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OBTAINING OF ANTIBACTERIAL COATING WITH SILVER NANOPARTICLES ON A TITANIUM IMPLANT

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Abstract. The formation of a microbial biofilm around implants is the main cause of postoperative complications, disruption of the osseointegration process, even leading to loss of biomaterial. Obtaining antimicrobial coatings in order to extend the life of implants in the body is a relevance of research. Coatings based on Na-carboxymethylcellulose (Na-CMC) and chitosan (Chit) with silver nanoparticles (AgNP) were obtained by the multilayer assembly method (layer-by-layer, LbL) to modify the surface of medical titanium implants and impart antibacterial properties to them. The surface of any substrate is not developed; for this purpose, the surfaces of titanium samples were activated by two methods. The wetting angle of titanium implants after etching was determined by the sessile drop method. The results showed the formation of a hydrophilic surface after the activation of titanium implants. The scheme for obtaining Na-CMC/Chit coating with AgNP is shown. Ascorbic acid was chosen as the reducing agent. Scanning electron microscopy revealed that when using 1 mM silver nitrate, the average size of AgNPs varies in the range of 40–95 nm. Bringing the concentration of a solution of silver nitrate to 0.01 M leads to an increase in the size of silver particles and their aggregation. The kinetics of the release of silver ions in physiological saline was studied to assess the prolongation properties of the coating with AgNP. The largest release was observed in the first 24 hours with a further decrease in the dose of silver ions passing into solution. Determination of antibacterial activity was carried

out by disk diffusion method. Coatings containing AgNP inhibited the growth of Escherichia coli bacteria.

Key words: antibacterial coatings, silver nanoparticles, chitosan, Na-carboxymethylcellulose, LbL method

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ТИТАНДЫ ИМПЛАНТАТ БЕТІНДЕ КҮМІС НАНОБӨЛШЕКТЕРІ БАР БАКТЕРИЯҒА ҚАРСЫ ЖАБЫН АЛУ

Аннотация. Имплантанттардың айналасында микробтық биожабынның пайда болуы операциядан кейінгі асқыну, остеоинтеграция үрдісінің бұзылуы тіпті биоматериалдың істен шығуының негізгі себебі болып табылады. Ағзадағы имплanttардың қызмет ету мерзімін ұзарту мақсатында микробқа қарсы жабын алу зерттеудің өзекті тақырыбы болып табылады. Медициналық титан имплanttарының бетін модификациялау және оларға бактерияға қарсы қасиеттер орнықтыру үшін көп қабатты жыйнақтау әдісі (layer-by-layer, LbL) көмегімен күміс нанобөлшектері бар Na-карбоксиметилцеллюлоза (Na-КМЦ) және хитозан (Хит) негізіндегі жабындарды алынды. Кез-келген қатты төсеніштің бетік қабаты белсенді емес, осы мақсатта титан имплантаттарын өңдеу екі әдіспен жүзеге асырылды. Өңдеуден кейінгі титан имплантаттарының жұғу бұрышы тамшының қатты дене бетімен жанасу әдісі арқылы анықталды. Нәтижелер титан имплanttарын белсендіргеннен кейін гидрофильді беттің түзілгенін көрсетті. Құрамында AgНБ бар Na-КМЦ/Хит негізіндегі жабынның алу схемасы көрсетілді. Тотықсыздандырғыш ретінде аскорбин қышқылы таңдап алынды. Концентрациясы 1 мМ күміс нитраты ерітіндісін қолданған кезде AgНБ орташа мөлшері 40–95 нм аралығында өзгеретіндігі сканерлеуші электронды микроскопия әдісімен анықталды. Ерітінді концентрациясын 0,01 М дейін жеткізу бөлшектер мөлшерінің артуы мен олардың бір-бірімен бірігуіне алып келеді. Құрамында AgНБ бар жабынның ұзартылмалы қасиетін бағалау үшін тұзды ерітіндіде күміс иондарының бөліну кинетикасы зерттелінді. Ерітіндіге өткен ион мөлшерінің ең көп шамасы 24 сағат көлемінде тіркелді, ары қарай бұл шаманың төмендегі байқалды. Бактерияға қарсы белсенділігі дискілі диффузиялық әдісі көмегімен анықталынды. AgНБ бар жабын жабындар Escherichia coli бактериясының өсуін тежеді. Осылайша

алынған көп қабатты жабын (AgНБ бар Na-КМЦ/Хит) медициналық-биологиялық қолдану үшін үлкен потенциалға ие болуы мүмкін.

Түйін сөздер: бактерияға қарсы жабын, күміс нано бөлшектері, хитозан, Na-карбоксиметилцеллюлоза**,** LbL әдісі

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ПОЛУЧЕНИЕ АНТИБАКТЕРИАЛЬНОГО ПОКРЫТИЯ С НАНОЧАСТИЦАМИ СЕРЕБРА НА ТИТАНОВОМ ИМПЛАНТЕ

Аннотация. Формирование микробной биопленки вокруг имплантов является основной причиной появление послеоперационной осложнении, нарушение процесса остеоинтеграции даже приводящий к потери биоматериала. Получение противомикробных покрытии с целью продление срока жизни имплантов в организме является актуальной темой исследования. Методом мультислойной сборки (layer-by-layer, LbL) получены покрытия на основе Na-карбоксиметилцеллюлозы (Na-КМЦ) и хитозана (Хит) с наночастицами серебра (НЧAg) для модификации поверхности медицинских титановых имплантов и придания им антибактериальных свойств. Поверхность любой подложки не развита, с этой целью активацию поверхностей титановых образцов проводили двумя методами. Методом лежащей капли определен угол смачивания титановых имплантов после травления. Результаты показали образование гидрофильной поверхности после активации титановых имплантов. Показана схема получения покрытии Na-КМЦ/Хит с НЧAg. В качестве восстанавливающего агента была выбрана аскорбиновая кислота. Методом сканирующей электронной микроскопии выявлено, что при использовании 1мМ нитрата серебра средний размер НЧAg, варьируется в интервале 40–95 нм. Доведение концентрации раствора азотнокислого серебра до 0,01 М приводит к увеличению размеров частиц серебра и к их агрегации. Исследована кинетика высвобождения ионов серебра в физиологическом растворе для оценки пролонгирующего свойтва покрытии с НЧAg. Самое большое высвобождение наблюдалось в первые 24 часа с дальнейшим уменьшением дозы ионов серебра перешедший в раствор. Определение антибактериальной активности проводили дискодиффузионным методом. Покрытия содержащие НЧAg ингибировали рост бактерий Escherichia coli. Многослойная покрытия (Na-КМЦ/ХЗ с НЧAg) полученная таким образом могут иметь большой потенциал для медико-биологических применений.

Ключевые слова: антибактериальные покрытия, нано частицы серебра, хитозан, Na-карбоксиметилцеллюлоза, LbL метод

Introduction

In practical medicine, implants made of various materials are used, which differ from each other in chemical nature, physical characteristics, etc (Patel & Gohil, 2012). However, not all implants can withstand the harsh conditions of the organism, and therefore fail soon. Implant rejection may be due to poor bone integration or biofilm formation (Quinn et al., 2020). Thus, the development of antibacterial coatings has become an important area of scientific research.

Currently, there are the following strategies for obtaining antibacterial polyelectrolyte multilayer coatings (PEMs) a: prevention of adhesion of microorganisms, b: killing by contact, c: killing by releasing active compounds near the implant (Seon et al., 2015).

The first two strategies for prolonging the life of the implant in the organism are not effective compared to the third method. Since the coatings are resistant to adhesion, they do not kill bacteria, but only due to the formation of a strong hydrophilic surface repel microorganisms (Xu et al., 2018). Contact-killing films are limited by surface functionalization, that is, in the absence of positively charged groups on the surface, the coatings are inactive against negatively charged bacteria (Qin et al., 2018). In this regard, there is a growing interest in obtaining PEMs containing an active component that exhibits a prolonging action against microorganisms due to the release of an antibacterial agent. Various antibiotics, antiseptics (Rakhmatullayeva et al., 2023) and active particles such as silver and gold nanoparticles, etc. are used as antibacterial agents in such coatings (Urrutia et al., 2012; Zhou et al., 2014).

The most common antimicrobial agents introduced into coatings are (Ag^+) ions (Woo et al., 2008) and silver nanoparticles (AgNP) (Daengngam et al., 2019). The composite structure obtained on the surface of titanium implants should provide a slow release of Ag^+, thereby exhibiting long-term antibacterial activity. Layer-by-layer self-assembly is a universal method in which a multilayer structure is created on a Ti surface by depositing alternating layers of oppositely charged polyelectrolytes (Ariga et al., 2022). Due to biocompatibility, multilayers consisting of positively charged chitosan and negatively charged hyaluronic acid (Jeon et al., 2015) carboxymethylcellulose (Rakhmatullayeva et al., 2023) and heparin (HEP) (Li et al., 2019) are widely used for drug delivery and release control.

In general, silver particles or ions are introduced into coatings by two methods: by impregnation into pre-assembled films with further reduction if necessary, or directly during assembly. In the work, the authors introduced AgNP into the coating after obtaining a polyelectrolyte reservoir (Fu et al., 2006). Films previously deposited on the substrates which have free carboxylic acids or sulfonate groups were immersed in a solution containing Ag^+ ions. Due to ion exchange with protons, silver ions enter the interlayer space. Subsequently, they were reduced to AgNP using $NaBH_4$ or irradiation with light in the UV range.

The authors in (Li et al., 2019) work obtained a coating with AgNPs for dental implants, which were biosynthesized by a simple “green” method. Chitosan

has been used not only as a stabilizer and reducing agent, but can also be used as a polycation in PEMs. After obtaining a solution of chitosan-NPAg, an assembly was designed with a combination of heparin, thereby including NPAg in the composition of multilayer during the PEMs process. These coatings promoted not only the adhesion and proliferation of human gingival fibroblasts, but also provided a continuous release of Ag^+ for 28 days before healing of mucous membrane.

In (Fu et al., 2006) work, a similar reservoir of chitosan/heparin was used to load AgNPs. Ascorbic acid was used as a reducing agent, which is a "soft" organic acid due to their low toxicity. Well-dispersed nanoparticles with a size of 10–40 nm had a bactericidal effect against Escherichia coli (E. coli), and also showed no cytotoxicity.

Despite the large number of works aimed at solving this problem, there are relatively few practical results in obtaining antimicrobial coatings with long-term antibacterial activity. Therefore, the aim of this study is to obtain multilayers on the surface of titanium implants based on chitosan and sodium carboxymethylcellulose containing an antibacterial agent of silver nanoparticles, to evaluate the prolonged action of AgNP embedded in PEMs, and to determine their antibacterial activity.

Materials and methods

Characteristics of materials and reagents. Low molecular weight chitosan (MW=50–190 kDa) with a degree of deacetylation of 75–85 % (Sigma Aldrich) and Na-carboxymethylcellulose (Na-CMC) (MW=700 kDa, Sigma Aldrich) were used as polyelectrolytes. The following reagents were also used in the work: low molecular weight polyethyleneimine (PEI) (MW=750 kDa, Sigma Aldrich), $AgNO_3$ (99.8–100.5 %), glacial acetic acid, acetone, ethyl alcohol (96 %), sulfuric acid (98 %), hydrogen peroxide (37 %). All reagents were used without any further purification. Medical titanium implants served as substrates.

Surface treatment of titanium implants. Since the surface of the titanium-based implant is hydrophobic, the layering of polyelectrolytes on its surface was carried out only after activation. For this purpose, two etching methods were used: in the first case, titanium implants in the form of plates were treated with a solution of concentrated sulfuric acid with the addition of hydrogen peroxide ("piranha" solution) for 15 minutes, then washed with a large amount of distilled water. In the second case, titanium implants were polished with sandpaper, then they were immersed alternately in solutions of acetone and ethyl alcohol. The process ended with washing with distilled water.

Obtaining of multilayers with silver nanoparticles. The obtaining of multilayers with silver particles was carried out by the LbL multilayer assembly method. To bind the multilayers to the substrate, titanium implants were first immersed in a 0.01 M solution of polyethyleneimine (PEI) for 30 minutes, which is a cationic polymer with complexing properties. As a result of this process, the surface of titanium implants acquires a positive charge due to the protonated amino groups of PEI.

The obtaining of multilayers began with the deposition of Na-CMC on a PEI layer fixed on the surface of titanium implants. Further, to remove non-

adsorbed particles, the substrate was washed with distilled water. The subsequent immersion of these samples in a chitosan solution leads to electrostatic interaction between the functional groups of the polyacid with the polybase and the formation of the first bilayer. A similar process was also carried out after the application of chitosan. By repeating this cycle, coatings with the required number of bilayers were obtained. The concentration and pH of the polyelectrolytes are 0.01 M and 4, respectively.

The synthesis and incorporation of silver nanoparticles into thin films was carried out as follows. Coated titanium implants were immersed in $AgNO_3$ solution (1 mM and 10 mM) for 12 hours. The solution was kept in a cold place to avoid oxidation of silver. Subsequent reduction ("in situ") of silver ions (Ag^+) to silver nanoparticles (Ag°) was carried out using a 0.01 M solution of ascorbic acid. The samples were stored in a dark place prior to the study.

Scanning electron microscopy. The surface structure was studied by scanning electron microscopy (SEM). SEM images were taken with an Auriga scanning electron microscope. Titanium implants were attached to the SEM stand with conductive tape. The surface of the samples was coated with Au-Pt by microwave plasma spraying for 10 seconds at a discharge voltage of 1 to 3 kV.

Determination of contact angle. The contact angle was determined using the sessile drop method at room temperature and normal pressure. The apparatus "DSA100-KRUSS GmbH" was used. The average droplet diameter averaged 2–5 mm.

Study of the release of silver ions in saline. To assess the release of silver ions, titanium implants with coating were immersed in freshly prepared phosphate buffer (pH-7.4) for 24 h and stored in a dark place. Then samples were taken and the implants were immersed in a fresh solution. The amount of silver ions that passed into solution every 24 h was determined by atomic absorption spectroscopy.

Determination of antibacterial activity. The determination was carried out by the disc diffusion method in agar-agar on a dense nutrient medium by comparing the sizes of the zone inhibition of the growth of test microbes. E. coli was used as a reference strain for antibacterial testing. 20 ml of nutrient agar were poured into sterile Petri dishes. The thickness of the agar layer affects the results of the determination; therefore, the indicated amount of the nutrient medium was strictly controlled in the experiments. Muller-Hinton medium and Sabouraud agar were used as a nutrient medium.

To obtain lawns, a homogeneous suspension of bacterial cells in physiological saline was prepared, corresponding to the standard of 0.5 units of turbidity according to McFarland. The bacterial suspension was applied with a sterile swab to the agar surface in three different directions. 5–10 minutes after inoculation, the dried agar surface was brought into contact with a titanium implant with antimicrobial properties. The dishes were left at room temperature for 30 minutes, and then, without turning, were incubated in a thermostat at a temperature of 28–37°C for 24 h. The formation of a transparent zone around the sample is an

indicator of the antibacterial activity of the obtained materials. Zones of inhibition of microbial growth were measured with a millimeter ruler.

Results and discussion

Surface treatment of titanium implants. Implants used in medicine, upon contact with oxygen, are naturally covered with an oxide layer, 3-10 nm thick, characterized by low chemical reactivity, affecting biocompatibility and roughness. In addition, when stored in the open air, the surface of the biomaterial becomes contaminated due to physical adsorption. Also, as is already known, the surface of any substrate is not developed, which consequently makes it difficult for chemical reagents to "stick" to the surface of the material (Lu et al., 2012). Therefore, the first step in obtaining the coating is the preparation of the active surface of the implanted products.

One of the methods to increase surface energy and improve implant integration is acid etching. The authors (Buuser et al., 2004) have shown that a sandblasted and acid-etched (SLA) surface provides tighter bone-to-implant contact than a conventional standard surface. A similar goal was achieved in (Giavaresi et al., 2003) using a 25 % HF solution followed by passivation with a 25 % HNO_3 solution.

As a result of the analysis of various etching methods, in order to improve the surface characteristics, we activated titanium implants in two ways: 1) polishing with sandpaper followed by washing successively with acetone and ethyl alcohol 2) treatment with a "piranha" solution (a mixture of sulfuric acid and hydrogen peroxide). The authors (Quinn et al., 2020) studied coatings against a strain S. aureus that can cause orthopedic infection. Most bacteria are hydrophobic and can cause various infections. Hydrophilic surfaces are more desirable when interacting with biological fluids, cells and tissues of the body, compared to hydrophobic ones (Nazarov et al., 2018).

The results are shown in figure 1. due to the heterogeneity of the surface of real titanium implants, the contact angle was determined using 5 points.

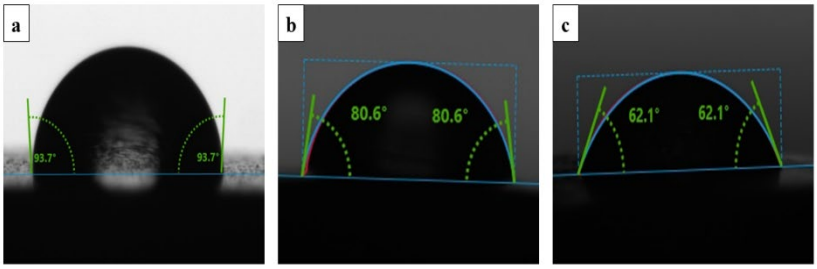

Fig. 1. Angle of contact of titanium implants with water
(a) the surface of the titanium implant before processing;
(b) surface after polishing with sandpaper followed by treatment with organic solvents;
(c) after etching with "piranha" solution

Wettability describes the interaction of a water drop with a surface. A wetted surface is hydrophilic and will have a contact angle of <90° while a non-wettable surface is hydrophobic and will have a contact angle of >90 ° (Quinn et al., 2020). As shown in figure 1 (a) before etching, the contact angle of titanium implants is in the range of 89–93.7^0. After etching the surface of titanium implants with organic solvents (figure 2 b), this value was 70–80.6^0. Treatment with the "piranha" solution reduced the contact angle to ~ 62^0 (figure 2 c), which indicates the formation of a hydrophilic surface. The formation of a less hydrophilic surface in the first way is due to the fact that the use of emery polishing leads to the disposal of only adsorbed grains of abrasives obtained during storage of the biomaterial in the open air. Sequential processing with organic solvents makes it possible to remove fatty impurities. At that time, the use of a "piranha" solution reduced the wettability of the surface by 30 ^{0}. Such changes are explained that sulfuric acid, which is part of the "piranha" solution, dissolves the oxide film and thereby excludes the surface polishing process. Hydrogen peroxide is a "provider" of atomic oxygen, which oxidizes organic and inorganic impurities that are on the surface of the samples.

Obtaining a coating with AgNP. Silver nanoparticles embedded in a polymer matrix are of great interest due to the large surface area that is in contact with bacteria and physicochemical properties dependent on size/shape. In addition, polyelectrolytes, which are the basis of coatings, have a pronounced potential to inhibit the aggregation of AgNPs, control the release of Ag^+, and thereby provide a stable antibacterial effect and reduce cytotoxicity.

As already reported above, AgNP films were obtained by dipping a coated solid substrate into a silver nitrate solution with further in situ reduction (fig. 2). Since the coating was obtained at pH-4, as can be seen from the figure, part of the carboxyl group (about 25 %) remains in the protonated form (COOH), and part of the deprotonated CMC groups binds to the amino groups of chitosan. Further holding of the film in the $AgNO_3$ solution will immediately lead to the replacement of the CMC proton by Ag^+.

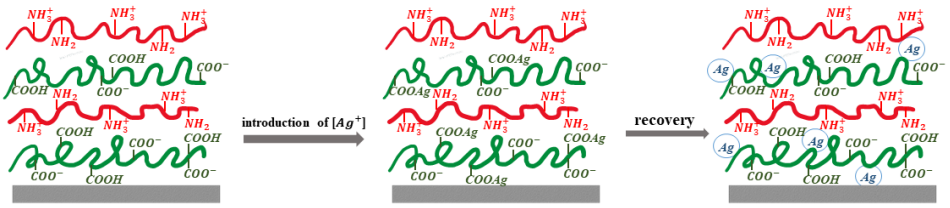

Fig. 2. "In situ" reduction of Ag^+ to AgNPs in a PEMs coating

After the immobilization of Ag^+ in the coatings, in situ chemical reduction was carried out using ascorbic acid. The choice of ascorbic acid (1 mM) as a reducing agent is associated with the low toxicity of the agent and can be carried out as follows (Fu et al., 2006):

$$2Ag^{+} + C_6H_8O_6 \rightarrow 2Ag^{0} + C_6H_6O_6 + 2H^{+} \quad (1)$$

Proton ions released from the reaction make it possible to regenerate carboxyl groups. Thus, the polycation is again ready for Ag^{+} rebinding.

In the study, silver nitrate was used at a concentration of 1 mM and 10 mM. As can be seen from Figure 3a, at a concentration of 1 mM, the size of silver particles fluctuates in the range of 40-130 nm, this is due to spontaneous "in situ" reduction and the process is difficult to control, as a result of which the formation of randomly arranged particles is observed, however, the average particle size was ~ 70 nm. However, as the concentration increases to 10 mM, the particle sizes reach up to microns (Fig. 3b). This is because with an increase in concentration, undoubtedly, more silver ions enter the ion exchange and the large particles that formed were a potential center for attracting more particles in themselves. Since not only particle size but also surface distribution is important, it can be observed from figure 3a that at low concentrations the surface is not completely covered with AgNPs. But, an increase in the concentration of silver nitrate will not only lead to aggregation of AgNPs, but also a large number of micron-sized particles can be seen distributed over the surface. This contributes to the showing of less antibacterial activity due to a decrease in the surface area which contact with bacteria. In addition, the process of particle aggregation is explained by the presence of a large amount of AgNPs, which leads to their enlargement.

The surface structure, distribution, shape, size, and content of silver nanoparticles in the obtaining multilayers were studied by scanning electron microscopy and SEM EDX. Figure 3c shows the results of EDX spectroscopy; it was revealed that silver is present in the composition of the multilayers. However, since this method provides information only on the elemental composition, it is possible that, in addition to metallic silver, silver oxide may also be present in the sample.

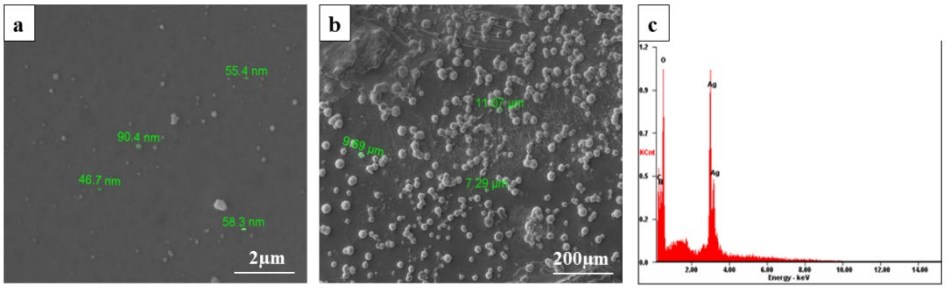

Fig. 3. SEM images of the surface of coating (Na-CMC/Chit) with AgNPs
(a) $AgNO_3 - 10^{-3}$ M; (b) $AgNO_3 - 10^{-2}$ M;
c) EDX spectrum of the sample

Thus, the size of nanoparticles in multilayers and their distribution over the surface can be controlled by choosing the initial concentration of $AgNO_3$.

Since a surgical wound heals within 10–14 days, we also decided to

investigate the release of an antibacterial drug in phosphate buffer in the presence of saline for 14 days. Figure 4a shows the results obtained for the system $(Na\text{-}CMC/Chit)_{10.5}$ with AgNPs where the concentration of $AgNO_3$ in the initial solution was 10^{-3} M. As can be seen from the figure, the maximum release of Ag^+ reached ~ 0.054 mM/day during the first day. However, the further release of silver ions decreases, which is a positive factor, since the continuous release of silver is not recommended due to cytotoxicity to host cells. The minimum concentration of silver ions that passed into the solution was observed on the 14th day, which is 0.0012 mM/day. The release of silver ions from the coating is explained by the fact that in aerobic solutions, metallic silver passes to Ag_2O (López-Carballo et al., 2013). Then the metabolism of the bacterium creates an acidic environment to convert of silver to its ionic form.

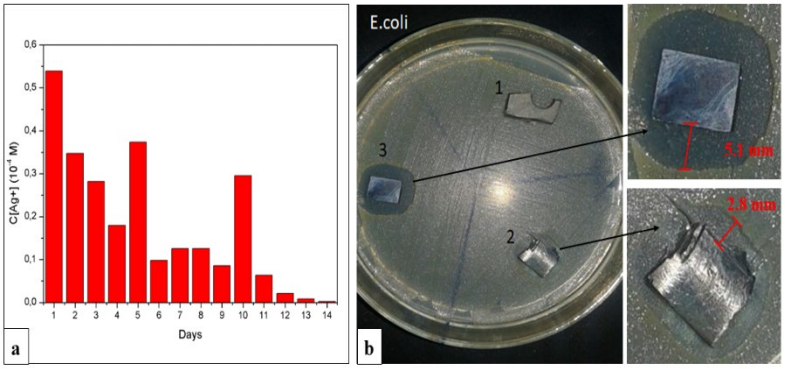

Fig. 4. (a) Release of silver ions from $(Na\text{-}CMC/Chit)_{10.5}$ coating with AgNP;
(b) antibacterial activity against E. coli bacteria
(1) implant without coating; (2) multilayer coatings $(Na\text{-}CMC/Chit)_{10}$ without AgNP;
(3) coatings $(Na\text{-}CMC/Chit)_{10.5}$ with AgNP

The release of silver ions in solution was not monotonous, which is explained both by the presence of aggregates on the surface and by the uneven distribution of nanoparticles between layers, which leads to different ion migration kinetics. However, it should be noted that not all of the silver ions are released from the coatings during the postoperative period. The initial burst of Ag^+ release prevents immediate colonization of bacteria on the Ti surface after surgery (Li et al., 2019). Then a sustained release of Ag^+ is needed to resist bacterial invasion from the outer edges of the wound until the healing mucous membrane.

The antibacterial activity of the obtained samples was determined on the museum strain of E. coli the bacterium. Figure 4b shows the results illustrating the antibacterial activity of the samples. The inhibition zone (IZ) around the original

titanium implants is 0 (sample 1). As can be seen from the figure, in samples 2 and 3, an inhibition zone is observed, and for the sample coated with layers $(Na\text{-}CMC/Chit)_{10}$, it is 2.8 ± 0.01 mm, while for the sample $(Na\text{-}CMC/Chit)_{10.5}$ with AgNPs the size of the zone inhibition increases to 5.1 ± 0.03 mm. The appearance of an inhibition zone around sample 2 is possible presence of a positive charge on the last layer, which further led to the destruction of the microorganism due to the contact killing properties. For both samples (2, 3) the appearance of IZ is associated with the presence of a film coating. However, it should be noted (sample 3) that the coating with AgNP was applied on silicon wafers not on titanium implants. The indication of the antibacterial effect for the 3rd sample is mainly due to the adhesion of the cell membrane of AgNP occurs, the change in its penetration, as a result, affects the respiratory system of cells. Therefore, this leads to the death of the bacterium. In addition, the antimicrobial effect of AgNPs is due to the penetration of particles into bacteria and the release of Ag^+, which interacts with thiol groups or phosphates that are part of the DNA/protein bacteria (López-Carballo et al., 2013).

Conclusion

Coatings based on chitosan and sodium carboxymethylcellulose containing silver nanoparticles were obtained by the method of multilayer assembly on the surface of titanium implants. To improve the adhesion of hydrophilic polyelectrolytes to the substrate, the surface of the implants was treated in two ways. Etching with a solution of concentrated sulfuric acid with the addition of hydrogen peroxide made it possible to obtain a more hydrophilic surface compared to the second method.

The mechanism of formation of multilayers is determined by the acid-base interaction of the polyacid with the polybase, which is accompanied by electrostatic interaction. Multilayer coatings based on Na-CMC and chitosan served as a reservoir for AgNPs, which maintained a prolonged release of silver ions for 14 days. Research was conducted to determine the antibacterial activity of the obtained coatings against E. coli strains. Coatings with/without AgNP were active showing 5.1 ± 0.03 mm and 2.8 ± 0.01 mm zone of inhibition, respectively.

The obtained results in the present work point to the prospects of research in this direction. In the future, it is planned to establish the kinetic features of the release of silver, to conduct more detailed research of the antibacterial activity of coatings in order to identify the optimal conditions for obtaining nanocoating with the required properties.

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