| ORIGINAL ARTICLE |

Spunbond-Meltblown-Spunbond or Non-Woven Fabric for respiratory protection of healthcare workers

Spunbond-Meltblown-Spunbond ou Tecido-Não-Tecido para proteção respiratória de trabalhadores da saúde

Spunbond-Meltblown-Spunbond o Tejido-no-Tejido para protección respiratoria de trabajadores sanitarios

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ABSTRACT: Objective: To analyze the fibers and porosity of Spunbond-Meltblown-Spunbond and Non-Woven Fabric materials used to manufacture surgical masks for respiratory protection of healthcare workers exposed to chemical and biological occupational hazards. **Method:** Descriptive analytical study, using scanning electron microscopy to analyze the materials. Conducted at the Electron Microscopy and Microanalysis Laboratory. Masks made with Spunbond-Meltblown-Spunbond wraps for sterilization and Non-Woven Fabric surgical masks were used in this research. **Result:** The mask made with Spunbond-Meltblown-Spunbond presents fibers distributed randomly — the inner filtering layer has fine fibers ranging from 1 to 5 μm and are well tangled. The Non-Woven Fabric mask has the filtering layer consisting of fine fibers and is less dense. **Conclusion:** The results of this study indicate variation in pore size and fibers of Spunbond-Meltblown-Spunbond and Non-Woven Fabric, which may result in improper filtering of chemical particles by fabric fibers. Microorganisms can vary from 1 to 5 μm, making these analyzed materials act as a protective barrier against biological risks.
Keywords: Masks. Biohazards. Chemical risks.

RESUMO: Objetivo: Analisar as fibras e a porosidade dos materiais *Spunbond-Meltblown-Spunbond* e Tecido-Não-Tecido utilizados para confeccionar máscaras cirúrgicas para proteção respiratória de trabalhadores da saúde expostos a riscos ocupacionais químicos e biológicos. **Método:** Estudo analítico descritivo, utilizando o microscópio eletrônico de varredura para analisar os materiais. Realizado no Laboratório de Microscopia Eletrônica e Microanálise. Foram usadas nessa pesquisa máscaras confeccionadas com envoltórios de *Spunbond-Meltblown-Spunbond* para esterilização e máscaras cirúrgicas de Tecido-Não-Tecido. **Resultado:** A máscara confeccionada com *Spunbond-Meltblown-Spunbond* apresenta fibras distribuídas de forma aleatória — a camada interna filtrante possui fibras finas, que variam de 1 a 5 μm e bem emaranhadas. A máscara de tecido-não-tecido possui a camada filtrante constituída por fibras finas e apresenta-se pouco densa. **Conclusão:** Os resultados deste estudo indicam que há variação no tamanho dos poros e das fibras do *Spunbond-Meltblown-Spunbond* e do Tecido-Não-Tecido, o que pode acarretar a não filtragem de forma correta de partículas químicas pelas fibras do tecido. Os microrganismos podem variar de 1 a 5 μm, fazendo com que esses materiais analisados se apresentem como barreira protetora relacionada a riscos biológicos.
Palavras-chave: Máscaras. Riscos biológicos. Riscos químicos.

RESUMEN: Objetivo: Analizar las fibras y la porosidad de los materiales *Spunbond-Meltblown-Spunbond* y Tejido-no-Tejido utilizados para la fabricación de máscaras quirúrgicas para la protección respiratoria de trabajadores de la salud expuestos a riesgos ocupacionales químicos y biológicos. **Método:** Estudio analítico descriptivo, utilizando el Microscopio Electrónico de Barrido para llevar a cabo los análisis de los materiales. Realizado en el Laboratorio de Microscopía Electrónica y Microanálisis. Se utilizaron en esta investigación máscaras fabricadas con envolturas de *Spunbond-Meltblown-Spunbond* para esterilización y máscaras quirúrgicas de Tejido-no-Tejido. **Resultados:** La máscara fabricada con *Spunbond-Meltblown-Spunbond* presenta fibras distribuidas de forma aleatoria. La capa interna filtrante tiene fibras finas que varían de 1 a 5 μm y están bien entrelazadas. La máscara fabricada con el material de Tejido-no-Tejido tiene la capa filtrante constituida por fibras finas y presenta una densidad baja. **Conclusión:** Los resultados de este estudio indican

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que hay variación en los tamaños de los poros y las fibras del *Spunbond-Meltblown-Spunbond* y Tejido-no-Tejido, lo que puede provocar que las partículas químicas no se filtren correctamente a través de las fibras del tejido. Los microorganismos pueden variar de 1 a 5 μm, lo que hace que estos materiales analizados se presenten como una barrera protectora relacionada con los riesgos biológicos.

Palabras clave: Máscaras. Riesgos biológicos. Riesgos químicos.

INTRODUCTION

Health workers often deliver patient care within environments deemed unsafe, thereby exposing themselves to various occupational risks, including chemical and biological hazards[1].

Workers may face accidental exposure to biohazards while performing their occupational duties, potentially coming into contact with contaminated body fluids from patients under their care. Such exposure can serve as a transmission source for viral diseases like COVID-19, tuberculosis, and meningitis[2].

Chemical risks are linked to long-term adverse health effects. For instance, exposure to chemical substances from surgical smoke can result in acute or chronic and prolonged intoxication for the exposed worker. This exposure can lead to damage to the nervous, respiratory, hematopoietic, or reproductive systems, and even contribute to the development of neoplastic pathologies[3].

Given the aforementioned chemical and biological hazards, it is imperative to employ adequate protection during work activities. This entails considering the nature, type of agent, and characteristics of the risk, as well as its concentration in the environment and its harmful effects on the human body. The respiratory barrier is regarded as a universal measure to safeguard healthcare workers[4].

In hospital environments, surgical masks are utilized for this type of protection. While they serve as a barrier against splashes and droplets that may impact the nose, mouth, and respiratory tract, it is important to note that surgical masks do not provide protection against airborne particles (aerosols) and are designed to filter particles ≥5 μm[5].

The size of the pores in the material used for respiratory protection and the particles intended to be filtered are crucial factors to consider when selecting respiratory protective equipment (RPE). These pores are measured in micrometers (μm), with 1 (one) micrometer equal to 1 (one) millionth of a meter, and classified based on the size of the particles it can effectively filter[6].

Smaller particles, typically measuring between 0.01 and 10 μm, include viruses, bacteria, and certain chemical components[7]. These particles can be easily inhaled and may lead to illnesses[6]. Conversely, larger particles, ranging from 10 to 100 μm, such as dust[7], have the potential to irritate the airways and cause respiratory problems[6].

Fine particles have the capability to penetrate the alveoli, leading to damage within the respiratory system. Ultrafine particles, on the other hand, pose an even greater risk as they can penetrate deeply into the lungs and even enter the bloodstream, making them particularly hazardous[6].

Due to the necessity and shortage of surgical masks, which are extensively utilized in healthcare settings for both clinical and surgical procedures, some hospital services have turned to using wraps for sterilizing materials used in patient care. These wraps are crafted from polypropylene and consist of Spunbond-Meltblown-Spunbond (SMS) fibers. These fibers form a matrix that prevents the penetration of microorganisms into the inner layer of the sterilization wrap, thus ensuring the sterilized material remains uncontaminated[8].

TNT is a synthetic and disposable material consisting of fibers bonded together through heat or pressure. Its versatility allows for various applications. SMS is composed of three layers of fibers, with the middle layer primarily responsible for filtration. It is commonly utilized in applications requiring protection against contaminants.

SMS layers are prepared in two ways: the first and third, called spunbonds, are produced with short fibers deposited on a hot surface, and the second, meltblown, is made of fused fibers, which are separated by a fine nozzle[9].

To utilize these materials for respiratory protection among healthcare workers, several criteria must be met. The outer layer should be resistant to the penetration of airborne fluids. Additionally, there should be a filtering layer to trap particles. The mask should effectively cover the nose and mouth area and feature a malleable nose clip made from adaptable material, facilitating proper adjustment to the contours of the user's face[10]. Moreover, the mask's pores should be smaller than the particles it is intended to filter.

Therefore, this study aimed to address the following research question: do surgical masks made with Spunbond-Meltblown-Spunbond and Non-Woven Fabric effectively protect healthcare workers who are exposed to chemical and biological hazards?

To address this question, the following objective was outlined: to analyze the fibers and porosity of Spunbond-Meltblown-Spunbond and Non-Woven Fabric materials used in the production of surgical masks, aiming to assess their effectiveness in providing respiratory protection for healthcare workers exposed to chemical and biological occupational hazards.

METHOD

This study employed a descriptive analytical approach, utilizing a scanning electron microscope (SEM) to analyze the materials. The research was conducted between March and April 2020 at the Electronic Microscopy and Microanalysis Laboratory (*Laboratório de Microscopia Eletrônica e Microanálise* – LMEM) of a state university in northern Paraná. Participants included teachers and students from the Study Group on Care Management, Scientific Publishing, and Occupational Health (*Grupo de Estudos em Gestão do Cuidado, Editoração Científica e Saúde do Trabalhador* – GeeST), as well as teachers and technicians from LMEM.

SEM is an incredibly versatile instrument commonly utilized for microstructural analysis of solid materials. Despite the complexity of the mechanisms involved in obtaining the image, the result is an image that is relatively easy to interpret. The maximum magnification achieved by SEM falls between that of the optical microscope (OM) and that of the transmission electron microscope (TEM)[11].

One of the significant advantages of SEM over OM is its high resolution, typically ranging from 2 to 5*nm* (20–50 Ao). In comparison to TEM, the primary advantage of SEM lies in the ease of sample preparation.

However, it is not just these characteristics that render SEM such a crucial and extensively used tool in materials analysis. The high depth of focus (images with a three-dimensional appearance) and the capability to integrate microstructural analysis with chemical microanalysis are additional factors that significantly contribute to the widespread utilization of this tool[11].

Surgical masks made with SMS and TNT sterilization wraps (Innova — triple layer — João Med), which were readily available at the hospital, were utilized in this research.

To analyze the SMS and TNT materials, ten samples, each measuring a maximum of 9 mm^2, were cut and evaluated by SEM, using the FEI Quanta 200 equipment (FEI Company, Netherlands) under a vacuum atmosphere of 106 *torr*. For SEM observation, the samples were mounted on aluminum supports using carbon tape and coated with a thin layer of gold film (Baltec SDC 050, Sputter Coater, Germany). Throughout the manipulation process, the professionals involved utilized PPE, including masks and protective goggles, to prevent contamination from droplets of the analyzed materials.

To ascertain the chemical composition of the analyzed materials, the technique of energy dispersive spectroscopy (EDS) in SEM was employed. This technique leverages the interaction of electromagnetic radiation with matter to gather information about its structure or composition. Electromagnetic radiation can take various forms, including visible light, X-rays, gamma rays, or other wavelengths[11].

Electron microscopy is a technique that utilizes a beam of electrons to generate images of extremely small objects. These electrons are emitted from an electron tube and accelerated by a potential difference. The electron beam is subsequently focused by an electromagnetic lens and directed toward the object under study. As the electrons interact with the atoms of the object, they produce a signal that is detected by a sensor and then converted into an image. The electron micrographs obtained via SEM were generated in topographic mode (secondary electrons) at 20 kV under high vacuum conditions[11].

As a result, it was possible to analyze the distribution of fibers and the size of the pores present in the materials selected for the study. The spectra were generated in both quantitative and mapping modes.

This type of research does not require evaluation by an ethics committee for research involving human participants, as the identity of those involved was safeguarded throughout the study.

RESULTS

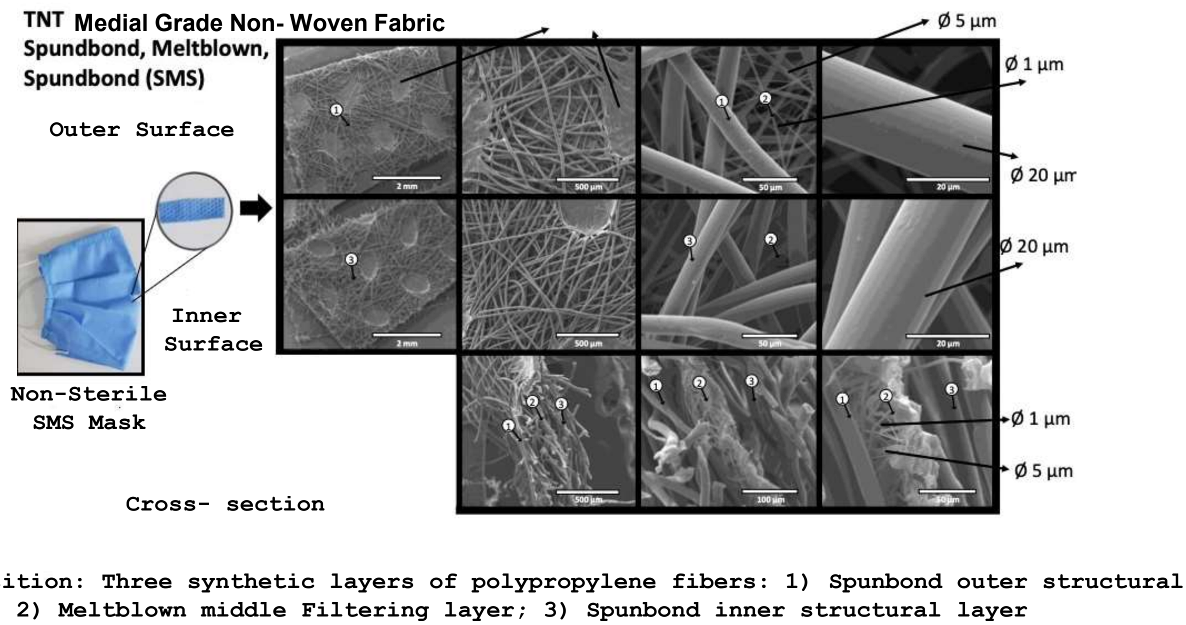
In Figure 1, electron micrographs and energy dispersive spectroscopy using SEM of the analyzed SMS samples are presented.

The sample analyses revealed that the SMS mask exhibits randomly distributed fibers, with the internal filtering layer comprising fine fibers ranging from 1 to 5 µm that are well entangled, thereby reducing porosity.

Figure 2 displays the electron micrographs and energy dispersive spectroscopy results obtained through SEM analysis of the analyzed TNT sample.

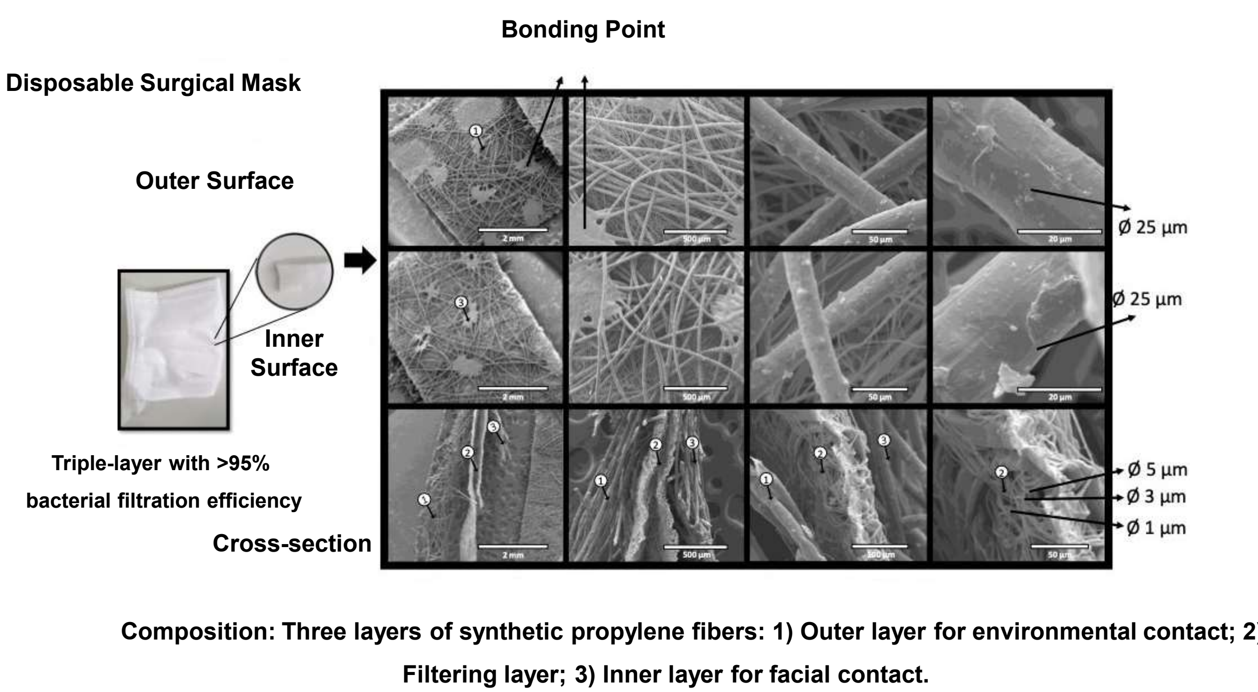
The material analysis revealed that the TNT mask comprises three layers; The filtering material consists of fine fibers, ranging from 1 to 5 µm, and is relatively sparse.

The analysis of the materials indicates that SMS has a denser filtering medium compared to TNT. Both fabrics feature fibers of the same thickness (1 to 5 µm); however, the arrangement and density result in the SMS fabric being less porous in the spaces between the fibers when compared to TNT.



Source: *Laboratório de Microscopia Eletrônica e Microanálise.*

Figure 1. Electron micrographs and energy-dispersive spectroscopy through scanning electron microscopy in the samples of Spunbond-Meltblown-Spunbond analyzed. Paraná, Brazil, 2024.



Source: *Laboratório de Microscopia Eletrônica e Microanálise.*

Figure 2. Electron micrographs and energy-dispersive spectroscopy through scanning electron microscopy in the samples of non-woven fabric analyzed. Paraná, Brazil, 2024.

DISCUSSION

This research revealed that both the mask produced with SMS and the TNT one consist of three layers of polypropylene. Two external layers serve as structural support for the filtering layer situated between them, aligning with recommendations in the literature for effectively filtering infectious particles. The disparity between the analyzed materials lies in the density and distribution of the fibers[12].

Surgical masks commonly worn by workers in surgical centers do not provide adequate protection against chemical risks when exposed to surgical smoke. These masks fail to prevent the inhalation of toxic gases, aerosols, and chemical components generated from tissue coagulation[12].

It was observed that the pores of the analyzed materials (SMS and TNT) exhibit varying sizes, typically ranging between 1 and 5 μm. Healthcare settings harbor various pathogens, including fungi, bacteria, and viruses. These pathogens differ in cellular dimensions and morphology; generally, fungi are larger than bacteria (measuring 1 to 5 μm), which, in turn, are larger than viruses. Pathogens can be transmitted through various carriers, such as respiratory droplets expelled by coughing or sneezing, as well as through the production of surgical smoke[13].

In addition to biological components, chemical compounds pose a risk to healthcare workers during their work activities due to their carcinogenic potential[14]. Ranging from 0.01 to 6 μm in size[15], these compounds can penetrate the layers of masks produced with SMS or TNT, as the pores of these materials were found to be larger than 0.01 μm, facilitating the entry of these particles into the human body. It is worth noting that particles of chemical compounds measuring 0.01 μm in diameter constitute 77% of the particulate material found in surgical smoke[14], which is one of the occupational risks to which healthcare workers are exposed.

Exposure to chemical compounds, such as those found in surgical smoke, can induce various signs and symptoms among workers. These may include coughing, burning sensation in the pharynx, sneezing, rhinitis, nasopharyngeal injury, sensation of a foreign body in the throat, nasal congestion, inflammation of the airways, tearing, nausea, vomiting, abdominal pain, weakness, cramps, dermatitis, headache, drowsiness, dizziness, and irritability. Furthermore, long-term exposure may lead to respiratory and cardiovascular diseases, anemia, rhinitis, conjunctivitis, hepatitis, and cancer, among other health issues[15].

Sterilization wraps (SMS and TNT) possess bacterial filtration efficiency ratings exceeding 95% when tested against 1 to 3 μm bacteria, according to a method outlined by the American Society for Testing and Materials[16].

According to a study on the safety of surgical masks manufactured with sterilization wrap[9], the particle filtration efficiency of the mask produced with sterilization wrap is notably lower than that of an N-95 respirator approved by the National Institute for Occupational Safety and Health (NIOSH) of the United States. However, it falls within the range of a surgical mask, demonstrating acceptable breathability. It is noteworthy that autoclaving these casings did not affect the particle filtration efficiency or the breathing resistance of SMS and TNT[16].

The filtration effectiveness of an RPE depends on the pore and particle size — the smaller the pore size, the greater the filtration effectiveness. However, excessively small pores can impede breathing[7], necessitating comprehensive testing of RPE with regard to various factors, including user breathability.

Masks manufactured with SMS exhibit adequate breathability and can provide a comparable level of barrier protection against droplets. They are suitable for use in clinical settings with a risk of exposure to high-velocity fluids[17]. This presents a viable solution to ensure the continuity of healthcare services when mask supplies are critically low, thereby safeguarding healthcare professionals with a protective barrier[17].

Hence, it is important to highlight that the materials analyzed, concerning pore size, can be deemed effective respiratory protectors in scenarios involving exposure to biological agents. However, they may not provide reliable respiratory protection for workers exposed to chemical agents.

This study is limited by the absence of particle filtration testing for the materials analyzed. This aspect will be addressed by the group of researchers in the subsequent stage of the research, which focuses on developing a prototype mask for respiratory protection for healthcare workers, named HeLP.

Nevertheless, the findings of this study hold promise as they contribute to advancing scientific knowledge concerning workers' health. The investigation revealed that in SMS and TNT materials, the presence of densely entangled fibers tends to decrease porosity, thereby generating a protective effect for workers exposed to biohazards. Moreover, the size of these pores aligns with the required standards. However, it is crucial to note that the materials tested do not offer respiratory protection for workers exposed to chemical hazards. This limitation arises from the small pore size, which prevents chemical particles from contacting the filtering material of masks made with SMS and TNT.

CONCLUSIONS

The pores exhibited by masks crafted from SMS and TNT are compatible (measuring between 1 and 5 μm), allowing for the penetration of pathogenic microorganisms within the same size range. Consequently, these microorganisms are filtered through the mask's filtering layer, thereby providing adequate respiratory protection for healthcare workers exposed to biohazards.

However, these pores are not compatible with the size of chemical particles, which typically range from 0.01 to 6 μm. As a result, these particles do not penetrate the filtering layer of masks made with SMS and TNT, leaving healthcare workers without protection against chemical risks.

It is recommended that additional types of analysis, such as filtration tests, breathability assessments, user acceptance studies, among others, be conducted with all existing respiratory protective equipment (RPE) as well as those incorporating technological innovations, such as the HeLP masks.

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None.

CONFLICT OF INTERESTS

The authors declare there is no conflict of interests.

AUTHORS' CONTRIBUTION

FF: Project administration, Formal analysis, Conceptualization, Data curation, Investigation, Methodology, Resources, Writing – original draft, Writing – review & editing, Supervision, Validation, Visualization. HFLL: Conceptualization, Data curation, Investigation, Methodology, Resources, Writing – original draft, Visualization. AFR: Investigation, Methodology, Resources, Writing – original draft, Visualization. RPR: Formal analysis, Conceptualization, Investigation, Methodology, Resources, Writing – original draft, Writing – review & editing, Supervision, Validation, Visualization.

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