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Field Study of Activity of Antimicrobial Polypropylene Textiles

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Abstract: In this work, an in situ study is presented of the impact of textile materials used in healthcare facilities on microbial colonization of textile surfaces. The available literature describes antimicrobial active textiles and their effectiveness in laboratory conditions. However, the quantification of the impact on the microbiome of healthcare facilities has not been investigated so far. Polypropylene yarns doped with silver phosphate glass and zinc pyrithione were prepared and used for the production of bed sheets and clothing for healthcare personnel. Subsequently, measurements of airborne particles and viable microorganisms on given textiles were conducted in a private surgery clinic for 3 weeks, comparing the counts of viable microorganisms before and after replacing staff clothing and bedding on examination and the surgical bed with said polypropylene cloth. A significant reduction in airborne particles and viable microorganisms was expected based on previous studies on the use of polypropylene textiles in operating rooms. In this study, a significant reduction in viable airborne fungi and viable microorganisms on monitored textiles was observed by multiple methods. However, the effect on airborne microorganisms seems insignificant in areas with frequent patient traffic. The textile described here represents a new additional way of protecting patients and medical personnel from healthcare-associated infections while using a modification of proven production procedures and commercially usable materials without legislative restrictions.

Keywords: healthcare; antimicrobial textile; polypropylene continuous multifilament yarns; polypropylene fabric

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1. Introduction

In healthcare settings, great attention is paid to cleanliness, and compliance with a range of routines, such as hand hygiene, is required to mitigate healthcare-associated infections (HAIs) [1,2]. The frequency of HAIs can be illustrated, for example, by the most recent summary report of the National Health Care Safety Network (USA), which states there were 331,897 cases of HAIs reported in 2015–2017, with surgical site infections accounting for 43% of cases being most prevalent [3]. The most recent surveillance report of the European Centre for Disease Prevention and Control states an average prevalence of HAIs in Europe at 5.9% of hospitalized patients, where prevalence values for individual countries ranged from 2.9% to 10.0% of hospitalized patients, with respiratory tract infections as the most frequently reported (21.4%) and cause and surgical site infections being the third most common cause (18.4%) [4]. A similar point prevalence survey conducted in Slovakia, where this study was conducted, states that 4% of hospitalized patients contracted an HAI in 2016–2017, with urinary tract infections (25.8%), pneumonia, and other lower respiratory tract infections (20%) being the most common and surgical site infections being the fourth most common (12.5%) [5]. As a measure to prevent the spread of pathogens in medical facilities, surfaces with antimicrobial properties, such as copper possessing an oligomeric effect, are utilized [6]. While most surfaces, such as floors, tables, and handles, are easily sanitized by wiping with appropriate disinfectants, the situation is different for textile surfaces. Textiles present porous surfaces prone to retaining moisture and possessing increased specific surface area to host microorganisms. In fact, in environments with controlled air quality, sources of airborne particles carrying microorganisms

may be traced to used textiles [7,8]. Studies examining the survival times of individual pathogens show that the base material of textile is also an important factor; in fact, the survival of bacteria at room temperature was the longest, up to 206 days, on polyester [6]. In fact, textile surfaces such as curtains and upholstery have been found to be contaminated over time in healthcare settings and host pathogens for up to 90 days [9]. To mitigate these risks, textiles utilizing new biocidal treatments are developed by many researchers, utilizing, for example, metallic nanoparticles, plasma treatments [10], new organic biocidal substances [11], and their combinations with inorganic nanoparticles [12]. However, new biocides have to comply with relevant regulations [13]; thus, their application in the near future is limited to prototypes.

In fact, the fiber-forming polymer itself may hinder the growth of bacteria and fungi; even the structure of the textile (woven, knitted, and spunbond) can affect its suitability for use in healthcare settings [7]. Additionally, active ingredients relying on metallic ions, such as zinc [14] and silver [15], have been demonstrated to be active toward antibiotic-resistant bacteria. In light of the above facts, one may suggest that polypropylene fabric [7] containing antimicrobial substances utilizing an oligodynamic effect may bring a substantial reduction in both airborne particles and present living microorganisms. The possible difference between laboratory settings and real-life working environments points to a necessity to conduct a study of the aforementioned hypothesis. During the investigation of standards for textiles in medical settings and textiles actually used in healthcare, the authors found a private surgery clinic in Levoča district, Slovakia, willing to participate in the study proposed above, albeit under the condition of anonymity due to public perception of any possible findings. As active ingredients, silver phosphate glass (SPG) and zinc pyrithione (ZP) were chosen as sources of silver and zinc ions since they are intended for use in thermoplastics and possess valid registrations required for use in the EU market. As for quantification of living organisms on textile surfaces, determination of present adenosine triphosphate was suggested: All living organisms produce and utilize adenosine triphosphate (ATP), and standardized methods that use the detection and quantification of present ATP are used to confirm and quantify the sum of all living microorganisms on the given surface [16].

2. Materials and Methods

2.1. Materials

Isotactic polypropylene homopolymer with melt flow index of 25 g/10 min. in form of pellets was supplied by Slovnaft a.s., Bratislava, Slovakia. Low-density polyethylene (LDPE) homopolymer wax in a powder form used as dispersing agent was produced by Honeywell, Morris Plains, NJ, USA. Pigments used to dope-dye polypropylene yarns, titanium dioxide, carbon black, PV-Echt-Rosa, copper phthalocyanine, and phthalocyanine green G, were purchased from NYLUS SK, Poprad, Slovakia. Active antimicrobial ingredients silver phosphate glass and zinc pyrithione were supplied by SANITIZED AG, Burgdorf, Switzerland. Both silver phosphate glass and zinc pyrithione were supplied in the form of fine ground powders with a nominal median particle size of 2 μm declared by the supplier.

Sets of ATP sampling tests UltraSnap, including SystemSURE luminometer, were purchased from Hygiena LLC, Camarillo, CA, USA. Envirocheck® Contact DC Disinfection Control contact plates, tryptic soy agar contact plates, blood agar plates, glucose, tryptone, yeast extract, and agar for agar plates were supplied by Merck KGaA, Darmstadt, Germany.

2.2. Methods

2.2.1. Textile Samples Preparation

Polypropylene (PP) yarns were produced in three steps: compounding, melt spinning, and false-twist texturation. A masterbatch containing 5% by weight of zinc pyrithione (ZP) was produced and prepared by thoroughly mixing 500 g of ZP and 250 g of fine powdered polyethylene wax in Mixaco vertical container mixer (MIXACO Maschinenbau

Dr. Herfeld GmbH & Co. KG, Neuenrade, Germany) and subsequent addition of 9.25 kg of polypropylene. The resulting mixture was compounded on ZSK-25 twin screw compounder (Coperion GmbH, Stuttgart, Germany). In a similar manner, a masterbatch containing 6% silver phosphate glass (SPG) was prepared by compounding 600 g of SPG, 300 g of polyethylene wax, and 9.1 kg of PP. Mixtures of pigments were compounded the same way to provide masterbatches containing 5% of pigments for corresponding resulting color shade in the form of pellets for dope dyeing for final yarn colors light-blue, gray-blue, and red. Six mixtures, each containing pigment masterbatch, masterbatch of chosen antimicrobial additive, and polypropylene, were prepared in a fashion to obtain one yarn containing 0.10% of ZP and one yarn containing 0.15% of SPG for each color produced; the recipes for each mixture are listed in Table 1.

Table 1. Recipes for individual doped polymer mixtures; quantities in grams.

Yarn Color	Additive	Additive Masterbatch	Pigment Masterbatch	Polypropylene
Purple	SPG	250	1560	8190
	ZP	200	1560	8240
Light blue	SPG	250	1200	8550
	ZP	200	1200	8600
Beige	SPG	250	1560	8190
	ZP	200	1560	8240

Each of the given mixtures was melt spun using an industrial melt spinning line with a single screw extruder (Research Institute for Man-Made Fibres, a.s., Svit, Slovakia) with D = 45 mm and L/D = 44, at 230 °C with melt throughput 151 g·min^{-1} through two shafts, each with one gear metering pump supplying four spinnerets with 50 orifices and orifice diameter 0.35 mm heated at 245 °C, supplying each spinneret with 18.9 g·min^{-1} of polymer melt. The as-spun fiber was oriented between two godets: the pull-off speed (1st godet) was set to 1480 m·min^{-1}, and the take-up speed was 1450 m/min. The speeds of second godets were adjusted to 1450 ± 20 m·min^{-1} individually for each mixture to ensure tension of pre-oriented fiber during winding to be 5 ± 0.5 cN. As-spun pre-oriented multifilament fibers were false-twist textured using Barmag AFK-6 draw texturizing machine (OC Oerlikon, Pfäffikon, Switzerland) at texturation speed of 400 m·min^{-1}, D/Y = 1.55 and draw ratio of 1.545, and heater temperature 170 °C, connecting two ends by intermingling in air jet at supply air pressure of 150 kPa resulting in yarns with linear density 167 ± 5 decitex.

A simple plain weave fabric was woven using pairs of PP yarns with the same color: PP fibers containing SPG were used for the warp beam with 26 ends per cm of warp width, and PP fibers containing ZP were used for the weft, resulting in weft density of 22.1 threads/cm and the resulting fabrics having a grammage of 95 ± 5% g·m^{-2}.

2.2.2. Replacement of Staff Clothing and Bedding in a Small Surgery Department and Frequency of Measurements

Of the aforementioned fabrics, the textiles dyed purple were used for production of four pairs of women's tunics; two pairs of men's tunics were made from the light blue fabric, while beige fabrics were used as bed sheets. The samples were then used in the private surgery clinic by staff and on two beds, replacing the currently worn cotton-polyester blend clothing and bedding. Men's tunics were to be worn by the attending physician, and women's tunics were to be worn by nurses. The light-blue fabrics were used as bed sheets on the examining bed in room no. 1 and the surgical bed in room no. 2. During examination and surgery, another disposable polymer sheet covered the bed sheet on both the examining and surgical beds. Two rooms of the clinic in question were examined: Room no. 1 is the doctor's office with an area of 32 m^2 and a high frequency of visits, approximately 35 patients each day with 1 physician and 1 nurse present. These persons were present in the room for 32.5 h per week. In this room, an ambient germicidal lamp

is in operation outside the business hours of the clinic. The doctor's office no. 2 has an area of 9 m^2 and is used for minor surgery and preparation of tools with only one patient, physician, and nurse present if used. The average weekly time of occupation of room no. 2 is 22.5 h, with a daily surface (floor and tables) disinfection and cleaning routine.

Of the below-mentioned samplings, for each method, the first sampling, numbered "0", was taken before replacing the usual staff clothing and bedding with presented polypropylene textiles with antimicrobial agents. Starting the next day, the staff clothing and beddings were replaced with the above-mentioned textiles; the measurements of air quality and textile viable microbe counts numbered sampling 1 were made one week after the replacement, and subsequent samplings numbered 2 and 3 were made with an interval of one week. Finally, after measurement 3 was taken, the 4 samples, nurse's tunic, physician's tunic, bedding from examination bed, and bedding from surgery bed, were each separately closed in a sealable plastic bag and left under ambient temperature for 24 h. Subsequently, new samplings with swabs for ATP and contact plates, as described below in the text, were taken, cultivated, and evaluated. This measurement is listed as measurement 4 and shows the rate of survival of microbes from measurement no. 3 without any additional bioburden.

2.2.3. Evaluation of Impact on Airborne Particles, Airborne Microorganisms, and Viable Microorganisms on Textile Samples

Concentration of airborne particles was measured using TROTEC PC220 discrete particle counter (Trotec GmbH, Heinsberg, Germany); in every measurement, five separate particle count measurements in short succession were taken between 9:30 and 10:30 during clinic operation with the discrete particle counter in the corner of a given room. For each size fraction of airborne particles, the counts were then averaged.

Counts of viable microorganisms in ambient air in observed rooms were determined using Aeroscop MAS-100 NT (Merck KGaA, Darmstadt, Germany) with perforated air inlet of 300 0.6 mm-wide orifices, performing three samplings with 600 L of air taken during 15 min of air in each sampling: one sampling used agar plates for counting of yeasts and molds; another used blood agar plates, and the last used glucose tryptone yeast extract agar plates (GTY plate) for counting of airborne bacteria. After each sampling, the agar plates were transported in cooling box (3–6 °C) to certified laboratory for cultivation and analysis (Public Health Authority of the Slovak Republic, Poprad, Slovakia). Plates from each sampling were cultivated 24 h at corresponding temperatures (25 °C for agar plates, 30 °C for GTY plates, and 37 °C for blood agar plates) and evaluated by a certified microbiological laboratory according to ISO 21527 for counts of yeasts and molds in the agar plates and bacteria on the blood agar and GTY plates.

A quantification of total surviving microorganisms on studied surfaces was conducted using UltraSnap Surface ATP test swab with subsequent luminometric quantification of present ATP. In each measurement, an area of 10 × 10 cm was provided according to provided user instructions. Used swab is then immersed in provided agent containing luciferase enzyme for 10 s and immediately evaluated by provided luminometer. The results are expressed in relative light units (LRU) and thus provide a means of monitoring relative change in the quantity of living organisms on the monitored surface over time.

Measurement of counts of viable microorganisms on textiles was conducted by two separate methods: Envirocheck Contact DC Disinfection Control and 55 mm tryptic soy agar contact plates.

Envirocheck Contact DC Disinfection Control are flexible contact paddles with two sides containing CASO tryptic soy agar with different neutralizers and inhibitors, one for determination of yeasts and bacteria, the other side for counting molds. After swabbing a surface with an Envirocheck paddle, the paddle was transported together with other samples in a cooling box to certified laboratory. On the same day, a 48 h cultivation of said paddle at 37 °C was initiated. After incubation, the density of microorganisms on the measured paddle of 9.4 cm^2 was determined by comparison with the model density chart supplied within the Envirocheck sets in limits of 10^3 to 10^7 for bacteria and yeasts

and 10^2–10^5 for molds. In a similar manner, the soy contact plates were open at the site of measurement, and the agar surface was pressed with steady pressure for a few seconds on the investigated textile surface, immediately closed and stored, and transported in the cooling box with other samples and brought to microbiological laboratory for cultivation and evaluation. Soy agar contact plates were cultivated for 48 h at 37 °C.

As a control for compliance with the necessary procedures and an indicator of sample contamination, in each measurement using agar plates, one additional unused agar plate of each type was transported to the site and from the site in the same cooling box. Respective discovery of microbial growth in this unused agar plate would indicate contamination, and such results would be ignored. All analyses of microbial cultivation were contracted to and conducted by accredited laboratory of the Public Health Authority of the Slovak Republic in Poprad, Slovakia.

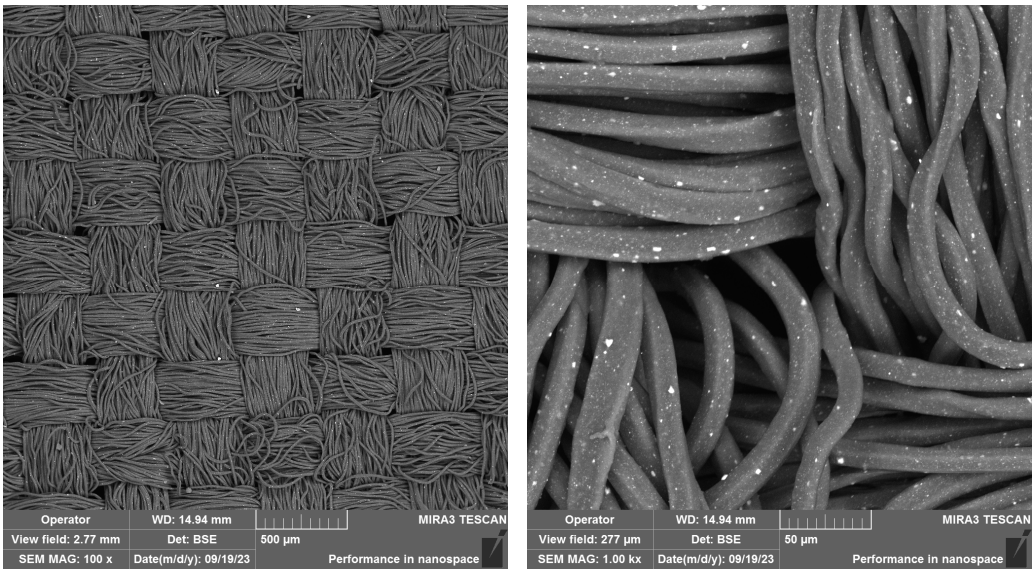
3. Results

3.1. Preparation of Yarns and Vowen Textile

Polypropylene yarns containing ZP a SPG were prepared according to the process described in Section 2.2.1 above. The tensile properties of the produced yarns are summarized in Table 2, and scanning electron microscope (SEM) images of the produced fabric are presented in Figure 1.

Table 2. Tensile properties of SPG- and ZP-doped yarns.

Yarn Color	Additive	Relative Tenacity (cN/dtex)	Strain at Break (%)
Purple	SPG	2.61	82.1
	ZP	2.60	81.6
Light blue	SPG	2.79	35.8
	ZP	2.71	34.2
Beige	SPG	2.87	39.8
	ZP	2.63	39.3



(**a**) (**b**)

Figure 1. SEM images of resulting woven textile: (**a**) 100× magnification showing the structure of the textile; (**b**) 1000× magnification showing the surface of produced yarns: the seemingly quadrangular cross section of filaments is a result of texturation process and particles of pigments, and additives protruding from surface of filaments are visible.

3.2. Evaluation of Airborne Particles and Airborne Microorganisms

On four occasions, with a weekly interval of measurements, an electronic discrete particle counter (DPI) was set up for a period of approximately 45 min, conducting five discrete measurements as described above, placement of the DPI devices shown in Figure 2.

(**a**) (**b**)

Figure 2. Placement of the DPIs in investigated rooms. (**a**) Placement of DPI in room no. 1—doctor's office with area 32 m^2; (**b**) placement of Aeroscop MAS-100 NT for airborne microorganism quantification in room no. 1.

The observed values of found airborne particles per m^3 of air in room no.1 are listed in Table 3, values observed in room no. 2 are listed in Table 4, and all listed values are averages of five independent readings on a given day and location. Sampling numbered 0 is the measurement of the initial conditions before the replacement of bed sheets and staff apparel with ZP and SPG doper polypropylene fabric.

Table 3. Distribution of dust particles according to size in individual samplings in room no. 1 and average values for each measurement.

	Particle Size						
No.	**0.3 µm**	**0.5 µm**	**1.0 µm**	**2.5 µm**	**5.0 µm**	**10 µm**	**Conditions**
0	72,613	22,688	6119	1296	247	129	21.9 °C/47.9%
1	109,189	29,491	5425	971	168	76	22.1 °C/49.3%
2	137,560	36,561	6226	1080	165	83	22.3 °C/48.1%
3	106,454	29,580	5923	1116	193	96	22.1 °C/47.7%

As described in Section 2.2.3 above, simultaneously with airborne discreet particle counting, three samplings of airborne microorganisms were conducted. Each sampling had a different plate to distinguish different types of microorganisms, with 600 L of ambient air passing through the aeroscope for each plate. The results for all four sampling dates expressed in colony-forming units per cubic meter of ambient air (CFU/m^3) are presented in Tables 5 and 6.

Table 4. Distribution of dust particles according to size in individual measurements in room no. 2 and average values for each measurement.

No.	Particle Size						Conditions
	0.3 µm	0.5 µm	1.0 µm	2.5 µm	5.0 µm	10 µm	
0	90,911	27,366	6053	1055	150	83	21.9 °C/47.9%
1	117,653	32,873	6273	1124	171	85	22.1 °C/49.3%
2	130,963	35,359	6450	1133	157	84	22.3 °C/48.1%
3	56,692	16,954	3766	661	93	49	22.1 °C/47.7%

Table 5. Analysis of cultivated aeroscope plates from room no. 1, results for each sampling expressed in CFU/m^3.

No. of Measurement	Yeasts and Molds	Cultivated on Blood Medium	Cultivated on GTK Medium
0	52	>535	>535
1	24	>535	>535
2	55	>535	>535
3	55	>535	>535

Table 6. Analysis of cultivated aeroscope plates from room no. 2, results for each sampling expressed in CFU/m^3.

No. of Measurement	Yeasts and Molds	Cultivated on Blood Medium	Cultivated on GTK Medium
0	57	>535	>535
1	23	>535	>535
2	37	>535	>535
3	32	>535	>535

The selected standardized method displays a range sufficient to reflect the effect of developed fabric on the numbers of yeasts and molds, whatever the impact on counts is.

3.3. Quantification and Identification of Microorganisms Present on Textile Surfaces

Simultaneously with aeroscopic sampling, swabs of clothing and bedding, as described in Section 2.2.3 and depicted in Figure 3, were conducted; all sampling sessions are numbered in accordance with the measurement description in Section 2.2.2. All results of ATP swabs are listed in Table 7.

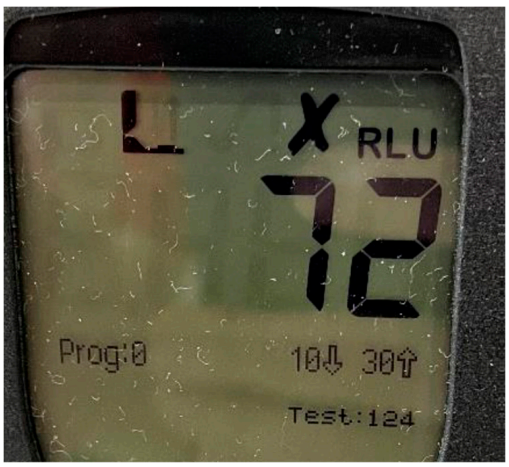
Table 7. Quantification of present ATP on examined textiles in RLU.

No.*	Bedding in Room No. 1	Bedding in Room No. 2	Tunic, Nurse	Tunic, Physician	Conditions **
0	400	106	67	72	21.9 °C/47.9%
1	54	1	19	40	22.1 °C/49.3%
2	16	3	21	14	22.3 °C/48.1%
3	8	13	57	9	22.1 °C/47.7%

* Number of sampling as stated in Section 2.2.2; ** conditions as ambient temperature in °C/relative humidity.

As illustrated in Table 7, there is observable variability in the data, but a reduction in living microorganisms is evident in all cases. For unambiguous quantification, averages of samplings 1 to 3 for a given surface can be compared to sampling 0; such comparisons are summarized in Table 8.

(**a**)



(**b**)

Figure 3. Determination and quantification of present ATP on physician's tunic before replacement with PP fabric tunic. (**a**) Application of UltraSnap swab; the wet stains are marks left by the soy agar contact plates; (**b**) output of subsequent luminometric measurement.

Table 8. Comparison of present ATP on examined textiles in RLU.

Result	Bedding in Room No. 1	Bedding in Room No. 2	Tunic, Nurse	Tunic, Physician
0	400	106	67	72
Average 1–3	26	6	32	21
Reduction	−94%	−94%	−52%	−71%

Further quantification of viable microorganisms is provided by the evaluation of Envirocheck contact plates, which allow estimation of the order of magnitude of numbers of CFU per the area of the given sampler, which is 9.4 cm^2. Also, more resolution of the number of molds vs. the number of bacteria can be made. A summarization of results from the cultivation of Envirocheck contact plates at 37 °C during 48 h is presented in Table 9 in logarithmic form, where a value of "0" means no yeasts and bacteria or molds were found to grow in the given sample.

Table 9. Decimal logarithms of CFUs as indicated by Envirocheck contact plates after incubation.

	Bedding in Room No. 1		Bedding in Room No. 2		Tunic—Nurse		Tunic—Physician	
No. of Sampling	Yeasts and Bacteria	Molds	Yeasts and Bacteria	Molds	Yeasts and Bacteria	Molds	Yeasts and Bacteria	Molds
0	3	3	4	4	4	3	4	3
1	3	2	3	3	3	2	4	3
2	3	2	3	0	3	2	3	2
3	3	0	3	2	3	2	3	0
4	3	0	3	2	3	0	3	2

The most detailed description of viable microbes found on monitored textiles is provided by cultivation and analysis of soy contact plates at 30 °C. The summarization of numbers and identified organisms across individual measurements are presented in Tables 10–12 below.

Table 10. Quantification of present microbes in CFU/contact plate and identified organisms found on bedding in room no. 1.

No. of Measurement	CFU per Contact Plate	Identified Organisms	Conditions **
0	60	aerobic sporulants, saprophytic staphylococci, micrococci, and two CFU micromycetes	21.9 °C/47.9%
1	47	aerobic sporulants, saprophytic staphylococci, micrococci, and bacillus cereus	22.1 °C/49.3%
2	22	aerobic sporulants, saprophytic staphylococci, and micrococci	22.3 °C/48.1%
3	2	aerobic sporulants	22.1 °C/47.7%
4	3 *	saprophytic staphylococci	21.8 °C/47.8%

* Present, number of CFU estimated; ** conditions as ambient temperature in °C/relative humidity.

Table 11. Quantification of present microbes in CFU/contact plate and identified organisms found on bedding in room no. 2.

No. of Measurement	CFU per Contact Plate	Identified Organisms	Conditions **
0	96	aerobic sporulants, saprophytic staphylococci, and micrococci	21.9 °C/47.9%
1	3 *	saprophytic staphylococci	22.1 °C/49.3%
2	5 *	micrococci	22.3 °C/48.1%
3	1 *	micrococci	22.1 °C/47.7%
4	14	aerobic sporulants, saprophytic staphylococci, and micrococci	21.8 °C/47.8%

* Present, number of CFU estimated; ** conditions as ambient temperature in °C/relative humidity

Table 12. Quantification of present microbes in CFU/contact plate and identified organisms found on nurse's tunic.

No. of Measurement	CFU per Contact Plate	Identified Organisms	Conditions ***
0	100 **	aerobic sporulants, saprophytic staphylococci, micrococci, and one CFU micromycetes	21.9 °C/47.9%
1	100 **	aerobic sporulants, saprophytic staphylococci, micrococci, *Streptococcus* sp., and two CFU micromycetes	22.1 °C/49.3%
2	100 **	aerobic sporulants, saprophytic staphylococci, and micrococci	22.3 °C/48.1%
3	100 **	aerobic sporulants, saprophytic staphylococci, and micrococci	22.1 °C/47.7%
4	30	aerobic sporulants, saprophytic staphylococci, micrococci, *Acinetobacter* sp., and *Pantoea* sp.	21.8 °C/47.8%

** high number of CFU per plate, probably >100; and *** conditions as ambient temperature in °C/relative humidity.

4. Discussion

In this study, a combination of two approaches of mitigation of transfer of pathogens described in the literature was chosen: substitution of usually used textiles woven using continuous filament polypropylene yarn-based fabric as described in [7] and doping of the polymer used with antimicrobial properties, such as described in [2,12,13,17,18] and others. Additionally, the impact of such textiles was verified and quantified in real-life conditions in a medical facility with frequent movement of staff and patients. The results listed in Section 3 demonstrate the viability of the presented method for the production of textiles for use in healthcare facilities. At the concentrations of ZP and SPG used in this study, no effect on coloring was observed, and the reduction in bacteria and fungi surviving on these textiles is apparent. However, no significant impact on airborne particles and airborne microorganisms, as described in [7], was observed. The reason may be attributed to the difference in other factors between this study and the study presented in [7] since the room investigated in the former study was an operating room, where all staff used surgical masks and proper surgical gowns at all times, and filtered air was continuously supplied to the room, while in our study, the patients came in their own clothes for short surgical procedures and, besides the use of germicidal lamps, no means of air purification were used.

Regarding the choice of antimicrobial agents and means of their implementation, one of the authors' previous experiences with antifouling modification of apparel and introduction of said goods to the markets of the European Union was of key influence: use of nanoparticles and antibacterial substances not recognized by current legislation [13] were avoided. Concerns for environmental and health risks associated with the use of nanoparticles were expressed and summarized in a recent literature review [19], and metal particles, especially copper, have an impact on textile color [18]. The use of ZP is also limited in the EU; however, this restriction only applies to use in cosmetic preparations [20]. By following this approach, a textile was developed that does not expect significant obstacles for further testing in similar environments and for subsequent market launch.

5. Conclusions

Application of presented polypropylene textiles doped with silver phosphate glass and zinc pyrithione in real-life conditions in a doctor's office exhibited a reduction in the count of bacteria and fungi surviving on their surfaces and was proven to retain their antimicrobial properties over a monitored period. The counting of discrete airborne particles showed an increase in the number of particles smaller than 0.5 µm by almost approximately 50% in the examination room, while a decrease in the number of particles of 10 µm of approximately 1/3 is indicated in the data for room no. 1. Relative differences are even smaller for room no. 2, which had much fewer attending patients per day. The impact on observed dust particles in ambient air in the observed rooms of the clinic is thus rather ambiguous, and the authors conclude that the expected reduction in airborne particles was not observed in this study. Regarding viable airborne microorganisms, a clear reduction in yeasts and molds was shown in room no. 2, the surgery room with a lower frequency of patient visits. However, this effect was not observed in room no. 1, the doctor's office, which had patient traffic multiple times higher. Most promising are the results of total viable counts on studied textile surfaces: all used methods confirmed the reduction in viable microorganisms by at least 44% (doctor's tunic) relative to measurement before the replacement of commonly used cotton and polyester-based textiles with presented antimicrobial-doped polypropylene. The relative reduction in viable microbes for both the examination table and surgical table was at least 80% in all cases. Visible differences between the observed rooms can be attributed to the number of passing patients and, thus, a higher bioburden in room no. 1. This reduction was most pronounced in the final observation after 24 h of isolation, which indicates that less than 8% of the original microorganisms survived on presented textiles after 24 h without an additional bioburden.

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Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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