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作品名稱　**surgical masks and microplastics in our airways**

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Abstract

The surgical mask has been our daily companion since the outbreak of the Corona pandemic. The nonwovens (outer layers, not the filter membrane) from which the surgical mask is constructed consist of very long and thin polypropylene fibers. This leads to the question of whether microplastics are released during breathing through the surgical mask, which could enter the respiratory tract or the lungs. This would have a negative impact on our health, depending on the size of the detached fiber fragments - the smaller the worse because they can enter much deeper in our respiratory tract.

In order to investigate the question of whether fiber fragments are released during breathing through a surgical mask, a filtration device was built. The filters were examined under an optical microscope after filtration. If fiber fragments would detach from the surgical mask, they would be found on the filter. Different surgical masks were tested, those that were not worn at all to surgical masks that were worn all day.

It was found that fiber fragments were coming off the surgical masks. There were different fiber fragment types. Some fiber fragments were still undamaged (exhibited nice fractures), while others were frayed. Clump-like fragments occurred, but also smaller fine fiber fragments. All these different fiber fragments had a certain size, so that they could be called microplastics.

The remarkable result of the whole study is that there is a direct correlation between the wearing time of the surgical mask and the number of detaching fiber fragments. In the case of the unworn surgical masks, 10 times fewer fiber fragments occurred during filtration than in the case of the surgical masks that were worn all day.

1 Introduction

1.1 Masks at the Bündner Kantonsschule

In early February in 2020, the Corona pandemic broke out in Wuhan. The first deaths were recorded and soon the virus spread all over the world. At the Bündner Kantonsschule we had no lessons on site for almost half a year. When we started the school again in late 2020, masks were compulsory in all rooms of the BKS and later they were even introduced on the whole school area (also outdoors), because the Corona virus is transmitted by respiratory droplets (Schulze-Röbbecke, Reska, & Lemmen, 2020, p. 123).

Three possible mask types are considered for the pandemic case. They are the full-face mask with P3 filter, the particle-filtering half mask, and the surgical mask (Käser, 2009, p. 30). The official recommendation at the national level for the pandemic case is the surgical mask (Käser, 2009, p. 39). Accordingly, the most widely used masks among students and teachers at BKS are the surgical masks. These masks protect the wearer from respiratory infections transmitted by droplets (Schulze-Röbbecke, Reska, & Lemmen, 2020, p. 125). The surgical masks have two ear loops, with which they can be fastened in front of the mouth and nose, and a bendable nose clip, with which the correct position of the mask can be controlled. The masks are constructed of nonwoven fabrics in 3 layers (Schulze-Röbbecke, Reska, & Lemmen, 2020, p. 124), two outer layers produced by the spunbond process and a middle layer produced by the meltblown process. The middle layer provides good filtration performance, and the outer and inner layers are used for wearing comfort. This combination of spunbond fabric-meltblown fabric-spunbond fabric (also called SMS fabric) is often used for medical fabrics (Dutton, 2008, p. 2). Polypropylene is used to make all 3 layers of surgical masks (Han & He, 2020, p. 1).

1.2 Spunbond-Process

The spunbond process, which is used to produce the two outer layers of the surgical mask (the side that touches the face and the side that is visible from the outside), is a method of producing a nonwoven fabric. This process has been around since 1940, but the methodology has been significantly optimized since then (Lim, 2010, p. 1). The spunbond process primarily uses polypropylene (Vinay Kumar Midha, 2017). This material is extremely cheap. Moreover, it has a low melting point compared to other polymers. The ratio between the strength of the fibers and the weight is also very high. The distribution of molecular weight is also very narrow and the ratio of fibers per kilogram is much higher than that of other materials (Vinay Kumar Midha, 2017). More about the material, however, in the chapter on polypropylene.

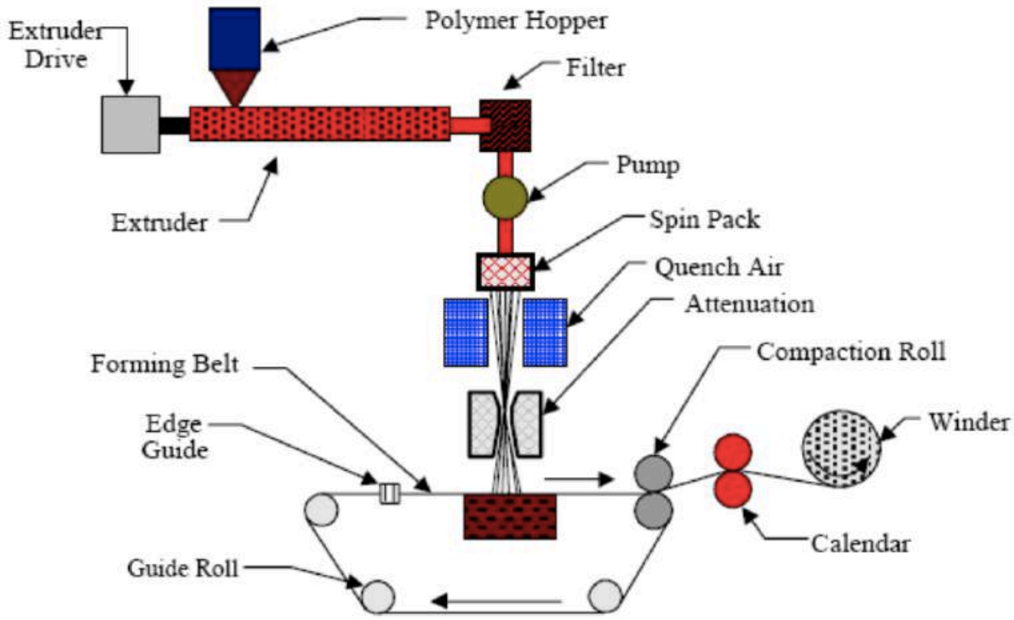

Figure 1 Schematic illustration of the spunbond process (Lim, 2010, p. 2).

The following explanation of the spunbond process is based on the explanations of Lim (2010, p. 2-5). Fig. 1 shows schematically how the nonwoven fabric is formed from the polypropylene pellets.

The first element in the spunbond process is the polymer feed, or polymer hooper. This is where the polypropylene to be processed is added. The polypropylene is in the form of pellets.

The second element in the process is the extruder.

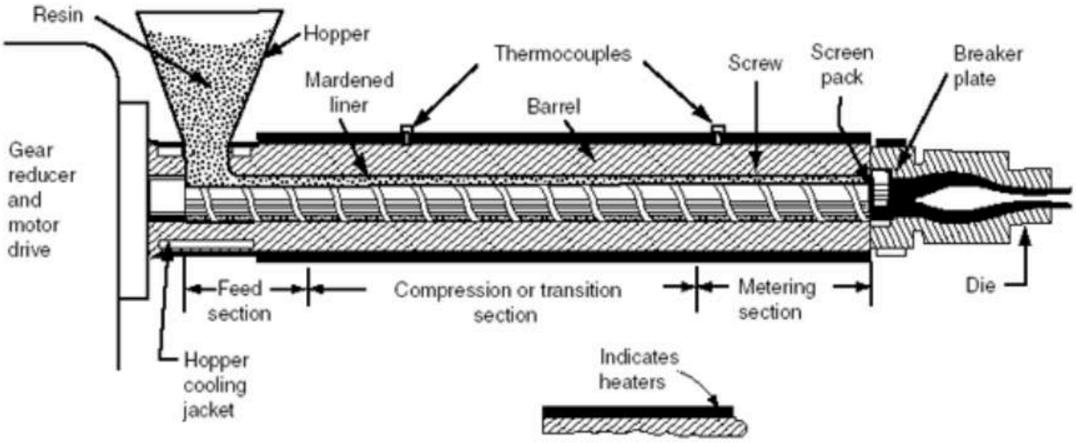

Figure 2 Schematic diagram of extruder (Lim, 2010, p. 3)

In the extruder, the polypropylene is heated and melted. Stabilizing additives are added and other additives such as colors, e.g. the blue color of the surgical mask exterior (see Fig. 2). The whole process takes place under precise control of temperature and pressure. In the first part of the extruder is the feed section, where the polypropylene is added in pellet form. It is transported further by a transport screw and melted. The next passage in the extruder is the compression or transition section, where the molten polypropylene is compressed and converted into the liquid phase. Finally, the material passes through the metering section, where the additives are added. These are also added in high doses.

After the extruder, the liquid polypropylene with the additives passes through the filter. In the filter, foreign particles such as metals or solid polymer particles are removed. These particles can later cause problems in the spinneret or lead to filament breakage.

After the filter, the filtered liquid mixture passes through a metering pump where the correct volume of polymer flow per time is controlled. The magnitude of the flow rate is expressed in kilograms per hour. In the spunbond process, the flow rate is 40-100 kg/h, but it depends on the machine. After melting the polypropylene, the temperature must always remain constant, and therefore the metering pump is temperature insulated.

After the metering pump, the correct flow volume is set and the polypropylene mixture goes into the spin pack. The spin pack consists of a polymer-feed distributor and a spinneret. The distributor provides uniform distribution of the polymer feed and maintains a uniform temperature to balance the polymer flow and run time in the nozzle. The spinneret is made of metal and has a high number of small holes from which the molten polypropylene is squeezed out. The design and construction of this nozzle ensures a uniform nonwoven fabric. In order to obtain a wide enough nonwoven fabric, such nozzles are lined up to generate a sufficient number of fibers over the entire width of the desired fabric size.

The now compressed polypropylene fibers are placed in the quench chambers. Cold air is blown onto the filaments to cool them sufficiently. During the cooling process, the temperature and other parameters must be constantly monitored. The filaments are now blown into a conical pipe with very fast air. This causes elongation and damping of the individual fibers. The damping leads to a polymeric molecular orientation to continuous filaments and the modification of the fiber diameter. In the case of polypropylene, 2000m of fiber is spun per minute.

Subsequently, the spun polypropylene fibers are positioned on the forming belt, a moving belt. Before reaching the belt, the individual fibers are separated by mechanical or aerodynamic forces or electro-static charge in order to obtain the greatest possible uniformity and coverage of the fibers on the belt. High pressure air from a pneumatic gun is used to move the fibers on the belt. In addition, a vacuum under the belt is used to form a nice fiber network. After that, the filaments are bound to form a fiber net. Four different methods are used for this. The methods are hydroentangled bonding, needle punched bonding, thermal bonding and chemical bonding.

1.3 Meltblown-Process

The meltblown process is used in the production of the middle fabric of the 3-layer surgical mask. The middle fabric is the particle-filtering layer in the surgical mask (Han & He, 2020, p. 1). The meltblown process produces a nonwoven material whose fiber diameter is in the submicroscopic range. A fiber has a diameter of 2-4 micrometers (Dutton, 2008, p. 3). Polypropylene is also used in the meltblown process for the middle layer of the surgical mask.

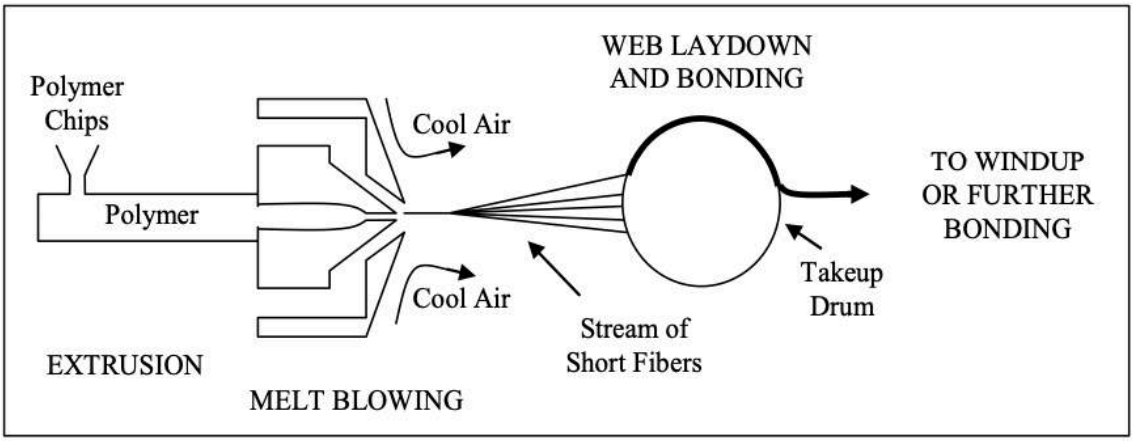

Figure 3 Schematic representation meltblown process (Dutton, 2008, p. 6).

The meltblown process described below can be followed continuously in Fig. 3. At the beginning of the meltblown process, exactly as in the spunbond process, the polypropylene granules are first fed into the extruder. In the extruder, the polypropylene is heated and melted until the appropriate temperature and viscosity have been reached. The polypropylene then enters the metering pump, which dispenses just the right amount of it into the die assembly. When the viscous polypropylene comes out of the nozzles, it is caught by a very fast and hot air jet, which forms the microfibers from it. The formed microfibers are blown (cool air) onto a drum where the nonwoven fabric is formed (Dutton, 2008). The meltblown process will not be discussed in detail in this paper, as it focuses on the fabric in the surgical masks, which was produced using the spunbond process.

1.4 Polypropylen

1.4.1 Structure

Polypropylene is a polymer. This is the name given to a product that is formed during chain polymerization (poly gr. = much, meros gr. = part). The polymerization results in macromolecules ("giant molecules"). This means that polypropylene is a chain of many individual propylene molecules strung together. It is also said: "Polypropylene is a polymer of propylene" (Günter Baars, 2008). A propylene molecule consists of three C atoms and five H atoms (Vincenzo Busico, 2000). Such a molecule can be seen in Fig. 4.

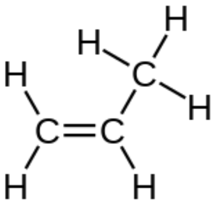

Figure 4 Propylene molecule in Lewis formula notation (https://de.wikipedia.org/wiki/Propen, last accessed 07/27/2021).

Polymerization involves the continued attachment of unsaturated propylene molecules to their double bonds. For this purpose, the double bond between the two C atoms is converted into a single bond and the propylene molecules rebond at the newly formed bonding sites (see Fig. 5). If one wants to name the resulting polymer, one first starts with the word poly- and then gives the name of the starting molecule (Günter Baars, 2008). In this case, the starting molecule is propylene and thus the polymer is called polypropylene.

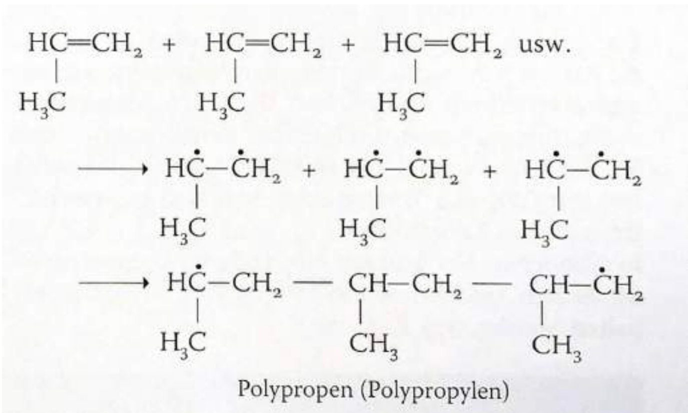

Figure 5 Schematic representation of the polymerization of propylene with the Lewis formula (Günter Baars, 2008).

1.4.2 Advantage of polypropylene

Polypropylene is used to manufacture the nonwoven fabrics in the surgical masks for certain reasons. On the one hand, polypropylene is very cheap. On the market, polypropylene is one of the cheapest materials available for the production of nonwovens using the spunbond and meltblown processes. Polypropylene also has a low melting point

(Midha & Dakuri, 2017). Another advantage of polypropylene is the outstanding chemical stability. In addition, it also has notable mechanical characteristics which means a nonwoven made of polypropylene should be quite durable. Polypropylene is also hydrophobic (Fei Sun, 2020). Thanks to the hydrophobic property, surgical masks made of polypropylene repel water, and thus spit droplets.

1.5 Mask certificate DIN EN 14683

The surgical masks with a certificate must be tested and verified for filtration performance and internal and external pressure difference. In Europe, such surgical masks comply with the European standard DIN EN 14683 (Schulze-Röbbecke, Reska, & Lemmen, 2020, p. 125). However, one very important criterion is missing from the certification of the masks: none of these standards require any regulations on inhalable debris such as microplastics that may be present in the product (Han & He, 2020, p. 2). Electron microscope images of top-selling surgical masks show the nonwoven fabric of the innermost layer (the layer lying on the skin). On them, one can see debris or scales (Fig. 6). which could come from the manufacturing process or packaging (Han & He, 2020, p. 3).

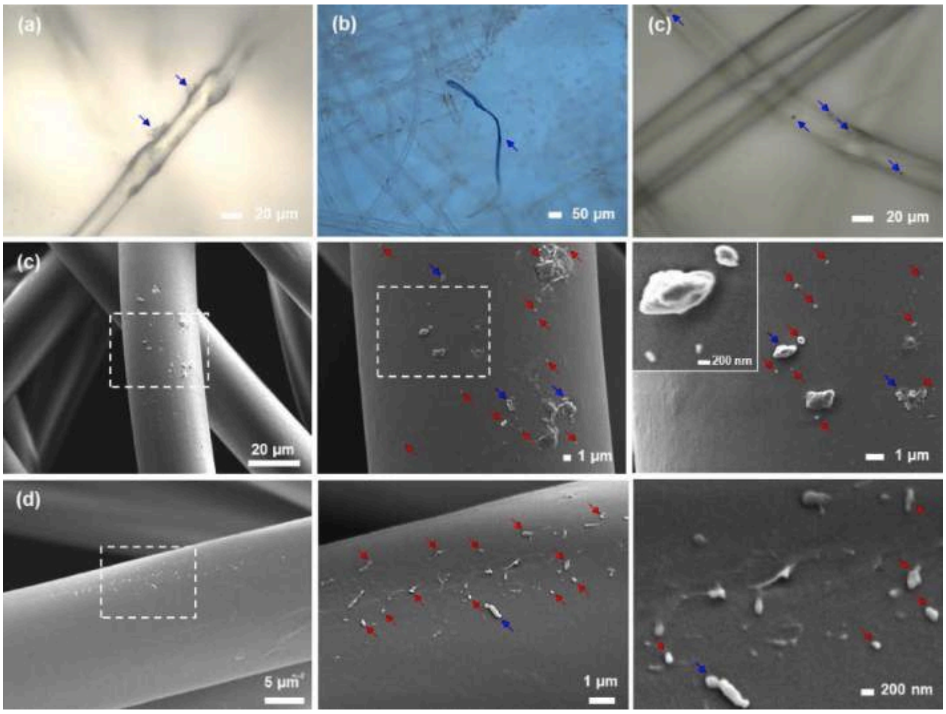

Figure 6 Electron micrographs of top-selling surgical masks (Han & He, 2020).

If such fiber fragments or fiber flakes were to detach from the surgical masks, they could enter the respiratory tract or even the lungs during inhalation. This could have a potential relevance for our health.

1.6 Microplastics in the lungs

1.6.1 The human lung

Orders of magnitude more than the skin,, our lungs have the largest contact surface with the environment. It has a surface area of 120m^2 (as large as half a tennis court). The human lung absorbs several million aerosol particles per breath. That is why it has a very reliable defense system. This defense system consists of sneezing, coughing, the mucociliary apparatus, absorption and phagocytosis (Haidl, 2008).

1.6.2 Deposition mechanisms of the lung

The first particle filter during inhalation is the nose. If we breathe only through the nose, a good 90% of the particles larger than 1-2 µm are deposited here. If we also breathe through the mouth (e.g. when playing sports), the oropharynx and glottis are added as deposition mechanisms (Haidl, 2008).

Particles larger than 10 µm generally cannot reach the bronchial system because they are stopped by the deposition mechanisms mentioned earlier. Particles larger than 5 µm are deposited by impaction. These large particles are unable to follow the airflow when it changes direction due to inertia and thus impinge on the airway wall. The particles are thus deposited in the oropharynx (Haidl, 2008).

Another deposition mechanism is sedimentation by gravity. This mechanism comes into effect for particles of size 1 µm to 5 µm. Since the particles are smaller and are not deposited by impaction, they penetrate deeper into the bronchial system. During the breathing maneuver, the particles sink because of gravity and can establish wall contact (Haidl, 2008).

There are several influencing factors in particle deposition. The particle size, the breathing maneuver, the anatomy of the oropharynx, the hygroscopy, the electrical charge and the solubility. Of very great importance is the breathing maneuver. The slower one breathes, the lower the impaction (Haidl, 2008). This dependence of the deposition on the breathing maneuver can be seen very well in Fig. 7, where two ventilation scintigrams are shown. A is the extremum of deposition by impaction during fast breathing with 7 µm particles and B is the extremum of deposition by sedimentation during slow breathing with 2 µm particles.

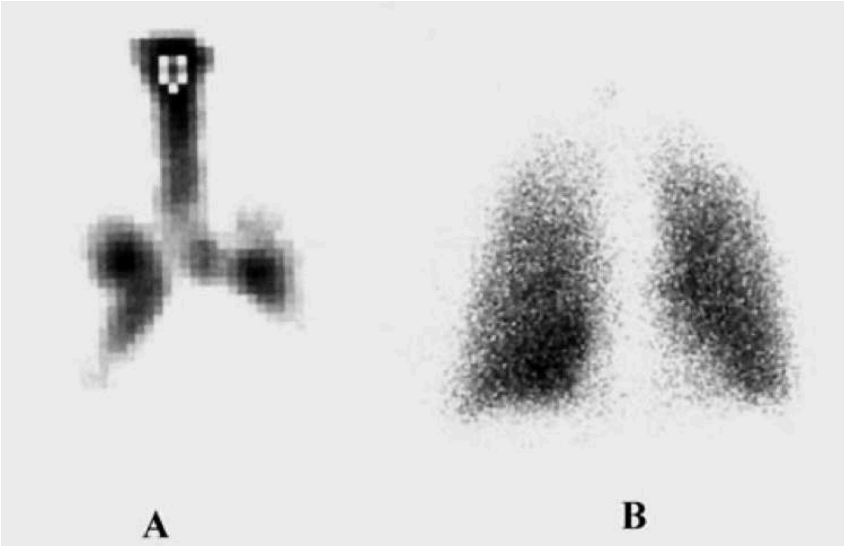

Figure 7 Ventilation scintigrams of impaction with 7 µm particles (A) and sedimentation with 2 µm particles (B) (Haidl, 2008).

Today, great attention is paid to particles smaller than 2.5 µm. In epidemiological studies, correlations between mortality and the dose of fine to ultrafine particles have been discovered (Haidl, 2008).

1.6.3 Particle elimination

The elimination of the deposited particles takes place through movements of the cilia. On each epithelial cell in our airways or lungs, there are approximately 200 kinocilia. These cilia are motile and range in length from 5 µm to 7 µm (Bučan-Dedič, 2019). The cilia move in a low viscosity fluid called the perciliary fluid. This fluid is set into circular motion by the cilia beating, thus propelling the mucus. The mucus is a gel located on the cilia. This gel consists mostly of water and glycoproteins (Stein, 2007). Inhaled aerosols are embedded in it. The aerosols are transported orally by the propulsion of the cilia and thus removed from the respiratory tract. (Haidl, 2008)

1.6.4 Asbestos as a case study from the past

In the past, materials have been made from fibers which, over time, have proven to be a great danger to the lungs. Asbestos fibers can be pointed out as a case study. The fiber size of asbestos is almost the same as the fiber size of the fiber fragments detached from the surgical masks. Industrially produced asbestos fibers were mass-produced because their properties such as strength, heat resistance, acid resistance and thermal insulation seemed very convincing. Only afterwards was it discovered that released asbestos fibers could enter the respiratory tract and increase the risk of developing lung cancer. Asbestos was subsequently classified as carcinogenic. In the years that followed, asbestos claimed numerous victim. Many workers who worked with asbestos-based materials without any protection lost their lives (Wikipedia, Asbestos). This fact suggests that released fibers from other materials might also pose a potential hazard to the lungs.

1.7 Question

As mentioned in chapter 1.5, the certification of surgical masks has a shortcoming: It only includes filtration performance and pressure difference from inside and outside. However, a key issue is also the durability of the surgical masks. If microplastics detach from the surgical mask and get into the lungs, this could have consequences for our health, as explained in chapter 1.6. Microplastics are defined as follows: Microplastics are polymers that may contain additives or other substances and are either 1nm to 5mm in size or fibers no longer than 15mm (Erny, 2020). Based on this, I wanted to investigate in my Matura thesis whether microfibers and microparticles are released during inhalation through a surgical mask.

2 Material und methods

2.1 Detection of detaching microfibers

In order to detect microfibers that detach from the surgical mask during breathing, a filtration device was built that worked with two air pumps. The surgical mask was fixed on a cylindrical glass with the help of a fixing rubber. All surgical masks used in the experiments were DIN EN 14683 certified products. At the lower edge of the cylindrical glass, it had a transition piece to an Erlenmeyer flask, which had a groove at the upper edge. A filter could be inserted between the two glasses. The air was then sucked out of the Erlenmeyer flask, so that air was inevitably sucked through the mask, through the cylindrical glass and through the filter. With this filtering device, a methodology was used which could be reproduced as often as desired and which can be described as close to reality (more on this later in the explanation of the air pumps).

The filters used are from the Macherey-Nagel company. They are cellulose filters (MN 640 w) with a diameter of 5.5 cm and a thickness of 0.2 mm. The filter have a retention capacity of 7-12 µm. In addition, the cellulose filter have a white color.

To pump the air out of the Erlenmeyer flask, two different pumps were used. The first was a water vacuum pump, which had to be connected to the water tap, and a second pump from the AGT company, which had to be operated by hand with a lever. The water vacuum pump continuously sucked air, which created a light air flow. The hand pump also sucked air in large quantities, similar to a human breath (simulating human breathing to make the filtration process more realistic). When the lever of the hand pump was lifted, it sucked the air through the filtration device. When the lever was lowered again, the sucked-in air was blown away through an outlet tube. To make the hand pump easier to operate, it was screwed to a wooden board. The two pumps were connected to the Erlenmeyer flask via PVC hoses (Fig. 8).

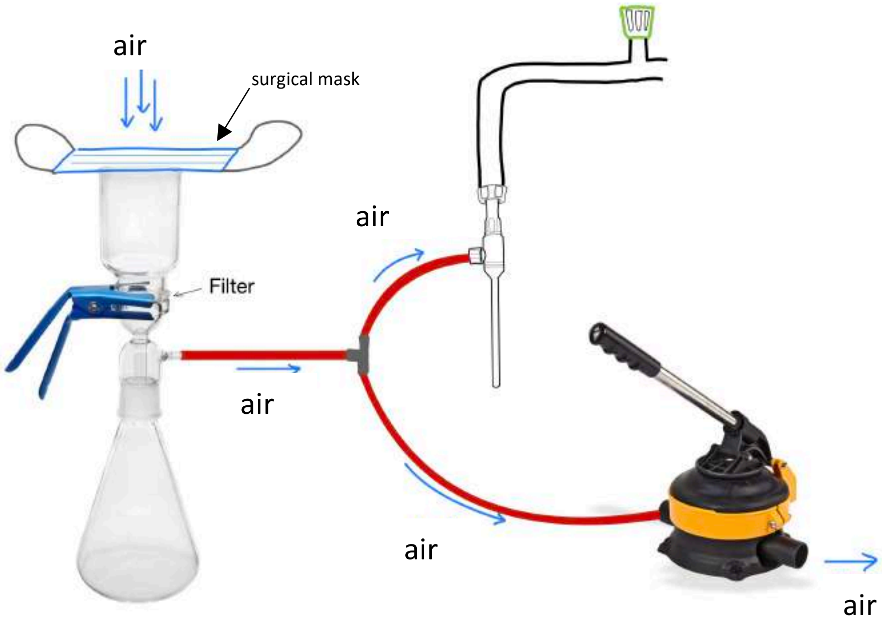

Figure 8 Schematic of filter apparatus: lower right hand pump (Retrieved 7/5/21 from https://dema-handel.ch/produkt/wasserpumpe-handpumpe-dwp-65/), upper right water vacuum pump connected to a faucet, left Erlenmeyer flask (Retrieved 7/5/21 from https://www.carlroth.com/de/de/filtrationsgeraete-filterhalter/vakuum-filtrationsgeraet-duran-47-mm-mit-schliff/p/xt09.1)with mask, Nutsche, and filter.

Filtration proceeded as follows:

- Mask with DIN EN 14683 certificate was fixed on the glass cylinder*.
- water vacuum pump was left running for 1 hour
- with hand pump was always pumped after 5 minutes for 1 minute
- every 5 minutes the mask was tugged (simulation of straightening during wearing)

*The surgical mask was attached with the blue side facing the glass cylinder. This was of great importance for examination under the light microscope, as only the blue fiber pieces could be seen. When the surgical mask was fixed with the white side towards the glass cylinder, no difference was seen on the white filter between the surgical mask fibers and the cellulose fibers of the filter. This inverted fixing is possible as far as the manufacturing method of the blue as well as the white mask layer is the same. They are both fabrics where the spunbond process was used to manufacture them. The only difference is that a dye was added as an additive to the outer blue mask layer during production in the extruder (see chapter 1.2 Spunbond process).

If surgical mask fibers came loose during the experiment, they landed on the cellulose filter. The cellulose filter was removed from the filtration apparatus after the 1-hour experiment and then clamped between two square slides. The slides with the filter in between were mounted on the stage of a light microscope and examined. The procedure for examining the cellulose filter under the light microscope was, to a certain extent, scanning. For this purpose, the filter was scanned for surgical mask fibers at 100x magnification. The objective stage was used to move the microscope one viewing width at a time and to move up and down along the filter (Fig. 9).

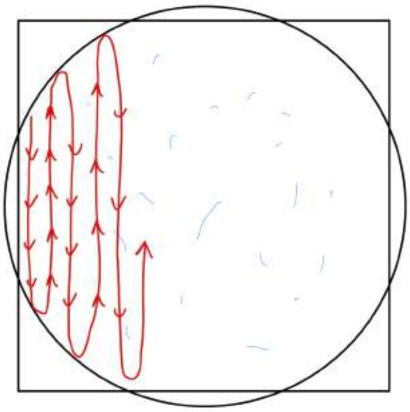

Figure 9 Procedure for scanning the round cellulose filter (clamped between two square slides) under the light microscope

This experiment was repeated with different surgical masks. Four surgical masks were filtered unworn and another five surgical masks were worn first (again with the blue side facing the face, as it was also fixed on the filter apparatus with the blue side facing the filter) and then filtered. The worn masks were again used in different time periods and activities. The first two surgical masks were worn in a sports training session for 1.5 hours, under intense physical stress and thus very heavy breathing. The third surgical mask was worn for approximately 8.5 hours, during a normal school day. The fourth surgical mask was worn for 2 hours at school, during an afternoon with 3 lessons. The last surgical mask was worn during a ski day on a weekend for 8 hours. With this study, an attempt was made to recreate a very realistic image. Therefore, the surgical masks were also worn during activities from the different areas of everyday life. This realistically recreates the wide use.

2.2 Detection of fiber scales

Another step that followed the qualitative and quantitative results was the examination of the surgical mask fibers for fiber flakes. According to Han & He (2020), such fiber flakes are found on the surgical mask fibers and look like irregularities on the smooth surface (Fig. 10). This investigation required a successful result of the first qualitative and quantitative investigation.

Such an examination was performed with a scanning electron microscope (SEM), because the fiber scales were too small for a light microscope.

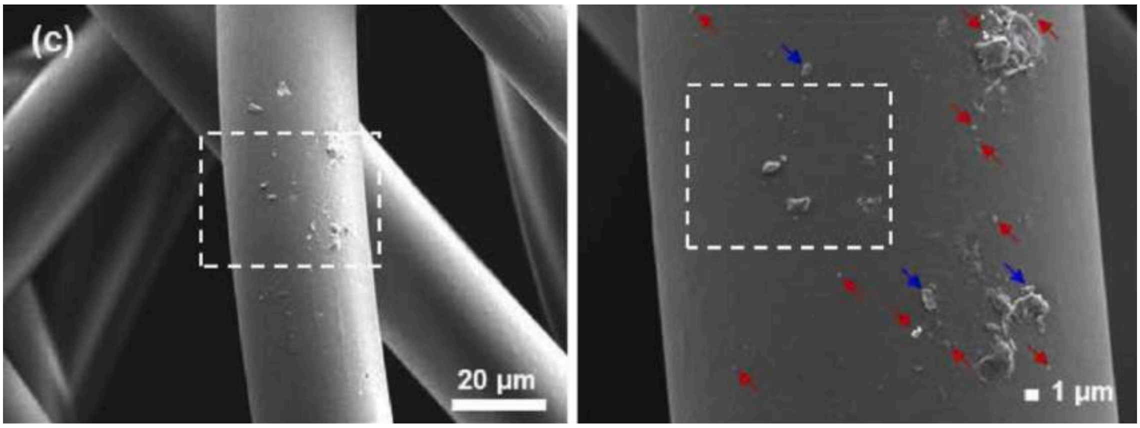

Figure 10 surgical mask fiber scales outlined with dashed white rectangle (Han & He, 2020).

3 Results

3.1 Number of surgical mask fiber fragments

In the four trials with the unworn surgical masks, an average of 9 fiber fragments were found on the cellulose filter. This is significantly less (p=0.002) than the average of the five worn surgical masks. The surgical mask worn for 2 hours at school left 37 fiber fragments on the filter sample. On the filter samples of the surgical masks worn for 1.5 hours during intense physical exertion and thus intense breathing, there were 82 and 86 fiber fragments, respectively. On the filter sample of the surgical mask used for 8 hours during a skiing day, there were 82 fiber fragments. From the surgical mask worn for 8.5 hours during a school day, 86 fiber fragments came off. From the tests with the surgical mask worn for 1.5h during sports there is no significant difference to the tests with the surgical mask worn for 8h and 8.5h (see Fig. 11).

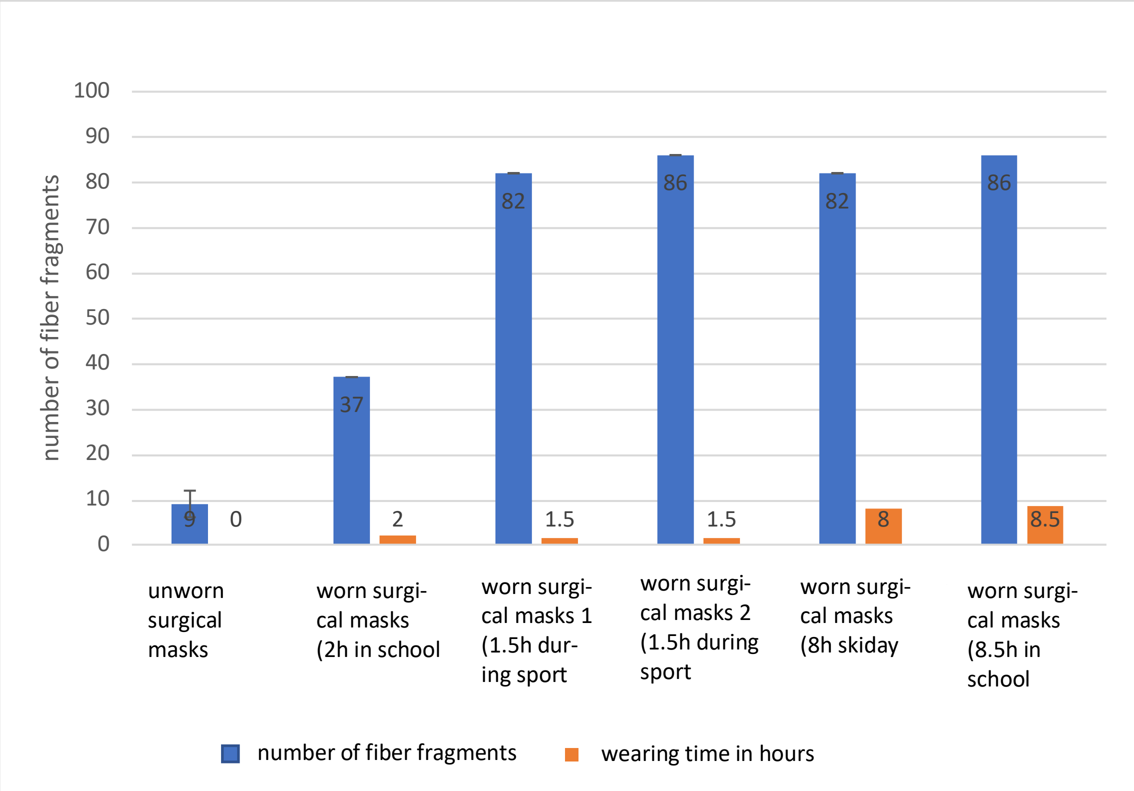

Figure 11 Number of fiber pieces on the filter samples depending on the wearing time of the surgical masks.

3.2 Size of the surgical mask fiber fragments

3.2.1 surgical Mask Fiber Fragments Length and Diameter

There were different sizes of fiber fragments found on the cellulose filter. The largest amount of fiber fragments had a length of 4 µm up to 500 µm (see Figs. 12, 13, 14, 15, 16). In all tests, fewer fiber fragments were seen that were longer than 500 µm. This smaller amount of fiber fragments had lengths between 500 µm and 1500 µm. Occasionally, there were also fiber fragments longer than 1500 µm, but only very few. In total, only four fiber fragments were found that had a length between 1500 µm and 2000 µm (see Figs. 12 and 16).

Most of the fiber fragments found had a diameter between 5 µm and 30 µm. Rarely, there were also fiber fragments with a diameter of more than 30 µm. However, this was at most 50 µm. A total of 12 fiber fragments were found which had a diameter between 30 µm and 50 µm. All these fiber fragments with a larger diameter had a fiber length of 40 µm to 100 µm (see Figs. 14, 15, 16). These were lumpy fiber fragments. For the longer (> 100 µm) fiber fragments, no diameters above 30 µm were measured.

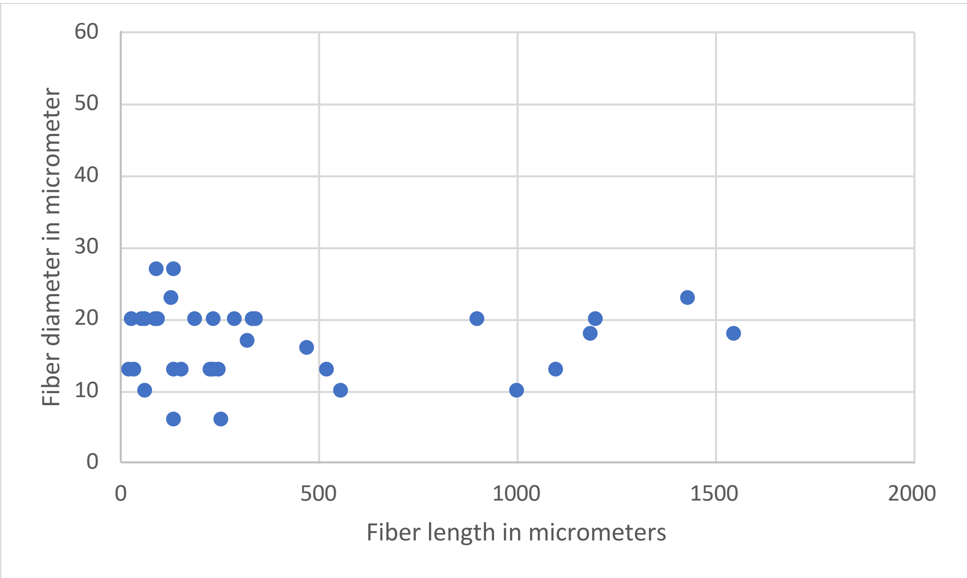

Figure 12 unworn surgical masks Size of fiber fragments (diameter and length), all data of the 4 experiments with unworn surgical masks recorded in this Fig.

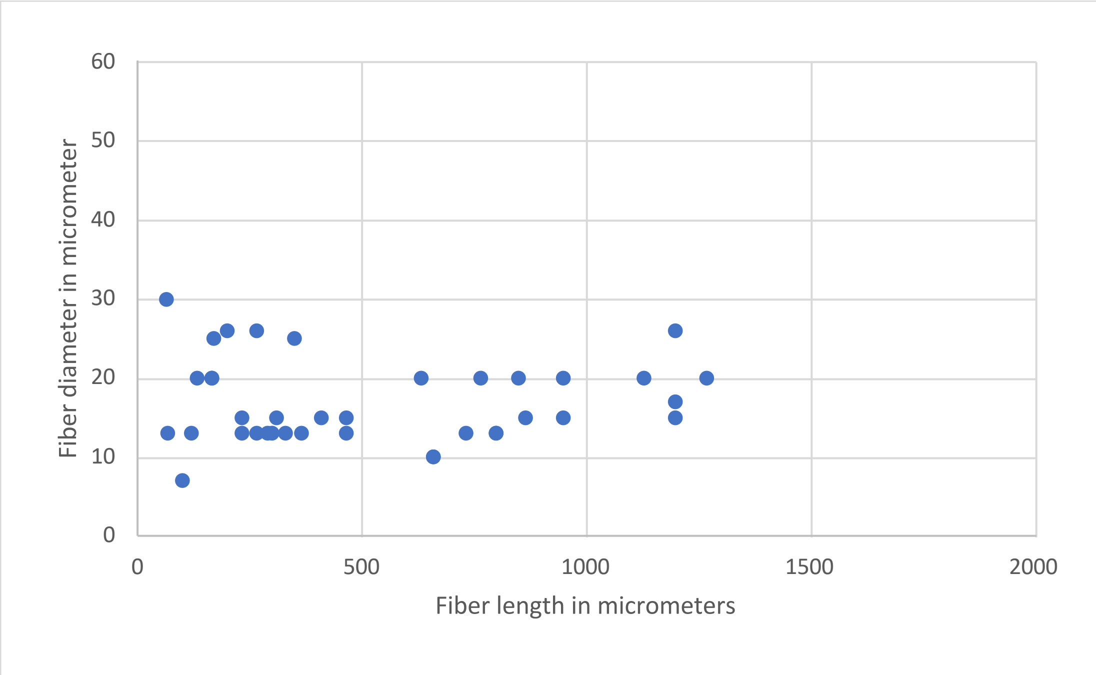

Figure 13 surgical mask worn (2h in school): Size of fiber fragments (length and diameter).

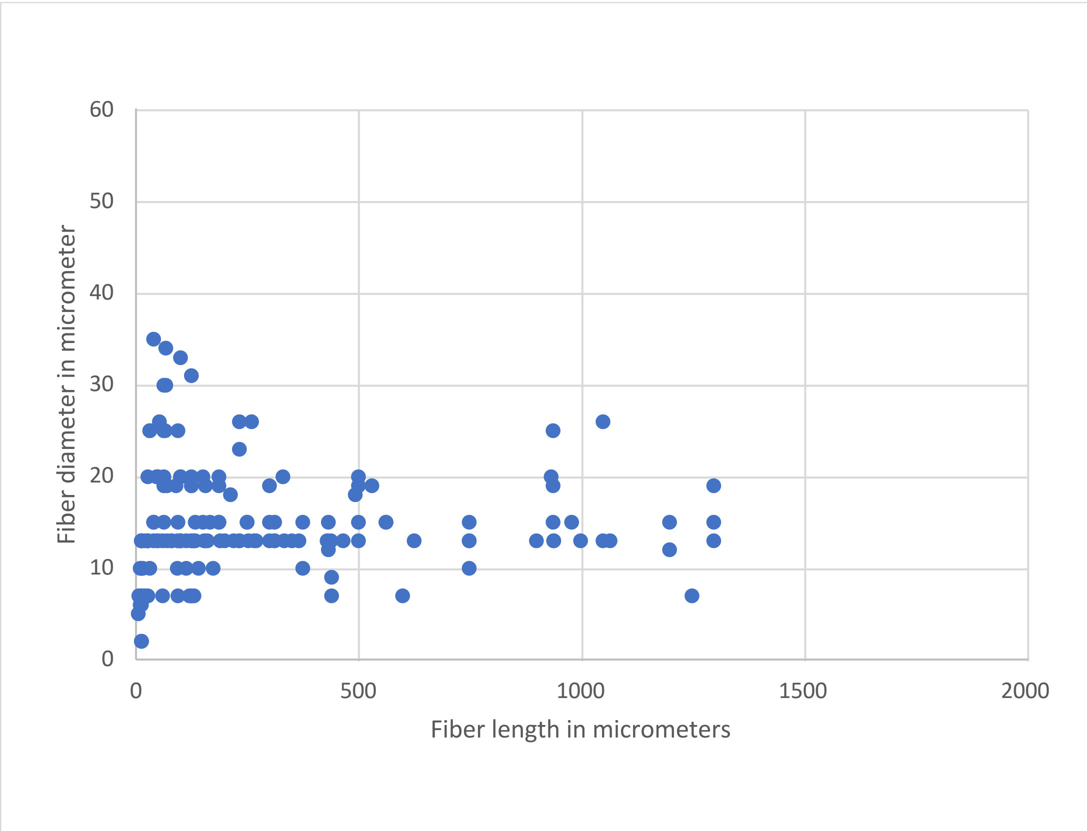

Figure 14 surgical mask worn1 and 2 (1.5h during intense sport): Size of fiber fragments (length and diameter).

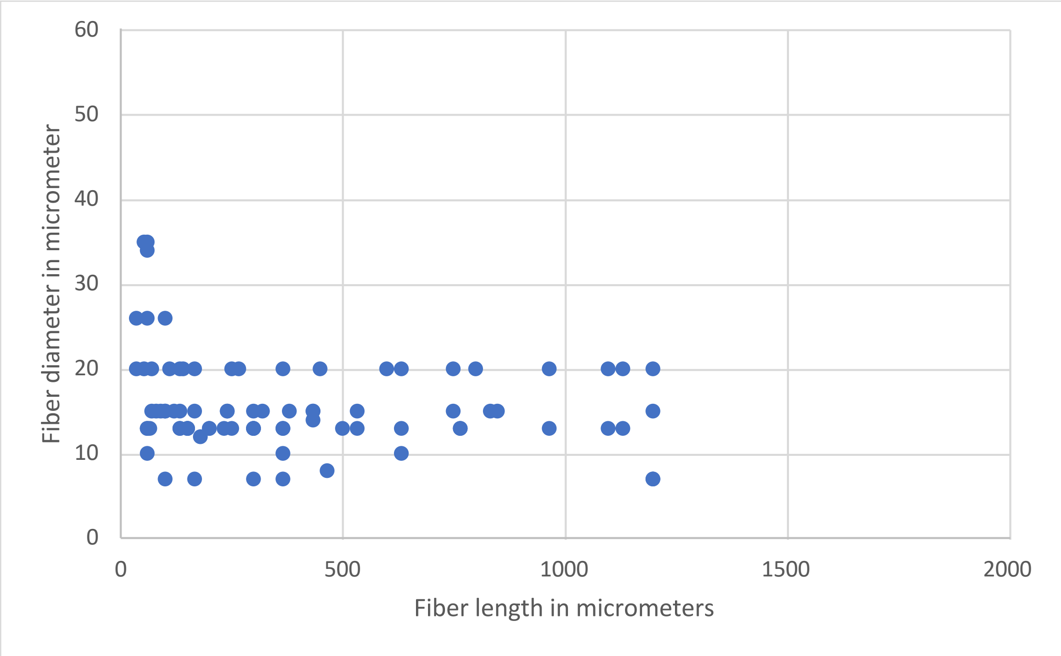

Figure 15 surgical mask worn (8h ski day): Size of fiber fragments (length and diameter).

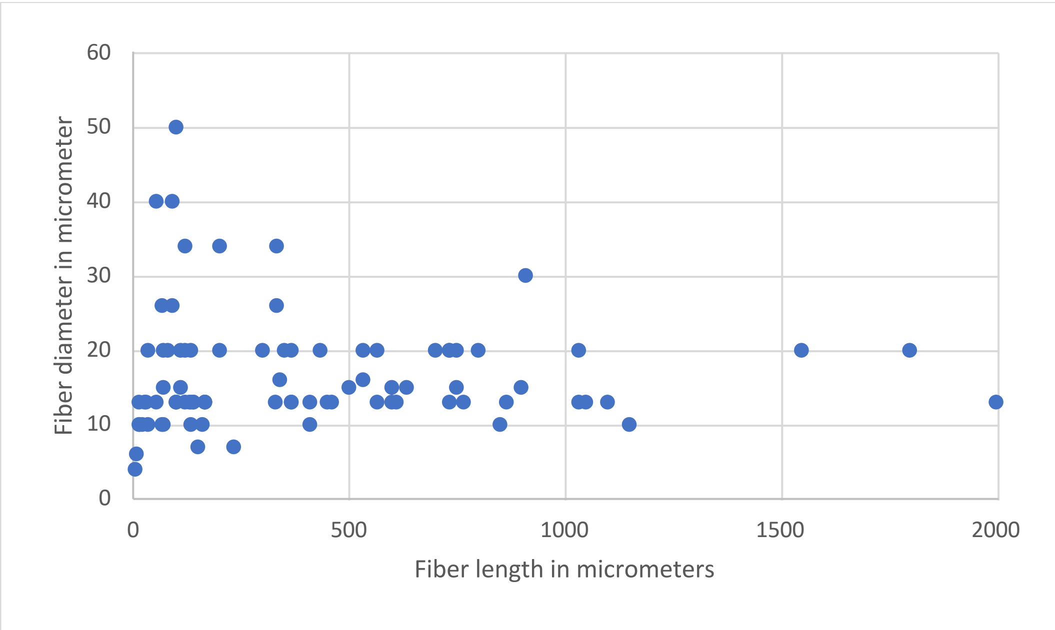

Figure 16 surgical mask worn (8.5h in school): Size of fiber fragments (length and diameter).

3.2.2 Average length of fiber fragments

The fiber fragments of the two surgical masks worn during 1.5 hours of sports training (1 and 2) had an average length of 274 µm (standard deviation 323.2 µm). Thus, the fiber fragments of these two filter samples were the shortest compared to the others (see

Fig. 17). The fiber fragments of the surgical mask worn for 8 hours on a ski day had an average length of 393 µm (standard deviation 346.8 µm). From the surgical mask worn for 8.5 hours at school, fiber fragments detached with an average length of 403 µm (standard deviation 409.7 µm). In the filter sample of the surgical mask, which was not worn, the average length of the fiber fragments was 405 µm (standard deviation 434.00 µm). The fiber fragments found in the filter sample of the surgical mask (worn for 2 h in school) (see Fig. 17) are the longest on average with a length of 530 µm (standard deviation 368.1 µm). The average lengths of the fiber fragments from the worn surgical masks do not differ significantly from the average lengths of the unworn surgical masks ($p=0.95$).

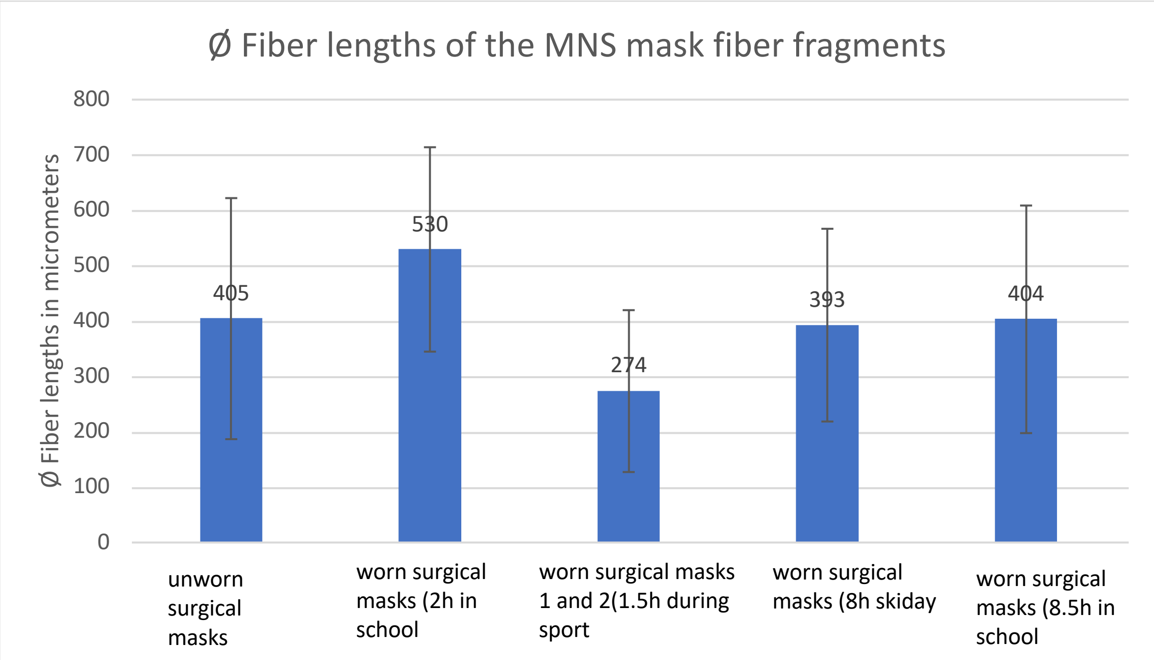

Figure 17 Fiber fragment length of surgical masks (mean values and standard deviations).

3.2.3 Average diameter of fiber fragments

On the two filter samples of surgical masks worn during 1.5 hours of sports training (surgical mask worn 1 and 2), the cut of the fiber diameter was 15 µm (standard deviation 5.9 µm). This is the smallest cut of the diameter compared to the others (see in diagram on Fig. 18). The surgical mask worn during 8 hours on a ski day showed fiber fragments with a mean diameter of 16 µm (standard deviation 5.6 µm). The filter samples of the surgical mask worn for 8.5 h at school and the surgical mask worn for 2 h at school both had fibers with a mean diameter of 17 µm (standard deviation 7.7 µm and 5.2 µm). The surgical masks that were not worn also had an average fiber diameter of 17 µm (standard deviation 5.2 µm). The average fiber diameters of the fiber fragments from the worn surgical masks were not significantly different from the average fiber diameters of the fiber fragments from the unworn surgical masks (p=0.31).

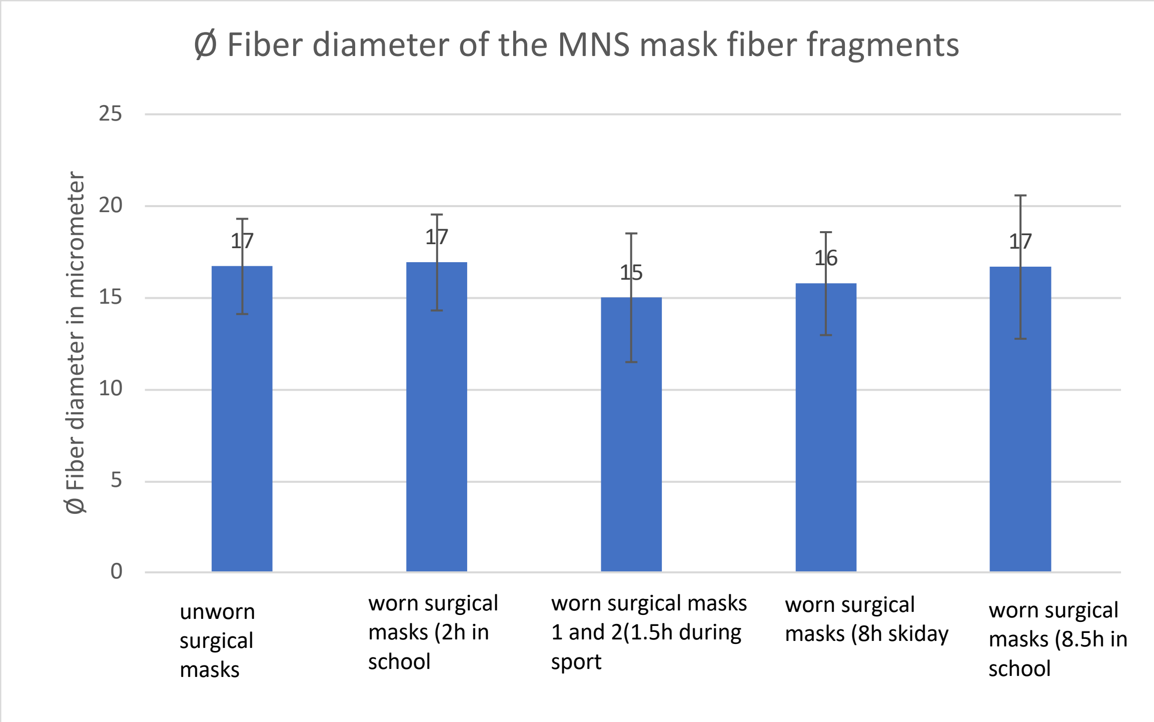

Figure 18 Diagram: Fiber fragment diameter of the surgical masks (mean values and standard deviations)

3.3 Fiber fragment types

3.3.1 Fiber fragment types in the worn surgical masks

Clearly recognizable fiber fragments were detached from the worn surgical masks. These blue fibers could be seen on the white cellulose filter and also different types of fiber fragments. Fig. 19 shows what most of the fiber fragments looked like. The fiber fragment shown in Fig. 19 is from the surgical mask worn during the 1.5 hour sports training session.

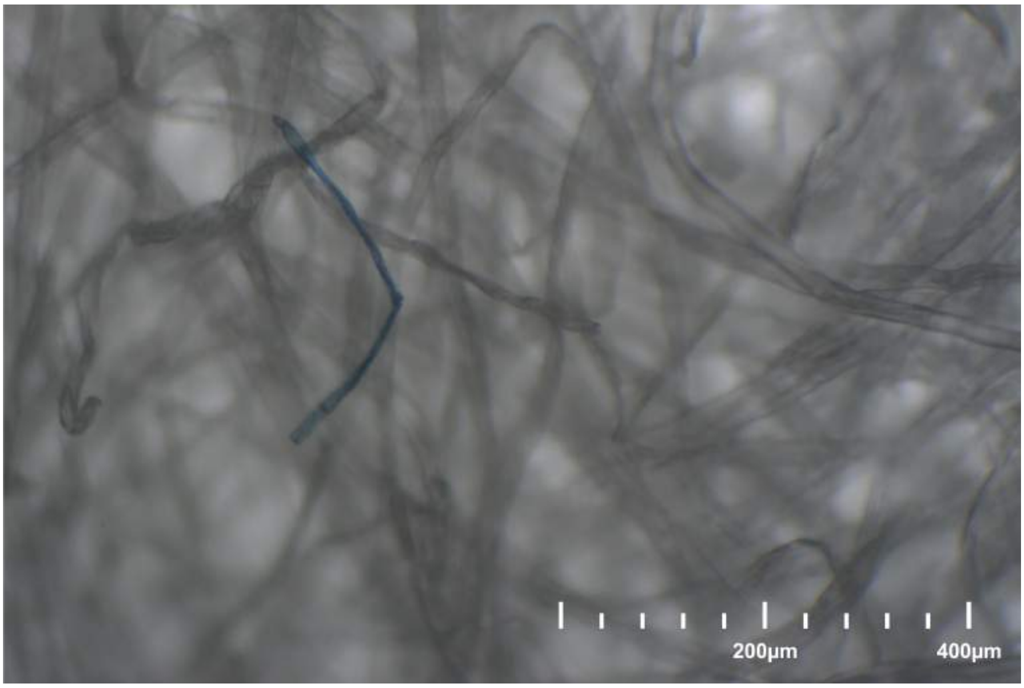

Figure 19 typical fiber fragment (blue) on the cellulose filter (gray-white) of sport surgical mask

There were many different fiber fragments, of which all fiber diameters and fiber lengths were measured and documented. In addition to the typical fiber fragment seen in Fig. 19, there were also multiple split and branched fiber fragments as seen in Fig. 20. The fiber fragment in Fig. 20 is from the surgical mask worn for 8.5 hours during a normal school day.

Figure 20 Fiber fragment (blue) with split and branched end (surgical mask 8.5h school) on the cellulose filter (gray-white)

In addition to the typical and the frayed fiber fragment, there were also very small fiber fragments, as can be seen in Fig. 21. This fiber fragment has a length of 13 µm and a diameter of 2 µm. However, such smaller fiber fragments occurred much less frequently than the fiber pieces in Figs. 19 and 20.

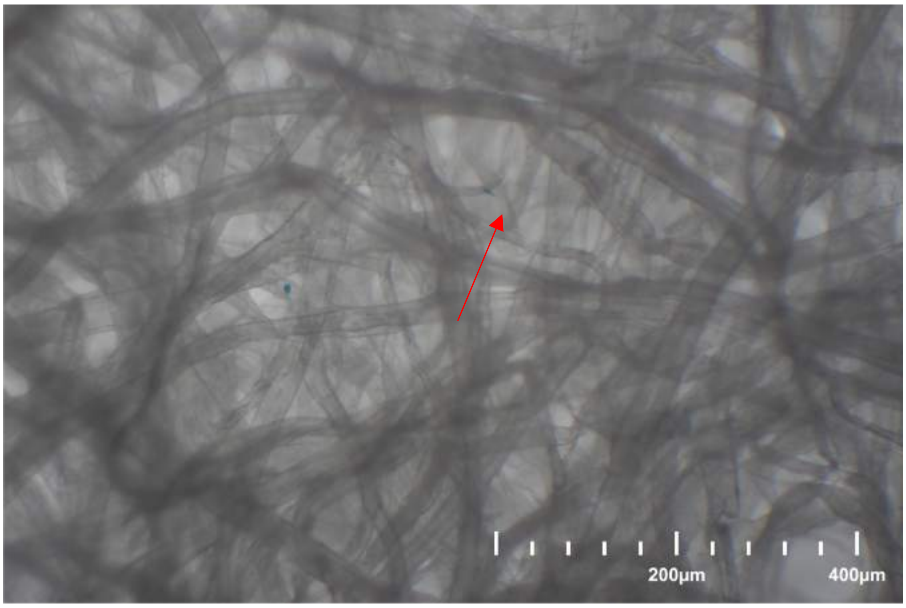

Figure 21 Fiber fragment (blue, marked with red arrow) with fiber length 13µm and fiber diameter 2µm (surgical mask 1.5h Sport) on cellulose filter (gray-white)

In addition, the surgical masks worn also had very lumpy fiber fragments that were short in fiber length and wide in diameter, as shown in Fig. 22.

Figure 22 Clumpy fiber fragment (blue) from surgical mask worn for 1.5h during intense sports training (on the gray-white cellulose filter).

3.3.2 Fiber fragment types in the unworn surgical masks

In the unworn surgical masks, as in the worn surgical masks, different types of fibers came loose. There were smooth and still whole fiber fragments, as can be seen in Fig. 23.

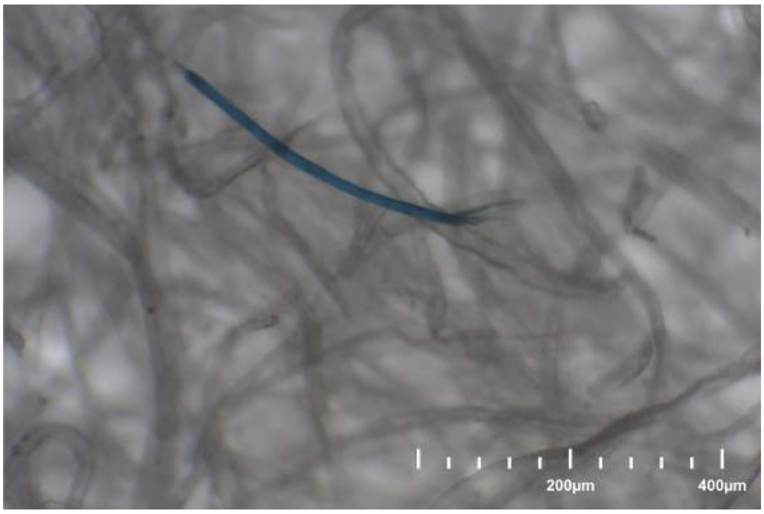

Figure 23 smooth fiber fragment (blue) of an unworn surgical mask on the cellulose filter (gray-white).

In addition, frayed and destroyed surgical mask fibers also appeared. These can be seen in Fig. 24.

Figure 24 Frayed fiber fragment (blue) of an unworn surgical mask on cellulose filter (gray-white).

Also in the unworn masks, in addition to the other types of fibers, there were still very small fragments, which can be seen in Fig. 25.

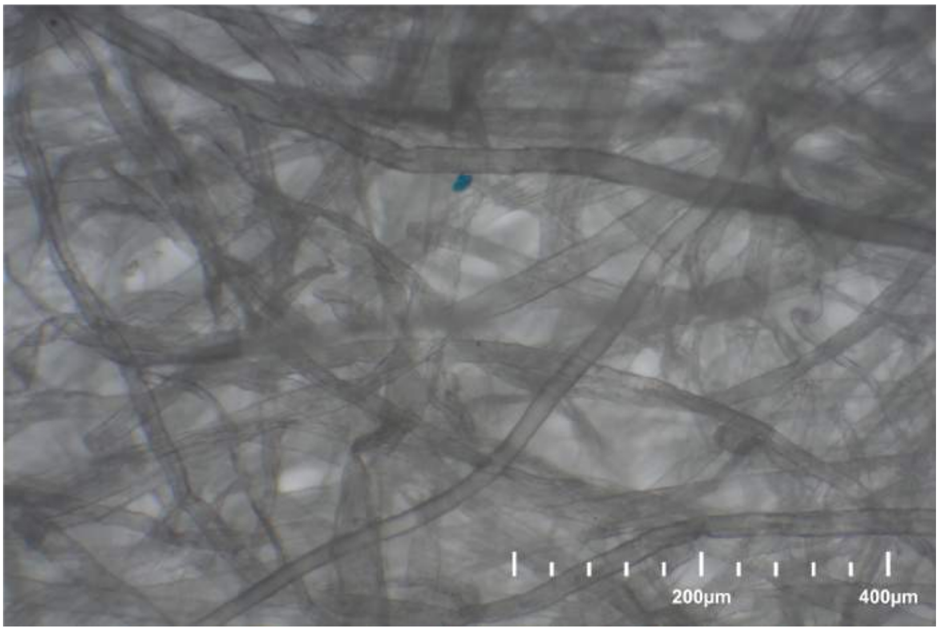

Figure 25 small fiber fragment (blue) of an unworn surgical mask on the cellulose filter (gray-white).

Overall, the same fiber fragments occurred in both worn and unworn surgical masks.

4 Discussion

4.1 Influence of the wearing time on the number of detached fiber fragments

When comparing the number of fiber fragments in the different tests, it can be seen that the number of fiber fragments increases with longer wearing time. This is an important result, because it can be deduced that there is a direct correlation between the number of fibers coming loose and the wearing time. Even with the surgical mask, which was only used for 2 hours during normal school, four times more fiber fragments came loose during filtration than with the unworn surgical masks. This shows how quickly the fibers begin to come loose from the moment the surgical mask is put on. The longer a surgical mask is worn, the more fiber fragments detach from it. Thus, on the filter sample of the surgical mask worn the longest, almost 10 times as many fiber fragments are found as on those of the unworn surgical masks. The reason for this could be the mechanical processing of the surgical mask by straightening with the fingers or the chin. Another possibility is the processing of the nonwoven layer lying on the skin by speaking. When speaking or even just breathing, the skin rubs on the inner nonwoven layer. Another reason for the fiber fragments coming loose could be the strong breathing air flow. The fibers flutter in the air stream and eventually break off because of the back and forth movement.

With strong breathing, more fiber fragments come off in a short time than with weak breathing. This can be seen in the experiments with the surgical masks, which were worn during 1.5 hours of intensive sports training. The intensive sports load resulted in stronger breathing, which led to coarser mechanical processing of the surgical masks. These surgical masks had on average the same number of fiber fragments after filtration as the two surgical masks worn for 8h and 8.5h. Intensive breathing thus increases the number of fiber fragments that come loose in addition to the length of time the masks are worn. It can be concluded that the mask should not be worn during intense physical exertion, otherwise many fiber fragments may enter the respiratory tract. And if the surgical mask is worn during physical exertion, it should be discarded immediately afterwards and a new surgical mask should be fitted.

4.2 Fiber fragments in our airways

4.2.1 Deposition and elimination of fiber fragments

The fiber fragments, while using a surgical mask, end up in the air we breathe. Consequently, these particles enter our respiratory tract. A large majority of the fiber fragments that were on the filter samples had a length that was more than 10 µm. Such fiber fragments basically do not enter the bronchial system thanks to the defense systems of our respiratory tract. Very rarely there were also fiber fragments smaller than 10 µm. These isolated particles are deposited by impaction in the oropharynx and are subsequently removed orally from the airways by cilia movement.

During intensive breathing (e.g. during sports), more fiber fragments are detached (cf. Fig. 11) than during normal breathing (e.g. during school). In contrast, the deposition due to impaction is much greater during heavy breathing. With low respiration, impaction is not dominant for small particles up to 5 µm and sedimentation serves more as a deposition mechanism (Haidl, 2008). In return, not as many fiber fragments are detached as in the case of intensive respiration. However, if the surgical mask is worn for a whole day at school, a large number of particles also become detached and the impaction is rather low during normal breathing, as mentioned earlier. This combination is not ideal for the lungs, because the small particles (smaller than 5 µm) can sediment into the bronchial system.

4.2.2 Danger of fiber debris

As already mentioned in the introduction in chapter 1.6.2 on deposition mechanisms in the lung, a great deal of attention is now being paid to fine particles smaller than 2.5 µm. This would be exactly the size of the fiber debris visible on the surgical fibers in Fig. 10. That means, the fiber debris could be a hazard to human health. However, no fiber debris could be detected in this work because the necessary means to do so were lacking. From the different fiber types, however, it can be concluded that there could well be even smaller fragments. Two frayed fiber fragments are shown in Figs. 20 and 24. It can be surmised that smaller fragments can still be detected in the fraying, which are too small to see under the light microscope and also have a correlation with mortality (Haidl, 2008). These fragments would be smaller than 2.5 µm.

The thesis with the fiber debris being a health hazard should be investigated in further scientific work, because there are studies that show a correlation between mortality and the dose of fine particles in the lungs (Haidl, 2008). It would be important if more research is done on this still unknown issue, because the surgical mask is now one of our daily companions. It would have fatal consequences if people had to experience a deterioration in health due to the fine particles.

4.3 Conclusion

Based on the tests conducted, it was finally confirmed that microplastics were released while breathing through a surgical mask. It seems that the longer the surgical mask was worn, the more microfibers were released. In addition, the intensity of breathing also seems to have had an effect on the amount of fiber fragments that detached. The more intensively the breathing was, the more the surgical mask was mechanically processed and the more fiber fragments came loose.

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The study focuses on the breakaway (and collection) of fibers from surgical masks after long wearing under various conditions and its potential adverse effects. However，even with the increased breakaway fibers after wearing，the surgical masks' capacity to block the environmental dust and fibers may still outpace the breakaway fibers. Therefore，considering all factors，the overall merit or the condition of wearing or changing surgical masks can be better evaluated.