchief, which must be immediately discarded after use and redoing hand hygiene, in addition to avoiding touching the mucous membranes of the eyes, nose and mouth, published on June 5th, 2020[19].

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Production, indication, and use of the masks

The mask made of a double layer of cotton and the streaky cellulose filter element make up the "LisLu20" model under analysis. The model is shown in Figures 3 and 4.

FIGURE 3: Lislu20® (front view). Rio de Janeiro, Brazil, 2020.

FIGURE 4: LisLu20® (opening on the back to place the cellulose material). Rio de Janeiro, Brazil, 2020.

It is noted that the use of masks made of fabric, with common and low-cost materials, has its indication recognized as a voluntary and effective measure to control the progress of the COVID-19 pandemic.

Due to the shortage of specific hospital units, which lately has been constantly informed by the media and denounced by unions and health professionals, it is necessary to consider the possibilities of extending the use of the masks developed in this study to the professionals who work in non-critical sectors of the health units without patients, such as entrance doors, elevators, warehouses, administrative areas, and material and sterilization centers.

To produce the masks described and for greater effectiveness with respect to the physical barrier, it is recommended that they be made with at least two layers of cloth (100% cotton, tricoline), and designed with elastics or straps to tie above the ears and below the neck.

To enhance the preventive measures, it is essential to properly sanitize the hands, use individual masks, and not sharing them even among family members. It is also recommended that each person should have at least five masks for individual use. And, if necessary to go out of the house, always carrying spare masks in a plastic bag[20].

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For the correct use of the mask, it is necessary to completely cover the mouth and nose, adjusting it to the face and ensuring there are no gaps on the sides, and avoid touching or adjusting the mask as much as possible after putting it on. If it gets wet, it is necessary to change it.

As for hygiene, it should be washed by the users themselves. Thus, when people get to their homes and before removing the mask, they must wash their hands thoroughly, dry them well, remove the mask by the loop or elastic band on the side of the face, avoiding touching the front. Then, the mask must be washed with coconut soap or diluted bleach, leaving it to soak for nearly 30 (thirty) minutes. After that, rinse and dry in a ventilated and breezy place.

Finally, after the testing procedures of phase 2 of this study, the template developed will be made available, with precise instructions for making the masks, in order to expand access to this technology and to contribute to the emergency process of reducing the potential risks of the progress of this biological disaster. This can even add financial profitability and social inclusion to the individuals who are willing to produce it because, in situations of change or interruption of social distancing measures in Brazilian cities and states, the population's demand for masks made of fabric tends to increase greatly.

It is therefore understood that the technology herein proposed has strong links with the development of serviceable equipment for human and environmental care, since the availability of items with high efficiency and in sufficient quantity, especially to more vulnerable and poor people and groups, make it possible for the measures taken post-crisis to be more effective, hoping for a better future.

CONCLUSION

The production of masks made of fabric is a necessary and urgent worldwide phenomenon. Recently, the Brazilian Ministry of Health mobilized the population through an extensive campaign for production and use of masks made of cloth, considering this to be a simple PPE item, with no difficulty in production and an essential ally in combating the spread of COVID-19.

Once the study proves the efficiency of the barrier implemented, through double cotton fabric and cellulose, it is believed that, in this urgent scenario, its use can be extended to non-critical sectors of some health units, such as entrance doors, screening rooms, and material and sterilization centers, in case the PPE shortage crisis is not resolved in the short term. However, other sectors should continue to use surgical masks or N95/PFF2 masks. These items are essential to the safety of care, and the market reserve must be directed to the exclusive use of health professionals and other first responders who act on the front lines of the response to the pandemic.

The need to reduce potential environmental impacts related to the improper disposal of masks is also considered. Thus, the proposed model consists of reusable and recyclable material with appropriate disposal, in domestic waste, without causing transmissions and environmental damage. Such measure can contribute to greater control of the disease and to the safety of the users and of the people who live close to them.

The publication of this article aims to bring contributions to public health in the current context of the Pandemic, as well as to communicate possibilities for the safe and valid use of masks made of fabric. Finally, it is clarified that the second phase of this study is under development and includes Tests in certified Physics and Microbiology laboratories, which will provide support to characterize the safety, quality, and effectiveness of the masks herein described.

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