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Research Article

Therapeutic Contact Lenses with a Nanomodified Surface for Corneal Rehabilitation After Donor Corneal Transplantation or Other Ophthalmosurgical Interventions on the Anterior Segment of the Eyeball

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Abstract

As the quality and complexity of surgical interventions improve, for example, in the anterior segment of the eyeball, it becomes necessary to improve the quality of not only medical instruments, but also the use of various methods for successful rehabilitation in the postoperative period. Upon completion of surgery on the eyeball, more precisely, on the anterior segment of the eyeball, Therapeutic Contact Lenses (TCL) are widely used to accelerate and correct the healing of the Cornea. Soft contact lenses (SCLs) are used instead of specially made therapeutic contact lenses (TCLs). Because there is no TCL production. Ophthalmologists are well aware of eye diseases in patients using SCL, sometimes very severe and dangerous, complications that occur more often due to violations of the mode and hygiene of wearing SCL and due to allergic reactions to the polymer material of the SCL. Many items widely used in medicine and biology are made using inexpensive polymer products that must meet specific clinical and cost requirements. The main requirements for polymer products are the need to ensure the aseptic properties of the polymer product, biocompatibility between the physiological environment and the polymer surface of the product, which can be achieved by treating the polymer surface by applying carbon-containing films (CCF), such as diamond-like, carbine-containing, carbine-containing, carbon nanotubes. Nano structuring of the surface of polymeric materials (Surface Nanomodification-SNM) is carried out to achieve biocompatibility, aseptic and thus certain multifunctionality properties of the polymeric materials used. The aim of our work was to create the first truly therapeutic contact lenses for use in the period of postoperative rehabilitation of the eye after operations on the anterior segment of the eyeball. So far, conventional corrective soft contact lenses (SCLs) have been used as TCLs (Therapeutic Contact Lenses).

For the manufacturing of TCL, the same polymeric materials are used: polyethylene terephthalate (PET), polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF) on the same line for the manufacturing of SCL; followed by treating of their surface by applying carbon-containing films deposition, additionally to the process of SCL obtaining. Modification is carried out by deposition of nanocomposites from directed ion-plasma flows of vapors of gas mixtures or by magnetron deposition.

The shape of the TCL is also modified in such a way that on the inner surface of the empirically aspherical shape of the manufactured TCL, which has a uniform smooth surface, there are no dividing zones, such as: optical, sliding, which makes the surface smooth, uniform, without surface irregularities that will have to come into contact with the surface of just operated cornea. The nanostructured surface of the TCL also excludes the growth of fibrous tissue in the underlying space of the TCL. In the cases of the observed eyes, the desired positive postoperative result of healing and restoration of living tissues was achieved in 100% of cases.

One of the most positive aspects of surface nanomodification technology is the possibility of simultaneous surface modification and its sterilization. The characteristic properties of the SCL surface provided by the use of surface Nano structurization are also: lack of toxicity, surface biocompatibility, certain adhesive and repulsive properties for certain living cells and their elements, which determines the desired properties of nano coatings. That is, such a polymer surface treatment improves the quality and safety of polymer products widely used in medicine and biology.

Keywords: Therapeutic Contact Lenses; Eyeball; Biology

Introduction

There are many indications for the use of TCLs in corneal and ocular surface diseases. The indications are divided into main broad categories: pain relief, enhancing corneal healing, corneal sealing, corneal protection, there is an undoubted medical need for specially made TCLs (therapeutic contact lenses), rather than random SCLs for the goals of rehabilitation, especially in the rehabilitation period after microsurgical operations on the anterior segment of the eyeball.

Study of the use of nanotechnologies to improve the surface quality of polymer products widely used in medicine and biology, as made from the cheapest and most accessible polymeric material, the possibility of using nanotechnologies to obtain the desired physical and chemical properties of polymeric surfaces of various polymers products for giving by means, of the polymer surface treating, the necessary surface properties: aseptic, biocompatible, biepitaxial. Having carefully studied the materials proposed since the discovery by Otto Wichterle in 1968 of the proposed method for the manufacture of soft contact lenses (SCL), which can still be considered fundamental, the new proposed methods for obtaining various SCLs are only modifications of the main Wichterle method. The level of modern development of ophthalmic surgery, especially microsurgery of the anterior segment of the eyeball, provides for the mandatory use of TCL in the postoperative period of rehabilitation. However, there is no production of special TCL; therefore, casual SCLs are still used instead of right TCLs. At the same time, the TCL should have certain parameters and surface quality obtained using the technology of appropriate polymeric surface treatment in order to have certain characteristics of the TCL surface, which in direct contact with the postoperative surface of the cornea of the eye. TCL must have certain parameters and surface quality, made using the technology of processing the polymer surface of the product, in order to obtain the proper characteristics of the TL surface as:

- Smooth and homogeneous empirically aspherical shape, without irregularities, for example, from the optical zone to the sliding zone, etc.;
- A certain form of curvature of the CL surface, which should be at least 164 degrees, it is this surface contour that provides the physiological processes of migration of corneal cells to restore corneal tissue;
- Nanomodification of the surface of the obtained TCL excludes the formation of a biofilm on its treated polymer surface.
- The determined characteristics and geometry with the correct surface treatment of TCL provide proper TCL, in contrast to conventional TCL, which are still used as TCL.

Materials and Methods

TCLs are produced on a conventional SCL production line. In shape, the obtained SCLs correspond to corneoscleral SCLs manufactured using the various polymers with high adhesion on their surface of carbon-containing nanofilms: polyethylene terephthalate (PET), polytetrafluoroethylene (PTFE), polyvinylidene fluoride (PVDF), in shape they correspond to corneoscleral SCLs, in the form of a spherical segment having the following dimensions: diameter 18 mm, thickness 0.3 mm, radius of curvature 8.8 mm in the center, height of the spherical segment 5.8-6.2 mm. The resulting SCR should also have an empirically aspherical shape with an external angle over the entire surface of at least 164 degrees, this form of surface curvature ensures the processes of physiological migration of corneal cells. The need for strict observance of the form and relief the surface of the SCL, which can ensure the maintenance of the physiological processes of the corneal tissues when using these SCLs in the future, as TCLs. At the final stage, to obtain due TCL, the surface of the obtained SCL is treated by Nano structurization its polymer surface and followed by its surface nanomodification using known methods of nanotechnology for SCL surface treating by means of nanofilm deposition on its surface in a special chamber.

The surface treatment of high-molecular polymeric materials SCL is carried out on traditional equipment.

with planetary-rotating plates designed to fix workpieces, the surface of which is nanostructured by treating the surface with ionic flows of chemically active and/or inert gases, for following nanomodification of the formed developed surface by applying carbon-containing films, such as: diamond-like, carbine, fullerene, nanotubes containing, which can also be combined (single-layer, multilayer, monophasic, multiphasic.

The uniformity of the films is 95%. I vary the methods of surface treatment (chemical, physical, electrochemical methods surface nanomodifications) can be used to obtain combined carbon-containing nanofilms with determined parameters, and therefore - certain surface properties such as: inertness, atomic structure, surface charge, its relief providing such specified surface properties as: aseptic, bactericidal properties, biocompatibility of the nanomodified polymer surface with living tissues. Thus, the chemical resistance and specified properties of the nanomodified surface provide safety for underlying living tissues when in direct contact them.

Materials with nanostructured surface are a separate class synthetic nanostructured material. NSS is very desirable on the surface of implant, because artificial substitutes that come in contact with humeral liquids require special surface treatments to enhance biocompatibility [1-3].

NSSs on the surface of polymers were formed by treating their surface with ions of reactive and noble gases and their mixtures (CF4, Ar, O2). Modification was carried out by two methods: deposition of CF4 from directed ion-plasma flows of hydrocarbon vapors with a thickness of 5–120 nm and magnetron sputtering of highly dispersed films.

The surface structure was studied using a FemtoScan atomic force microscope with a maximum scanning area of 10x10 μm. For each surface of the sample, photographs were taken at different points.

After receiving due results of toxicity studies of HC-treated PET, PTFE, PVDF (the results of studies are described in detail, antimicrobial activity, polymers were chosen as starting materials with α-C:H (100 nm) deposition strips.

The experimental study carried out on polymers with NSS formed by ion-plasma methods have shown that the degree of dispersion of the surface and the methods of its modification defines its surface characteristics and effectiveness, in particular, antimicrobial activity [4].

NSS on substituted polymers have been formed by treatment of their surface by ions of chemically active and noble gases and their mixtures (CF4, Ar, O2). Modification was carried out using two methods: by a deposition of CF4 from directed ion-plasma flows of hydrocarbon vapors with 5-120 nm thickness and by magnetron deposition of highly dispersed films.

An atomic force microscope "FemtoScan" with a maximum scan square 10x10 μm has been used for the study of the surface structure. For every sample surface, photographs on different points have been obtained.

Gram-positive Staphylococcus aureus ATCC 29213 and Gram-negative Pseudomonas aeruginosa ATCC 27853 have been used for the antimicrobial activity study. For this purpose, 3-4 colonies of microorganisms cultured in 18-20 hours have been suspended in 3 ml of saline solution. The suspension had a turbidity standard of 0, 5 according to the McFarland scale (1,5·108 cfu/ml). The base suspension was then diluted in saline solution serum dilutions until the concentration was 15 cfu/ml.

NSS polymers foils were cut into fragments of size 15x15 μm. The fragment of substrate was put into a tube with liquid nutrition medium for control of the sterility of the coatings. Muller-Hinton Bovril was used as a nutrition media. From every tube with different concentration 25 μl of suspension was extracted using a pipette and were deposited on separate fragments of the polymer substrate with NSS for control of the growth of the culture.

Such infected fragments were incubated in wet media with a thermostat at 37ºC for 2 hours. After incubation, all fragments were put into tubes with 4 ml of nutrition media again incubated in the thermostat at 37ºC for 48 hours. Antibacterial activity was estimated by the appearance of visible growth in tubes with nutrition media after 48 hours.

After positive results had been obtained from investigations of CF treated PET, PTFE, PVDF toxicity (the investigation results are described in details in, NSS surface modification by means of CF deposition using ion-plasma processes has been developed to attain specific surface properties [4]. The unique surface modification that can be achieved by using the plasma film deposition process results from the effects of the photons and active species in the plasma; these react with surfaces in certain depths without changing the bulk properties of the substrate material. Processing parameters, such as gas types, treatment power, treatment time and operating pressure, which can be varied.

Ion-plasma deposition process can change surface energies. Certain film deposition can modify almost any kind of substrate geometry. The most important feature is the ability of the CF deposition on the polymer surface - to function, which chemical surface treatment cannot offer.

CF treated surface charge characteristics can assist the adhesion features or impart repulsion for chemical compounds, proteins, cells from interface through created active functional groups. Surface ammonia plasma treatment, for example, allows the enabling of covalent immobilization of cell-binding peptides derived from the extra cellular matrix proteins: fibrinogen, fibronectin, laminin, and the grafted peptides can provide an adequate matrix for the following cell migration.

Obligatory properties provided with CF deposition: the absence of toxicity, biocompatibility, and dispersed surface can give the possibility for the effectively TCL manufacturing,

Results

№	Polymer/deposition Conditions	Indicator m/o	Innoculation dose (cfu/ml)				
			10^5	10^4	10^3	10^2	10
1	PTFE: 1. treated CF_4 2. α-C:H (50 nm)	*Ps. aerug.*	+	+	+	+	±
		S. aureus	+	+	±	–	–
2	PTFE, smooth 1. α-C:H (50 nm)	*Ps. aerug.*	+	+	+	+	+
		S. aureus	+	+	+	+	+
3	PTFE: 1. treated CF_4 2. α-C:H (100 nm)	*Ps. aerug.*	+	+	+	±	±
		S. aureus	+	+	–	–	–
4	PTFE, smooth 1.α-C:H (100 nm)	*Ps. aerug.*	+	+	+	+	+
		S. aureus	+	+	+	–	–
5	PET: 1. treated CF_4 2. α-C:H (50 nm)	*Ps. aerug.*	+	+	+	+	+
		S. aureus	+	+	+	+	+
6	PET, smooth 1. α-C:H (50 nm)	*Ps. aerug.*	+	+	+	+	+
		S. aureus	+	+	+	+	+
7	PET: 1.treated CF_4 2. α-C:H (100 nm)	*Ps. aerug.*	+	+	+	+	+
		S. aureus	+	+	+	–	–
8	PET, smooth 1.α-C:H (100 nm)	*Ps. aerug.*	+	+	+	+	+
		S. aureus	+	+	+	+	–
9	PVDF: 1. treated CF_4 2. α-C:H (50 nm)	*Ps. aerug.*	+	+	+	+	±
		S. aureus	+	–	–	–	–
10	PVDF, smooth 1. α-C:H (50 nm)	*Ps. aerug.*	+	+	+	+	+
		S. aureus	+	–	–	–	–
11	PVDF: 1.treated CF_4 2. α-C:H (100 nm)	*Ps. aerug.*	+	+	+	–	–
		S. aureus	+	–	–	–	–
12	PVDF, smooth 1. α-C:H (100 nm)	*Ps. aerug.*	+	+	±	–	–
		S. aureus	+	–	–	–	–
13	PTFE(relief): 1. treated CF_4 2. α-C:H (100 nm)	*Ps. aerug.*	+	+	±	–	–
14	PTFE(relief), 1. α-C:H (100 nm)	Ps. aerug	+	+	–	–	–
15	PVDF(relief): 1. treated CF_4 2. α-C:H (100 nm)	*Ps. aerug.*	+	–	–	–	–
16	PVDF (relief), 1. α-C:H (100 nm)	*Ps. aerug.*	+	±	–	–	–

Table 1: Antimicrobial properties of samples.

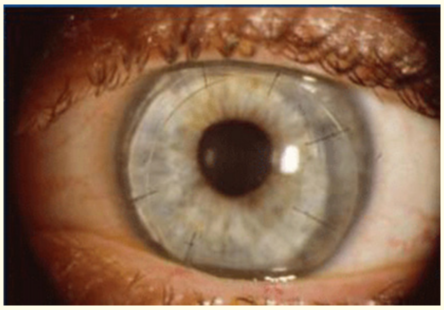

Figure 1: The patient, after through keratoplasty, with a spherical rigid gas-permeable lens, which can freely slide along the surface of the cornea, which, of course, is annoying and can slow down the healing process of the post operated cornea.

Figure 2: TCL is made from a polymer, in a form corresponding to the forme of cornea-scleral contact lens, of an segment, with an angle of surface, at least 164 degrees and no less, like an empirically asperic surface shape, smooth, without optical, peripheral, sliding and transitions between the zones, on ordinary production lines for the manufacturing of MCL; Parameters: diameter 18 mm, thickness 0.2-0.3 mm, radius of central curvature lenses 8.8, sagittal height 5.8-6.2 mm.

Discussion and Conclusions

Nanotechnology is a relatively new field of science, applicable to the creation of new materials with new characteristics and expansion of their scope. So, for example, these new technological capabilities open up prospects for a new approach to solving some medical problems through the programming of certain physical-chemical characteristics of the Nano-Modified Surface (NMS) designed to achieve the desired properties of the treated polymer surface, such as imparting aseptic properties to prevent the danger of the formation of components biofilms. In the early 90s, there was such a boom with the idea to treating many items and devices of medical and biological use with a nanofilm: joints (damaged and artificial, various silicone prostheses (chest, for example). But the silicone under the film coating decomposes with the release of poisonous silicone oil. Subsequently, for example, statistics were given on cases of malignant neoplasms in such patients with silicone prostheses. Thus, it was realized that, at the current level of technological capabilities, nanomodification of polymer surfaces is appropriate, for this period of deeper research and for the subsequent development of this direction in nanomedicine, for extracorporeal use, for a certain period of use in rehabilitation time; products with nanomodified polymer surfaces, such as: containers for aseptic storage and transportation, proper storage donor implants in special packaging, the manufacture of TCL for use for several days in the postoperative rehabilitation period, supported by patents for inventions.

The chemical - physical properties of NMS can contribute to the adhesive ability or repulsion, transferring chemical compounds, proteins, cells from the media interface, through the active functional groups of nanostructured surfaces. The physical-chemical properties of NMS are determined by the composition, atomic structure, and surface charge of the treated surface, and can affect the cells of the underlying NMS surface of living tissue, maintaining the polarization of the cell membrane and influencing the behaviour of the cells of the underlying tissue. This phenomenon can be successfully used both to restore the structure of the cornea and to control its correct path of regeneration. Epithelial and stromal cells of the cornea, having a different nature, change their shape and functional activity in different ways depending on the characteristics of the extracellular matrix, biochemical properties and geometric configurations.

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