·Clinical Research·

Study on the surface properties of surface modified silicone intraocular lenses

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Foundation item: A Foundation for the Author of National Excellent Doctoral Dissertation of PR China(No.10021201)
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Received:2011-10-10 Accepted:2012-01-17

Abstract

• AIM: To prepare a new-type soft intraocular lens (IOL) that silicone intraocular lenses (IOLs) were modified by surface modification technique to assess IOLs biocompatibility.

• METHODS: With the technique of ion beam combined with low temperature and low pressure plasma, the surface characteristics of the IOLs including physical and optical properties were determined by the instruments of IOLs resolution, UV/VIS scanning spectrophotometer, contact angle measurement system, electron spectroscopy for chemical analysis (ESCA) and scanning electron microscope (SEM).

• RESULTS: The color of titanium (Ti) modified IOLs was light yellow and that of titanium nitride (TiN) modified IOLs was light brown. The absorptive degree of ultraviolet rays and the hydrophilicity of the surfaces of modified IOLs were increased, and appeared suitable chemical compositions. The resolution of unmodified and modified IOLs reached normal standard. The surfaces of unmodified and Ti-modified IOLs appeared uniform. The surfaces of TiN-modified IOLs presented fine porcelain structure.

• CONCLUSION: The optical properties of all IOLs and the surface morphology of the modified IOLs were not affected by modification processes. The surface properties of the modified IOLs were improved.

• KEYWORDS: silicone; intraocular lenses; surface modification technique; surface property; biocompatibility
DOI:10.3980/j.issn.2222-3959.2012.01.17

Wang GQ, Gu HQ, Peng XJ. Study on the surface properties of surface modified silicone intraocular lenses. *Int J Ophthalmol* 2012; 5(1):84-87

INTRODUCTION

Combination of cataract phacoemulsification and soft intraocular lenses (IOLs) implantation has become a standard technique in sight restoration operation on cataract patients. However, at present, any type of medical biomaterials used could not satisfied with all the needs of clinical usage, completely reached and replaced the physiological requirements of normal human, the IOL is the same too. Silicone IOLs, a type of soft IOLs, are developed and applied to clinical in China firstly, with the properties such as soft texture, good mechanical elastisity, foldable, durability and biocompatibility, *etc* [1]. However, it still has some defects that are related to the surface properties like strong hydrophobic and adhesion. If these defects can be overcome, the IOLs will be applied in a wider clinical field. Titanium and titanium matrix composites are generally accepted for their better biocompatibility and has been widely applied in medical science. And ion beam technique is a new surface modification method developed in recent years. Therefore, for seeking a high quality material that adapts well to physiological properties and a wider application on clinic, we use the technique of ion beam combined with low temperature and low pressure plasma to make titanium (Ti) and titanium nitride (TiN) modification on the surface of soft silicone IOLs.

MATERIALS AND METODS

Materials The soft foldable silicone IOLs were provided by AMO company. Main instruments were multi- function ion beam apparatus (Institute of Electrical Engineering Chinese Academy of Sciences), ANSI Z80.7.1984 IOLs instrument (USA), JSM-25S scanning electron microscope,UV-VIS TU-1901 spectrophotometer, G1023-MK3 contact angle measurement system (Germany) and Perkin Elmer PHI 5600 ESCA System (USA).

Methods

Surface modification technique Cleaned foldable silicone IOLs were placed on 40-hole plate and set up into a vacuum container with multi-function ion beam.

After extracted vacuum, the surfaces of IOLs were washed at low-energy, sputtered on substrate, bombarded by ion beam, coated by sputtering product and modified double sides, thus the IOLs were coating with Ti- and TiN separately(each group 4 pieces IOLs).

Intraocular lenses resolution Ti-(4) and TiN-modified(4) IOLs and the unmodified IOLs(4) were separately placed on the bracket of detection instrument. We zoomed till the night-target was clear. All results of IOLs resolution were recorded.

Intraocular lenses ultraviolet spectrum The samples were placed on the 40-hole plate, only the optical part of 5.5mm in the center was exposed. The absorptive degrees of 200-380 UV were detected.

Intraocular lenses contact angle The sample IOLs were separately soaked in distilled water for 36 hours, took out and dried, placed on sample stage and dropped one drop distilled water. Contact angle was measured by Tangent Method-2. The results were analyzed with SPSS software package, F test.

Electron spectroscopy for chemical analysis The cleaned sample IOLs were stuck at bevel of sampling bar and directly radiated by X ray. Photoelectron entered into the electron energy analyzer through a slit of ionization chamber. Electron detector was used to map the atlases of energy distribution

Scanning electron microscope The IOLs were separately put into 2.5% $C_5H_8O_2$ (3% $(CH_2O)_n$, preparing by $C_2H_6AsNaO_2$, pH7.2) to make anterior fixation, and after washed by the same buffer, 1% OsO_4 was used to make posterior fixation. The samples were dehydrated in gradient ethanol, dried at CO_2 critical point in HCP- Ⅱ drying device, received Au target sputtering, 5-10nm thickness, by IB- Ⅲ ion beam sputtering equipment and observed under JSM-25S scanning electron microscope.

RESULTS

Surface Modification The color of Ti-modified IOLs was light yellow and that of TiN-modified IOLs was light brown.

Intraocular Lenses Resolution The resolutions of Un-, Ti- and TiN-modified IOLs were all 179 line pair/mm, which were accorded with the standard of IOLs resolution(≥156 line pair/mm).

Intraocular Lenses Ultraviolet Spectrum The UV absorptivity of Un-, Ti- and TiN-modified IOLs reached maximum at 220-280nm wavelength. And UV absorptivity of Ti-modified IOLs was higher than that of other two groups at 280-320nm wavelength (Figure 1).

Intraocular Lenses Contact Angle The contact angle of modified IOLs was small than that of unmodified IOLs and the surface hydrophilicity of modified IOLs was increased. There were significant statistical differences among the three groups (all P<0.01, Table 1).

Chemical Composition of Intraocular Lenses Surface ESCA analysis results of unmodified IOLs showed that the samples were very pure without any impurities. The chemical compositions of unmodified IOLs surface were C, O and Si atom (Figure 2A). The chemical compositions of Ti-modified IOLs were C, O, Si and Ti, of which Ti was existed on the form of TiO (Figure 2B). The chemical compositions of TiN-modified IOLs were C, O, Si, Ti and N (Figure 2C).

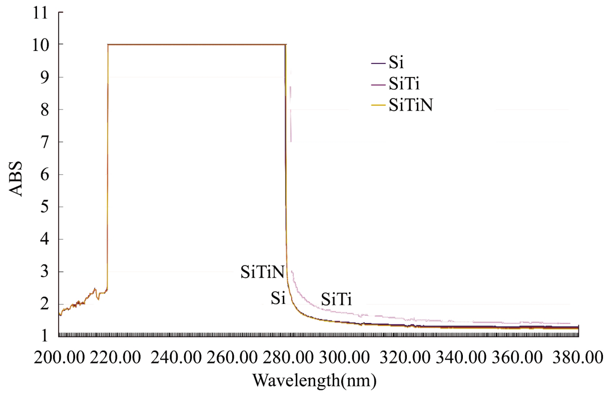

Figure 1 UV spectrum comparison of IOLs.

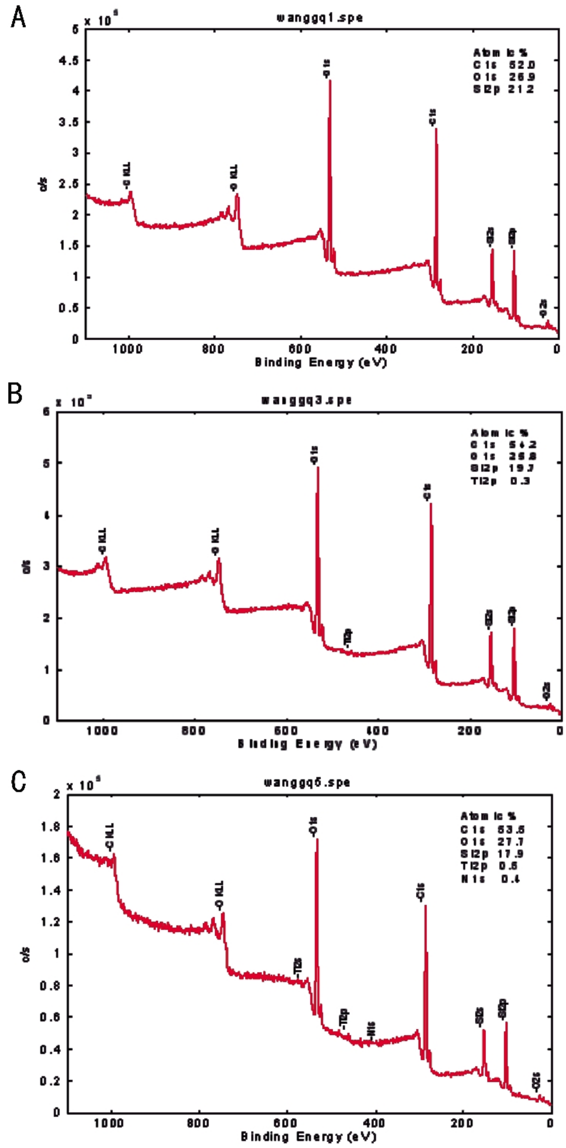

Figure 2 Chemical compositions of IOLs surface A: unmodified IOLs; B:Ti-modified IOLs; C:TiN-modified IOLs.

Table 1 The comparison of contact angle (degrees)

Groups	n	mean±SD
Unmodified	4	102.39±1.58
Ti-modified	4	95.75±1.16[b]
TiN-modified	4	92.25±1.88[a,c]

[a]P<0.05 TiN-modified *vs* Ti-modified, q=4.49; [b]P<0.01 Ti-modified *vs* unmodified, q=8.51; [c]P<0.01 TiN-modified *vs* unmodified, q=13.

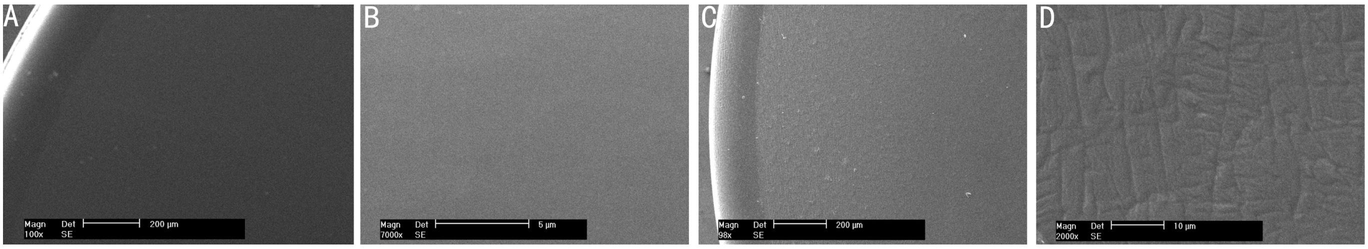

Figure 3 Surface morphology of IOLs A: Unmodified IOLs (×100); B: Ti-modified IOLs (×7000); C: TiN-modified IOLs (×98); D: TiN-modified IOLs (×2000).

Scanning Electron Microscope Unmodified IOLs surface was homogeneous without identifiable structure (Figure 3A). Ti-modified IOLs surface was also homogeneous with no morphology changes (Figure 3B). Fine texture like the glaze of fine porcelain was visible on TiN-modified IOLs surface (Figures 3C,D).

DISCUSSION

Biocompatibility means compatibility to life and is defined as "the capability of a prosthesis implanted in the body to exist in harmony with tissue without causing deleterious changes" [2-5]. The purpose of the modification on medical biomaterials' surfaces is to increase the biocompatibility and physiological activity. As for IOLs, an implant, the biocompatibility is the most essential condition. Ion beam, the most successful surface modification technique, has incomparable advantages which gains high attention on biomaterials surface modification research [6,7]. In this study, we used ion beam technique combined with low temperature and low pressure plasma to make Ti- and TiN-modification on silicone IOLs surface.

Titanium is the best metal material with excellent biological properties, such as high mechanical strength, corrosion resistance, biocompatibility and so on. For its wide application at various medical aspects, Ti affirmatively has a good prospect as biomedical engineering material [7-9]. Injecting nitrogen ion could improve corrosion resistance and abrasion resistance, so we prepared Ti and TiN film on IOLs surface used this kind of composite as implant. Therefore, the implant has not only IOLs' properties, but also less abrasion, corrosion resistance and better biocompatibility.

The color of Ti-modified IOLs was light yellow and that of TiN-modified IOLs was light brown, which was closer to the color of senile natural lens. By detecting the optical transparence, it was proved that the resolutions of surface modified IOLs were accorded with the standard of ≥ 156 line pair/mm, showed modification technique did not affect basic optical transparence.

There is interaction between the surface of implant and human body, so implant surface physicochemical properties will influence its biocompatibility and other functions. Meanwhile, for the implant surface contacting with tissues and cells of body directly, surface property is one of the most important criteria to evaluate the biocompatibility of medical materials [10].

Contact angle could be used to measure hydrophilicity and hydrophobicity and to evaluate IOLs biocompatibility [11,12]. The smaller contact angle is, the better hydrophilicity has. In this study, the contact angles of Ti-modified and TiN-modified IOLs were smaller than that of unmodified IOLs, thus the modified IOLs surface hydrophiliciy was increased with statistical significance.

Ultraviolet (UV) mainly comes from sunlight in nature and classified as UVC, UVB and UVA, in which UVB is considered to the strongest bioinjured ability, especially at 295-320nm wavelength, and has more ecology and medical significance [13,14]. The results showed that the UV absorptivity of Un-, Ti- and TiN-modified IOLs reached maximum at 220-280nm wavelength. And UV absorptivity of Ti-modified IOLs was higher than that of the other two groups at 280-320nm wavelength. With surface modification, IOLs UV absorptivity was increased a bit.

ESCA as a conventional surface analysis method has been applied to detect chemical composition, microimpurities and pollutants of polymer surface [15,16]. ESCA analysis results showed that the samples were very pure without any impurities. Ti existed on the form of stable phase-TiO, and the oxide film on the Ti-modified surface provided excellent corrosion resistance.

It will increase contiguous area between cells and material, if material has a granulated surface, it can improve cells' humidification function and affect adhesion intensity of the cells. That is to say when material surface has tiny notch or other microstructure, cells adhesion intensity will increase[17,18]. It was found that the unmodified IOLs surface was homogeneous without identifiable structure; Ti-modified IOLs surface was also homogeneous with no morphology changes; Fine texture like the glaze of fine porcelain was visible on TiN-modified IOLs surface; Ti- and TiN-modified film was homogeneous with no defects. Therefore, the surface modification technique will not affect IOLs surface conformation.

Biomedical material and biotechnology have become research front and focus in the 21st century. Surface modification is one of the important directions of biomedical material research. The results of this experiment showed that surface-modified silicone IOLs obtained suitable chemical composition, structural morphology and surface functions. Meanwhile, surface modification technique will not affect IOLs properties, thus ion beam technique combined with low temperature and low pressure plasma is a new and effective method for medical biomaterials surface modification.

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