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ORIGINAL ARTICLE

Handmade face mask can be sterilized without compromising their efficacy

Máscara facial artesanal pode ser esterilizada sem comprometer sua eficácia

La mascarilla facial hecha a mano se puede esterilizar sin comprometer su eficácia

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ABSTRACT

Background and Objectives: COVID-19 caused by SARS-CoV-2 is transmitted by contact, droplets and aerosols. The World Health Organization recommends the mandatory use of surgical masks for health professionals and encourages countries to adhere to their use, en masse, in order to minimize the transmission of the virus. Since the lack of this personal protective equipment is a cause for concern, the objective of this study was to evaluate the characteristics of facial masks regarding (i) the mechanical properties of elongation, rupture stress and resistance to air passage and (ii) the morphometric properties of thickness, fiber diameter and pore distribution after autoclave sterilization. **Methods:** The masks were made in TNT Spunbonded (100% polypropylene, 60 g/m^2), autoclaved at 70 °C for 5 minutes and stored in plastic films at room temperature. Then, the mechanical properties were determined in an Instron universal testing machine and Gurley type automatic densimeter and the morphometric properties in a semi-automatic thickness gauge and scanning electron microscope. **Results**: It was observed that a cycle of sterilization of facial masks, by moist heat under pressure, increased the blanket's stiffness, did not produce physical damage and did not reduce the blanket's barrier capacity. **Conclusion**: The sterilization of face masks made of TNT can be considered a strategy to increase safety in their production and use.

Keywords*: Communicable Disease Prevention. Disease Control. SARS-CoV-2. Coronavirus infections. Individual protection equipment.*

RESUMO

Justificativa e Objetivos: A COVID-19 causada pelo SARS-CoV-2 é transmitida pelo contato, por gotículas e por aerossóis. A Organização Mundial da Saúde recomenda a obrigatoriedade do uso de máscaras cirúrgicas aos profissionais da saúde e incentiva os países a aderirem ao seu uso, em massa, a fim de minimizar a transmissibilidade do vírus. Posto que a falta desse equipamento de proteção individual causa preocupação, o objetivo deste trabalho

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foi avaliar as características de máscaras faciais quanto (*i*) às propriedades mecânicas alongamento, tensão de ruptura e resistência a passagem de ar e (*ii*) às propriedades morfométricas espessura, diâmetro das fibras e distribuição de poros após esterilização em autoclave. **Métodos**: As máscaras foram confeccionadas em TNT Spunbonded (100% polipropileno, 60 g/m^2), autoclavadas a 70 °C por 5 minutos e armazendadas em filmes plásticos a temperatura ambiente. Na sequência, as propriedades mecânicas foram determinadas em máquina de teste universal Instron e densímetro automático tipo Gurley e as propriedades morfométricas em medidor de espessura semiautomático e microscópio eletrônico de varredura. **Resultados:** Observou-se que um ciclo de esterilização das máscaras faciais, por calor úmido sob pressão, promoveu o aumento da rigidez da manta, não produziu danos físicos e não diminuiu a capacidade de barreira da manta. **Conclusão**: A esterilização de máscaras faciais confeccionadas em TNT pode ser considerada uma estratégia para aumentar a segurança na sua produção e uso.

Descritores: *Prevenção de Doenças Transmissíveis. Controle de Doenças. SARS-CoV-2. Infecções por Coronavírus. Equipamento de Proteção Individual.*

RESUMEN

Antecedentes y objetivos: El COVID-19 causado por el SARS-CoV-2 se transmite por contacto, gotitas y aerosoles. La Organización Mundial de la Salud recomienda el uso obligatorio de mascarillas quirúrgicas para los profesionales de la salud y alienta a los países a adherirse a su uso, en masa, con el fin de minimizar la transmisión del virus. Dado que la falta de este equipo de protección personal es motivo de preocupación, el objetivo de este estudio fue evaluar las características de las **máscaras** faciales en cuanto a (i) las propiedades mecánicas de elongación, tensión de rotura y resistencia al paso del aire y (ii) la morfometría propiedades de espesor, diámetro de fibra y distribución de poros después de la esterilización en autoclave. **Métodos:** Las **máscaras se** fabricaron en TNT Spunbonded (100% polipropileno, 60 g / m2), se esterilizaron en autoclave a 70 °C durante 5 minutos y se almacenaron en películas plásticas a temperatura ambiente. Posteriormente, se determinaron las propiedades mecánicas en una máquina de ensayo universal Instron y densímetro automático tipo Gurley y las propiedades morfométricas en un medidor de espesor semiautomático y microscópio electrónico escaneando.**Resultados:** Se observó que un ciclo de esterilización de mascarillas faciales, por calor húmedo a presión, incrementó la rigidez de la manta, no produjo daño **físico y no** redujo la capacidad barrera de la manta. **Conclusión:** La esterilización de mascarillas faciales fabricadas con TNT puede considerarse una estrategia para aumentar la seguridad en su producción y uso.

Palabras Clave: *Prevención de enfermedades transmisibles. Control de Enfermedades. SARS-CoV-2. Infecciones por coronavirus. Equipo de protección individual.*

INTRODUCTION

The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) causes the respiratory disease COVID-19, which quickly evolved into a pandemic.[2] SARS-CoV-2 is transmitted by direct, indirect or close contact with infected people, objects or surfaces. In direct contamination from person to person, the coronavirus is transmitted to healthy individuals through breathing by droplets and aerosols produced during the speech, coughing, and sneezing of infected individuals or during medical procedures that involve the respiratory tract and generate aerosols.[3-7] In this context, health professionals are particularly vulnerable to contamination, and one of the challenges of the respiratory pandemic is their effective protection. The World Health Organization (WHO) recommends that in procedures that generate aerosols, professionals should use personal protective equipment (PPE), such as N95 respirators, isolation gowns and gloves.[3, 4] For low-risk patients without fever, patients without respiratory symptoms, and patients not requiring procedures that generate aerosols, the use of surgical masks is required to protect against droplet transmission when in close contact.[1] WHO also encourages countries to adhere to the use of face masks, en masse, in order to minimize the transmissibility of the virus.[8]

Widespread use of face masks combined with physical distancing increases the control of SARS-CoV-2.[9] However, wide availability of this personal protective equipment is a challenge, and stimulates the development of technologies in products, services and processes to control the disease, including the production of surgical masks with tissue-non-tissue (TNT).

According to the ABNT NBR-13370 standard[10], TNT is a flat, flexible and porous structure with a veil or blanket of fibers or filaments consolidated by mechanical (friction), chemical (adhesion), or thermal (cohesion) processes, or a combination of these processes. In addition, two of its main features are non-toxicity and semipermeability.[11]

Commercial TNT surgical masks have three layers of the spunbonded-meltblown-spunbonded (SMS) type, with 100% polypropylene filaments, that are thermobonded and had particle filtration efficiency ≥ 98% and bacterial filtration efficiency ≥ 95%.[12]

Autoclave sterilization is a safe, easy, rapid, and cost-effective method that does not leave toxic residues.[13] However, TNT can be thermosensitive, limiting the

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use of autoclaves for sterilization. Because there are few studies on the effects of autoclave sterilization on TNT, the objective of the present study was to evaluate the characteristics of face masks made with spunbonded TNT (100% polypropylene, 60 g/m^2) after autoclaving. The study evaluated the mechanical properties of elongation, rupture tension, and resistance to air passage, and the morphometric properties of thickness, fiber diameter, and pore distribution.

METHODS

Face masks

The face masks, purchased in the Brazilian market (Guarulhos, SP), were made of spunbonded TNT (60 g/m^2) with bacterial filtration efficiency ≥ 99% (Assay Report 96586/2020A, Controlbio, SP, Brazil) according to Brazilian Technical Standards (ABNT NBR 14873/2002; ABNT NBR 15052/2004).[14, 15]

The masks were placed in cotton bags and sterilized in an autoclave (FABBE, 104, Brazil) at 70 °C for 5 minutes, according to the recommendations of ABNT NBR ISO 15883-1/2013.[16] Then, the masks were stored in plastic film at room temperature until the analyses.

Mechanical properties

Elongation and tensile strength were evaluated using a universal testing machine (Instron, 2712-002) using a 1 kN charge cell according to TAPPI 494 OM-06.[17] Resistance to airflow was measured by an automatic Gurley densimeter (Regmed, PAG-1000) according to TAPPI 536 OM-07.[18] The tests were carried out at 23 °C ± 1 °C and 50% ± 2% relative humidity.

Morphometry

The thickness of the masks was measured at six different points, in triplicate, using a semi-automatic thickness gauge (Regmed, ESP/SA-2/10) according to TAPPI 551 OM-06.[19]

Characterization of the polypropylene fiber was performed in triplicate. 1 cm^2 samples of the control and autoclaved masks were fixed on aluminum stubs with double-sided tape and gold-covered (approximately 15 nm thick) in a metallizer (Balzers, FDU 010).[20] Then the samples were analysed with a scanning electron microscope Leo 1430VP (Carl Zeiss, Jena, Alemanha) at 10 kV. The pore distribution and fiber thickness were obtained with Image ProPlus software, version 4.5.0.29.

Statistical analysis

R software, version 4.0.1, was used for descriptive statistical analysis and analysis of variance (ANOVA) of the data, at a 5% significance level.

RESULTS

The elongation and tensile strength of the masks varied between control and treatment (Table 1). The tensile strengths were 1.10 ± 0.03 N/mm and 1.35 ± 0.03 N/mm for the control and autoclaved masks, respectively. The average elongation percentage decreased from 78.21 ± 7.6% in the control to 64.38 ± 1.9% in the autoclaved samples, whereas the resistance to airflow was 0.47 ± 0.01 s/100cm^3 in both control and autoclaved masks.

Table 1. P value for the variance analyses between control and treted groups.

Mechanical Properties	**P-value**
Tensile Strenght	0.000002446*
Elongation	0.005581*
Airflow resistance	0.1099
Morphometry	**P-valor**
Thickness	0.0003439*
Fiber diameter	0.0007964*
Pore area	0.1303

Values with (*) indicate diferences at 5 % of significance level

The morphometric characterization showed a significant difference for thickness and fiber diameter (Table 2). The resistance to airflow did not vary between the control and treatment masks. The mean thickness increased from 280 ± 10 μm in the control masks to 313 ± 4.4 μm in the autoclaved masks. The pore area in the autoclaved masks did not differ statistically from the control masks.

Scanning electron microscopy showed disordered fiber entanglement in both control and autoclaved samples, with circular fibers without fusions or aggregations (Figure 1).

The minimum, maximum and mean values of fiber diameter and pore area (Table 2) were very close with a tendency of reduction for the samples treated in autoclave when compared to the control, as observed by the distribution of the pore area showed in Figure 2.

Table 2. Descriptive statatistics to fiber diameter and pore area.

Parameters	**Fiber Diameter (μm)**		**Pore Area (μm2)**	
	Control	**Treatment**	**Control**	**Treatment**
Minimum	18.07	18.17	22.68	37.39
Maximum	34.18	34.44	3260.22	3142.65
Mean	25.71*	24.90*	442.30	371.11
Standard Deviation	2.24	2.18	344.24	277.81

Values with (*) indicate diferences at 5 % of significance level

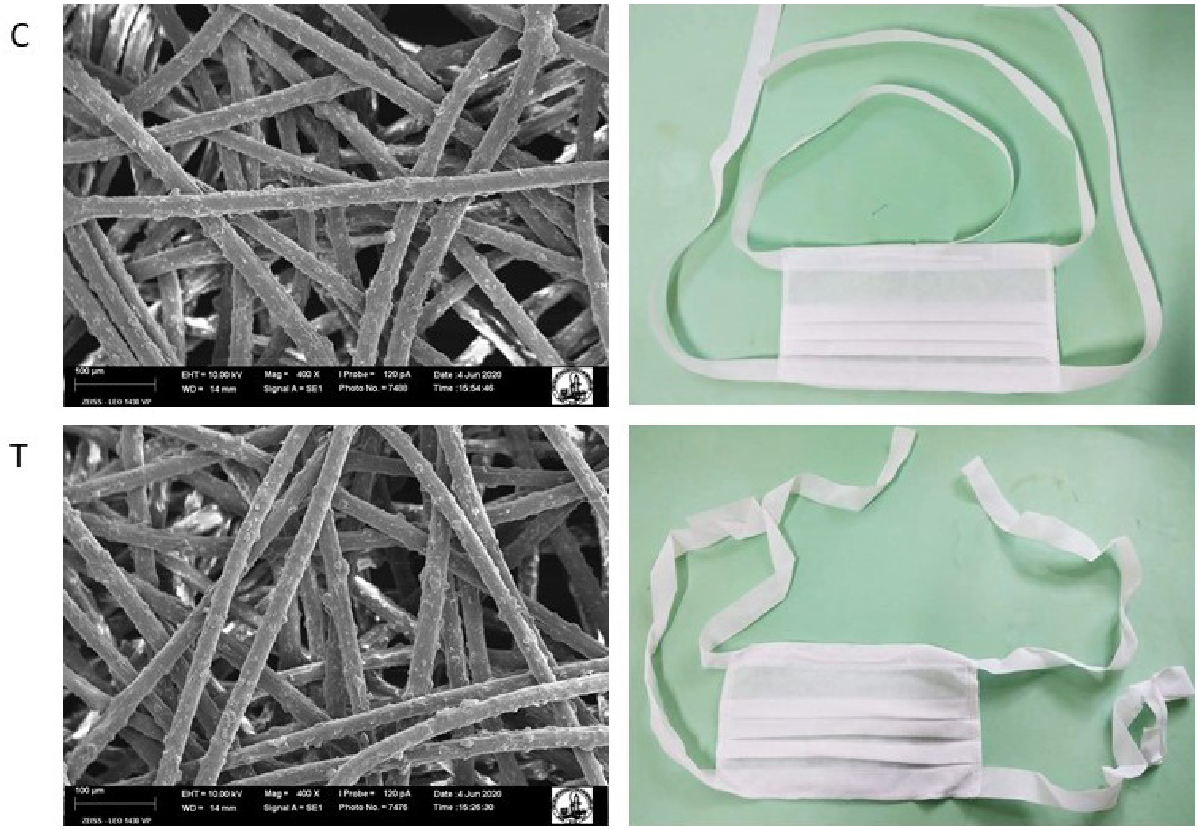

Figure 1. Scanning electron Micrographs of face masks produced in TNT (60g/m^2). C) Control. T) Sterilization treatment at 70 °C for 5 minutes with autoclave. 400x magnification.

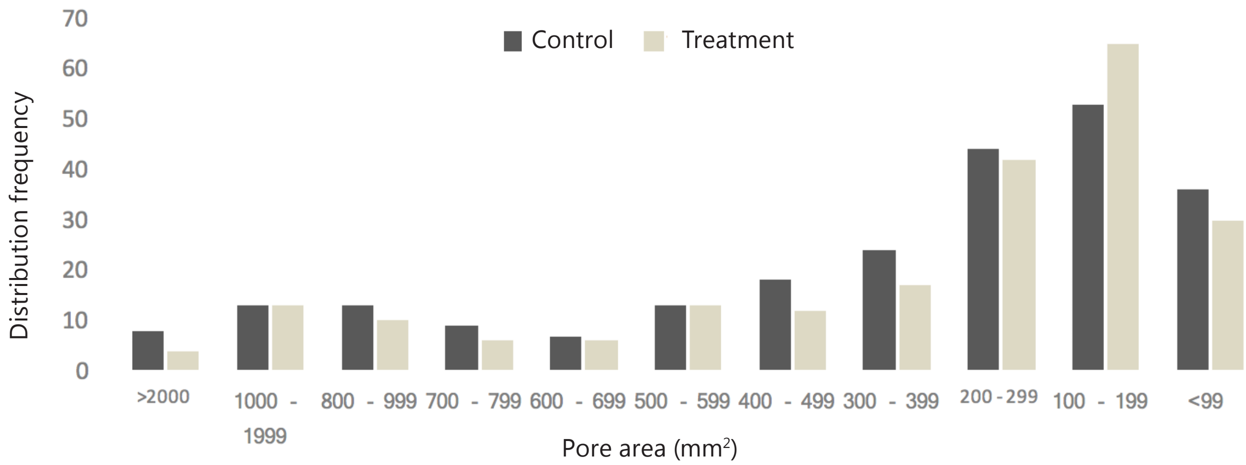

Figure 2. Pore area distribution of face masks produced in TNT (60g/m^2) obtained in scanning electron microscopy. Control and Treatment by sterilization at 70 °C for 5 minutes with autoclave..

DISCUSSION

The results obtained indicate that the autoclaved face masks have uniform thickness, in addition to higher capacity of tensile strenght and lower percentage of elongation. No significant difference ($p>0.05$) was observed in the resistance to airflow with autoclave sterilization. Thus, sterilization provided the material with greater mechanical strength and also reduced its ability to elongate in relation to the initial length until rupture. This characteristic allows us to infer that the heat treatment increased the mask's stiffness without interfering with its droplet retention property, since the resistance to airflow did not varied significantly ($p>0.05$).

The results of the present studt corroborate the data from Dutch researchers[21] who evaluated the effect of reprocessing some models of FFP-2 and FFP-3 respirators. In the research, a medical autoclave with a total cycle of 34 minutes and vapor decontamination at 121 °C was used. The respirators FFP-2 and FFP-3 were used by healthcare workers during the pandemic. Most of the tested respirators maintained their shape, without visible physical damage and change in resistance to airflow with treatment, except for the FFP-3 model. A gradual reduction in the filtering capacity as a function of the number of sterilizations was observed, but this was more expressive after 3 cycles. Therefore, breathability remained adequate for the masks tested and the authors concluded that it is possible, with caution, to reuse respirators of the types evaluated after moist heat treatment.

Sterilization by heat, dry or wet, when intense, can cause degradation of polymers by oxidation and change their properties in terms of changes in molecular weight, embrittlement, breakage, color, and ductility.[22,23] Some polymers can lose structural integrity due to the high temperatures used in autoclave, causing distortion and breakage.[24] In this sense, the high crystallinity of polypropylene gives the polymer high tensile strength, rigidity and hardness. The polymer softens at temperatures above 170 °C.[23] Thus, the results of the present study indicate torsion points in the mooring loops of the heat-treated masks, however, without ruptures and conformation changes in the autoclaved fibers.

The data for the mechanical properties obtained in this study indicate that the blanket became more rigid after sterilization due to the tendency of decrease in the fiber diameter (Table 2) and pore area distribution (Figure 2).

Regarding the use of personal protective equipment for respiratory infections in health environments in low-income countries, a study revealed that PPEs were not available and were reused, in addition to non-compliance with its use.[25] It is noteworthy that protective measures for healthcare workers, which include strict adherence to basic hygiene standards and the use of face masks, protect during short periods of contact with symptomatic COVID-19 cases. Therefore, periodic replacement of PPEs is recommended.

In countries where the use of face masks was mandatory or was highly encouraged by the government during the early stages of the Covid-19 outbreak, population adherence rates were above 90%, which improved disease control. In other countries, where low adherence combined with little or no confinement may have contributed to the high number of deaths.[8] Therefore, the widespread use of face masks by the population is a measure considered prudent to prevent the spread of Covid-19.

The present study demonstrated that a cycle of sterilization of face masks made of TNT Spunbonded (60g/m^2) by humid heat under pressure, at 70 °C for 5 minutes, increased the rigidity, did not produce physical damage, did not affect the resistance to airflow, and did not change the pore area of the blanket. Physical damage could decrease the mask's barrier ability, which was not observed. Thus, it is relevant to know the physical effects of sterilization on TNT used to manufacture personal protective equipment, since the demand for this equipment worldwide is high. Therefore, humid heat sterilization of TNT surgical mask to protect against the transmissibility of the virus can be considered a strategy to increase the availability of these personal protective equipment.

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CONFLICT OF INTEREST

The authors declare no conflict of interests.

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Cristiane do Carmo Cesário analysis and interpretation of data, writing of the article, guarantee of the accuracy and integrity of the work and final approval of the version to be published.

Jamile Fernanda Silva Cossolin analysis and interpretation of data, writing of the article, guarantee of the accuracy and integrity of the work and final approval of the version to be published.

Andréia Guerra Siman conception and design, relevant critical review of the intellectual content, guarantee of the accuracy and integrity of the work and final approval of the version to be published.

Flávia Batista Barbosa de Sá Diaz conception and design, relevant critical review of the intellectual content, guarantee of the accuracy and integrity of the work and final approval of the version to be published.

Maria Clara Nunes analysis and interpretation of data, writing of the article, guarantee of the accuracy and integrity of the work and final approval of the version to be published.

José Eduardo Serrão relevant critical review of the intellectual content, guarantee of the accuracy and integrity of the work and final approval of the version to be published.

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