UNIVERSIDADE ESTADUAL DE CAMPINAS
Faculdade de Odontologia de Piracicaba

BRUNA GABRIELA ARAÚJO XIMENES

O IMPACTO DAS ETAPAS LABORATORIAIS NO ESPELHAMENTO E ALTERAÇÃO CROMÁTICA DE PRÓTESES OCULARES

THE IMPACT OF LABORATORY STEPS ON MIRRORING AND CHROMATIC CHANGES OF OCULAR PROSTHESES

PIRACICABA

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Tese apresentada à Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas como parte dos requisitos exigidos para a obtenção do título de Doutora em Clínica Odontológica, Área de Concentração Prótese Dental.

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Orientador: Profª. Drª. Celia Marisa Rizzatti Barbosa

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RESUMO

A reabilitação ocular reinsere o indivíduo na sociedade e o grande impacto estético dessas próteses depende do quanto a mesma pode ser dissimulada. Dentre as diversas estruturas do olho artificial, a íris é a principal responsável por esta dissimulação, podendo ser comprometida pela alteração cromática e espelhamento. Apesar de ser um problema corriqueiro, ainda são necessários estudos que analisem detalhadamente os modos de falha das próteses oculares e encontrem protocolos laboratoriais que aumentem o sucesso dessa reabilitação. Com o intuito de verificar o impacto das etapas de produção da prótese no comprometimento estético, foram delineados dois estudos: I) Estudo in vitro que avaliou a influência do material de selamento das íris artificiais no espelhamento das próteses oculares. Após a obtenção de amostras em tamanho real por duas técnicas de pintura (direta e indireta) e selamento destas com três tipos de materiais (acetato de vinila, monopoli e cianoacrilato+polímero), a área de comprometimento pelo espelhamento foi quantificada através do software ImageJ com imagens obtidas em estereomicroscópio e complementado qualitativamente por imagens internas entre as camadas da prótese por microscopio eletrônica de varredura (MEV). II) Estudo in vitro que avaliou o impacto de diferentes tipos de polimerização na estabilidade cromática e espelhamento dos olhos artificiais. Nesse estudo, as amostras foram obtidas por diferentes técnicas de pintura (direta e indireta) e três tipos de polimerização da resina acrílica escleral (química, térmica convencional e microondas), onde o espelhamento foi avaliado por imagens de estereomicroscópio e quantificado pelo *software ImageJ* e a alteração cromática foi avaliada antes e após o ensaio de envelhecimento acelerado (AAA) através de espectrofotômetro de reflexão. Os resultados do estudo I mostraram que o material de selamento das íris artificiais está diretamente relacionado ao espelhamento, sendo a associação do acetato de vinila com a técnica direta (DV) não apresentou índices de comprometimento (0,00 ± 0,00). No estudo in vitro II, observamos que a técnica direta não apresentou espelhamento, independente do tipos de polimerização utilizada. Todos os processos de polimerização apresentaram alterações de cor, tendo-se obtido os menores valores no grupo que associou a técnica direta com termopolimerização convencional (1,028 ± 0,52). Diante dos resultados conclui-se que o bom desempenho estético dos olhos artificiais está intimamente relacionado às etapas laboratoriais de confecção da prótese, sendo o uso de acetato de vinila como material selador, técnica direta de pintura e termopolimerização convencional as melhores escolhas para os menores índices de espelhamento e alteração cromática.

Palavras-chave: Olho artificial; prótese ocular; cor; envelhecimento.

ABSTRACT

Ocular rehabilitation reinserts individuals in society and the great aesthetic impact of these prostheses depends on how it can be concealed. Among several structures of the artificial eye, the iris is the main responsible for the concealment, which might be compromised by chromatic alteration and mirroring. Although it is a common problem, studies have not sought to analyze in detail the failure modes of ocular prostheses and search for solutions to determine laboratory protocols that increase the success of this rehabilitation. In order to verify the impact of the production stages of the prosthesis on the aesthetic commitment, two different studies were delineated: I) In vitro study that evaluated the influence of the sealing material of the artificial irises on mirroring of the ocular prostheses. After obtaining actual size samples by two painting techniques (direct and indirect) and sealing them with three types of materials (vinyl acetate, monopli and cyanoacrylate + polymer), the area of commitment by the mirroring was quantified through ImageJ software with images obtained in stereomicroscope and complemented qualitatively by internal images between the layers of the prosthesis by scanning electron microscopy(SEM). II) In vitro study that evaluated the impact of different types of polymerization on the chromatic stability and mirroring of the artificial eyes. In this study, the samples obtained by different painting techniques (direct and indirect) and three types of polymerization (chemical polymerization, conventional thermal and microwave), where the mirroring was evaluated by stereomicroscope images and quantified by ImageJ software, followed by quantification of chromatic changes variation was evaluated before and after the accelerated aging test (AAA) through a reflection spectrophotometer. The results of study I showed that the artificial iris sealing material is directly related to the mirroring, and the association of vinyl acetate with direct technique (DV) did not present mirroing values. In vitro study II, we observed that the direct technique did not present mirroring, independent of the types of polymerization used. All types of polymerization showed color changes, obtaining the lowest values in the group that associated the direct technique with conventional thermopolymerization (1.028 ± 0.52). In view of all the compiled results, it is concluded that the good aesthetic performance of the artificial eyes is closely related to the laboratory stages of prosthesis making, with the use of vinyl acetate as a sealant material, direct painting technique and conventional thermopolymerization the best choices for the lowest indexes of mirroring and chromatic alteration.
Keywords: Artificial eye; ocular prosthesis; color; aging.

SUMÁRIO

1 INTRODUÇÃO

O olhar identifica o ser humano e o comunica com o meio externo. A desfiguração e assimetria desta região em consequência de lesões congênitas, traumáticas ou oncocirurgicas provocam desequilíbrio estético, culminando em transtornos social e pessoal (Mark&Lemon, 2001; Jain *et al*, 2010; Goiato *et al.*, 2013). O impacto direto e profundo na autoestima, interfere nos relacionamentos interpessoais, dificultando o estabelecimento de vínculos afetivos e organização da vida frente às novas circunstâncias, além do sentimento de inferioridade e rejeição em relação ao meio de convivência. A restauração estética e funcional atenua o comprometimento que a perda tecidual provoca, pois a face é a região de identificação do indivíduo, e os olhos nela contidos, o fator de maior relevância nesta identificação e o foco principal das relações interpessoais. (Song *et al.*, 2006; Pine *et al*, 2011; Goiato *et al.*,2013).

A reabilitação estética dos pacientes que sofreram enucleação ou evisceração do globo ocular é feita através de próteses oculares, sendo esta uma alternativa segura, estética e satisfatória de tratamento (Soares, 2010). Uma vez que a visão não pode ser reconstituída por meios artificiais, a peça protética recupera aloplasticamente a estética da face, restaurando e embelezando o rosto cuja expressão fora comprometida. Além disso, a prótese ocular também promove a sustentação da tonicidade muscular da pálpebra superior, evita o empastamento de cílios e a ressecamento da conjuntiva, dirige o lacrimejamento ao seu ducto excretor fisiológico, impede o colapso palpebral, protege a cavidade contra agressões externas como poeira, fumaça e outros poluentes e reduz o acúmulo de fluidos na cavidade anoftálmica (Taylor, 2000). É responsável, também, pela reintegração do indivíduo à sociedade, livrando-o dos entraves impostos pelo preconceito contra a deficiência, devolvendo ao usuário uma condição de conforto com relação ao seu convívio social e aceitação de sua deformidade, melhorando significativamente sua qualidade de vida (Song *et al.*, 2006).

Por ser uma prótese com impacto primordial voltado à estética, seu sucesso está intimamente vinculado ao quanto essa prótese pode ser dissimulada. Esse disfarce pode ser alcançado através da mobilidade da prótese, mas principalmente ao perfeito comportamento biomimético da íris pintada e dos componentes resinosos resultantes da sua confecção e frente ao envelhecimento pós operatório (Brown *et al.*, 1970; Da Costa *et al.*, 2017). Para que este resultado biomimético seja favorável, torna-se imprescindível o conhecimento e o domínio dos biomateriais, bem como critérios técnicos e artísticos na reprodução dos detalhes.

Na confecção do olho artificial, a pintura da íris artificial é o passo mais delicado que requer método e rigor técnico. A coloração realística e a estabilidade de cor das próteses são características cosméticas primordiais para a reabilitação, que devem ser observadas logo após sua confecção e também durante o uso contínuo ao longo do tempo (Taylor, 2000; Goiato *et al*., 2010; Da Costa *et al*., 2017). A íris artificial pode sofrer comprometimento estético, seja após a confecção, com o espelhamento, ou alterações de cor decorrentes do envelhecimento por ação da exposição aos fluidos e à radiação ultravioleta (Pannat, 1946; D'Almeida, 2002; Goiato et al., 2009; Bannwart *et al.,*2013). Ambas as situações podem culminar com a indicação da confecção de nova prótese, mesmo quando esta ainda apresenta uma boa adaptação.

O espelhamento se apresenta como artefato que compromete esteticamente o trabalho, apresentando-se como bolhas que se formam entre a tinta e a calota, resultando em um efeito óptico de reflexão semelhante a um espelho (Pereira, 2007). Esta alteração pode inviabilizar todo o trabalho realizado pelo impacto negativo significativo na dissimulação da prótese. Acredita-se que a omissão ou falha no selamento da pintura da íris seja a principal causa do comprometimento da pintura pelo contato com resina escleral adjacente (D'Almeida, 2002; Pereira, 2007). Porém, apesar de ser um problema presente na rotina laboratorial, a literatura reporta apenas análises qualitativas do comportamento visual e microscópico entre as camadas da prótese, impossibilitando a identificação precisa das possíveis causas e, consequentemente, inviabilizando soluções para essa alteração.

No que tange ao desempenho das próteses frente ao envelhecimento, a fotodegradação das cores na pintura da íris protética é um problema corriqueiro. Estudos com envelhecimento acelerado e avaliação colorimétrica têm demonstrado a instabilidade de algumas cores de pigmentos e tintas frente à radiação ultravioleta (Silva&Carvalho 1994; D'Almeida 1999; Alves &Carvalho 2004; Fernandes *et al*, 2005; Kawabata, 2006;), podendo estar vinculado à qualidade da tinta utilizada, às diferenças entre as técnicas de pintura do botão da íris artificial e até ao processo de polimerização.

Os processos convencionais de polimerização das resinas acrílicas demandam a cura por ativação química ou térmica, seja por fonte de energia externa através do calor úmido, ou por agitação molecular, através de ondas eletromagnéticas. Ciclos de polimerização foram criados e avaliados, variando-se o tempo, temperatura da água de imersão da resina e de exposição a ondas eletromagnéticas; porém pouco se sabe sobre o impacto destes processos no comportamento estético da prótese ocular (Reis *et al*., 2008; Canadas *et al*., 2010). Apesar da vasta gama de estudos analisando isoladamente a alteração de cor da íris, pouco se atentou ao impacto dos diferentes tipos de polimerização sobre a estabilidade da lâmina de pintura e espelhamento da peça protética. O estudo destes fatores podem impactar na escolha do material com o melhor comportamento frente as etapas de produção da prótese que não comprometa a íris protética, prevenindo a ocorrência de fatores limitantes na longevidade da prótese ocular, como o comprometimento estético do olho artificial.

Este trabalho objetiva, através de análises *in vitro*, comparar as técnicas mais utilizadas na confecção de próteses oculares, avaliando o espelhamento da íris e suas possíveis causas, bem como a alteração cromática das íris artificiais frente o envelhecimento acelerado, buscando assim o desenvolvimento de protocolos de confecção de próteses oculares que permitam satisfazer com rapidez e excelência a demanda de atendimento de pacientes portadores de perdas do bulbo ocular, bem como a obtenção de próteses oculares com melhores qualidades estéticas.

2 ARTIGOS

2.1 ARTIGO –

The influence of sealing material and painting technique on "mirroring" of ocular prostheses

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2.2.1 ABSTRACT

Ocular rehabilitation reinserts individuals into society. The great aesthetic impact of these prostheses depends on how it can be disguised. Failures obtained from the manufacturing process or use, such as chromatic changes and "mirroring", may disrupt the camouflage, compromising the rehabilitation. Mirroring is a reflective optical effect that directly affects the concealment of the prosthetic eye, but there are no studies that analyze this problem in detail and seek solutions. The objective of this study was to evaluate the influence of the sealing material of iris paint applied in different painting techniques on mirroring by ocular prostheses. From a model of an anophthalmic cavity, 60 specimens were prepared, varying the painting technique and the sealing material (n = 10): direct paint / vinyl acetate (DV) painting technique; direct painting technique / sealing with monopoly (DM); direct painting / sealing technique with cyanoacrylate and polymer (DC); indirect painting / vinyl acetate (IV) sealing technique; indirect painting / cyanoacrylate and polymer (IC) sealing technique; and indirect painting technique / sealing with monopoly (IM). Iris images were obtained using a stereomicroscope (Stemi DV4 / DR; Zeiss, Jena, Germany), followed by quantification of the compromised area by mirroring with ImageJ software. The qualitative analysis was performed by analyzing the behavior between the resin / paint / sealant layers of each group by scanning eletron microscopy (S.E.M., JEOL, JSM 5600 pv, Japan). Data were analyzed by the SAS program procedure GENMOD considering a significance level of 5%. Statistically significant differences were observed between groups ($p < 0.05$). The vinyl acetate associated with the direct technique did not present a mirroring index, presenting the best performance among the materials, followed by monopoly and cyanoacrylate / polymer in the indirect technique. Ultra-structurally, the excellent relationship of vinyl acetate with scleral resin and the direct painting technique was verified, without the presence of a failure between them, which was not the case in all other groups. The choice of technique and sealing material have a direct effect on the compromise of the prosthetic iris by mirroring; among the combinations studied, the direct technique with acrylic paint and vinyl acetate as the sealant material presented the lowest mirroring indexes and consequently the bests results for clinical application.

Keywords: Pigmentation in prosthesis; eye color; artificial eye; maxillofacial prosthesis.

2.1.2 INTRODUCTION

Facial harmony plays an active role in social life. The functional and aesthetic impairment of the ocular region, caused by cancer surgery, congenital malformations, or trauma, can affect individuals' social lives and result in severe psychological disorders. Prosthetic restoration of facial deformation plays an impressive role in aesthetic, functional, and mental rehabilitation as well as playing a therapeutic role in the maintenance of tissue in a position that provides support for surgical healing (Engelen et al., 2014; Goiato et al., 2012).

Repair of facial deformity using in vivo tissues shows excellent results, although it is not applied to all cases. Depending on the compromised area, tissue limitations may hinder plastic surgery, making alloplastic repair the treatment of choice. In contrast with others parts of the body, such as the nose and ear (Ghassemi et al., 2013; Medved et al., 2015) , ocular damage often cannot be repaired using other tissues and a prosthesis is the best choice for the rehabilitation of eyeball loss (Taylor, 2000).

The aesthetic impact of ocular rehabilitation depends on the perfect disguise obtained with an artificial íris, so obtaining this structure is one of the most important steps in prosthetic eye making (Bannwat, 2013). This procedure requires professional attention and care with details in the laboratory steps so that the paint job will not be compromised. In order to preserve the paint layer, protective materials are used to prevent the penetration of this region by acrylic resin from scleral body (Pereira, 2007). It is believed that omission of the sealing process leads to artifacts that culminate in aesthetically undertake the work (Alves & Carvalho, 2004; D'Almeida, 2002). This problem is called "mirroring", in which bubbles are formed between the ink and the cap, resulting in an optical effect when light is incident upon the prosthetic eye, causing reflections similar to a mirror, which ends up compromising the aesthetic of the whole work, resulting in the loss of the prosthesis (Pereira, 2007). However, despite the existence of this problem, there are no studies analyzing its causes in depth in order to offer solutions to this problem.

The relevance of prosthetic rehabilitation has stimulated research focusing on improving techniques (Artropoulo II et al., 2006; Reis et al., 2008; Goiato et al., 2010; Fernandes, 2009) for fabricating prosthetic eyes that aim to satisfy the demand for treatment of patients with eyeball loss, but none of them have sought to analyze the question of mirroring in detail. The aim of this study was to test, through an in vitro study, whether the sealant material affects mirroring by prosthetic eyes. The null hypothesis is that the and sealing material and painting technique did not influence the prosthetic mirroring.

2.1.3 MATERIAL AND METHODS

Sixty specimens were prepared, varying the painting technique and the sealing material, organized in the following study groups (n = 10): direct painting technique / vinyl acetate (DV); direct painting technique / sealing with monopoly (DM); direct painting / sealing technique with cyanoacrylate and polymer (DC); indirect painting technique/ sealing with vinyl acetate (IV); indirect painting technique / sealing with cyanoacrylate and polymer (IC) and indirect painting technique/sealing with monopoly (IM), as shown in Table 1.

Table 1. Distribution of study groups according to the variables sealing material and painting technique

	PAINT TECHNIQUE	***SEALING MATERIAL***
DV	**DIRECT**	**VINYL ACETATE**
DM	**DIRECT**	**MONOPOLY**
DC	**DIRECT**	**CYANOACRYLATE+POLYMER**
IV	**INDIRECT**	**VINYL ACETATE**
IM	**INDIRECT**	**MONOPOLY**
IC	**INDIRECT**	**CYANOACRYLATE+POLYMER**

Iris painting step

Pre-fabricated acrylic caps (Articles Classic Dental, São Paulo, Brazil) with a diameter of 12 mm were used. Iris painting was always performed by the same operator with the help of a brush #0 (Tigre, SP, Brazil) using sepia and black colors for the direct technique with acrylic paint (Acrilex, SP, Brazil) and sepia and black oil paints (Acrilex, São Paulo, Brazil) for the indirect technique. For the standardization of the techniques, the following protocol was applied: two layers of paint, a paint drying time of 10 minutes between layers, and radial and centrifugal movements as the types of movement used for the realization of the painting.

For the direct technique, performed directly on the acrylic cap, the pupil was painted in black color and then a sepia layer; then a new layer of black color was added; and then the final drying took place for 24 hours. The indirect technique, executed using disks of black acetate, involved painting the two layers of sepia color and later the pupil in black color.

Paint sealing

After the 24-hour period of ink drying, the iris paintwork applied by both techniques was sealed with vinyl acetate (Liquid Silicone Glue, Rendicola, Paraná, Brazil), cyanoacrylate (SuperBonder, Henkel Ltda., São Paulo) with thermoactivated polymer (Jet, Dental Articles Classic LTDA, São Paulo, Brazil), or monopoly (Table 2). A period of 24 hours was allowed for drying of the sealing layer and the beginning of the inclusion process. To this end, the monopoly was made from an unsaturated monomer / thermoactivated polymer mixture in a ratio of 6.25: 1, and after total solubilization of the polymer, the mixture was submitted to heating at 40 °C in a water bath for 4 minutes until thickening of the liquid occurred, forming a kind of fluid glue (Bankoti,2016).

Table 2. Composition of sealing materials

	COMPOSITION	BRANDS
VINYL ACETATE	Polyvinyl acetate, ethanol and aditives	Silicon Glue – Rendicola Produtos Químicos Ltda- PR- Brasil
MONOPOLY	Monomer :Methylmethacrylate; topanol Polymer: Copolymer, dibutyl and benzoyl peroxide	Articles Classic Dental LTDA, São Paulo, Brazil
CYANOACRILATE + POLYMER	Cyanoacrilate: Cyanoacrilate esther Polymer: Copolymer, dibutyl and benzoyl peroxide	Henkel Ltda.; SP- Brasil Articles Classic Dental LTDA, São Paulo, Brazil

Inclusion procedures

All specimens from each group were included in the same flask, seeking to standardize the temperature and pressure conditions to which each sample was submitted. The caps were placed with the face sealed by the experimental material in contact with a wax pattern previously made from a standard model of an anophthalmic cavity to reproduce the dimensions of an actual ocular prosthesis. The set was included in a flask with Type III plaster stone (Herodent, Vigodent RJ, Brazil), positioning the portion referring to the cavity background facing the flask and the pins of the acrylic caps directed towards the counter-flask, where they were kept. After the stone setting time, the flask was opened and washed with warm water to remove the wax, while the iris remained in position in the counter-flask . The patterns inside the flask and counter-flask were again isolated with a sodium alginate based insulation (Cel-Lac; SS White Artigos Dentários Ltda., Rio de Janeiro, Brazil), and the chemically activated resin was manipulated according to the manufacturer's recommendations, condensed in the flask, and pressed with 1 ton for 2 minutes. After that time, the flasks of each group were inserted in a polymerizer under 60 pounds of pressure and water at room temperature, heated to 60 °C, and kept at that temperature for 30 minutes to release the residual monomer (Bural et al., 2011). After reaching room temperature, the set was removed from the polymerizer and the specimens were then deflasked and subjected to finishing and polishing procedures with mini cut and abrasive papers of decreasing roughness (#400, #600, #800, #1200) under cooling and polishing with a pumice stone and white of Spain around a bench with slow rotation.

Mirroring analysis

The specimens were analyzed quantitatively and qualitatively. The quantitative step was performed by image captures performed with a stereomicroscope (Stemi DV4, DR; Zeiss, Jena, Germany), where the area of commitment by mirroring was measured by multidimensional scientific image processing software (ImageJ). The qualitative analysis was performed through the analysis of the behavior among the resin, ink, and sealant layers of each study group by scanning eletron microscopy (JEOL, JSM 5600 pv, Japan). For this purpose, a cross-section of the median region of a sample from each group was cut using a diamond disk (Isomet 1000 Low Speed Saw, Lake Buff, Illinois, USA) under refrigeration. After cutting, the pieces were passed through a sequence of finishes and sonication processes (Ultra Cleaner 800, Unique,SP, Brazil) for 10 minutes between stages

Statistical analysis

Through the macroscopic examination of the specimens in stereoscopic loupes, mirroring signals were detected in most samples. Measurement of the compromised area was performed, and the average results of the mirror area (mm²) were obtained. These data did not meet the assumptions of the analysis of variance as they presented an asymmetric distribution. Then, after transformation of the data into X + 0.5, because of the groups in which all the observations were zero, generalized linear models were adjusted considering the gamma distribution (asymmetric form). The analyses were performed using the GENMOD procedure of the SAS program considering a 5% level of significance.

2.1.4 RESULTS

MACROSCOPIC ANALYSIS

Statistically significant differences were observed among groups (p = 0.014) (Table 3). It was found that different iris-painting techniques as well as different sealing materials have a direct impact on the mirroring area of ocular prostheses.

Table 3. Mean (standard deviation) of the mirror area (mm²) as a function of the sealing material and the painting technique

Material	Technique	Mirroring area
Vinyl acetate	Direct	0.00 (0.00) c
Monopoly	Direct	6.92 (8.44) b
Cyanoacrylate/polymer	Direct	22.35 (24.34) a
Vinyl acetate	Indirect	34.84 (13.62) a
Monopoly	Indirect	3.56 (4.91) b
Cyanoacrylate/polymer	Indirect	3.21 (6.77) b

Means followed by the same lowercase letter differ (P < 0.05).

The groups treated by the direct technique present an average mirror area of 9.75 mm² while those treated by the indirect technique present one of 13.87 mm², showing the superiority of the former in this regard. Regarding the sealing materials, it is possible to highlight vinyl acetate in the direct technique (DS) as the best result among all groups, as it did not present an area impaired by mirroring (0 mm²), which is the opposite result to that observed with the same material in combination with the indirect technique, which showed the highest mean mirroring area among all study groups (34.84 mm²). On the other hand, the use of monopoly for the sealing of the paints led to a mirroring area of 6.92 mm² with the direct technique and 3.56 mm² with the indirect technique, while the use of cyanoacrylate/polymer led to the highest index of mirroring with the direct technique, 22.35 mm², but only 3.21 mm² with the indirect technique (Table 3).

SCANNING ELECTRON MICROSCOPY (SEM) ANALYSIS

The quantitative data obtained by measurement of the area compromised by mirroring were related to the ultra-structural analysis through scanning electron microscopy (SEM), where peculiarities in the different associations between the layers (surfaces of the acrylic cap, ink, sealing material, and scleral resin) could be observed, explaining the participation of each component in the mirroring process.

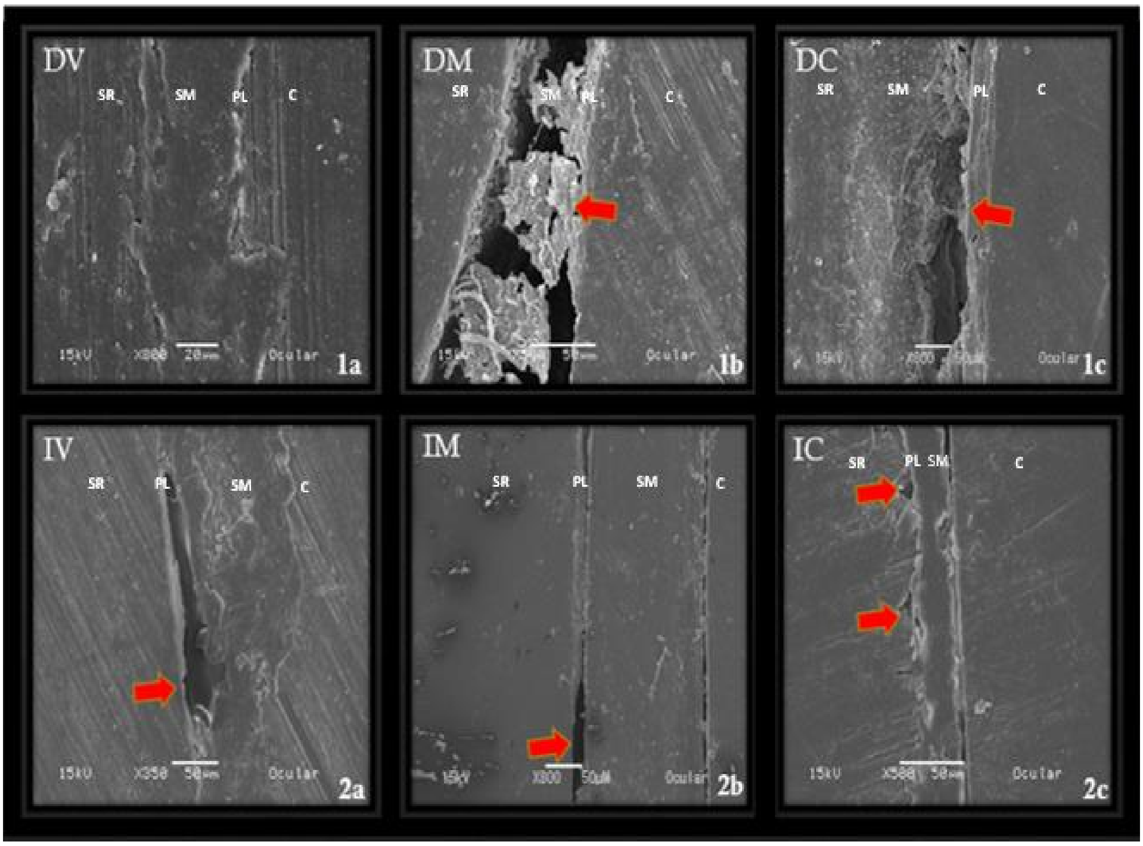

Fig. 1a DV group: harmonic relationship between acrylic cap (C), paint layer (PL), sealant material (SM), and scleral resin (SR).

Fig. 1b DM group: degradation of the paint layer into small islands with small connections with the remaining sealant material

Fig. 1c DC group: cracks between the sealant material and the paint layer, in addition to projections of the sealant material toward the paint layer, with thinning of the paint layer in some locations.

Fig. 2a IV group: many cracks caused by the detachment of the sealing material

Fig. 2b IM group: disappearance of some parts of the paint layer, probably compromised by the action of the sealant material

Fig. 2c IC group: projections of the scleral resin toward the sealant material, showing an intimate relationship. The intermediate layer of ink has been compromised in some regions

In the DV group (Fig. 1a), it can be observed that the interface between the materials remains intact, with a continuous relationship and without cracks between the acrylic cap, paint, sealant material, and scleral resin, which is a possible explanation for the absence of mirroring in this group. In Group IV (Fig. 2a), the same sealing material proved to be ineffective for this function in this technique, since many cracks were caused by the detachment of the ink sealing material, explaining the higher mirror index of this group (34.84 mm²).

In the DM group, the detachment of the acrylic paint from the surface of the cap and the appearance of degradation of the paint sheet into small islands with small connections to the remaining sealant material (Fig. 1b) was observed. Despite these changes, an intimate relationship was found between the sealant material and the scleral resin. The IM group (Fig. 2b) showed the formation of a single regular body of sealant material, similar in appearance to the scleral resin and acrylic shell. However, in spite of the similarity, the disappearance of the paint sheet was observed in some areas, probably because it was compromised by the action of the sealant material.

In the DC group, intimate contact was verified between the acrylic paint layer and the cap surface and between the sealant material and the scleral resin. However, large gaps were observed between the sealant material and the paint sheet, as well as projections of the sealant material towards the latter with thinning of the blade at some locations (Fig. 1c). In the IC group, the projections of the scleral resin toward the sealant material are evident, showing an intimate contact relationship (Fig. 2c). The intermediate layer of ink has been compromised in some regions, which is possibly related to the interaction of these layers. The block scleral resin, oil paint, and cyanoacrylate were found to be completely detached from the surface of the acrylic cap, causing a continuous crack between these layers.

2.1.5 DISCUSSION

The null hypothesis tested in this study – that paint sealing material not have an effect on mirroring – was not accepted, since statistically significant differences were observed among groups (Table 3).

The results indicate that the use of the vinyl acetate polymer did not present any impairment when combined with the direct technique (0 mm²), where no mirroring was observed (Fig. 1a). This combination is the most effective for the sealing of prosthetic iris paints, presenting advantages in relation to cyanoacrylate and monopoly because it is a more easily handled material with better performance and low cost, corroborating studies by D'Almeida (1999) and Pereira (2007). However, when associated with the indirect technique, the highest mirroring values of the study (34.84 mm²) were found, pointing to an ineffective association (Fig. 2a). Ultra-structurally, the presence of many cracks caused by the detachment of the ink sealing material (Fig. 2a) can be observed, reflecting an expressive degree of mirroring in this group. This can be justified by the low fluidity of the material that was interposed between the acrylic cap and the paint layer, besides its incompatibility with the resin, which would make adhesion difficult.

The use of monopoly for the sealing of paints led to a mirroring area regardless of which technique was used, but in spite of their low levels, the mirroring was present, and may render the prosthesis clinically unfeasible due to the aesthetic compromise. These findings disagree with some studies those of Grassle (1946), Stewart (1947), , Silva and Carvalho (1994), Vilas-Boas Sousa et al. (2003), Bankotti (2016), and Taylor (2000), who argue that this sealant material offers the best method of obtaining ocular prostheses; however, none of them evaluated mirroring as a variable. The most expressive value with regard to the direct technique is possibly related to the effect of the sealing material on the acrylic paint layer. Degradation of this structure was observed, supposedly due to the action of the excessive residual monomer released by the monopoly during its polymerization process, making it impossible to associate this sealing method with this painting technique. Similar behavior occurred with the indirect technique, where the disappearance of the paint layer observed at microscopic scale, possibly caused by the excessive amount of residual monomer in places, due to the use of the monopoly either to fix the pigment to the oil or as a sealing material. This is also justified in the studies by Stewart et al. (1947), who reported the negative role of the residual monomer in the failure of the ocular prosthesis.

Another point to consider is the use of cyanoacrylate/polymer as sealing material, which presents high levels of commitment in study. The high levels of mirroring obtained by the direct technique can be explained by the connections between the sealing material and the paint layer, as evidenced microscopically (Fig. 1c), indicating the possible interaction of the polymer present in the sealant with the existing monomer droplets during the polymerization of the paint acrylic resin. This chemical compatibility between the components makes it impossible to use this sealing technique, in agreement with Alves and Carvalho (2004) and Pereira (2007). In the indirect technique group, microscopically, it is possible to visualize projections of the scleral resin in relation to the sealant material (Fig. 2c), evidencing that sealant material did not act as a barrier method because of the chemical interaction of the polymer present in the sealant with residual monomer from polymerization of the scleral body, which explains the possible cause of the involvement of the paint layer in some regions, which in turn explains the mirroring found.

It is possible that analysis of mirroring has not been performed previously due to the scarcity of experimental methodologies that enable the quantification of the affected area in an accurate way. For this purpose, stereomicroscopy was used to obtain standardized images of the prosthetic irises and quantification of the impairment through multidimensional scientific image analysis software applied in several medical areas (Dougherty, 2009; Collins, 2007).

Regarding the techniques employed, a greater consensus in the literature indicates that better aesthetic results can be obtained by the technique of direct painting on the acrylic cap with acrylic paint and by the indirect painting technique on a black acetate disc with oil paint (Benson, 1980; Couillard, 1976; Meissner, 1960; Taylor, 2000). Although there are a range of studies comparing techniques with main focus on their behavior with regard to color alteration (Moreno et al., 2015; Reis, 2008; Goiato et al., 2011; Fernandes et al., 2009; Andreotti et al., 2014) of the prosthesis, none of them analyzed the impact of these techniques, their relationship with the sealing material used, or the best results with regard to paint mirroring, a recurrent problem in the fabrication of prostheses that directly affects the clinical viability of these prosthetic structures.

In the present study, it was observed that the direct technique groups with acrylic paint (DV, DC, DM) had a smaller average compromised area than the groups treated by the indirect technique with oil paint (IS, IC, and IM), but both showed a sufficient area to aesthetically compromise the ocular prosthesis, in contradiction with the studies of Pitton (1945) Erpf, Dietz, and Wirtz (1945), Couillard (1976), Meissner (1960), and Artopoulou II (2006), who argue that both techniques are excellent choices for obtaining a favorable aesthetic result.

It is possible that the difference between the techniques is mainly due to the behavior of the inks used. Corroborating the findings of Mayer (2002), we could see that the acrylic paint, in spite of having water as the solvent, has acrylic resin as the pigment-carrier vehicle, and after the solvent volatilization, the resin particles agglutinate with the pigments, forming a resistant, flexible, and waterproof film. However, in spite of this resistance, the polymerization process occurs in plots (0.01 μm) dispersed in aqueous medium with growing monomer and polymer, and during this process still larger monomer droplets are present (1 μm), which act as reservoirs for the supply of monomers to the polymerization growth chains (Turner, 1980; Carvalho and Nogueira, 2006). Thus, we believe that the small areas of mirroring found in these groups also occurred due to the influence of the residual monomer released in the polymerization of the scleral resin, which surpassed the sealing layer, interfering in the paint layer, either by dissolving this region or causing contraction of the adjacent layer and consequent trapping of this layer during the polymerization process. This can be confirmed by SEM images, which reveal the behavior between the layers (Figs. 1b, 1c, and 2a).

In the indirect technique, the oil paint presented significant aesthetic results due to the possibility and clarity of the reproducibility of details that this material allows (Fernandes et al., 2009; Mayer 2002). However, the indirect technique with oil paint is nothing more than a small dilution of this paint in resinous medium (monopoly) with the aim of fixing the layers and reducing the drying time (Taylor, 2000; Bankoti, 2016). The excellent aesthetic result is due to the vitreous aspect achieved through the immiscibility of the oil in the resinous substrate, resulting in an area of transparency between layers, which provides a deeper view, bringing an unusual resemblance to the human eye. However, in spite of this aesthetic advantage, the oily vehicle present in the paint acts on the acrylic resin of the monopoly fixative agent, which interferes in the polymerization of the acrylic resin, allowing the release of a greater quantity of residual monomer as well as the formation of bubbles in the interface of this layer of paint, resulting in mirroring, which we could confirm by the ultra-structural analysis (Figs. 2a, 2b, and 2c).

Besides, the paint has a component that can directly interfere in the polymerization of the fixative agent, and the preparation of the monopoly already adds a greater amount of residual monomer to the solution. The unsaturated monomer/thermopolymerizable polymer blend at the ratio of 6.25:1 differs from the ideal 1:3 ratio of polymer/monomer, as advocated by Anusavice et al. (2013); such the fixative solution will tend to continuously release residual monomer or leave available monomers in the solution body. A higher amount of monomer causes a greater contraction of the final resin (Anusavice et al., 2013), which explains the higher mirroring results obtained in the study through this technique, corroborating Stewart's (1947) findings that it is necessary to avoid using excess monomer during the making of the iris button, which could cause blistering or overflow of paint.

Although the results show that the choice of paint technique plays a critical role in problems that arise in the prosthesis, an isolated analysis is not enough to avoid the aesthetic compromise of this final structure. It is necessary that this painting be sealed to avoid interference with the products of the polymerization in the stage to which the iris will be submitted soon after painting. There are few studies evaluating the importance of the sealing material used in any alteration of the ocular prosthesis (Alves & Carvalho, 2004; D'Almeida, 2002; Pereira, 2007). These components are used for the preservation of iris painting as a barrier method for the protection and waterproofing of the paint, preventing the scleral resin from penetrating the paint region, which would damage it.

While vision cannot be artificially replaced, the primary objective of alloplastic rehabilitation through the use of an ocular prosthesis is facial aesthetic reconstruction through the recovery of the harmony of the compromised expression. Therefore, the concern with obtaining desirable aesthetic and functional results with maximum benefits for both professional and patient makes the improvement of techniques the main route to success in this rehabilitation environment. Therefore, an ideal technique in ocular rehabilitation should be easy to handle, low cost, durable, and aesthetically excellent. In the present study, mean areas of impairment of 0 mm^2 (DS), 6.92mm^2 (DM), 22.35mm^2 (DC), 34.84 mm^2 (IS), 3.56mm^2 (IM), and 3,21 (IC) were observed, evidencing the impact of the choice of sealing material and painting technique on the mirroring, and consequently the null hypothesis of the study was rejected.

It was observed that the combination of the direct painting technique with the use of vinyl acetate for paint sealing presented the best aesthetic results because it did not present any degree of mirroring, evidencing the efficiency of the method and the feasibility of using this association in clinical practice. In addition to the lower possibility of aesthetic compromise through mirroring, this association has advantages because it can be executed in a shorter clinical time, can be easily handled, and increases the aesthetic behavior of the prosthetic eye.

2.1.6 CONCLUSION

The paint technique and sealing material directly interfere with the compromise of the prosthetic iris by mirroring. The associations of the direct technique with acrylic paint and vinyl acetate as the sealant material presented the lowest mirroring levels and consequently the best results for clinical application.

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2.2 ARTIGO

Impact of polymerization and painting technique on color stability and mirroring in artificial irises of ocular prostheses

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2.2.1 ABSTRACT

The iris is the structure of an artificial eye responsible for its concealment and esthetics. However, processes for making the scleral body may indirectly affect the stability of the prosthetic iris, promoting chromatic alteration and mirroring. The purpose of the present study was to evaluate color change and mirroring in artificial irises of ocular prostheses made using different polymerization and painting techniques. From a model of an anophthalmic cavity, 60 specimens were prepared, varying the painting technique and the polymerization cycle. The study groups were organized as follows (n = 10): direct painting technique/autopolymerization (DA); direct painting technique/conventional thermopolymerization (DT); direct painting technique/microwave thermopolymerization (DM); indirect painting technique/autopolymerization (IA); indirect painting technique/conventional thermopolymerization (IT); indirect painting technique/microwave thermopolymerization (IM). Images of the artificial irises were obtained using a stereomicroscope (Stemi DV4/DR, Zeiss, Jena, Germany), then the mirroring area was quantified by ImageJ software. After that, the samples were subjected to an artificial accelerated aging chamber for 348 hours. A reflection spectrophotometer (CM 700d, Minolta, Osaka, Japan) was used to analyze the color variation, and the data were analyzed according to the CIE2000 System. The results were analyzed by the GENMOD procedure, considering a level of significance of 5%. The direct technique did not present mirroring, independent of the type of polymerization used. All types of polymerization showed color changes, but association of the direct technique with conventional thermopolymerization showed the smallest change, making it the best indication for clinical use.

Keywords: Pigmentation in prosthesis; eye color; artificial eye; maxillofacial prosthesis.

2.2.2 INTRODUCTION

In addition to functional impairment, facial loss leads to severe psychological consequences, and rehabilitation returns a condition of normalcy and acceptance in society (McGrouther, 1997; Newell et al.,2000.; Clarke et al., 2003; Rumsey et al.,2004). Ocular prosthesis is the treatment of choice for alloplastic recovery in patients who have suffered total or partial loss of the eyeball. Even though the initial intention is to restore esthetic harmony, which also provides social harmony, these structures also act to maintain local muscle tone, avoiding collapse of the remaining structures due to lack of use, as well as directing drainage of lacrimal secretion to physiological ducts, protecting local mucosa from external aggressions (Porter et al., 1989; Kakizaki et al., 2009; Yi et al., 2012; Goiato et al., 2015).

Reconstitution of the eyeball has been important since the time of ancient civilizations, which used precious stones and adornments to reestablish facial harmony (Rezende, 1987). Later, glass was inserted in this context, and presented excellent esthetic results despite causing damage to adjacent structures due to its weight and interactions with lacrimal fluid (Mulles, 1885). However, since the middle of the 20th century, acrylic resin, a polymethylmethacrylate (PMMA)-based polymer for artificial sclera (color N1 and colorless), is the material of choice for prosthetic eyes due to its durability, ease of hygiene, low cost, and biocompatibility (Fernandes et al., 2009; Mundim et al., 2012; Moreno et al., 2013). In addition, this material has excellent resistance and a similar color to human sclera; the translucency of acrylic resin presents good optical behavior, an important factor for the dissimulation of ocular prostheses (Vichi et al., 2004). In addition to use in prosthetic eyes, variations of PMMA have been applied for medical purposes in rehabilitating the anophthalmic cavity, from the use of grafts to maintaining the volume of the cavity, and even in contact lenses, supporting the good biological performance of this biomaterial (Gautam et al., 2012; Baino et al., 2014).

The polymerization process for this material occurs after mixing the powder with liquid, which allows monomer to polymer conversions (Canadas et al., 2010). The reaction can occur by heat-activated methods, using a conventional water bath or microwave energy, or through chemically activated polymerization. The main problem is that the acrylic resin polymerization reaction is exothermic, and the amount of heat involved in the process can affect the properties of the material. Incomplete reactions result in the presence of residual monomers of methyl methacrylate (MMA) and other potentially toxic chemicals such as formaldehyde, benzoic acid, methacrylic acid, phenyl salicylate, dibutyl phthalate, and phenyl benzoate (Santos et al., 2016).

Although problems related to the rigidity inherent to the material can affect the adjacent mucosa, the main problem encountered after the use of ocular prostheses is color instability (Goiato et al., 2011). Exposure to ultraviolet radiation causes clinically discernible changes in both the iris and the scleral body, significantly affecting esthetics and compromising rehabilitation (Reitemeier, 2004). Sometimes, this color mismatch is sufficient to indicate preparation of a new prosthesis, even if the current prosthesis is a good fit (Alves, 2004; Fernandes et al., 2009).

Studies suggest several techniques with different pigments for reconstitution of the ocular iris, by freehand painting or digital reconstruction of this structure, and chromatic alteration can be found in both (Murphy et al., 1945; Couillard, 1976; Benson et al., 1977; Dyer et al., 1980). Gouache and acrylic paint are used to color the iris, but show chromatic alteration; other authors indicate oil paint, arguing that it presents better color stability when exposed to degradation and environmental agents such as ultraviolet rays (Fernandes et al., 2009; Moreno et al., 2015). In addition to instability due to the environmental action of UV rays, the pigments used to paint the iris also show instability after acrylic resin polymerization (Goiato, 2010; Goiato, 2011). Color change tends to promote distortion in the reflection of light (Pannat, 1946).

The reflective optical effect is another problem that affects concealment of the prosthesis. Known as mirroring, this alteration compromises esthetics and may render use of the prosthesis unfeasible. This unusual optical behavior may be related to failure to seal the paint layer during its preparation, but the relevance of other steps in making the prosthesis to this alteration is not known (Pereira, 2007). Although chromatic change in artificial irises has been evaluated in the literature (D'Almeida, 2002; Alves et al., 2004; Reis, 2008; Fernandes et al., 2009; Goiato et al., 2010; Goiato et al. 2011; Bannwart et al., 2013; Moreno et al., 2015), there has been no concern reported about the influence of polymerization cycle and painting technique on color stability and prosthetic eye mirroring. The objective of this study is to evaluate the influence of polymerization type and painting technique on chromatic changes and mirroring in irises of ocular prostheses. The null hypothesis is that the painting technique and polymerization type does not influence the prosthetic mirroring.

2.2.3 MATERIAL AND METHODS

Sample preparation

Sixty specimens were prepared, varying the painting technique and polymerization cycle, organized in the following study groups (n = 10): direct painting technique/autopolymerization (DA); direct painting technique/conventional thermopolymerization (DT); direct painting technique/microwave thermopolymerization (DM); indirect painting technique/autopolymerization (IA); indirect painting technique/conventional thermopolymerization (IT); indirect painting technique/microwave thermopolymerization (IM) (Table 1).

Table 1. Paint and polymerization techniques used for sample preparation

	Paint technique	*Polymerization type*
DA	Direct	Chemical polymerization
DT	Direct	Conventional heat polymerization
DM	Direct	Microwave polymerization
IA	Indirect	Chemical polymerization
IT	Indirect	Conventional heat polymerization
IM	Indirect	Microwave polymerization

Artificial iris preparation

Prefabricated acrylic caps (Articles Classic Dental Ltda, São Paulo, Brazil) with 12 mm diameter were used. Iris painting was always performed by the same operator, using a # 0 brush (Tigre S/A, São Paulo, Brazil) and acrylic paint (Acrilex, São Paulo, Brazil) in sepia and black colors for the direct technique, and oil paint (Acrilex, São Paulo, Brazil) in sepia and black for the indirect technique. To standardize the techniques, a protocol was followed: 2 layers of paint were applied, with 10 minutes of drying time between layers, and radial and centrifugal movements were used for painting.

For the direct technique, performed directly on the acrylic cap, the pupil was painted in black and then a sepia layer; then a new layer in black was added, waiting 24 hours for final drying. For the indirect technique, performed on disks of black acetate, 2 layers were painted in sepia, and later the pupil was painted in black.

After the 24-hour drying period, iris painting was sealed with vinyl acetate (Liquid Silicone Glue, Rendicola, Paraná, Brazil) for irises made by the direct technique, and with monopoly syrup for irises made by the indirect technique. The monopoly syrup was made from an unsaturated monomer/thermoactivated polymer mixture in a ratio of 6.25:1; after total solubilization of the polymer, the mixture was submitted to heating at 40°C in a water bath for 4 minutes until the liquid thickened to form a kind of fluid glue (Bankoti, 2016). A period of 24 hours was allowed for drying the sealing layer before beginning the inclusion process.

Inclusion and polymerization

The specimens from each group were included in the same flask. For this, caps were positioned with the face sealed by the experimental material in contact with a preformed wax pattern measuring 15 × 17 × 9 mm, from a standard model of an anophthalmic cavity, to reproduce the dimensions of a real ocular prosthesis. The set was included in a flask with type III plaster stone (Herodent, Vigodent SA Indústria e Comércio, Rio de Janeiro, Brazil), positioning the portion referring to the cavity backgroung facing the flask, and the pins of the acrylic caps directed towards the counter-flask, where they were kept. After the stone setting time, the flask was opened and washed with warm water to remove the wax, the iris remaining in position in the counter-flask. The flask and counter-flask were again isolated with sodium alginate-based insulation (Cel-Lac; SS White Dental Products, RJ , Brazil), and the specific resin for each type of polymerization was manipulated following the cycles previously determined, as described in Table 2.

Table 2. Polymerization materials and cycles

GROUP	POLYMERIZATION TYPE	POLYMER COMPOSITION	MONOMER COMPOSITION	POLYMERIZATION CYCLE
DA/IA	Chemical polymerization	N1-Copolymer, dibutyl and benzoyl peroxide	Methyl methacrylate; hydroquinone; glycol and dimethyl para-toluidine	Autopolymerization and postpolymerization at 60°C for 30 min
DT/IT	Conventional heat polymerization	Copolymer, dibutyl and benzoyl peroxide	Methyl methacrylate; topanol	Heat polymerization in a resin water bath: immerse flask in liquid water, apply low heat for 30 min, turn off heat for 30 min, boil for 1 h
DM/IM	Heat polymerization by microwave	Copolymer, dibutyl and benzoyl peroxide	Methyl methacrylate; topanol and ethylene glycol dimethacrylate (EGDMA)	Polymerization by microwave energy: place flask in microwave (Brastemp), microwave for 3 min at 100% power, 4 min at 0% power, and 3 min at 100% power

After polymerization cycles, samples were finished with # 300, # 400, # 600 and # 1200 silicon carbide sandpaper, followed by polishing with pumice stone and white of Spain around a bench, with low rotation speed.

Mirroring analysis

Mirroring was quantified using stereomicroscope imaging (Stemi DV4/DR, Zeiss, Jena, Germany); the area of impairment was measured using multidimensional scientific image processing software (Image J).

Initial color spectrophotometry

The color reading for each specimen was performed using a spectrophotometer (CM 700d, Minolta, Osaka, Japan) in a room with ambient light conditions (GTI MiniMatcher MM 1, GTI Graphic Technology, New York, NY, USA) in daylight. The spectrophotometer collects spectral data from reflected light, and automatically translates this data into 3-color coordinates, where L indicates brightness (ranging from 0 black to

100 white), a indicates the amount of red (positive values) and green (negative values), and b indicates the amount of yellow (positive values) and blue (negative values). These data were analyzed according to the CIEDE2000 System. Prior to measurement, the spectrophotometer was calibrated using white and black reflectance standards, according to the manufacturer's protocol. These measures were considered the initial values.

Artificial accelerated aging

The specimens were fixed with device plates using silicone, and taken to a condensation chamber under a light source at a distance of 50 mm. The operational program was standardized at 4 hours of exposure to UV-B light at 37°C and 4 hours of condensation at 37°C, with a maximum aging time of 384 hours. This exposure can produce physicochemical degradation corresponding to 1 year of clinical use (Douglas, 2000). After the accelerated artificial aging (AAA) process, the specimens were again submitted to color analysis using the spectrophotometer, to determine the color change (ΔE_{00}). The color variance (ΔE_{00}) is calculated by the formula:

$$\Delta E_{00} = [(\Delta L/K_L \,.\, S_L)^2 + (\Delta C/K_C \,.\, S_C)^2 + (\Delta H/K_H \,.\, S_H)^2 + R_T \,.\, ((\Delta C/K_C \,.\, S_C)^2 \text{ x } ((\Delta H/K_H \,.\, S_H)]^{0.5}$$

Values of $\Delta E \geq 3.3$ are considered clinically unacceptable (Ruyter, 1987).

Statistical analysis

After quantification of the colorimetric variation (ΔL, Δa, Δb, ΔE_{00}) and the mirror impairment area, the means for each group were calculated. The data did not meet the assumptions of the analysis of variance, presenting asymmetric distribution, so adjusted generalized linear models were used, considering the gamma distribution (asymmetric form) and the factors painting technique and polymerization cycle, and the interaction between them. Analyses were performed using the GENMOD procedure of the SAS program, considering a level of significance of 5%.

2.2.4 RESULTS

Mirroring analysis

Comparison of the averages showed that there were significant differences between the different painting techniques (Table 3), but no statistically significant differences were observed between the different polymerization groups ($p = 0.0023$). The direct paint technique did not present mirroring values in any of the polymerization groups tested (Table 3), in contrast to the indirect technique, which showed significant values of 3.56 mm^2 for chemical polymerization and 4.54 mm^2 for conventional heat polymerization groups. The highest value found was 7.07 mm^2, in specimens submitted to microwave energy.

Table 3. Mean (standard deviation) mirroring area according to painting technique and polymerization cycle

	Direct technique	Indirect technique
Chemical polymerization	0.00 (0.00) Ba	3.56 (4.91) Aa
Conv. heat polymerization	0.00 (0.00) Ba	4.54 (6.15) Aa
Microwave polymerization	0.00 (0.00) Ba	7.07 (3.95) Aa

Means followed by different letters differ (capitals vertically and lowercase horizontally) from each other ($P \leq .05$).

Color analysis

ΔE_{00} values presented a significant statistical difference between the different polymerization groups and painting techniques submitted to accelerated aging ($p = 0.0012$) for the parameters tested (Table 4). When polymerization types were compared, ΔE_{00} variations were elevated, especially for microwave energy-polymerized specimens for both painting techniques (3.646 and 2.999); the combination of indirect painting and conventional heat polymerization showed the next highest variation (2.114). Chemical polymerization groups showed similar results for both painting techniques, but were no better than conventional heat polymerization in combination with the direct painting technique, which showed the smallest amount of color change (Table 4).

Table 4. Mean (standard deviation) color change (ΔE_{00}) after accelerated artificial aging as a function of painting technique and polymerization cycle

	Direct technique	Indirect technique
Chemical polymerization	1.344 (0.808) Ab	1.392(0.733) Ab
Conv. heat polymerization	1.028 (0.524) Bb	2.114 (1.579) Aab
Microwave polymerization	3.646 (2.534) Aa	2.999 (2.224) Aa

Means followed by different letters differ (capitals vertically, within each painting technique, and lowercase horizontally, within each polymerization technique) from each other ($P < .05$).

2.2.5 DISCUSSION

Several possibilities exist for the manufacture of ocular prostheses, with variation in the painting technique, polymerization cycle, and pigments used, as well as prefabricated options being available in the market (Murphy, 1945; Meissner, 1950; , 1970; Macedo, 1982), but there is no consensus in the literature regarding the influence of these variables on the major obstacles to this type of rehabilitation: chromatic alteration and mirroring. The null hypothesis of this study was rejected, considering that both painting technique and polymerization type have significant effects on chromatic changes and mirroring, and significant interaction between them was observed (Table 4).

Realistic paint and chromatic stability allow total disguise of the prosthetic eye, and are essential for the success of this type of rehabilitation (Goiato, 2010; Bannwart, 2013). To achieve these, technical refinement and quality pigments are essential for good esthetic behavior. The literature reports that, despite the possibility of digital printing of prosthetic irises (Reis, 2008), direct painting using acrylic paint, and indirect painting using oil paint are seen as the most suitable techniques for painting artificial irises to obtain good esthetic performance (Brown, 1970; Rezende, 1987; Taylor, 2000). The results show that both techniques present chromatic alteration on accelerated aging, regardless of the type of polymerization performed (Table 4), in agreement with the studies of Fernandes (2007), Reis (2008), Bawnnwart (2013), Moreno (2015), and Goiato (2011). Although color change is mainly linked to UV-B sun exposure, which is responsible for 95% of radiation during the summer (Okuno, 2005), the choice of pigment and polymerization technique during the prosthesis manufacturing process can have an impact on this change. The paint undergoes degradation by photo-oxidation and hydrolysis, caused by exposure to sunlight, air, moisture, and temperature (Mayer, 2002). These processes are correlated and accelerate with increasing temperature, as occurs in laboratory stages of prosthesis fabrication. Photodegradation processes cause complete or partial rupture of polymer chains, leading to the reduction of polymer properties (Martinez, 1972). Our results show that the association of the direct technique with conventional heat polymerization presented the lowest values for chromatic alteration (Table 4). This can be explained by the greater stability of the acrylic paint layer against UV radiation and the high temperatures of the conventional polymerization process, corroborating the findings of Pestana (2014) that prove the superiority of the material to other pigments used for iris painting. Despite oil-based paint being indicated because of its more stable behavior when subjected to ultraviolet radiation (Fernandes et al., 2009; Bannwart et al., 2013), several studies have shown that acrylic pigment exhibits superior physical behavior to oil paint for color change and drying (Reis, 2008; Goiato, 2010; Moreno, 2015).

Despite the resistance of acrylic pigment, the association of chemical polymerization with the direct technique presented significant chromatic alteration, similar to that observed for the indirect technique (Table 4). It is possible that the greater amount of residual monomer found for this type of polymerization can significantly affect the paint, corroborating the findings of Reis (2008), which explain that direct contact of these components affects the chemical bonds in the paints, and promotes exchange or breakage of these bonds, weakening the paint layer.

In contrast to most studies that used microwave energy due to the practicality and speed of obtaining prosthetic eyes (Sykes, 1996; Fernandes, 2009; Goiato, 2010), our results show that this alternative has the greatest impact on esthetic stability of artificial irises, since they presented the highest values for chromatic alteration (Table 4). Although the reaction between acrylic resin and the resin used in the paints has not yet been clarified in the literature, it can be suggested that the action of magnetic waves and the products of this reaction have more impact on the stability of the paint layer, making it susceptible to change. Studies show that polymerization by microwave energy occurs through dielectric heating, in which friction between moving charges and molecules results in a release of energy in the form of heat, and a consequent increase in system temperature (Nishi, 1968; Braun, 1998; Fortuny, 2007). The energy generated in the process is simultaneously absorbed by the surface and internal area of the resin. Thus, the time required to transfer the heat from the hot water to the flask, to the coating gypsum, and finally to the resin is eliminated, making this process quite quick and easy (Levin et al., 1989). However, despite being advantageous in other medical areas (Consani, 2015; Gandhi, 2017) because it does not affect the physical behavior of the material, use for this purpose causes damage to the iris paint since the high temperature generated in the process accelerates photodegradation of pigments (Martinez, 1979). Previous studies may not have presented deleterious microwave polymerization results as significant because of methodological limitations, since most did not reproduce the prosthetic parts in real sizes, which may affect the amount of by products that may harm the paint layer.

Regarding mirroring, the actual cause of this change in prosthetic irises has not yet been elucidated. It is speculated that byproducts of the polymerization reaction of the scleral resin can affect the paint layer, causing areas of discontinuity, which culminates in this reflective effect (Pereira, 2007). Our results showed excellent behavior for the direct technique; no mirroring areas were observed, regardless of the polymerization technique adopted (Table 3). In addition to higher resistance of the acrylic pigment, the paint layer may not have been compromised due to the sealing material used in this paint which, because of its lack of chemical compatibility with the components of the scleral resin, served as a physical barrier to scleral resin polymerization byproducts, isolating the region.

The same did not occur with the indirect technique; all types of polymerization presented impaired areas (Table 3). This could be attributed to the fragility of the oil paint affecting not only the color, but also discontinuity of the paint layer. The role of sealing may also have an impact when using this technique. As the monopoly syrup used is an unsaturated acrylic component (Bankoti, 2016), chemically compatible with the scleral resin, it is possible that polymerization byproducts reacted with the sealant component. This would compromise the paint layer, justifying the inferior behavior observed for this technique, in accordance with the findings of Bannwart (2013).

A limitation of this study is that the in vitro laboratory procedures simulating the manufacture of ocular prostheses were not exactly the same as the protocols used by other authors. Despite the use of prefabricated acrylic caps for painting prosthetic irises, to reduce the presence of residual monomer (Moreno, 2015), and the use of pigments in dark colors to provide resistance to UV radiation (Reis, 2008; Bannwart, 2013; Moreno, 2015), factors pointed out as attenuating laboratory interference in chromatic alteration, significant changes in irises were still observed. Other factors may influence the color stability of artificial irises, including porosity (inherent in the manufacturing technique), material surface defects, surface polishing, and protective materials for the paint layer. Thus, studies complementary to this to elucidate the issues around the theme are required.

2.2.6 CONCLUSIONS

The association of direct painting technique with conventional thermopolymerization represents the best combination to reduce color change and mirroring levels and consequently shows the best results for clinical application.

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3 DISCUSSÃO

O aprimoramento da técnica de confecção de próteses oculares contribui para a autoestima dos indivíduos que delas necessitam, em vários e complexos aspectos que a perda da visão e a mutilação do órgão implicam (Song et al., 2006; Pine et al., 2011). A reconstituição facial data das civilizações mais antigas, pois a preocupação com a harmonia sempre foi um entrave na sociedade (Rezende, 1987). Porém a excelência nessa reabilitação caminhou paralelamente ao aprimoramento dos biomateriais e permanece em evolução até os dias atuais.

As primeiras aplicações da resina acrílica na indústria datam de 1933 (Plexiglas, Perspex). Em 1936, foi introduzida na Odontologia, em sua forma termo-ativada (Vernonite), como material para base de próteses totais. Por volta de 1945 e 1950, a forma quimicamente ativada (Sevitron) ganhou seu espaço (Peyton, 1975; Anusivace, 2000). Paralelamente a criação desse polímero, com eclosão da II Guerra Mundial, esse material, inicialmente utilizado em próteses odontológicas, começou a substituir o vidro na confecção de olhos artificiais (Murphey et al, 1945). Nesta época houve grande demanda devido à legião de mutilados provenientes do conflito que necessitavam de recuperação estética.

Os primeiros polímeros usados para essa finalidade possivelmente já provocavam danos à estabilidade da íris protética, como relatado por Pannat (1946) onde a alteração de cor e distorção na reflexão da luz foram relatadas. Porém, apesar das primeiras próteses já apresentarem esses problemas, a escassez de metodologias precisas para análises dessas alterações representou um entrave no aprimoramento nessa alternativa reabilitadora. Apenas no inicio do seculo XXI, foram realizados os primeiros estudos de avaliação colorimétrica nessa área o que possibilitou o início do avanço estético da íris artificial (Alves & Carvalho, 2004; Fernandes et al., 2005). Pela possibilidade de quantificação que as metodologias trouxeram, a avaliação colorimétrica ganhou espaço, e diversos pigmentos e técnicas de pintura passaram a ser melhor analisados. Porém, por um bom tempo, este foi o único modo de falha analisado nas próteses oculares.

O espelhamento é um problema que afeta fortemente a dissimulação da prótese ocular. E apesar de ser relatado desde as primeiras reabilitações (Pannat,1946) e ser frequente na rotina clínica e laboratorial, a limitação metodológica atrapalhou a avaliação precisa dessa alteração. São escassos os estudos em torno do tema (D'Almeida et al, 2002 e Pereira,2007) e neles, a alteração foi analisada apenas qualitativamente. O presente estudo veio trazer a possiblidade de mensuração dessa falha e assim, analisar o real impacto de todas as variáveis na confecção do olho artificial, visando o aprimoramento das técnicas já utilizadas até o momento. Por se tratar de uma alteração linear, a obtenção de imagens das íris protéticas padronizadas através do estereromicroscópio possibilitou a visualização da área comprometida, sendo delimitada com precisão e quantificada por meio do Image J.

Essa possibilidade de quantificação veio mostrar que apesar de diversas técnicas de pintura e pigmentos serem testados e aprimorados, outras importantes variáveis impactam na qualidade estética dessa reabilitação. Além da resistência do pigmento à altas temperaturas e radiação UV ter sido um fator a contribuir significativamente na estabilidade da lâmina de pintura, o material de selamento da pintura e o tipo de polimerização adotado afetam diretamente a estabilidade dessa região e consequentemente a longevidade da peça protética.

Diferente da vasta gama de estudos que analisam o comportamento físico dos olhos artificiais (Fernandes, 2007; Reis et al., 2008; Fernandes et al., 2009; Goiato et al., 2011; Bannwart et al., 2013, Moreno et al. 2015), os resultados foram consistentes pelo dimensionamento mais próximo da realidade apresentado pela amostra. A confecção de próteses oculares em tamanhos reais possibilitou uma referência mais exata do comportamento dos materiais frente ao procedimentos de obtenção da prótese, especialmente na interferência da polimerização do corpo escleral sobre a íris.

Outros estudos complementares a esse são necessários para elucidação do papel de todos os componentes envolvidos nessas duas imperfeições técnicas: alteração cromática e espelhamento. Além disso, o aprimoramento dos materiais de selamento para ação efetiva como método de barreira em todas as técnicas de pintura, bem como pigmentos com resistência a radiação UV e métodos de polimerização que determinem uma menor quantidade de monômero residual podem reduzir significativamente os danos e trazer excelência e longevidade a esse tipo de reabilitação, contribuindo significativamente para a reabilitação dos portadores de perda do bulbo ocular.

4 CONCLUSÃO

O principais modos de falha (espelhamento e alteração cromática) podem ser evitados ou reduzidos a depender das técnicas e materiais empregados na reabilitação. O espelhamento está diretamente relacionado ao material de selamento da pintura de íris artificiais, sendo a associação do acetato de vinila com a técnica de pintura direta, a melhor escolha por não apresentar índices de comprometimento. O tipo de polimerização da prótese não interfere no espelhamento, porém tem impacto significativo na alteração cromática. Assim, a associação da técnica de pintura direta/selamento com acetato de vinila/ polimerização química convencional é a melhor associação para aplicação clínica por apresentar os menores índices de espelhamento e alteração cromática, mostrando-se como um protocolo seguro para o comportamento estético na reabilitação através de próteses oculares.

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