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MATERIALS FOR MANUFACTURING PROTECTIVE BARRIER CLOTHING OF MEDICAL WORKERS AND TESTING OF THIS CLOTHING FOR COMPLIANCE WITH THE REQUIREMENTS OF THE APPLICABLE REGULATIONS

Introduction. *An integrated scientific approach to the protection of healthcare professionals requires the development of modern barrier clothing for them, especially that for surgical staff who in the course of their professional duties may be exposed to various types of infectious diseases.*

Problem Statement. *The creation of effective protective barrier clothing for surgical department staff necessitates the development of a range of fabrics and measures for antimicrobial treatment of sutures at the junction of clothing items, as well as the testing of the developed clothing in accordance with the applicable regulations.*

Purpose. *The purpose of this research is to justify for the choice of materials for the manufacture of protective barrier clothing for medical workers and the development of measures for antimicrobial treatment of sutures at the junction of clothing items.*

Materials and Methods. *The object of the study are textile materials and modified threads used for the manufacture of barrier medical clothing. Experimental studies have been conducted in the laboratories of the Kyiv National University of Technology and Design according to the standardized and original methods for evaluating the properties of textile materials and threads.*

Results. *The principles for the application of new composite materials with protective properties for designing surgeon barrier clothes to be worn in a surgery room have been defined, the dependences of the indicators of textile material quality on the number of washing and sterilizing cycles have been established, and measures on antimicrobial treatment of seams in joints of clothing elements have been offered. The developed clothing has been tested in accordance with the applicable regulations.*

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Conclusions. *The results have shown that from the standpoint of the protection of medical workers, the most effective is the zonal principle of using different types of fabrics for the manufacture of barrier medical clothing. It has been also determined that among the developed and studied threads, the most suitable for sewing technologically clean clothes are POM 529, POM I and POM II.*

Keywords: barrier medical clothing, textiles, and antimicrobial treatment.

Creating safe working conditions and implementing in Ukraine the best European and world practices of industrial safety, occupational health, and working environment is impossible unless new types of special clothing to protect workers are designed, manufactured, and given to the users. Under such conditions, it is important and relevant to raise the effectiveness of barrier clothing designed to protect the skin of the human body from the effects of hazardous and harmful factors during operation.

Today, clothing for medical surgeons shall have barrier properties to protect against so-called "surgical infections". The problem of surgical infections, such as *Pseudomonas aeruginosa*, *Clostridium difficile*, *Candida albicans*, has been being studied for a long while [1, 2].

Medical clothing made of advanced materials with blood-repellent and dirt-repellent properties and a color palette that provides a positive mood for both the health worker and the patient may be a reliable means of protection [3]. However, for modern barrier clothing, only protective functions are not enough for medical workers; It is also important to provide a user with favorable conditions in the process of operation, which may be achieved by proper selection of materials, design and manufacturing technology [4].

Today, progress and competitiveness in the field of medical and biological sciences are achieved through the development of innovative biological, medical, pharmaceutical science-intensive technologies and R&Ds, which are the result of research works and projects. The rapid development of medical and biological sciences and the demand for research results in these fields contributes to the commercialization and speedup of the implementation of many innovation products in healthcare, which increases the effectiveness of diagnosis and treatment [5].

Therefore, the substantiation of the choice of materials for protective barrier clothing of medical workers and the development of measures for antimicrobial treatment of its seams are a relevant research problem to address which is the purpose of this research.

Table 1. **Structural Properties of Textile Materials for Protective Barrier Medical Clothing**

Sample No.	Description	Type of material	Composition, %	Weave
1	Gore-Tex 1 (Netherlands)	Three-layer fabric with blood-repellent and antimicrobial treatment	100% PES + polyurethane film	Combined
2	Gore-Tex 2 (Netherlands)			
3	TEKABLOK (Netherland)			
4	ARALKA (Czech Republic)	Fabric with water-repellent treatment (hydrophobic)	99% polyester continuous thread 1% conductive carbon thread	Twill
5	GELIOS (China)			
6	Microfiber (Netherlands)	Fabric with blood-repellent treatment (hydrophobic)	100% PES	Plain
7	TD – 143 (China)			Twill
8	3M (Russia)			Twill
9	KG-9539 (China)	Mixed fabric	35% cotton; 65% polyester	Twill
10	KT-147 (Russia)	Homogeneous fabric	100% cotton	Plain

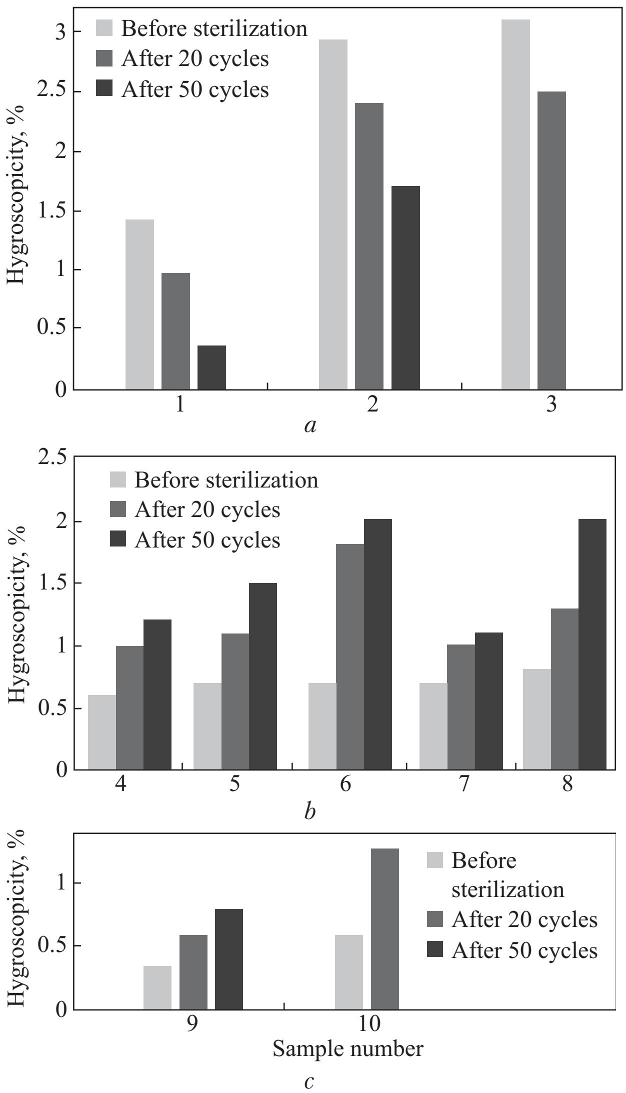

Fig. 1. Indicators of hygroscopicity of textile materials before and after washing and sterilization: *a* — three-layer materials; *b* — polyester materials; *c* — mixed and homogeneous materials

The list of the main tasks aiming at achieving this goal is as follows: to study the operating conditions, the range of protective barrier medical clothing, and advanced materials used for its manufacture; to substantiate the rational choice of textile materials and threads for the manufacture of surgical robes; to develop and to propose measures for antimicrobial treatment of seams at the joints of clothing items.

While analyzing scholarly research publications in the field of the subject, we have noted that studies [4, 6, 7] deal with the basic principles and approaches to the design of protective clothing of various functional areas, including the clothing that possesses the barrier properties. However, the issue of integrated design of effective protective barrier clothing for surgeons remains unresolved.

The analysis of the current use of medical barrier clothing has shown that there are two types of surgeon clothing made of natural, mixed fabrics, and synthetic materials: disposable and reusable. The reusable cotton surgical robes neither provide sufficient protection nor fully meet the specific level of requirements for them. The disposable medical clothing has also been found to have low ergonomic performance, which creates additional discomfort during professional activities and requires special conditions for storage and disposal after use.

The global trends in the development of protective medical clothing are the use of new high-tech materials to increase comfort during operation and the development of technological designs of clothing with special elements having improved barrier functions. The analysis of advanced materials with barrier properties has shown that the most suitable for the manufacture of surgical gowns are three-layer membrane materials such as Gore-Tex and single-layer hydrophobic fabrics made of polyester fibers. The tendency to a significant decrease in the segment of the domestic textile market of barrier materials and the critical situation in terms of regulatory and technical support of the manufacture of medical fabrics have indicated a problematic research issue.

Numerous scholarly research sources cover various indicators of the quality of materials for the manufacture of surgical robes, but there has been little information about changes in their characteristics over time and under the influence of hazardous factors, including washing and sterilization.

The analysis of the technological parameters of the joints of surgical robes has shown that gene-

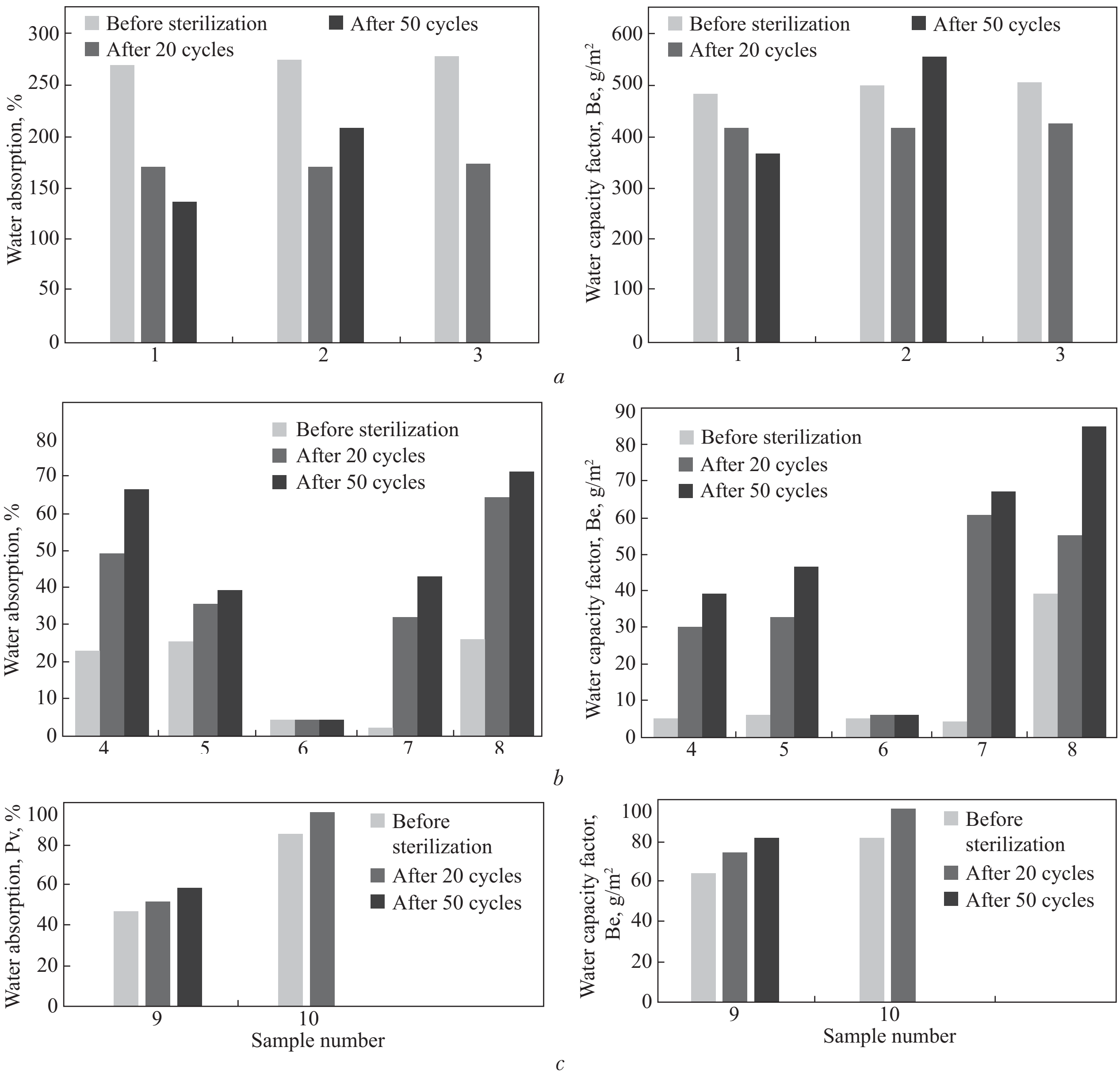

Fig. 2. Indicators of water absorption and water content coefficient of textile materials before and after washing and sterilization: *a* — three-layer materials; *b* — polyester materials; *in* — mixed and homogeneous materials

ral-purpose sewing threads are used for their production. The sewn joints create additional risk factors in places where surgical robes are contaminated with the patient's biological fluid due to its penetration underneath the clothing in the places where the fabric is punctured with a needle.

For research we take advanced textile materials that are divided into the three groups: 1) three-layer (membrane) textile materials (Gore-Tex 1, Gore-Tex 2 and TEKABLOK); 2) polyester (hydrophobic) materials (ARALKA, GELIOS, Microfiber, TD 143 and MR); and 3) mixed (KG-9539) and homogeneous (CT-147) fabrics (see Table 1).

In order to establish changes in the properties of selected materials before and after washing and

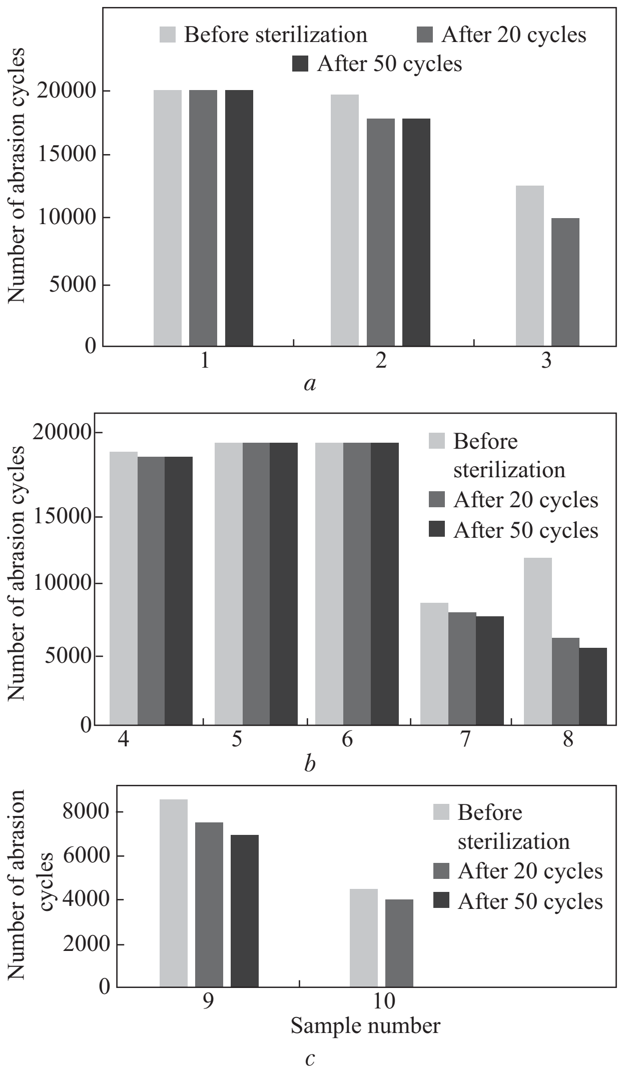

Fig. 3. Indicators of the number of abrasion cycles on the plane of textile materials before and after washing and sterilization: *a* — three-layer materials; *b* — polyester materials; *in* — mixed and homogeneous tissue

sterilization, experimental studies have been conducted. With the use of the methods specified in DSTU GOST 3816:2009 (ISO 811—81) [8], the following parameters: hygroscopicity, water absorption, capillarity, and water resistance have been determined. The samples have been tested before and after 20 and 50 washing and sterilizing cycles. The changes in linear dimensions of fabrics have been measured in accordance with DSTU ISO 5077-2001 [9].

The research results are given in Table 2.

Having analyzed the data in Table, we conclude that almost all samples of materials, except for three-layer material (sample No. 3) and cotton fabric (sample No. 10), after 50 washing and sterilizing cycles, change the linear dimensions by no more than 2%.

To study the impact of washing and sterilizing processes on the hygienic properties of textile materials selected for the comparative analysis, changes in hygroscopicity and water absorption after 20 and 50 washing and sterilizing cycles have been determined.

Repeated washing and sterilizing process has been determined to lead to an almost twice increase in the hygroscopic properties of the studied textile materials (samples Nos. 4—8) and a decrease for samples No. 1 and No. 2.

The largest increase in percentage in water absorption and water content coefficient is reported for samples Nos. 4, 7 and 8.

Waterproofing that characterizes the resistance of the material to the penetration of water through it, is one of the important requirements for medical fabric. Since the ability to resist water penetration in textile materials is usually achieved by either very dense weave of hydrophobic threads, or appropriate types of finishing, it is necessary to study how repeated washing and sterilizing process affects this property.

The results of determining the effect of washing and sterilization on the resistance of materials to abrasion have demonstrated that this indicator for all fabrics, except for sample No. 8, changes very little as a result of these factors: the number of abrasion cycles after 50 cycles of wet treatment does not change, for materials Nos. 1 and 6; decreases by 7—15%, for materials Nos. 2, 7, and 9, and by up to 50%, for material No.8.

Given the results of research for the manufacture of surgical robes, the following materials have been chosen: sample No.1, for the front and lower parts of the sleeves; samples Nos. 6 and № 9, for other parts. The chosen samples of materials in the best way meet the established requirements and have the best operational properties. For the manufacture of surgical robes with zonal application of different types of fabrics the following materials should be taken: Gore-Tex 1 (the front of the robe, bottom of the sleeves), Microfiber and KG-9539 (the top of the sleeves, the back of the robe).

During the use of surgical robes, there is observed a large accumulation of bacteria of various kinds in the stitches, namely in the places of puncture of the fabric with a needle. The main disadvantage of the threads currently used for the manufacture of surgical clothing is the lack of protective properties. Therefore, our proposal to improve the technology of surgical robes is to use sewing threads with antimicrobial properties [10].

Antimicrobial additive (AMA) based on substituted diphenyl ether, in the form of a powder with high antibacterial and antifungal activity with a wide range of applications in medicine, cosmetology, and everyday life, has been chosen as a modifier. The antimicrobial additive (0.5% wt.) is introduced into the granules of fiber-forming polymers (polyoxymethylene (POM), polypropylene (PP), and polyethylene (PE)) by thorough mixing of the components. The studies have shown that increasing the content of AMA to 1.0% wt. leads to the deterioration of the formation and spinning of complex threads (increased rupture rate of elementary threads), resulting in reduced multiplicity of spinning and significantly deteriorating their physical and mechanical properties.

Table 2. **Changes in the Linear Dimensions of Textile Materials after Washing and Sterilization**

Sample No.	Changes in the Linear Dimensions of Textile Materials, %			
	20 sterilizing cycles		50 sterilizing cycles	
	warp	weft	warp	weft
1	−1.0	0	−1.5	−0.5
2	0	−1.5	−0.5	−2.0
3	+4.2	+2.0	delamination	
4	0	0	0	0
5	0	0	−0.5	−0.5
6	−2.3	−0.6	0	0
7	−2.3	−0.8	−1.0	−0.5
8	−3.0	0	−0.5	−0.5
9	−1.5	−1.5	−1	−0.5
10	−6.5	−4.3	destruction	

For ensuring a more uniform distribution of AMA, the POM, PP, and PE granules containing 0.5% wt. AMA are processed in a laboratory extruder LHP-00, in stable mode.

The optimal temperature for each studied polymer mix is given in Table 3.

Prior to the further machining, for the formation of synthetic threads UFTP the original (POM, PP, PE) and modified (POM + AMA, PP + AMA, PE + AMA) polymer granules are dried in a vacuum oven for 6 hours, at a temperature of 85 °C.

When creating the antimicrobial threads, we solve the two tasks: providing the antimicrobial action without a significant reduction in the physical and mechanical properties. Such threads are created with the use of laboratory equipment that allows S/Z spinning of 2—3 thread components, as it is done in the practice of manufacturing synthetic threads.

The following threads that have antimicrobial action are chosen for the experimental studies: POM 529 + 0.5% AMA; POM 529; PP; POM I; POM II.

The most important condition for processing polymer melts into fiber and obtaining high-quality fiber with good physical and mechanical properties is high thermal stability of polymer melts (i.e. the resistance to elevated temperature and air oxygen during the formation of fibers). Thermoplastic materials shall be sufficiently heat-resistant to withstand heating up to a viscous-

Table 3. **Temperature Conditions of Modified Polymer Granule Treatment**

Type of granule	Temperature of cylinder, °C	Temperature of attachment, °C
POM + AMA*	185 ÷ 190	185
PP + AMA*	210 ÷ 215	225
PE + AMA*	260 ÷ 270	255

* The content of AMA is 0.5% wt.

fluid state during their processing. The chemical transformations that occur during thermal oxidative degradation are characterized by decreasing sample mass (release of volatile products during destruction), changing color, decreasing sample strength, etc., which makes changes in the samples obvious. Therefore, for fibers obtained from polymer melts, it is important to determine their thermal stability and ways to improve this indicator.

To study the thermal stability of the initial granules of polymers POM, PP, PE and those containing AMA, we have used the method of isometric heating, which is based on measuring the loss of polymer mass for a certain period of time at elevated temperature.

The antimicrobial additive with the thermal stability that does not exceed 300 °C is also the subject of research, since the effect of this additive on the thermal stability of polymer melts and the properties of the obtained fibers has been understudied.

Table 4. **Effect of AMA on the Thermal Stability of POM Granules**

Type of granules	Temperature, °C	Sample weight, g	Weight loss, %
POM	190	0.9967	0.33
POM + AMA	190	0.9963	0.37
AMA	190	0.9944	0.56

Table 5. **Effect of AMA on the Thermal Stability of PP Granules**

Type of granules	Temperature, °C	Sample weight, g	Weight loss, %
PP	260	0.9960	0.40
PP + AMA	260	0.9955	0.45
AMA	260	0.8547	14.53

Table 6. **Effect of AMA on the Thermal Stability of PE Granules**

Type of granules	Temperature, °C	Sample weight, g	Weight loss, %
PE	290	0.9944	0.56
PE + AMA	290	0.9942	0.60
AMA	290	0.7492	25.08

The dependence of the thermal stability of the studied samples on the nature and amount of introduced AMA has been estimated by the kinetics of polymer weight loss in the air for 15 minutes. Increasing the duration of polymer granulation and the time of fiber formation leads to a decrease in the thermal stability of polymer melts.

Tables 4—6 show the results of the studies of the thermal stability of original polymer granules, the modified granules containing 0.5% wt. AMA and powdered AMA for 15 minutes at the proper temperature for each type of polymer. The mass of each sample is 1.0 g.

The studies have shown that in the case of short-term heating, all the original polymer compositions have higher thermal stability as compared with that of the polymer compositions containing AMA; an increase from 190 to 290 °C in the temperature of pure AMA leads to a sharp weight loss of 0.56%, at 190 °C, 14.53%, at 260 °C, and up to 25.0%, at a temperature of 290 °C.

Despite the fact that the polymer compositions containing AMA have lower thermal stability than the original ones, this does not significantly affect the process of obtaining complex synthetic threads.

In order to determine the minimum inhibitory concentration of AMA, we have made microbiological studies with the use of test cultures of *E. coli* and *Candida* fungi. The measurements involve serial dilutions in saline to determine the antimicrobial activity by standard agar diffusion

Table 7. **Dependence of the Bacterial Activity on AMA Concentration**

AMA concentration, %	Test culture growth *	
	Candida	*E. coli*
0.005	+	+
0.05	—	+
0.1	—	—
0.5	—	—

Note: (+) – bacteria growth; (—) – no bacteria growth.

test with *E. coli* as test object; for *Candida* fungi, the method of serial dilutions in Sabouraud broth has been used (Table 7).

Thus, the minimum inhibitory concentration of the tested sample of AMA against *Candida* fungi is 0.05%; that is against *E. coli* is 0.1%.

The effect of sterilization (number of sterilization cycles $n = 20$, $n = 50$) on the air permeability coefficient, change in the linear dimensions, hygroscopicity, capillarity, water absorption, and water resistance of Gore-Tex 1, Gore-Tex 2, TEKABLOK, ARALKA, GELIOS, Microfiber, TD-143, ZM, KG-9539, and KT-147 has been studied experimentally. Gore-Tex 1 (the front of the robe, the lower part of the sleeves), Microfiber and KG-9539 (the upper part of the sleeves, the back of the robe) have been selected for the production of surgical robes with zonal application of different types of fabrics.

The properties of sewing threads developed in the KNUTD laboratory and changes in them after the use of threads for stitching the elements of medical clothing have been studied. Among all the studied threads, the most suitable for sewing the medically clean clothing are POM 529, POM I, and POM II threads.

REFERENCES

1. Korolyuk, A. M. (1998). So we will win?! (A microbiologist's view on the problem of surgical infection). *Surgery Herald,* 157(5), 148—151 [in Russian].
2. Shevchenko, Yu. L., Onishchenko, G. G., Krilov, N. N. (2005). Risk factors for infection of surgeons with viral hepatitis. *Surgery,* 2, 58 [in Russian].
3. Maryutin, P. V., Kostyuchenko, A. L. (1998). Infection in surgery. Hopes and Reality. *Surgery Herald,* 157(4), 121—121 [in Russian].
4. Suprun, N. P. (2005). Comfort of barrier clothing and methods of its evaluation. *Bulletin of KNUTD,* 6, 110—116 [in Ukrainian].
5. Pyatchanina, T. V., Ogorodnik, A. M., Vasiliev, O. V., Choch, V. V. (2020). Patent information search as a modern research tool in the field of medical and biological sciences. *Sci. innov.,* 3, 81—87. https://doi.org/10.15407/scin16.03.081 [in Ukrainian].
6. Vlasenko, V. I., Bereznenko, N. P., Dubinevich, O. G. (2003). Study of barrier properties of textile materials for medical protective clothing. *Bulletin of the Podillya University of Technology,* 6, 129—132 [in Ukrainian].
7. Joint, M. O., Suprun, N. P. (2000). Changing the structure and properties of clothing material for clean rooms as a result of operation. *Bulletin of DALPU*, 2, 149—152 [in Ukrainian].
8. GOST 3816–81. Textile fabrics. Methods for determining hygroscopic and water-repellent properties. Moscow [in Russian].
9. DSTU ISO 5077 — 2001. Textile materials. Method for determining the change in linear dimensions after washing and drying. Kiev [in Ukrainian].
10. Grigorova, L. S. (2017). *Methodical instructions on the subject "Technology of clothing production"* (second edition). Kharkiv [in Ukrainian].

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ДОСЛІДЖЕННЯ МАТЕРІАЛІВ ДЛЯ ВИГОТОВЛЕННЯ ЗАХИСНОГО БАР`ЄРНОГО ОДЯГУ МЕДИЧНИХ ПРАЦІВНИКІВ ТА ЇХ ВИПРОБУВАННЯ У ВІДПОВІДНОСТІ ДО НОРМАТИВНИХ ДОКУМЕНТІВ

Вступ. Комплексний науковий підхід до вирішення питань захисту медичних працівників створює підґрунтя для розробки сучасного бар'єрного одягу для них, а особливо одягу співробітників хірургічних відділень, які під час виконання професійних обов'язків можуть зазнавати інфікування.

Проблематика. Створення ефективного захисного бар'єрного одягу для лікарів хірургічних відділень обумовлює необхідність розробки асортиментного ряду тканин та заходів антимікробної обробки швів в місцях з'єднання елементів одягу, а також випробування розробленого одягу відповідно до нормативних документів.

Мета. Обґрунтування вибору матеріалів для виготовлення захисного бар'єрного одягу медичних працівників та розробка заходів антимікробної обробки швів в місцях з'єднання елементів одягу.

Матеріали й методи. Об'єктом дослідження слугували текстильні матеріали та модифіковані нитки, що застосовуються при виготовленні бар'єрного медичного одягу. Експериментальні дослідження проведено в лабораторіях Київського національного університету технологій та дизайну за стандартизованими та оригінальними методиками оцінки властивостей текстильних матеріалів та ниток.

Результати. Визначено принципи застосування нових композиційних матеріалів з захисними властивостями при проєктуванні бар'єрного одягу для хірургів операційного блоку, встановлено залежності показників якості текстильних матеріалів від кількості циклів прання та стерилізації, а також запропоновано заходи з антимікробної обробки швів у місцях з'єднання елементів одягу. Проведено дослідження розробленого одягу відповідно до нормативних документів.

Висновки. Отримані результати показали, що найбільш ефективним з точки зору захисту медичних працівників є зональний принцип застосування різних типів тканин для виготовлення бар'єрного медичного одягу. Визначено, що з розроблених та досліджених ниток найбільш придатними для відшивання технологічно чистого одягу є нитки ПОМ 529, ПОМ І та ПОМ ІІ.

Ключові слова: бар'єрний медичний одяг, текстильні матеріали, антимікробна обробка.