In Vitro and In Vivo Assessment of Titanium Surface Modification for Coloring the Backplate of the Boston Keratoprosthesis

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PURPOSE. Recent use of a titanium (Ti) backplate has improved the design and biocompatibility of the Boston Keratoprosthesis (BKpro). Titanium’s shiny metallic appearance, however, makes the cosmetic outcome less favorable. The purpose of this study was to develop and test a coloring surface modification of Ti.

METHODS. Ti coloring was achieved using electrochemical anodization. Color assessment included scanning electron microscopy, atomic force microscopy (AFM), X-ray diffraction crystallography (XRD), and Fourier transform infrared spectroscopy (FTIR). Biocompatibility assessment of Ti disks included in vitro proliferation and cytotoxicity in coculture with human corneal limbal epithelial (HCLE) cells, primary human corneal fibroblasts, and immortalized human corneal endothelial cells (HCEnCs), and in vivo intralamellar implantation in rabbit corneas. Histologic appearance (hematoxylin-eosin and trichrome staining) and presence of cell inflammation (CD45), apoptosis (TUNEL), and neovascularization (CD31) were evaluated 27 and 53 days post implantation.

RESULTS. Blue and brown coloration of Ti was achieved. Analysis showed the presence of a nanoporous oxide surface with no chemical change of the modified Ti surface. In vitro assessment showed no significant differences in cell proliferation and cytotoxicity between anodized and nonanodized Ti (P > 0.05; ANOVA for all cell types). Analysis of corneal tissues harboring the Ti disks showed normal cellular appearance, and lack of CD45, TUNEL, and CD31-positive cells.

CONCLUSIONS. A biocompatible Ti backplate coloring was achieved by electrochemical anodization. In vitro and in vivo results suggest that the anodized Ti is equally biocompatible and as safe as the standard nonanodized Ti. The color modification of the BKpro may improve the cosmesis and acceptance of the BKpro by patients.

Keywords: keratoprosthesis, titanium, backplate, anodization, cornea

The Boston Keratoprosthesis (BKpro, Massachusetts Eye and Ear Infirmary) is an artificial cornea that is applicable for a broad array of corneal conditions not amenable to standard corneal transplantation.1 The device is designed like a collar button, with a plastic stem and a backplate supporting the donor corneal tissue. In the initial prototype, the BKpro was manufactured exclusively from medical-grade polymethyl methacrylate (PMMA). Following its Food and Drug Administration (FDA) approval for marketing in 1992, incremental steps and significant improvements have been made to the BKpro.2-3 It is now the most commonly used prosthetic cornea in the world, with approximately 7500 devices implanted worldwide to date (Dohlman CH, personal oral communication, 2013). Of those, roughly 5000 devices have been used in the United States. Although aesthetically acceptable due to its transparency, the PMMA design of the backplate can be associated with the formation of a retroprosthetic membrane and the congestion of the anterior chamber. The medical-grade titanium (Ti) backplate, introduced in 2005 at the Massachusetts Eye and Ear Infirmary, was found to be more biologically inert than PMMA.4 The Ti backplate implementation also resulted in marked improvement in retroprosthetic membrane formation5 and has enhanced the device by providing higher tensile strength, corrosion resistance, bio-inertness, ductility, and lightness (4.5 g/cm3). This new design contains a medical-grade Ti that is identical to the one used in orthopedic and dental prosthetics. However, despite the apparent advantages of Ti over PMMA, its metallic shiny silver appearance makes it less aesthetically desirable and socially acceptable by patients.

This study presents a surface modification technique of coloring the Ti backplates with an inert and biocompatible oxide layer. This modification was assessed in vitro using cell proliferation, cytotoxicity, and cell-coverage assays, as well as in vivo with histological morphology and immunohistochemistry of explanted rabbit corneas. Moreover, the Ti surface was characterized by scanning electron microscopy, x-ray diffraction crystallography (XRD), Fourier transform infrared spectroscopy (FTIR), atomic force microscopy (AFM), and chemical/color stability.
MATERIALS AND METHODS

Experimental disks were made of Ti 6-4, extra low interstitials (ELI) titanium-grade 23 (Ti-6Al-4V-ELI or Ti 6-4 ELI) containing 6% aluminum and 4% vanadium (ISO 9001:2008 certification; President Titanium Co., Inc., Hanson, MA); it is the same material used to manufacture the Ti backplate for the BKpro, currently under FDA review for marketing. This material is characterized by lower oxygen, nitrogen, and iron concentrations, with maximal oxygen content of 0.13% compared with other Ti grades, such as grade 5 (0.2%).

A computer numeric control microlathe was used to shape the Ti disks in the experiments. Two versions were made: a 3 mm in diameter \times 0.15 mm in thickness disk for animal implantation in vivo, and an 11 mm in diameter \times 0.15 mm in thickness disk for testing the cellular response to the anodization in vitro. The diameter of the 11-mm disks was adjusted so as to have a surface area equal to 50% of the area of each well on a 24-well plate (disk area: 0.95 cm$^2$, 24-well plate area: 1.9 cm$^2$). In addition to the standard polished Ti disc, an additional type was fashioned by surface sandblasting for reduction of the optical reflectance. The implantable sandblasted Ti backplate used for comparison was identical to those currently under FDA consideration.

Before anodizing, standard cleaning per BKpro manufacturer protocol was performed (Boston Keratoprosthesis SOP, WI-002 Rev.02, DCR 004) to remove residual debris. The coloring was achieved in a temperature-controlled circulating ionic solution (1 L dH$_2$O with 0.5% sodium tetraborate decahydrate at 58°C). In detail, the ionic bath was continuously circulated using an electromagnetic rotary pump made of inert polyvinyl chloride (PVC) material. The cathode was connected to a pure platinum mesh (Sigma-Aldrich Co. LLC, St. Louis, MO), submerged into the ionic bath, and the anode was connected to the target Ti disk. A direct current (DC) generator with maximum current of 3 amps was used to generate the oxidation and the field-driven ion diffusion that led to the formation of the oxide layer on the anode surface.

The main chemical reactions are shown below.

At the Ti/Ti oxide interface:

\[
Ti \leftrightarrow Ti^{2+} + 2e^- 
\]

At the Ti oxide/electrolyte interface:

\[
2H_2O \leftrightarrow 2O^{2-} + 4H^+ \\
2H_2O \leftrightarrow O_2 + 4H^+ + 4e^- 
\]

At both interfaces:

\[
Ti^{2+} + 2O^{2-} \leftrightarrow TiO_2 + 2e^- 
\]

The thickness of the oxide film growth was linearly proportional to the voltage bias (1.5 nm/V), as performed previously. The variation in the oxide film thickness resulted in coloration of the Ti due to constructive and destructive light interference. This method excludes the use of dyes or other chemical substances that can potentially leak and cause toxicity to the cells and tissues. The color is solely based on the controlled thickness of the Ti oxide layer.

Characterization of the anodized Ti was undertaken using scanning electron microscopy, XRD, FTIR, and AFM, as previously described. High-resolution scanning electron microscopy images (10 nm) were acquired using the field emission scanning electron microscopy (FESEM) Ultra Plus (Carl Zeiss Microscopy GmbH, Jena, Germany) for surface morphology evaluation as previously described.

The homogeneity of the oxide film was assessed using atomic resolution topography images acquired by the Asylum-1 MFP-3D AFM (Asylum Research, Santa Barbara, CA). The type of the Ti oxide film was evaluated using the Scintag XDS2000 XRD (Scintag, Inc., Cupertino, CA), while the surface chemistry was analyzed at the molecular level using the Perkin Elmer FTIR (Perkin Elmer, Inc., Waltham, MA). In addition, chemical and color stability was assessed after exposure to 70% alcohol at room temperature for 3 months.

FIGURE 1. Successful implementation of the electrochemical anodization for coloring the titanium (blue and brown). Anodized and nonanodized Ti backplates (left), panoramic \times 4-magnification images (right top row) of sandblasted Ti disks with diameter of 11 mm, as used in the in vitro experiments and \times 20-magnification images (right bottom row).
FIGURE 2. XRD patterns (left column) and FTIR spectroscopy (right column) of nonanodized Ti (a), blue (b), and brown (c) Ti disks. The anodized Ti has the same crystal composition as the nonanodized, as measured by XRD, made of a mixture of anatase and rutile phases. Surface chemistry analysis with FTIR showed identical surface chemistry between the anodized and nonanodized Ti (c), suggesting similar cell interaction.
In Vitro Assessment

The biocompatibility of the Ti was assessed in vitro in coculture with immortalized human corneal limbal epithelial (HCLE) cells, primary human corneal fibroblasts, and immortalized human corneal endothelial cells (HCEnCs). Three separate experiments were conducted using HCLE cells with the following material modifications:

1. Polished 11-mm Ti disks: nonanodized, blue color anodized, and brown color anodized;
2. Sandblasted 11-mm Ti disks: nonanodized, blue color anodized, and brown color anodized;
3. Sandblasted BKpro Ti backplates: nonanodized, blue color anodized, and brown color anodized.

Similar experiments were performed with primary human corneal fibroblasts and HCEnCs using immobilized sandblasted Ti disks. The disks were preimmobilized on the bottom of the culture wells so as to avoid movement while changing media. A small amount of polydimethylsiloxane (PDMS; approximately 100 nL) was used to anchor the disks. PDMS is a biocompatible polymer and was used only at the center of the disks, minimizing direct contact with the cells.

Triplicates of each Ti variation were placed in a 24-well plate and incubated together with HCLE cells for 4 days in 37°C humidified, 5% CO₂ atmosphere. The initial cell population was 1 × 10⁴ cells/cm², as measured by the Countess Automated Cell Counter (Life Technologies Corporation, Grand Island, NY). The nonanodized Ti disks or backplates served as material controls, whereas positive and negative cell controls were used either by plating cells alone or using the feeding medium alone. Cell proliferation (CellTiter 96 AQ One Solution Cell Proliferation Assay; Promega, Madison, WI) and cytotoxicity assays (CytoTox 96 Nonradioactive Cytotoxicity Assay; Promega) were used for biocompatibility assessment, as previously described.

The epithelial cell coverage of the Ti was assessed using 1% Rose Bengal staining dye (Sigma-Aldrich Co. LLC) as previously described.

In Vivo Assessment

All animals in this study were used in accordance with the ARVO Statement for the Use of Animals and were approved by the Massachusetts Eye and Ear Infirmary Animal Care Committee (Boston, MA).

The biocompatibility of the sandblasted Ti disks, with and without anodization, was assessed in rabbit corneal pockets for 27 and 53 days. The experiment included six eyes of six rabbits with Ti implantation and one surgical control. Two eyes received nonanodized Ti disks, two received blue anodized Ti disks, and two received brown anodized Ti disks. All disks were 3 mm in diameter and sandblasted. The surgical control received a corneal pocket without a Ti disk implantation.

Dutch belt pigmented rabbits (Millbrook Farm Breeding Laboratory, Amherst, MA) were anesthetized using intramuscular injection of ketamine HCl (35 mg/kg) and xylazine HCl (10 mg/kg). Proparacaine HCl 0.5% was applied topically into the conjunctival sac of the eye. Using aseptic precautions, one eye was prepared in the usual ophthalmic fashion (lid areas were cleaned with 10% povidone-iodine, one drop of 5% povidone-iodine was applied on the ocular surface, and a lid retractor was placed). The animals were placed in a laterally recumbent position for visualization under the surgical ophthalmic microscope (Carl Zeiss Surgical GmbH).
A superior clear corneal intralamellar pocket was constructed using a 2-mm, 45-degree angled bevel up 20-gauge crescent blade. At the end of each procedure, a temporary tarsorrhaphy was performed to protect the cornea and prevent dryness on the surface. Topical medications were administered for 1 week, including trimethoprim/polymyxin B (Polytrim; Allergan, Irvine, CA) twice a day, and prednisolone acetate ophthalmic suspension, USP 1% (Pred-Forte; Allergan) once a day. Rabbits were photographed every 5 days using a digital camera (Nikon D90 SLR; Nikon, Inc., Melville, NY) mounted on the surgical microscope (Carl Zeiss Surgical GmbH, Oberkochen, Germany). The animals were evaluated daily for signs of distress or ocular infection.

The animals were euthanized and the corneas were harvested for further evaluation at two time points: 53 days post implantation \((n = 3 + 1\) surgical control) and 27 days post implantation \((n = 3)\). The corneas were fixed for 2 hours in 4% paraformaldehyde. Dividing the area over the Ti disk implant, half of the tissue was embedded in paraffin for histologic evaluation using hematoxylin and eosin (H&E) and trichrome stains, while the other half was embedded in optimal cutting temperature (OCT) medium for CD45 and TUNEL immunolocalization assessment. Corneal neovascularization (NV) was evaluated under the dissecting microscope (Carl Zeiss Surgical GmbH) and with CD-31 antibody immunolocalization of corneal tissue sections (Carl Zeiss Surgical GmbH).

**Statistical Analysis**

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS), version 13.0 (SPSS, Inc., Chicago, IL). The normality of continuous variables was tested with a Shapiro-Wilk test. Quantitative variables were expressed as the mean \(\pm\) SD and qualitative variables were expressed as frequencies and percentages. The two-way mixed analysis of variance was performed to assess differences in cell cytotoxicity and proliferation between the anodized and nonanodized Ti disks. All tests were two-tailed and statistical significance was considered for \(P\) values less than 0.05. Bonferroni
correction was applied according to the order of multiple comparisons.

**Results**

**Anodization**

To color modify the Ti, a film of titanium oxide was formed on the surface of the Ti, resulting in blue and brown color. The film thickness was controlled by the applied voltage between the anode and the cathode. The anodization process was completed when the ohmic drop in the oxide film (dielectric) was equal to the applied voltage between the anode and cathode. Blue and brown colors were achieved using 30.0 and 16.5 volts respectively, at a maximum supplied current of 3 amps (Fig. 1).

To assess the crystal composition and surface chemistry of the anodized Ti oxide film, XRD and FTIR analysis were performed. The resulting patterns indicated a mixture of anatase and rutile phases for anodized and nonanodized disks. Blue- and brown-colored Ti oxide exhibited identical crystal phases. Similar results were obtained with the nonanodized Ti, in which the naturally formed oxide was similar to the anodized. The surface analysis of the anodized and non-anodized Ti oxide exhibited identical FTIR patterns, suggesting identical surface chemistry properties (Figs. 2a–c).

For the analysis of the surface topography of the anodized Ti, scanning electron microscopy images were taken. The analysis depicted the presence of low-density nanoporous oxide film, homogeneously covering the entire surface area of the disk (Figs. 3a, 3b). In an attempt to further analyze the surface topography, AFM imaging was employed. However, due to the high surface anomaly of the sandblasted Ti and the inherent atomic-level resolution of the AFM system, the analysis failed to provide usable information. On the contrary, AFM was performed successfully on control polished disks showing concentric marks from the lathe processing of the alloy (Fig. 3c).

Finally, the stability of the oxide film was assessed by submersion of the anodized disks in 70% alcohol for 3 months. No change in color was noted, indicating color stability over time (data not shown).

**In Vitro Assessment**

To test the biocompatibility of the anodized Ti, we first compared Ti with and without anodization using cell proliferation and cytotoxicity assays. Standard proliferation and cytotoxicity curves were generated using serial dilution of HCLE cells, corneal fibroblasts and HCEnCs obtained after their labeling for proliferation of cytotoxicity using the CellTiter 96 AQuueous One Solution Cell Proliferation Assay and the CytoTox 96 Non-Radioactive Cytotoxicity Assay (Promega).

HCLE: \( R^2 = 0.977, Y = 0.086 + 2.936 \times 10^{-6}X \) [proliferation]; \( R^2 = 0.998, Y = 0.109 + 5.724 \times 10^{-3}X \) [cytotoxicity].

Fibroblasts: \( R^2 = 0.868, Y = 0.443 + 1.569 \times 10^{-4}X \) [proliferation]; \( R^2 = 0.995, Y = -0.003 + 1.804 \times 10^{-2}X \) [cytotoxicity].

HCEnC: \( R^2 = 0.908; Y = 0.144 + 4.444 \times 10^{-6}X \) [proliferation]; \( R^2 = 0.992; Y = 0.966 + 1.092 \times 10^{-3}X \) [cytotoxicity].
All standard curves exhibited satisfactory linearity as suggested by the adjusted $R^2$. No significant differences in cell proliferation or cytotoxicity were found between the cell lines cocultured with surface anodized and nonanodized Ti ($P > 0.05$; ANOVA for all cell types) (Fig. 4). Cell morphology was similar in the anodized and nonanodized disks, as well as in the polished and sandblasted disks using HCLE cells (Figs. 5a, 5b).

Epithelial cell coverage of the Ti, by Rose Bengal staining, showed variable cell distribution between the polished and sandblasted disks. Polished disks appeared to have larger area covered with HCLE cells, exhibiting increased density at the center, whereas sandblasted disks appeared to have less area covered, with more uniform distribution (Figs. 6a, 6b). No difference in cell coverage was found between anodized and nonanodized Ti, using either corneal fibroblasts or HCECs. In fact, cell coverage ranged from 85% to 100% (Figs. 6c, 6d) of the disk area, with cell morphology comparable to the control wells (Fig. 6e). The proliferation on the polished disks was significantly higher than on the sandblasted disks ($P < 0.001$) (Figs. 7a, 7b); however, no difference was found using HCECs, presumably due to the immobilization of the Ti disks in this experiment (Fig. 7c).

**In Vivo Assessment**

To further evaluate the biocompatibility of the anodization, the interaction with corneal tissue was assessed in rabbits. Anodized and nonanodized sandblasted Ti disks were compared in seven rabbit eyes. Six eyes received either a nonanodized ($n = 2$), blue anodized ($n = 2$), or brown anodized ($n = 2$) Ti disk, 3 mm in diameter. One rabbit was used as surgical control, in which a corneal pocket was formed.

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**Figure 6.** Cell coverage of the Ti disks assessed using Rose Bengal staining. HCLE cell coverage on (a) polished and (b) sandblasted Ti disks. Covered area is notably higher in polished disks compared with sandblasted disks. Anodization had no obvious effect on cell coverage that was driven by surface topography roughness. Cell coverage ranged from 85% to 100% with (c) corneal fibroblasts and (d) HCECs. (e) Endothelial cell morphology was no different between anodized and nonanodized Ti (photos with ×20 magnification of the edge of the Ti disks).
but no disk was implanted. All disks were placed in the intralamellar space approximately 3 mm off the center superiorly. All surgical procedures were uneventful with no intraoperative or postoperative complications.

At the end of the study, the corneas harboring the Ti disks and the surgical control were harvested for further evaluation using H&E and trichrome staining. No differences were found between the groups, all having normal morphological appearances (Figs. 8a–c). No signs of ocular inflammation or neovascularization were noted during the follow-up period. In addition, no epithelial defects or incidents of corneal melting were noted (Fig. 8c).

**TUNEL, CD45, and CD31 Immunolocalization**

Apoptotic cells were not present in any of the corneas with the implanted Ti disks or the surgical Ti control, as indicated by lack of TUNEL labeling. To provide a labeling control, a naive rabbit cornea was treated with DNase. Apoptotic cells were found in this positive control group (Fig. 9a, 9b).

To assess the presence of inflammatory cells at the tissue site harboring the disks, anti-CD45 antibody was used to identify infiltrating immune cells. No CD45-positive cells were found in the corneas harboring the anodized Ti disk. Similar results were obtained using the nonanodized Ti disks. A positive control (rabbit spleen) was used for comparison (Fig. 9a, 9b). The presence of neovascularization was assessed using CD31 immunolocalization for vascular endothelial cells. No CD31-positive cells were present in the tissue sections harboring the Ti disks (results not shown). No corneal neovascularization was evident in the examinations using the ophthalmic and dissecting microscope (Fig. 9).

**DISCUSSION**

This study demonstrates the successful implementation of electrochemistry (anodization technique) for improving the cosmetic outcome of the Ti backplate in BKpro. Colored contact lenses can also be used to improve cosmesis, but are generally expensive and require regular replacement. Ideally, we could preclude the necessity of a colored contact lens by coloring the backplate.

The anodization technique was evaluated and compared with the standard nonanodized Ti. Analysis was undertaken to characterize the coloring based on its crystal type and surface properties. In addition, the biocompatibility of the anodization was assessed in cell cocultures using human corneal epithelial, human corneal fibroblasts, and HCEnCs and in vivo corneal pockets in rabbit eyes, to further elucidate the biological and immunological interactions.

Two main colors were created using anodization, a well-established technique for surface treatment and surface passivation in orthopedic and dental implants. The color change was based on the thickness of the oxide film, controlled by the voltage between the anode and cathode. One of the advantages of this coloring technique is that it eliminates the need for dye coloring, because the oxide film acts as a selective filter, performing constructive and destructive light interference.

The Ti oxide layer forms spontaneously on the surface of the metal on exposure to air. This natural process provides excellent chemical inertness, corrosion resistance, repassivation ability, and biocompatibility of Ti. The oxide layer is typically 2 to 5 nm thick and is responsible for the well-documented corrosion-resistance property of Ti and its alloys.16,17 Previous reports have shown that the naturally occurring oxidization of pure Ti is not appropriate for biomedical applications and some surface modification is necessary.17 Normal manufacturing steps of Ti usually lead to an oxidized, contaminated surface layer that is often stressed and plastically deformed, nonuniform, and rather poorly defined. It is for these reasons that further and controlled oxidization is suggested before implantation.

In this study, several advanced techniques were used to analyze the anodization of Ti-6Al-4V-ELI titanium. The characterization included assessment of the crystal type using XRD, surface chemistry using FTIR, surface topography using AFM and scanning electron microscopy, and chemical color stability by exposure to 70% alcohol for 3 months. Both the XRD and the FTIR showed that the oxide film that results from the anodization process has the same crystal phase and shares the same surface chemistry as the native oxide Ti film. Thus, the difference between the colored and noncolored anodized Ti is the thickness of the oxide film, which is precisely controlled during the anodization process.
The surface topography, assessed using AFM microscopy on polished Ti disks, showed machinery marks with concentric circles, resulting from the lathing process. Unfortunately, AFM on sandblasted Ti had less translational meaning due to the increased roughness for meaningful AFM measurements. Thus, scanning electron microscopy was used for the sandblasted anodized Ti and showed a homogeneous oxide film with low-density nanometer porosity across the surface. These results are consistent with previously published reports on surface topography after Ti electrochemical anodization.

In addition, Ti color after prolonged exposure to ethanol was stable, demonstrating that the passivation oxide film is resistant to degradation.

The in vitro assessment of the biocompatibility of Ti anodization was assessed using chromogenic assays of 3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide and lactate dehydrogenase, as previously described. No differences were found in HCLE cell proliferation and cytotoxicity between anodized and nonanodized Ti (P < 0.98 for proliferation and P < 0.53 for cytotoxicity; ANOVA), suggesting that the color anodization does not alter the biocompatibility of Ti. Our results also showed differences in cell proliferation and coverage between polished and sandblasted Ti disks. These differences were likely due to the surface topography, results that are in concordance with previous studies. With the anchoring of the Ti disks in the wells, we were able to eliminate differences in proliferation and cytotoxicity that were previously seen with the HCLE cells. Immobilized Ti disks, cocultured with corneal fibroblasts or HCEnCs, showed equal proliferation and cytotoxicity levels between anodized and nonanodized disks. In addition, the results of the wells with the Ti disks or cells only were equal, suggesting that titanium, anodized or nonanodized, is well tolerated by HCEnCs and human corneal fibroblast cells. Presumably, small disk movements during cell media change may have caused cell stress in the HCLE cell experiment, reducing the proliferation and increasing the apparent cytotoxicity in vitro. However, no such difference was observed using fibroblasts and HCEnCs, the most relevant cells for the backplate in vivo, signifying the importance of anchoring the disks in such experiments.

In vivo assessment of biocompatibility was performed with intralamellar implantation of the Ti disks into rabbit eyes. To avoid the inevitable inflammation associated with a full-thickness corneal implantation, we chose intralamellar implantation to assess the biocompatibility of the anodized titanium. Analysis of the explanted corneas, harboring the anodized and nonanodized Ti disks, was performed at two time points (27 and 53 days post implantation). Both time points confirmed the biocompatibility of the anodized Ti, as assessed with TUNEL, CD45, and CD31 assays. In addition, histological examination of the tissues harboring the anodized and nonanodized Ti disks showed normal cell and tissue morphology.

The above findings suggest that the Ti anodization technique is biocompatible with no evidence of abnormal interaction with the harboring tissue. This suggests that Ti anodization is a feasible biocompatible method to modify the color of the Ti for the BKpro backplates.

**CONCLUSION**

In conclusion, electrochemical anodization of Ti is a safe, simple, low-cost, and reproducible technique for coloring and
improving the cosmesis of the BKpro Ti backplate. The surface anodization was proven biocompatible and equally as safe as the nonanodized pure Ti, currently under FDA consideration for marketing as a backplate for the BKpro.

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