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"Optical properties of resin composites used in biomimetic and aesthetic direct restorations"

"Propriedades óticas das resinas compostas em restaurações diretas estéticas e biomiméticas"

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*“All our dreams can come true,
if we have the courage to
pursue them.”*

Walt Disney

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Abstract:

Introduction: Nowadays dental materials, including resin-based composites, are gaining a big importance due to an increased awareness about facial and dental aesthetics. Thus, studding the different optical properties (translucency, opacity, opalescence, colour and fluorescence) of resin-based composites, what influences them and what their stability through time depends on, have some relevance because it allows the achievement of more biomimetic and long-lasting final restorations that are appealing to the patient and to the clinician.

Objectives: Understand which factors influence optical properties of each resin-based composite, comprehend which resin-based composites optical properties are fundamental to perform aesthetic and biomimetic definitive direct restorations and, lastly, understand which characteristics and properties of resin-based composites and final restorations allow the maintenance of aesthetic results over time.

Methods and Materials: The bibliography used was obtain through bibliography researches in Pubmed® e Scopus Preview® databases. The inclusion criteria used included time limit of 5 years, Portuguese and English languages, free full text available and articles as documents types.

Development: Several types of resin-based composites, with different compositions, present their own optical properties, which intend to be as closer as possible to natural tissues optical properties. That similarity allows definitive direct restorations, performed with resin-based composites, to be integrated with the remaining teeth. Filler particles and polymeric matrix, present in resin-based composites composition, influence their optical properties in different ways. Besides that, absorption, reflection, transmittance, scattering and even light attenuation of the incident light that hits resin-based composite surface can result in different optical properties. Also, colour parameters (hue, chroma and value) may influence those optical properties. Consider other parameters, such as resin-based composites aging, is also important, as different mediums to which resin-based composites are exposed to, *in vitro*, influence the stability of optical properties, putting at risk the stability of final restorations over time.

Conclusion: Optical properties of resin-based composites seem to be influenced by several factors. Besides, different optical properties may present opposite behaviours and even the same light phenomena may result in different optical properties. Different resin-based composites that differ in their optical properties seem to present different behaviours regarding their stability when exposed, *in vitro*, to different situations that pretend to simulate what happens to definitive direct final restorations done with resin-based composites *in vivo*.

Keywords: “Optical properties”, “Composite restorations”, “Fluorescence”, “Opalescence” and “Dental restorations”

Resumo:

Introdução: Atualmente os materiais dentários, entre os quais as resinas compostas, têm ganho uma grande importância devido à crescente preocupação com a estética facial e dentária. Assim, estudar as diferentes propriedades óticas das resinas compostas (translucidez, opacidade, opalescência, cor e fluorescência), o que as influencia e de que depende a sua estabilidade ao longo do tempo, detém relevância por permitir a execução de restaurações finais mais biomiméticas e duradouras, que agradam tanto ao paciente quanto ao médico dentista.

Objetivos: Perceber que fatores influenciam as propriedades óticas de cada resina composta, compreender quais as propriedades óticas das resinas compostas são fundamentais para realizar restaurações diretas definitivas biomiméticas e estéticas e, por último, perceber quais as características e propriedades das resinas compostas e das próprias restaurações finais permitem a manutenção dos resultados estéticos ao longo do tempo.

Materiais e Métodos: A bibliografia utilizada foi obtida recorrendo a pesquisas bibliográficas nas bases de dados Pubmed® e Scopus Preview®. Os critérios de inclusão utilizados incluíram limite temporal de 5 anos, idiomas português e inglês, texto disponível como texto integral grátis e artigos como tipos de documentos

Desenvolvimento: Os vários tipos de resinas compostas, com diferentes composições, apresentam diferentes propriedades óticas próprias, que pretendem aproximar-se o mais possível das propriedades óticas dos tecidos dentários naturais. É essa semelhança que permite a integração das restaurações diretas definitivas, realizadas em reina composta, com a dentição remanescente. As partículas e a matriz polimérica que constituem as resinas compostas influenciam de forma diferente as várias propriedades óticas. Além disso, a absorção, a reflexão, a transmissão, a distribuição e a própria refração da luz incidente na superfície das resinas compostas podem resultar nas diferentes propriedades óticas. Também os parâmetros da cor (matiz, croma e valor) podem influenciar as propriedades óticas. Considerar outros parâmetros como o envelhecimento das diferentes resinas compostas é também importante, uma vez que diferentes meios a que as resinas compostas são expostas, *in vitro*, influenciam a estabilidade das suas propriedades óticas pondo em risco a estabilidade das restaurações finais a longo prazo

Conclusão: As propriedades óticas das resinas compostas parecem ser influenciadas por diversos fatores. Além disso, as diferentes propriedades podem apresentar comportamentos opostos e o mesmo fenómeno da luz incidente pode resultar em propriedades diferentes. Diferentes resinas compostas que diferem nas propriedades óticas parecem apresentar distintos comportamentos no que respeita à sua estabilidade, quando são expostos, *in* *vitro*, a diferentes situações que pretendem simular o que acontece às restaurações finais diretas definitivas em resinas compostas *in vivo*.

Palavras chave: “Propriedades óticas”, “Restaurações em resinas compostas”, “Fluorescência”, “Opalescência”, “Restaurações dentárias”

General index

Tables' index

Abbreviations:

ΔE	Colour changes
BAG	Bioactive glass
BAG-F	Fluoride coating BAG
CAP	Colour adjustment potential
CIE	Comission Internationale de L'Eclairage
CQ	Camphorquinone
DGP	Dental glass powder
FDI	Fédération Dentaire Internationale
RBC	Resin-based composite
RBCs	Resin-based composites
$TATP_{00}$	Translucency acceptability threshold
TP	Translucency parameter
TPT_{00}	Translucency perceptibility threshold
UV	Ultraviolet

Introduction

Introduction

The increased need for achieve the ideal material with ideal characteristics for each clinical situation, such as performing functional and biomimetic dental restorations, makes dental materials a subject of great interest nowadays.

A restoration can be done directly in the patient mouth (direct restoration) or indirectly, when they are done outside the patient mouth, by the dental technician or ceramist, and later placed and cemented in the tooth preparation (indirect restoration). Besides those two techniques, there also semi-direct definitive restorations. Direct restorations, done with resin based composites (RBCs), are one of the most used ways to restore a tooth, due to their longevity, their satisfactory aesthetic results and to their lower cost, comparing with the indirect ones.[1]

Aesthetic direct restorations, can be done applying a layering technique, used since 1980.[2] That technique consists on adding layers of enamel and dentin RBCs shades with different characteristics and properties (translucency, opacity, chroma, etc) as well as other effect colours and pigments. It aims to achieve an aesthetic and satisfactory dental restoration, in the posterior and, mainly, in the anterior teeth, depending on some other factors.[2, 3] So, when a restoration is done with that technique, its colour and optical behaviour are determined by the colour and different optical properties of all translucent RBCs placed and by the dark oral environment itself. [2, 4] Despite allowing the clinic to perform a biomimetic restoration, which can mix harmoniously with the surrounding teeth by mimicking their anatomy and optical characteristics, that technique consumes more in-chair time and requires high technical abilities.[2, 5]

RBCs, a material primarily introduced in 1962 by Bowen and then optimized[6], are becoming more popular to perform both direct and indirect restorations. They show improved physical and aesthetic properties and an easier manipulation, that allows the clinic to correctly place and sculp them in an anatomical shape before their photoactivation[5-7]. They are also able to blend with their surroundings, while providing the strength to deal with most clinical situations[8], are available in different shades and opacities and have a lower cost, then other restorative options.[2, 9-11] However, despite all their advantages, RBCs also have some characteristics that might compromise restorations longevity, such as the inability to maintain their colour through all their lifetime on the oral cavity and their need for repolishing periodically. [10]

Furthermore, RBCs are composed by four main components (organic polymeric matrix, inorganic filler particles, a coupling agent and a photo-initiator system) [5, 12] and by some added ones that seek to improve RBCs properties and characteristics.[6]

RBCs polymeric matrix is a highly cross-link structure and is, classically, based on aromatic and aliphatic dimethecrylate monomers, as bisphenol-A glycidylmethacrylate (Bis-GMA) and/or urethane dimetracrylate (UDMA), to which low viscosity monomers like triethylene glycol dimethacrylate (TEGDMA) and/or bisphenol-A ethoxylate dimethacrylate (BisEMA) can be added in order to improve RBCs properties.[13] To produce new RBCs with possibly improved aesthetics and properties under the oral environment the introduction of silorane as a resin matrix has been made. Using silorane seems to reduce RBCs susceptibility to water absorption, which is important for their optical properties.[9] Also inorganic-organic hybrid polymers, also known as ORMOCER, are gaining importance as they also bring some advantages for RBCs.[11]

Adding filler particles is also a way to improve resin properties. Those particles can have many compositions but silicon dioxide (SiO_2) particles are the most common.[4, 11, 12] Besides, they can have several shapes, although spherical shape seems to present some advantages. Furthermore, resin matrix viscosity also influences the quantity of smaller fillers present in the RBCs composition.[13] As Habib *et al.*[13] described, UDMA resin combined with TEGDMA allows more particles to be incorporated into the matrix, when that particles are smaller, as UDMA resin is less viscous than Bis-GMA resin.[13]

Another issue that must be taken in consideration is the filler size, which can vary from 100 μm (macroparticles) to 0.005 μm/1nm (nanoparticles).[6]

Regarding to the coupling agent, it's a bonding agent which is applied to particles' surface in order to assure that they bound chemically to the polymeric matrix, being the organo-silane the class of coupling agents most used.[6]

The final RBCs main component is a photo-initiator system[6, 12] that allows a soft and mouldable material to result in a hard and long-lasting restoration, by a polymerization process, namely a chemical or photo-activation, or the combination of both.[6] The most commonly used photo-initiator system is camphorquinone (CQ), a stable yellow compound, whose presence might lead to an undesirable yellow effect after polymerization, which can increase over time.[5] Monoacylphosphine oxide (Lucirin TPO) is another type of photo-initiator system and, its usage can lead to increased colour stability upon aging and to reduced photo-yellowing effects.[5]

Several kinds of RBCs are commercially available. Universal RBCs, used for posterior and anterior restorations, are one of them and consist on RBCs that try to simulate both natural enamel and dentin properties.[2] Another type are RBCs with different shades that intend to restore each natural tissue of a tooth. Those shades are, among others, artificial enamel, artificial dentin and body shades. Enamel and dentin shades refer to different RBCs, which were designed to mimic mechanical and optical properties of natural enamel and dentine respectively and are indicated for building different parts of a tooth.[2, 14] As for body shades, they are RBCs shades whose opacity and translucency are between the ones of natural enamel and dentin, allowing the replacement of those two tissues to be done with one layer of RBC.[14]

Different factors, related to those components, might influence RBCs properties, including the optical ones (colour, fluorescence, opacity, translucency and opalescence)[6]. Some of those factors include wear, degradation of polymeric matrix and/or particles and weakening of the bond between organic and inorganic components. Filler size, as well as their surface area, which differs with the particles size, and their concentration are also important factors that can influence RBCs optical properties and manipulation characteristics.[15, 16] In short, in order to obtain different RBCs with different optical properties and light phenomena, they must differ in their composition.[17] Optical properties of RBCs can also be influenced by surface roughness and by water uptake/sorption, so the conversion degree of a photo-activated RBC must also be considered as it influences the ability of a RBC to absorb water.[8]

Furthermore, optical properties are also a result of incident light phenomena such as absorption, scattering[18] transmittance and reflection. Those phenomena seem to also depend on particles size, composition and distribution and on the polymeric matrix,[17] as well as on light wavelength.[4] Therefore, they will result in RBCs optical properties, as, for example, translucency and perceived colour are related to incident light scattering.[12, 18]

Some optical phenomena, like light scattering, depend also on the match between refractive indexes of particles and polymeric matrix of RBCs.[14, 19] Thus, RBCs with nanoparticles seem to offer better optical properties than those with bigger particles. However, even nanoparticulated RBCs, may not be able to fully reproduce the optical properties of natural teeth[19] because their natural tissues have optimal optical properties that go beyond colour.[5] As those light phenomena are so important to optical properties, it becomes relevant explore them regarding each optical property they influence. Also, it's important to note that as those light phenomena also depend on RBCs composition, it can be restated that RBCs composition highly influences their aesthetic.[18]

In order to archive a full aesthetical and biomimetic RBC restoration, beyond being able to mimic the optical properties of natural teeth at the moment, RBCs also need to be able to keep that match over time[18] because, depending on the aging treatment RBCs samples are exposed to, their optical properties might change, even *in vitro*.[8]

Besides incident light phenomena, there are also some parameters, namely hue, chroma and value, that may be related to colour and translucency, as optical properties. As so, it is important to say that hue and chroma are the parameters that define the Vita shade of each RBC (Vita Classical shade guide (Vita, Vita Zahnfabrik, Bad Säckingen, Germany)), while luminescence, or value, is more related to RBCs translucency. Value is reported to be more important than hue and chroma as the human eye is more sensible to grey scale variations than to all the other colours.[2] Enamel and dentin RBCs shades have different translucency in order to better mimic the natural tissues, as high value and low chroma are characteristics of natural enamel, while natural dentin presents higher amount of chroma and lower value.[5]

Besides all that, RBCs optical properties can vary in function of RBCs colours and trademarks.[17]

As so, understanding RBCs' optical properties and their physics is becoming imperative to perform aesthetical dental restorations[16] because of the increased awareness of facial and dental aesthetics which leads to a higher need for dental restorations capable of mimic natural tissues and structures. Also, understanding the relation between those properties and dental morphology becomes essential to achieve optimal and stable restorations, never forgetting that selecting the right technique to perform them also influences the final result.[14, 15]

Thus, the objectives of this bibliographic review are to understand which factors influence the optical properties of each RBC, understand which RBCs optical properties are fundamental to perform biomimetic and aesthetic direct definitive RBCs restorations, and, finally, understand which characteristics and properties of RBCs and final restorations allow the maintenance of the final aesthetical results over time.

Methods and Materials

Methods and Materials

To write this monography, Pubmed® and Scopus Preview® databases were used, between October 2020 and March 2021, to collect information and bibliography.

Keywords and inclusion criteria of each research, 3 done in Pubmed® and 1 in Scopus Preview® are listed in Table 1, regarding the database they were performed in.

Finally, in order to obtain general information about RBCs and their properties, two books about the subject were consulted.

Database: Pubmed®	
Keywords	“Optical properties” AND “Composite restorations”
Inclusion criteria	Time limit: 2015-2016
	Languages: English and Portuguese
	Results selected due to relevance to the subject and objectives of the monography
Keywords	“Fluorescence” AND “” composite restorations
Inclusion criteria	Time limit: 2016-2021
	Languages: English and Portuguese
	Text availability: Free full text
	Results selected due to relevance to the subject and objectives of the monography
Keywords	“Opalescence” AND “Dental restorations”
Inclusion criteria	Time limit: 2016-2021
	Languages: English and Portuguese
	Text availability: Free full text
	Results selected due to relevance to the subject and objectives of the monography
Database: Scopus Preview®	
Keywords	“Optical” AND “Properties” AND “Composite AND “Restorations”
Inclusion criteria	Time limit: 5 years
	Document type: Article
	Results selected due to relevance to the subject and objectives of the monography

Table 1: Keywords and inclusion criteria of each research

Results and Discussion

Results and Discussion

The final results from each research are listed in Table 2. In this bibliography review were used 25 articles and 2 books, resulting in a total of 27 bibliography references.

The materials, objectives and principal optical property/parameter analysed in some articles used to write the following chapter are listed in Attachment 1, as well as some articles cited by other authors.

Database: Pubmed®		
		Results
Keywords	"Optical properties" AND "Composite restorations"	21
Keywords	"Fluorescence" AND "" composite restorations	1
Keywords	"Opalescence" AND "Dental restorations"	1
Database: Scopus Preview®		
		Results
Keywords	"Optical" AND "Properties" AND "Composite AND "Restorations"	2

Table 2: Final results from each research

The researches results will be explored regarding the optical properties of RBCs and the variables that influence them in the next chapters.

1.Optical properties

Translucency

Definition:

Translucency is situated between total opacity and total transparency[4, 9, 11, 12] and it's the property that allows the incident light to pass through the material while being distributed in it.[4, 9, 12] In short, the translucency parameter (TP) of each RBC is defined by the final amount of light that is transmitted through its thickness.[14] On a natural tooth, enamel is more translucent than dentin, thus, when a layering technique uses translucent and opaque RBCs shades, final restorations will be more biomimetic.[11]

Parameters:

RBCs translucency, which is very important for shade matching with the adjacent teeth, is influenced by many factors that can also contribute to translucency instability as well as some extrinsic ones such as pigmentation, ultraviolet (UV) radiation and thermal alterations.[9]

RBCs composition

Translucency also results from the relation between RBCs particles and matrix refractive indexes, which are related with light scattering.[14, 15, 18] Bigger differences between those indexes lead to less translucent RBCs that are more different from the natural enamel.[8, 15]

According to some authors, filler particles are the biggest responsible for RBCs translucency because their size, amount and shape influence light scattering and transmittance.[4, 15, 18] When particles are smaller than the wavelength of visible light (380 a 780nm), the human eye won't be able to detect the effects of light absorption and scattering, resulting in more transmitted light. So, theoretically, nanoparticulated RBCs, whose particles have between 1 and $100nm^2$, are more translucent and aesthetic.[4, 15]

According to Salas *et al.*, 0.62 and 2.62 are, respectively, the 50:50% translucency perceptible threshold (TPT_{00}) and the 50:50% translucency acceptability threshold (TAT_{00}) for translucency changes and determine if RBCs present an acceptable or even perceptible translucency change.[19]

Regarding particles composition and its influence on RBCs translucency, Salgado *et al.*[15] observed that when the nanoparticles incorporated into the matrix were smaller and in lower quantity, the material presented higher translucency. Those observations allowed them to conclude that translucency didn´t depend on the surface area of filler particles but it was influenced by their size and amount.[15] Those results are in agreement with Pecho *et al.*[4], who observed that translucent shades from a nanoparticulated RBC, which had lower particles volume, presented higher translucency and transmittance values.[4] Also, Habib *et al.*[13] incorporated different sized particles into Bis-GMA/TEGDMA or UDMA/TEGDMA resins and evaluated the experimental final material. They verified that smaller particles led to higher translucency values due to the decreased percentage of light scattering and reflection caused by smaller particles. Besides that, they also observed that when UDMA/TEGDMA resin was used the translucency was higher due to the smaller difference between resin matrix and filler particles refractive indexes. Thus, they concluded that RBCs with smaller filler particles seem to present higher transparency and, subsequently higher translucency, as this property depends on the amount of transmitted light.[13]

There are also studies that evaluate the importance of polymeric matrix. Some recent RBCs have silorane as polymeric matrix, instead of a methacrylate matrix, despite the contradictory conclusions regarding their optical properties. Thus, Shirinzad *et al.*[9] used methacrylate resins with different particles sizes and a silorane resin, exposed them to artificial aging treatments and evaluated the influence of artificial accelerated aging on translucency of both matrixes. At base line, silorane RBC presented lower translucency than methacrylate RBCs. After aging treatments all RBCs tested reduced their translucency with only the changes from methacrylate RBCs being significant. It was also observed that translucency differences seem not to depend on particles size but to depend on spaces between them.[9]

Different RBCs with different resin matrixes have different water absorption susceptibilities. As so, RBCs with Bis-GMA/TEGDMA matrix present higher susceptibility to absorb water, which lead their translucency to decrease after aging treatments. As for the silorane RBC evaluated, as silorane is hydrophobic, its translucency was more stable when it was exposed to aqueous environments. Thus, Shirinzad *et al.*[9], concluded that silorane RBC had different translucency from methacrylate RBCs and that its translucency decrease after artificial aging treatments wasn't significant.[9] Azzopardi *et al.* had already reported a direct relation between RBCs translucency and the amount of Bis-GMA resin.[9]

Kolb *et al.*[11] developed experimental RBCs with different ORMOCERs as resin matrix and dental glass powder (DGP) as filler particles and evaluated their translucency regarding material thickness. Those experimental RBCs increased their translucency as the resin matrix refractive index increased, due to the addition of either Zirconium dioxide (nanoparticles) or 4-Methylthiophenol, and approached the DGP particles refractive index. When both refractive indexes matched, the maximum translucency values were obtained but they decreased when resin matrix presented a higher refractive index than DGP.[11]

Different experimental RBCs produced with different ORMOCERs resins presented different translucency values as Kolb *et al.*[11], verified in their study.

They also verified that photopolymerization increased experimental RBCs translucency, as polymeric resin refractive index also increased, leading to a better match between particles and matrix refractive indexes. As samples increased their thickness, that difference between liquid and polymerized RBCs translucency also increased.[11]

Regarding their results, Kolb *et al.*[11], concluded that refractive index adaptation using Zirconium dioxide nanoparticles or 4-Methylthiophenol allowed the production of highly translucent hybrid RBCs and that there was an exponential relation between material thickness and translucency.[11]

RBCs shades with different degrees of translucency allow to reproduce natural tissues optimal characteristics.[20] A study that evaluated different RBCs brands reported higher translucency values in enamel than in dentin shades and intermediate values in body shades.[19] Translucent shades of some RBCs differ from conventional ones regarding their ability to transmit and disperse incident light, probably due to their particles size and amount. In order to understand that difference and evaluate the optical properties of different shades of RBCs, Pecho *et al.*[4] used samples from conventional (Enamel (E), Body (B), Dentin (D) and Translucent (T)) and whited (WhE and WhB) shades from a nanoparticulated RBCs group. As expected, translucent shades presented the highest transmittance and translucency values. It was also concluded that, regarding the whitened shades, WhB had different optical properties from conventional B shade and WhE showed higher transmittance and translucency values than the conventional E shade. They also found that dentin (D) and WhB shades presented higher scattering values, indicating that those shades could have higher content of filler particles and pigments and that their translucency, despite presenting the lowest values was the closest to natural dentin translucency.[4] Besides that, dentin shades used also presented lower translucency values, whereas enamel shades presented the highest. Also, Kamishima *et al*. and Ikeda *et al.* showed that opaque RBCs seemed to be less translucent than other shades in several RBCs groups.[14]

Marjanovic *et al.*[21] evaluated dentin nano-hybrid and micro-hybrid RBCs among other artificial dentin materials, placed under different enamel shades from the same RBCs groups, regarding their colour and translucency. Thus, they found that each enamel shade translucency, used without an underlying dentin restoration, was influenced by layer thickness, as RBC translucency seemed to decrease when layer thickness increased. Besides that, it’s important to note that thinner layers of enamel RBCs are more affected by discolouration of underlying natural tissues or of artificial dentin restoration.[21]

As so, when highly translucent restorations are needed, modifying RBCs layer thickness affect more the final result than the RBC selected.[21]

RBCs translucency seems to decrease after aging processes.[18] Regarding that decrease, some authors, have reported that translucency of RBCs can be altered after water storage due to a water layer that infiltrates between particles/matrix interface, changing the relation between their refractive indexes, and to a surface energy increase.[15] However, Diamantopoul *et. al.* defended that those changes magnitude depended on RBC shade and brand. Shirinzad *et al.*[9], evaluated different RBCs from the same commercial group, before and after artificial aging and reported that nano RBC was the one with the highest initial translucency but presented a more significant translucency decrease after artificial aging treatments in distilled water then the remaining tested materials, that also decreased their translucency.[9]

<u>External parameters</u>

Sulaiman *et al.*[8] exposed samples of a nano RBC among other resin restorative materials, to distilled water, coffee, grape juice and thermocycling and evaluated their influence on RBCs translucency. Their results showed that exposing RBCs to coffee led to the highest translucency modifications. Considering the 50/50% acceptability threshold for relative TP, defined as 2.62, all RBCs exposed to coffee were labelled as unacceptable because they surpassed that value, whereas the samples exposed to the other treatments remained acceptable. Besides that, RBCs translucency seems to be directly influenced by their colour stability, as hot drinks are able to influence colour stability and translucency of RBCs.[8]

Universal RBCs translucency should approach both natural enamel and dentin translucency.[2] As so, Miletic *et al.*[19] evaluated RBCs, medium and time interactions on translucency changes of some universal RBCs enamel shades. For that, they analysed various RBCs, which differ on their composition and whose samples were stored in staining mediums (red wine, coffee and distilled water). Apart from the ultrafine hybrid RBC when exposed to wine, whose resistance can be explained by its discolouration resistance, lower solubility and sorption, all RBCs showed decreased translucency after staining in any medium. Besides that, when samples were exposed to red wine, their translucency changes were higher than those obtained when samples were exposed to coffee, with nano RBC samples presenting the highest changes and the ultrafine hybrid RBC samples the lowest changes. That indicates that translucency was more affected by wine than by coffee. Regarding the acceptance threshold, all tested RBCs translucency changes were considered acceptable, as all of them were below 2.62. Regarding the 50/50% perceptibility threshold (0.62), all samples stored in distilled water presented translucency changes below that limit, except for the nano RBC samples, whose values were similar to the values they presented when exposed to other mediums.[19]

Besides that, translucency presented a positive correlation with water sorption, which indicates that differences in light diffusion through the stained polymer could be affected by absorbed pigments and by structural changes.[19]

Finally, regarding to repolishing RBCs after staining, Lee and Lee showed that it may increase its translucency although that increase may be related with RBCs shades they studied.[9] As for Miletic *et al.*[19], they found that repolishing samples had little or even no effect on translucency changes, except for ultrafine hybrid RBC samples exposed to wine, what indicates that its translucency was affected either by changes in pigment absorption either by internal mechanisms, such as water uptake.[19]

Opacity

<u>Definition:</u>

Opacity is characterized by total blockage of light transmittance through a material. RBCs with high opacity levels are suitable for masking dentin discolorations and for avoiding the perception of the oral cavity throughout the restoration, depending on its thickness. Although using opaque RBCs, even in a thinner layer can result in a greyish restoration. As so, this property must be taken into consideration when highly aesthetical restorations are needed.[20]

<u>Parameters:</u>

<u>RBCs composition:</u>

Opacity is the opposite of total transparency and it also depends on the refractive index of each RBCs component. The bigger the difference between the refractive indexes, the opaquer RBCs present. Also, RBC with high absorption and scattering coefficients present higher opacity, than those with low values of those coefficients, and have a more intense colour.[12, 20] As so, it can be said that, as opacity is the opposite property of translucency, nanoparticles confer low opacity to RBCs with low staining, allowing the existence of a lot of different shades and opacities inside the same RBCs group[4] as natural dentin have higher opacity levels than natural enamel.[5]

Santos *et al.*[20] verified that the highest opacity values were obtain for a nano RBC enamel shade while the lowest values were obtain for a nano-hybrid RBC enamel shade. Those differences can be attributed to their different compositions and allowed those authors to verify the need of thicker layers of translucent RBCs when the underlying tissues are discoloured. They also found that opacity changes within each dentin RBC shade, were obtained by reducing samples thickness.[20]

Supra-nano spherical filled RBCs, due to its particles, are stated to be able to produce a similar opacity to natural tissues, as they are capable of reflect and scatter the incident light. These capacities make supra-nano spherical filled RBCs able to better blend with the surrounding tissues giving clinicians the ability to control chroma, hue and value of RBCs.[16]

Some new RBC groups present conventional and whited shades which are supposed to present higher opacity and gloss than the conventional RBCs from the same group.[4]

Finally, if RBCs translucency and opacity corresponded exactly to natural enamel and dentin optical properties, placing a layer of RBC with the same thickness of the natural tissue would result on an optical effect similar to the natural one. However, as there are a variety of RBCs with different translucencies and opacities, it mustn't be forgotten that some might have higher translucency or opacity than natural tissues.[20]

Opalescence

Definition:

Natural enamel is more able to scatter shorter light wavelengths than longer ones and so, it presents a bluish aspect when observed under reflected light and a yellowish/brownish aspect when observed under transmitted light, a phenomenon known as opalescence.[22, 23] Blue light scattering and reflection as a bluish light, gives enamel a bluish aspect, despite being colourless, and teeth their characteristic incisal third blue halo. However, despite that third being where the opalescent effect is more visible, there is no specific areas of opalescence in the natural enamel.[22]

Opalescence is responsible for teeth brightness, depth and vitality, so it must also be considered for RBCs as it gives their restorations a more natural and vital look. Besides that, opalescence can help masking colour of underlying substrate of RBCs restorations and is reported to vary with material type and RBCs shade.[22]

While hydroxyapatite crystals are responsible for scattering blue light in natural enamel, RBCs opalescence is determined by resin matrix and filler particles refractive indexes and is defined as the difference of chroma between reflected and transmitted light colours.[22, 23]

Parameters:

RBCs composition:

Thickness of RBCs samples influences the opalescence as it was concluded on a study that evaluated different RBCs samples with three different thickness and found that opalescence values increased when increasing samples thickness, even when samples were more than 1mm thick and their translucency decreased.[22] Tabatabaei *et al.*[23] and Arimotoa *et al.*, reached the same conclusion.[23]

Regarding to translucent RBCs shades, Pecho *et al.*[4] observed that translucent shades from a nano RBCs group showed high opalescence values, due to the ability of their nanoparticles to scatter blue light.[4]

Besides, opalescence seems to be different between different RBCs shades and brands and higher when filler particles were present.[22]

Tabatabaei *et al.*[23] used two different shades from two RBCs brands and evaluated their opalescence and the effect of thickness, enamel or body shades and brand on it. Regarding their results, they found that a microhybrid and a reinforced nanofilled RBCs presented higher opalescence than the nanoparticulated RBC, in all tested groups, as the former is more translucent and has smaller particles. As so, the differences observed in opalescence of both RBCs tested can be justified by their different composition and particles size. Those results allowed them to concluded that thickness, shade and brand influenced those RBCs opalescence.[23]

Lee *et al.* found that adding titanium dioxide (TiO2) to experimental RBCs increased their opalescence and that 1mm thick RBCs samples with 0.1 to 0.25% of those nanoparticles could simulate natural enamel opalescence. As so, adjusting RBCs filler composition and matrix phase, seems to allow RBCs to better mimic natural enamel opalescence.[22, 23] Those authors also found that opalescence is lower under daylight than in the presence of fluorescent light and that it changed under irradiated light.[23]

External parameters:

Polymerization also affects RBCs opalescence as it decreases after polymerized due to polymeric matrix refractive index increase.[23] Also, when exposed to different accelerated aging treatments, different RBCs presented different changes in their opalescence.[22]

Fluorescence

Definition:

Fluorescence consists on the emission of less energized photons, after incident light absorption.[17, 23] Moreover, both inorganic and organic compounds can present it.[17]

As natural enamel has a small amount of organic component, it produces a weak fluorescence, while natural dentin, due to its higher amount of organic component, presents a higher fluorescence.[17]

Regarding natural teeth fluorescence and its intensity, it seems to be similar between teeth of the same individual, upper or lower, and between genders. Although, within a tooth, fluorescence seems to be greater in the cervical area, as it present a higher amount of dentin, than in the incisal area.[17]

Natural teeth present a blue fluorescence under UV light, thus restorative materials, in order to produce the same effect, and be fully integrated in the oral environment, must also emit the same strong blue fluorescence under strong UV light. As UV light, especially long waves, allows a better fluorescence perception, when performing dental restoration this property mustn't be forgotten.[17]

Parameters:

RBCs composition:

As RBCs basic components are unable to promote fluorescence, adding fluorescent matrixes, luminescent species[17] and fluorescent pigments[23], to the mix can provide that property to RBCs.[17] Despite of RBCs final fluorescence not being equal to the sum of the fluorescence of each individual luminescent agent used,[7, 17] it seems to depend on RBCs shade and type.[23]

Ameer and Mualla evaluated a microhybrid, a nanohybrid and a nanoparticulated RBCs from the same commercial brand and concluded that different particles sizes lead to different fluorescence.[17] Besides, Reis *et al.* found that a nano RBC presented the lowest fluorescence values.[17]

Lopes *et al.*[7] evaluated different RBCs and found that some RBCs had lower fluorescence values than natural enamel, while others showed higher values. They noted that fluorescence seemed to be influenced by RBCs polymeric matrix and filler particles, namely their composition, proportion and type.[7]

Tabatabaei *et al.*[23]*.* evaluated the fluorescence of different RBCs shades and brands as well as the effect of thickness, shade and brand on it. That study showed that, in a nanoparticulated RBC group, dentin shade presented higher fluorescence than enamel shade regardless their thickness, opposite to what happen in in other tested RBC group, mainly when samples were 1mm thick. Regarding samples thickness, thicker samples presented lower fluorescence in either of the RBCs groups evaluated. Also, the other RBCs group showed higher fluorescence than the nanoparticulated RBCs group.[23] As so, authors concluded that fluorescence of the tested RBCs was influenced by their thickness, type and brand. Previously, Meller and Klein, already concluded, that, within the same brand, different shades present different fluorescence values.[23]

Besides, when thickness and fluorescent particles density are constant between different RBCs, opaquer RBCs are less fluorescent as incident light has less change to reach fluorescent particles, as confirmed by Tabatabaei *et al.*[23]

Attending to RBCs restorations, their final fluorescence may result from the fluorescence of the last placed layer or, if that last layer is too thin, from the combination of fluorescence of all applied layers, resulting in an intermediate fluorescence level.[17]

<u>External parameters:</u>

RBCs restorations, as well as natural teeth can have their fluorescence influenced by, age, temperature and bleaching agents.[17]

When RBCs are subjected to accelerated aging under UV radiation or thermocycling, their fluorescence seems to reduce, probably due to resin' water sorption capacity. RBCs polymeric matrix can be degraded by temperature because it acts as a catalyst, accelerating the degradation process, as bleaching with hydrogen peroxide does.[17]

Silva *et al.* submitted RBCs samples to different beverages and smoke and found that tabaco and some drinks, especially coffee, provoked a reduction in RBCs fluorescence.[17]

Antonov *et al.*[24], also found that exposing a microhybrid RBC to different beers resulted in reduced fluorescence, with samples exposed to Bernard dark beer (dark lager, Bernard Brewery, Czech Republic) showing the largest decrease while samples exposed to Leffe beer (brown abbey beer, NV/SA InBev, Belgium) presented the lowest. Those authors also noted that, unlike its intensity, fluorescence spectrum shape wasn't influenced by pigmentation.[24]

Takahashi *et al.,* concluded that some nanoparticulated and microhybrid RBCs reduced their fluorescence after aging, with only one nanoparticulated RBC being able to maintain its fluorescence, as Jablonski *et al.* also proved.[17]

Finally, maintaining RBCs restorations fluorescence though time reveals to be essential as, without fluorescence, RBC restorations and natural teeth would present decreased luminosity, especially under high UV radiation levels.[17]

Colour

Definition:

Light is colour's physical definition.[14, 22] When light hits an object surface, depending on its heterogenicity, it can be absorbed, scattered, transmitted, refracted, reflected or attenuated on its way through the material thickness. When studying colour, those light phenomena have much importance as colour perception seems to depend on them.[14] After suffering those phenomena, the remaining light leaves RBCs structure and is received by an observer´s eyes as information referent to the object colour.[4]

Clinically, RBC shades and colours are selected using a guide. Classical VITA shade guide (Vita, Vita Zahnfabrik, Bad Säckingen, Germany), which is based on hue and chroma, and VITA 3D-MASTER (Vita, Vita Zahnfabrik, Bad Säckingen, Germany), which is based on value, are some of those guides.[19]

Natural teeth have a variety of different colours, due to their different and complex layers (pulp chamber, dentin and enamel) with different optical properties and structure.[5] As so, it became necessary to develop RBCs with different shades.[2]

Natural teeth colour is also influenced by intraoral environment, namely its general darkness and the surrounding soft tissues. Those factors also influence the perception of colour differences between natural tissues and restorative materials.[5, 25] Besides that, usually less coloured and highly translucent RBCs, like nanoparticulated ones, allow a better visualization of the oral background.[4]

Parameters:

RBCs composition:

Elgendy *et al.*[14] studied light phenomena on natural tissues and on some nanoparticulated RBCs shades when a restoration was done with different shades. They observed that dental tissues can absorb less light then RCBs, which makes natural tissues more transparent. Besides that, they also found that using a lighter RBC shade, resulted in less light lost through the material thickness and that using only one RBC shade resulted in the highest light absorption and scattering rates. The same study showed that light scattering is higher on dental tissues than on the studied RBCs and that, when all RBCs layers placed have the same thickness, light absorption shows an inverse correlation with light transmittance. As so, authors concluded that there is no monochromatic RBC able to replicate the complex colour orientation of natural teeth, which means that, different RBCs shades must be selected and placed in irregular and undulated layers in order preform a restoration capable of reflect, absorb, refract and transmit light as natural tissues do.[14]

Perez *et al.*[16] evaluated light absorption, scattering and transmittance of supra-nano spherical filled RBCs and compared them with nanoparticulated, nanohybrid and microhybrid RBCs. They found statistically significant differences between supra-nano spherical filled RBCs and the remaining RBCs studied regarding light phenomena coefficients. Besides that, those authors also found, for all RBCs, that the absorption coefficient was lower for longer light wavelengths, while transmittance spectra presented the opposite behaviour.[16]

Different sized RBCs particles may lead to different RBCs colours. Also, RBCs colour may also be influenced by RBCs translucency.[18]

<u>Colour parameters CIELAB L* (value), a* and b* (chroma and hue):</u>

International Commission on Illumination (CIE) recommends colour measurements using both CIELAB L*, a* and b* or CIEDE2000 formulas, despite of the former being the most recent.[5] Both formulas use CIELAB L* (lightness), a*(red-green) and b* (yellow-blue) coordinates which express RBCs colour numerically, mainly on research context.[19]

Lightness or CIELAB L* (L*) is defined as visual perception of light, according to which a material can reflect a portion of an incident light.[4] As for CIELAB a*(a*) coordinates, they represent red-green axis (positive value: redness; negative value: greenness). Finally, CIELAB b* (b*) coordinates represent the yellow-blue axis, (positive values: yellowness; negative values: blueness). When achromatic colours are evaluated, a* and b* values are near zero and increase when more intense colours are evaluated.[5]

In order to fully mimic natural teeth, *in vivo*, RBCs must have their L*, a* and b* values adjusted. Also, it must be considered that dark oral background of a restoration decreases its value, mainly with translucent RBCs, contributing for a mismatched RBC restoration.[5]

Experimental RBCs developed by Salgado *et al.*[15] differed in their nanoparticles sizes and coupling treatment, but not in their particles surface area. Their results showed higher L* values when smaller nanoparticles were used, regardless the aging treatment to which samples were exposed to. Nevertheless, those L* values might be influenced by materials translucency. They also verified that a* and b* values decreased when increasing nanoparticles size due to different percentages of inorganic component present in each experimental RBC. That's because, as experimental RBCs had different particles sizes, when they were bigger it was necessary a bigger amount of them to maintain their surface area similar to the surface area of smaller particles. As so, authors concluded that a* and b* parameters depend on each experimental RBC particles quantity and coupling treatment but didn't depend on their surface area.[15]

Marjanovic *et al.*[21] showed that RBCs with darker shades had lower lightness (L*) and higher yellowish effect (higher b* values) when compared to lighter shades from the same RBCs group. Besides that, L* values were the highest for samples with 1.0mm thick. Also, according to a* and b* values obtained, they verified that the appearance of RBCs is determined by higher L* and b* values (yellowish appearance).[21]

AlSheikh[5] evaluated different shades of a nanoparticulated RBC, namely A and B from enamel and dentin RBCs and found that there was a positive correlation between a* and b* values and between those values individually with the material type. That means that when a* values increased the same happened to b* values. The author also verified that chroma increased from lighter to darker shades. Regarding enamel shades, L* values decreased from lighter to darker shades. As for dentin shades they presented lower L* values than enamel shades, as was expected since natural enamel is more translucent and has higher L* value than dentin.[5]

Miletic *et al.*[19] saw that L* values from RBCs they evaluated decreased after being immersed in wine and coffee, while increased after immersion in distilled water. Those L* values justify the lighter appearance of RBCs after water immersion, motivated by water sorption, and consequent changes in the polymer network, and their darker appearance after immersion in colouring liquids. Authors observed that, when exposed to wine, a* values seemed to increase while b* values decreased, making RBCs samples appear reddish-blueish, except for microhybrid RBC samples, whose b* values slightly increased. Exposing RBCs samples to coffee resulted in a yellowish discoloration as b* values increased. Thus, immersion in both wine and coffee made all tested RBCs samples appeared darker, as pigment and water absorption within the polymeric matrix caused a decrease of lightness. However, when exposed to distilled water, a* and b* values remained virtually the same for all tested RBCs. An analysis to RBCs principal components showed changes in diffuse reflection spectra of all tested RBCs after their immersion in coffee and wine, although changes caused by wine were greater, resulting in reddish discoloration and greater ΔE. Besides that, repolishing RBCs samples seemed to slightly increase L* values.[19]

When Antonov *et al.*[24] exposed samples from a microhybrid RBC group to different beers, they verified that b* values increased. That increase indicates a reduction of blue component of the RBC, giving it a yellowish aspect, since the RBCs reflectance in the blue spectra region also decreased. That means that b* coordinate was highly influenced by RBCs staining.[24]

Hyun *et al.*[18] evaluated experimental RBCs with bioactive glass particles and different surface roughness and verified that, when initial surface roughness decreased, translucency of each experimental RBC increased while L* values decreased. As so, what increases translucency, decreased RBCs luminosity.[18]

Colour changes (ΔE):

As stated by Fédération Dentaire Internationale (FDI), colour stability is very important for RBCs restorations to keep their favourable aesthetic for a long time[8, 19] as discolouration, or ΔE, are one of the most common causes for replacing them.[24] In order to act as a quality control tool, CIEDE2000 50:50% colour perceptibility and acceptability thresholds were defined as 0.8 and 1.8, respectively.[19]

RBCs restorations, in the oral environment, are exposed to intrinsic and extrinsic staining. Besides that, colour of RBC also varies with time, leakage, chemical degradation, deficient adhesiveness and surface roughness, among other factors.[21] Regarding extrinsic staining factors they can be controlled by keeping RBCs restorations polished over time.[5]

Polymerization process can alter RBCs colour due to changes it causes on resin matrix and particles refractive indexes and to the initiator system present in RBCs composition.[21]

Marjanovic *et al.*[21] found that colour was affected by RBCs shade and thickness of each layer, with ΔE values increasing with the increase of layer thickness. The highest ΔE values were found in A3 shade RBCs samples with 2mm thickness, regardless the RBC brands they evaluated.[21]

In their study, Salgado *et al.*[15] observed that a* and b* values varied when experimental RBCs with bigger nanoparticles (12 and 16nm) were storage in water, registering an increase of a* values, tending to redness, while b* values decreased and tended to blueness. Although, the same wasn´t observed for experimental RBC with the lowest size particles (7nm). They also verified that experimental RBCs with highest inorganic component/weight ratio (16nm nanoparticles) presented lower colour stability while experimental RBC samples with lowest inorganic component/weight ratio (7nm nanoparticles) presented higher colour stability. As so, it was possible to say that colour stability increased when particles size decreased. The same tendency after water storage was already observed by other authors.[8, 15]

Miletic *et al.*[19] observed that, regarding RBCs polymeric matrix, BisEMA/TEGDMA matrix showed better colour stability than BisGMA/TEGDMA and UDMA/TEGDMA, what may justify the higher colour stability of the ultrafine hybrid RBC as it has a higher amount of BisEMA than the remaining RBCs tested. As for ΔE observed after immersing samples in distilled water, they might be related to differences on polymeric resin matrix composition as different resin monomers and their combination present different water sorption and solubility abilities, which affect RBCs colour and its stability.[19]

It is known that melanoidins, present in coffee, and anthocyanes, present in red wine, are possible responsible for pigment RBCs restorations, when they are exposed to them.[24] Besides, among all mediums used, red wine provokes more colour instability, usually leading to ΔE above perceptibility and acceptability thresholds.[19]

Sulaiman *et al.*[8] evaluated the effect of aging in some restorative materials, including a nano RBC, when their samples were exposed to water, coffee, grape juice and thermocycling. RBCs samples showed the highest ΔE when they were exposed to coffee, while grape juice provoked a bigger ΔE than distilled water. Those authors also verified that RBCs, due to their methacrylate hydrophilic resin base, have a higher water sorption rate, which leads them to be more susceptible to pigmentation. As so, they concluded that hot pigmentated beverages have a greater influence on RBC colour stability than distilled water. Considering CIEDE2000 50:50% acceptability threshold (ΔE=1.8), all ΔE found were considered acceptable, except when samples were exposed to coffee.[8]

Miletic *et al.*[19] also evaluated the main effects of RBCs, medium and time on ΔE of enamel shades from universal RBCs, as well as their interaction, using samples from different RBCs with different compositions that were stored in red wine, coffee and distilled water. Their results showed a similar discolouration pattern in all RBCs exposed to wine and coffee, despite wine led to greater ΔE than coffee. Besides that, after being exposed to pigmented solutions, all RBC samples presented ΔE above the CIEDE2000 50:50% perceptibility and acceptability thresholds, which classified them all as clinically unacceptable. As for samples exposed to distilled water, their ΔE remained below the CIEDE2000 50:50% acceptability threshold, except for nano filled body RBC. Contrary to other authors, these results seem to indicate that discolouration capacity is not material-dependent. Enamel and dentin shades from ultrafine hybrid RBC group have different particles sizes as enamel shades are highly dense with nanoparticles and dentin shades are composed by a mix of hybrid particles close to micro range. The higher colour stability presented by that enamel shade is due to a higher amount of particles and to a more favourable distribution, allowed by the inclusion of nanoparticles into the mix.[19]

Repolishing all RBC samples after their last immersion period resulted in a decrease of their discolouration, except for the microhybrid RBC. That decrease might be justified by the removal of the superficial layer which contains the absorbed pigments, especially for the ultrafine hybrid RBC whose discolouration seems to be mainly due to pigment absorption. Microhybrid RBC presented the highest ΔE values and the least ability to decrease that discolouration after being repolished. That behaviour can be justified by resin matrix of that RBC, as it's mainly composed by UDMA resin, which has a lower colour stability, and by the slightly lower amount of microhybrid particles present in that RBC. As for both shades of nanoparticulate RBC, body shades showed a greater discolouration decrease after repolished than enamel shades, which showed resistance especially in coffee. Thus, authors concluded that ΔE didn't show any relation with solubility and sorption, that ultrafine hybrid RBC showed a higher colour stability than nanoparticulated and microhybrid RBCs and that repolishing reduced discolouration of all RBC tested.[19]

Antonov *et al.*[24] evaluated ΔE of a microhybrid RBC after being immersed in distilled water and in five different types of beer. Their results showed that all types of beer provoked higher ΔE than the CIELAB 50:50% clinically acceptability threshold of 2.7 (calculated with a different formula from CIDED2000 thresholds), classifying them as unacceptable.[24] Different beers present different light absorption spectra as they have different protein absorption and different amounts of amino acids (tryptophan, tyrosine and phenylalanine) and riboflavin which influence their light absorption spectra. Besides, beers with higher concentration of those colourant agents produce higher ΔE as they present higher light absorption spectra. On that study, Bernard beer showed the highest absorption spectra, leading to higher ΔE, while Tuborg beer led to lower ΔE. Besides that, all RBC samples increased their discolouration with the elongation of the staining period, what seems to be according to results obtained for other pigmentating liquids.[24]

Thus, those authors concluded that exposing RBC samples to dark or light beers resulted in changes of their optical properties, comparable to the ones caused by red wine, tea and coffee. Besides that, they also concluded that a higher absorption potential of a beer resulted in a stronger discolouration and that darker beers stain RBCs more intensively that lighter ones.[24]

When samples are exposed to beer, coffee and tea, ΔE result from changes in RBCs chroma and not from the change in its lightness. However, when exposed to wine, their ΔE result from changes in chroma and in lightness at the same extend.[24]

Ozera *et al.*[26] used three RBC groups and, after exposing them to acidic solutions (Coca-Cola, cranberry juice, coffee) and artificial saliva, evaluated their degradation. Their results showed that influence of each acidic solution in RBCs was material dependent. Coffee seemed to provoke higher ΔE in all tested RBCs then the remaining solutions. Besides, one of the nanoparticulated RBC, despite presenting its higher colour changing when exposed to coffee, presented lower ΔE than the others RBCs exposed to the remaining solutions. As so, authors concluded that acidic drinks with different pH values are capable of deteriorating RBCs colour stability as they promote changes in RBCs restorations surface, increasing their sorption ability.[26]

AlSheikh[5] evaluated the colour stability of a nanohybrid RBC, whose photo-initiator system is Lucirin-TPO. Samples' colour was evaluated before and after exposing them to coffee, coffee with milk or sugar, red tea, red tea with milk or sugar, tomato juice, pomegranate juice, coke and distilled water. AlSheikh[5] observed that coffee provoked the highest ΔE among all the tested groups while, samples exposed to pomegranate and tomato juices present the lowest ΔE.[5] Yellow staining molecules present in coffee composition have higher affinity to polymer molecules, what may contribute to the higher staining potential of coffee, as well as its acidic condition.[5, 26] Contrarily to those yellow stain molecules the ones present in coke have low polarity which leads to a lower staining potential.[5] As for tea staining potential, it can be due to tannic and stains present in its composition.[5, 24] Thus, AlSheikh[5] concluded that the nano-hybrid RBC presents a high capacity to resist staining over time, which can be attributed to its different photo-initiator system.[5]

Finally, exposing RBCs restorations to organic acids and enzymes produced by oral biofilm bacteria may compromise their colour stability as those organic acids and enzymes can increase surface staining.[18]

Colour adjustment potential (CAP):

RBCs colour shifting consists of two aspects: a subjective concept (blending) and an objective concept which is related to translucency. The quantification and description of their interaction is known as colour potential adjustment (CAP), and it reveals a big importance for correcting mismatched colours.[2, 25]

Trifkovic e*t al.*[25] evaluated two shades of eight RBCs with different particles sizes and used one RBC as a control. According to them, a blending effect and a high translucency can contribute to CAP. Also, two universal nanohybrid RBCs and a nanoparticulated RBC showed the highest CAP as they presented significant interactions with the control RBC, used to mimic natural enamel. Therefore, RBCs with high CAP proved to be able to interact with natural tissues, resulting in lower colour differences, facilitating the performance of undistinguishable restorations. Finally, authors concluded that CAP depends on RBCs and their shades.[25]

Universal RBCs seem to have a high CAP as so, de Abreu *et al.* [2] evaluated that potential of different universal RBC in class III restorations, using a single shade RBC and three multi-shade RBCs to restore those cavities in denture central incisors with one layer of each RBC. Regarding 50:50% perceptibility and acceptability CIEDE2000 thresholds, all RBCs tested presented values above the acceptability threshold, mainly the single shade RBC, whose values were far above that threshold. Opposite to those observations, a previous study tested the same single shade RBC and reported lower ΔE values although that study used different formulas, thresholds and test conditions.[2]

The single shade RBC, despite being stated to be able to match all Vita Classical shades due to their uniform sized spherical particles, presented lower colour match to the denture teeth with different shades than multi-shade RBCs evaluated. Considering those results, authors concluded that multi-shade universal RBCs tested in anterior restorations presented acceptable and higher colour matching ability.[2]

Furthermore, increasing RBCs translucency, seems to increase their blending effect.[2]

2.Light phenomena

Light absorption

Perez *et al.*[16] verified that there weren´t any statistically significant differences between absorption values of supra-nano spherical filled RBCs and of nanoparticulated RBCs, although their different polymeric matrixes. However, those results may also result from pigments present in RBCs composition. Besides, RBCs absorption values were different from those of natural dentin, as RBCs differ from natural dentin composition and structure.[16]

Some metallic oxides, are commonly added to opaquer RBCs and result in higher absorption coefficient values. Pecho *et al.*[4] used a nanoparticulated RBC group and observed that dentin shades showed higher absorption values, what can indicate the presence of different filler particles or a higher fraction of them. Thus, decreasing the amount of polymeric matrix seems to increase light absorption, which also varies with the wavelength of incident light.[4]

Condò *et al.*[27] in their study evaluated an universal nanohybrid RBC among other restorative materials. Regarding that RBC those authors verified that, when the incident light had a wavelength inside infrared radiation spectrum, the absorption values registered were the lowest, while light near UV radiation wavelengths led to some light to be absorbed. As for light whose wavelength was inside visible radiation spectrum, there weren't detected any significant differences between all restorative materials evaluated, regarding their light absorption.[27]

Light reflection

Reflection results from combining the different angles at which light travels after colliding with a surface[18] and seems to be influenced by incident light wavelength and by nature of some pigments present on RBCs.[4]

When light reflection is high, transmittance must be proportionally reduced, resulting in a less translucent material.[18]

Light Scattering

On RBCs, light scattering results from light refraction and reflection inside the material itself and depends on some factors, such as RBCs components (matrix, filler particles, porosities and pigments).[16,18] The most important factor is RBCs filler particles because, as their size increases, light scattering also does, until it reaches the visible light wavelength, and stars to decrease for bigger particles.[23] Besides that, filler particles refractive index is also important as the increase of its difference from polymeric matrix refractive index increases light scattering and a perfect match between them leads to no light scattering. [19, 23] Incident light wavelength and particles dispersion in the matrix are other import factors.[16]

Perez *et al.*[16] verified that microhybrid RBCs presented the highest scattering values while supra-nano spherical filled RBCs presented the lowest. Those lowest values led to higher transmittance values, especially for shorter wavelengths and were due to the presence of spherical shape particles, whereas the remaining RBCs presented irregular particles. Besides that, supra-nanoparticles have a similar refractive index to the matrix refractive index, which leads to smaller differences between refractive indexes. Regarding their results, authors concluded that supra-nano spherical filled RBCs have an angular light scattering similar to natural enamel.[16]

Finally, translucency and colour perception are related with light scattering and, as Arikawa *et al.* stated, incident light transmittance and scattering depends on RBCs shade, particles size, shape and amount.[16]

Light transmittance

RBCs with smaller filler particles and better distributed within polymeric matrix, as well as similar refractive indexes between both components, promote a higher light transmittance.[20]

Sulaiman *et al.*[8] evaluated light transmittance blockage of some materials, including a nanoparticulated RBC, when samples were aged by exposing them to some treatments. They observed that coffee, probably due to higher pigmentation capacity, was the medium that caused the biggest blockage.[8]

Refractive indexes

RBCs refractive index is determined by RBCs particles volume and fraction. Besides the match between polymeric matrix and filler particles refractive indexes is related to some optical properties.[4, 11]

Kolb *et al.*[11] showed that resin matrix refractive index can be adjusted inside a certain range, by adding Zirconium oxide nanoparticles and 4-Methylthiophenol to the mix.[11]

Also, during polymerization, while refractive index of RBCs particles remains the same, its polymeric matrix refractive index increase.[23]

3.Final restorations

Thicker layers of darker RBCs shades result on darker restorations as shade, opacity and translucency of RBCs, as well as the thickness of each layer influence the final colour of RBCs restorations.[19-21] Changing RBCs layer thickness may affect the final result more than RBC shade or type, when translucent restorations are needed.[21]

Marjanovic *et al.*[21] evaluated the influence of dentin restorative materials on RBCs final restorations optical properties, using dentin restorations with unsatisfactory aesthetics under a layer of enamel shade RBC with different thicknesses. They observed that capping RBCs layers were able to change considerably the optical properties of an underlying layer. Thus, authors concluded that 2mm thick layer of universal microhybrid or nanohybrid RBCs is recommended to cover an unpleasing artificial dentin restoration, although, depending on the dentin restorative and on the RBC, only 1mm thick layer of RBC could be sufficient. However, capping layers thinner than 1mm, especially of light shades, are not recommend to cover unsatisfactory dentin restorations.[21]

Santos *et al.*[20] evaluated the threshold of thickness reduction of a dentine RBC necessary to result in clinically perceptible and acceptable ΔE of RBCs restorations, using different dentin and enamel shades from three commercial RBCs. They verified that, in order to maintain acceptable ΔE , the artificial dentine layers, placed under 1.0mm thick enamel shade RBCs layer, must have, at least, 1.44mm (Filtek Z350XT (3M/ESPE)), 1.30mm (IPS Empress Direct (Ivoclar Vivadent)) or 1.15mm (Charisma Diamond (Heraeus Kulzer)) respectively.[20]

Considering samples done with dentin and enamel shades, their different translucency values seemed to depend on the enamel layer, as there weren't found significant differences regrading different dentin shades translucency. Authors concluded that, despite RBCs chosen for their study presented different opacities, similar reductions of their thickness resulted in similar clinically important and perceptible ΔE.[20]

Rauber *et al.*[3] proposed a technique which aimed to correct unsatisfactory restorations and to perform class IV restorations. To test their technique, they used dentin shades A3.5 and A4 from a nanohybrid RBC to simulate unsatisfactory restorations, which were then prepared with 0.5, 0.7 or 1mm thick preparations in order to evaluate the necessary preparation depth to modify their colour. As layers thicker than 1mm of RBCs enamel shades result in a greyish appearance due to a decrease of RBCs value and translucency, preparations couldn´t be deeper than 1mm. All unsatisfactory restorations done A3.5 dentin shade had their colour altered after applicating the proposed technique. However, A4 dentin shades, presented a major luminescence reduction. As so, it was concluded that the technique can be used to achieve the proposed objectives.[3]

Modelling agents placed over the final layer of RBC restorations can affect their optical properties. Resin adhesives are gaining importance as modelling agents, despite bringing some problems regarding colour stability of RBCs final restorations.[1]

Araujo *et al.*[1] used samples from a microhybrid RBC which were covered with no adhesive system, a solvated universal adhesive or a non-solvated adhesive. Those samples were exposed to 200 thermal-cycling procedures in grape juice, water or coffee, each medium with different temperatures, as a solutions temperature can increase its staining ability. After those expositions, samples suffered a bleaching procedure (35% hydrogen peroxide for 45 minutes).[1]

Before aging treatments, adding a modelling agent resulted in a reduction of samples opacity. When samples were exposed to staining liquids, it was possible to relate the absorption of that staining substance to an increase in opacity values. ΔE were primarily affected by lightness decrease, which was the only parameter affected by the addition of modelling agents because, after absorbing the pigments, samples became darker and opaquer.[1]

The bleaching procedure was able to reduce colour and opacity changes provoked by thermocycling in any medium. Although those changes weren't enough to obtain the initial values, despite of the closest values obtained after beaching samples with solvated adhesive. Besides, samples without any modelling agent presented a lower reduction of colour and opacity changes then the remaining samples. According to some authors, the beaching effect observed might be related to degradation of pigment molecules, as it happens on natural tissues.[1]

Also, samples built with modelling agents presented a higher yellowish aspect due to the adhesives higher b* values. Thus, Araujo *et al*.[1] concluded that a solvated universal adhesive, used as a modelling agent, reduced the staining susceptibility of RBCs samples exposed to thermocycling in staining liquids, while the use of a non-solvated adhesive didn't.[1]

Surface sealants are another modelling agent that can reduce porosities within RBCs restorations. In order to evaluate both systems, regarding RBC restorations surface gloss and ΔE, Cortopassi *et al.*[10] evaluated four adhesive systems and four surface sealants and created a control group in which samples weren't covered by any material.[10]

Regarding colour stability, samples with self-etching adhesive system presented the lowest value. Between adhesive systems and surface sealants, the first class presented lower colour stability than the former and samples from the control group, except for samples with the universal adhesive system. Those results may be explained by the presence of hydrophilic monomers in adhesive systems which lead to higher pigmentation and red wine absorption while surface sealants present more hydrophobic monomers.[10]

There was also found a weak inverse relation between surface roughness and ΔE as incident light reflection and scattering are different in rough and smooth surfaces. Thus, authors concluded that adding a coating material to RBCs restorations didn't bring any benefit regarding colour stability and surface roughness despite of surface sealants Bioforty (Biodinâmica), Fortify (BISCO Schaumburg) and Permaseal (Ultradent Product Inc) and the universal adhesive system, showing a better colour stability than the control group.[10]

4.Advances regarding RBC

The constant search for the development of a biomimetic and aesthetic direct definitive RBC, lead to advances regarding them. Once RBCs optical properties seem to greatly depend on filler particles, some investigations are being led in this direction.

Hyun *et al.*[18] aimed to evaluated how bacterial biofilm influences colorimetric value and translucency changes of new RBC modified with Bioactive glass (BAG), whose samples differ in their initial surface roughness.

Thus, those authors developed three new RBCs namely, one control group with silane-treated aerosol-silica particles, one with BAG65 particles (BAG group) and one with fluoride-containing micronized BAG61 particles (BAG-F group). All experimental RBCs had the same polymeric matrix. Samples were then exposed to culture mediums with and without *S.mutans*.[18]

Initially, both BAG and BAG-F experimental RBCs were darker than the control experimental RBC, with higher yellow and red hues. Also, before treatment, BAG and BAG-F RBCs presented higher translucency as the refractive indexes of their components presented a lower difference between them. Results obtained in each group suggest that discolouration was influenced by intrinsic factors and by surface roughness changes.[18]

All experimental RBCs showed a decrease in their TP after being storage in either of the mediums, probably due to dissolution of their particles, leaving void spaces in RBCs structure. That observation is according other studies that found that RBCs tend to become opaquer with aging.[18]

Authors concluded that BAG and BAG-F presented lower ΔE when exposed to biofilm, possibly due to some surface protection conferred by the biofilm itself. As for translucency, all samples had decreased translucency after treatment with and without *S.mutans*, with BAG-F RBC showing a higher decrease at the highest polishing level when exposed to biofilm, than BAG RBC. Finally, they proved that despite the expected RBCs discoloration when exposed to biofilm, the addition of bioactive glass didn’t increase discoloration when compared to the control group.[18]

Despite being true that biofilm is an extrinsic factor of RBCs discolouration, it may be less harmful than the medium itself.[18]

Conclusion

Conclusion

RBCs optical properties seem to depend on many factors, among which, filler particles size seems have the biggest impact. However, RBCs hue seems to don't influence them, as no referred study reported big optical properties differences among different hues.

Also, some properties seem to be opposite to each other, as it happens with translucency and opacity, as higher translucency values lead to lower opacity values and the opposite is also true.

Besides, light phenomena are related to more than one optical property, mainly due to filler particles and polymeric matrix refractive indexes and the differences between them.

Thus, to perform a biomimetic and aesthetic direct definitive restoration, all RBCs optical properties must be taken into consideration, as is the interaction between them that allows a restoration to be fully integrated in oral cavity.

As some available RBCs present a great colour change after their exposition *in vitro*, to some pigmenting beverages, their usage in heavy drinkers of the same beverages needs to be avoided, mainly for anterior restorations, in order to not compromise their lifetime.

As so, some RBCs seems to present some advantages over others regarding their composition, revealing better optical properties and a greater ability to maintain them.

As a final conclusion, it's possible to say that all proposed objectives were achieved and that advances regrading RBCs and their optical properties are still under development.

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Bibliographic References

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Attachment

Attachments

1. Salgado *et al*., 2017.[15]	
Objectives	To evaluate the optical and surface properties of experimental RBCs with different nanoparticles sizes but equal surface areas, among them and before and after aging
Restorative Materials	Experimental RBCs with different sizes nanoparticles and Bis/GMA and TEGDMA (50:50 mol%) resin matrix
Optical Properties/parameters discussed	Colour changes (ΔE) and translucency parameter (TP)
2. Pecho *et al.*, 2016.[4]	
Objectives	To evaluate relevant optical properties of aesthetical dental direct restorative materials, focusing on translucent and whitened shades
Restorative Materials	Filtek Supreme XTE (3M/ESPE)
Optical Properties/parameters discussed	Reflection spectra, Luminosity (L*), Light Absorption (K), Light Scattering (S), Light Transmittance (T%), Absolute reflectance, Translucency parameter (TP), Opalescence (OP) and Whitened index (W*)
3. Habib *et al.*, 2016.[13]	
Objectives	To formulate and evaluate the influence of size and load on mechanical and light transmittance properties of experimental RBCs formulated with different sized spherical silica filler particles (75, 150, 350, 500 and 1000 nm)
Restorative Materials	Experimental spherical filled RBCs formulated with spherical particles and BisGMA/TEGDMA or UDMA/TEGDMA resin matrix
Optical Properties/parameters discussed	Light transmittance and translucency
4. Shirinzad *et al.*, 2016.[9]	
Objectives	Compare the effect of accelerated artificial aging (AAA) on the translucency of methacrylate and silorane RBCs
Restorative Materials	Methacrylate RBCs: Filtek Z250, Filtek Z250XT and Filtek Z350 XT (3M/ESPE) Silorane RBC: Filtek P90 (3M/ESPE)
Optical Properties/parameters discussed	Translucency
5. Kolb *et al.*, 2020.[11]	
Objectives	Formulate a biocompatible a highly translucent RBC and determine the influence of its thickness on its translucency
Restorative Materials	Experimental RBCs with different ORMOCER resin matrixes and dental glass powder particles reinforced with highly refractive ZrO_2 nanoparticles and/or 4-Methylthiopentol as resin modifier
Optical Properties/parameters discussed	Translucency

6. Marjanovic *et al.*, 2018.[21]	
Objectives	To evaluate optical properties of "sandwich" RBCs restorations done with unaesthetically unfavourable dentin restorations.
Restorative Materials	RBCs: Gardia Direct Posterior (GC), Filtek Z250 and Filtek Z550 (3M/ESPE) Other artificial dentin materials: EverX Posterior, Biodentin (Septodont) and experimental hydroxyapatite (HAP)
Optical Properties/parameters discussed	Translucency and colour
7. Sulaiman *et al.*, 2020.[8]	
Objectives	Compare optical properties of different restorative materials before and after artificial aging.
Restorative Materials	Bisacryl-resin: LuxaCrown (DMG); RBC: Filtek Supreme Ultra (3M/ESPE); Ceramic-resin: Enamic (VITA)
Optical Properties/parameters discussed	Colour changes (ΔE), Translucency, Contrast Ratio and Transmittance block
8. Miletic *et al.*, 2020.[19]	
Objectives	To evaluate the effects of "composite", "medium" and "time" on some properties of sculptable universal RBCs for enamel layering upon immersion in coloured beverages.
Restorative Materials	Essentia (GC), G-aenial Anterior (GC), Filtek Ultimate Enamel (3M/ESPE) and Filtek Ultimate Body (3M/ESPE)
Optical Properties/parameters discussed	Translucency changes and colour changes
9. Santos *et al.*, 2018.[20]	
Objectives	To determine the dentin shade thickness reduction threshold necessary for significant, acceptable and perceptible colour changes of RBCs restorations, keeping constant the thickness of each RBC enamel shade layer.
Restorative Materials	Charisma Diamond (Heraeus Kulzer), IPS Empress Direct (Ivoclar Vivadent) and Filtek Z350XT (3M/ESPE)
Optical Properties/parameters discussed	Colour changes (ΔE) and Opacity/translucency
10. Tabatabaei *et al.* 2019.[23]	
Objectives	To evaluate and compare two RBCs regarding their fluorescence and opalescence
Restorative Materials	Filtek Z350 XT Enamel (3M/ESPE), Filtek Z350 XT (3M/ESPE), Aelite Aesthetic Enamel (BISCO Schaumburg) and Aelite All Purpose Body (BISCO Schaumburg)
Optical Properties/parameters discussed	Fluorescence and Opalescence

11. Antonov *et al.*, 2016.[24]	
Objectives	To access changes occurred on RBCs colour and translucency after being exposed to beer.
Restorative Materials	Gardia Direct extra bleach white (GC Corp)
Optical Properties/parameters discussed	Colour and Fluorescence changes
12. Lee, 2008	
Objectives	To evaluate the influence of particles size and volume on the difference between reflected and transmitted colours and on translucency of experimental RBCs
Restorative Materials	Experimental RBCs
Optical Properties/parameters discussed	Transmitted and Reflected colours and Translucency
13. Ameer and Mualla, 2015	
Objectives	To determine fluorescence of RBCs with different particles sizes, before and after accelerated aging and to do a comparison between them and human enamel-dentin specimens
Restorative Materials	Filtek Z250 (3M/ESPE), Filtek Z250 XT (3M/ESPE) and Filtek Z350 XT (3M/ESPE)
Optical Properties/parameters discussed	Fluorescence
14. Reis *et al.,* 2017	
Objectives	To access the fluorescence of 10 RBCs against the fluorescence of tooth structure using contrast differences
Restorative Materials	Filtek Supreme (3M/ESPE), Filtek Z100 (3M/ESPE) and Filtek Z250 (3M/ESPE), Charisma (Heraeus Kulzer), Fill Magic (Vigodent), Esthet X (Dentsply) and TPH Spectrum (Dentsply).
Optical Properties/parameters discussed	Fluorescence
15. Lopes *et al.*, 2021.[7]	
Objectives	To do a comparative evaluation, with visual methods, in vivo and in vitro, the intensity of fluorescence of six RBCs which differ in their classification and viscosity compared to natural enamel
Restorative Materials	Opallis (FGM), Filtek Z350XT (3M/ESPE), Vittra (FGM), Opus Bulk Fill Flow APS (FGM), Filtek Bulk Fill (3M/ESPE) and Opus Bulk Fill (FGM)
Optical Properties/parameters discussed	Fluorescence

16. Silva *et al.,* 2014	
Objectives	To determine the fluorescence intensity of distinct RBCs and compare them with the fluorescence intensity of dental tissues
Restorative Materials	Esthetic-X (Dentsply), Durafill VX (Heraeus Kulzer), Filtek Z350 (3M/ESPE), Amelogen Plus (Ultradent Products) and Charisma Opal (Heraeus Kulzer).
Optical Properties/parameters discussed	Fluorescence
17. Takahashi *et al.*, 2008	
Objectives	To evaluate the intensity of fluorescence of different RBCs with different opacities and translucencies after accelerated aging
Restorative Materials	4 Seasons (Ivoclar Vivadent), Charisma (Heraeus Kulzer), Esthet -X (Dentsply), Filtek Supreme (3M/ESPE), Opallis (FGM), Vit-1-escence (Ultradent Products).
Optical Properties/parameters discussed	Fluorescence
18. Jablonski *et al.*, 2014	
Objectives	To evaluate quantitatively the fluorescence of RBCs as compared to human teeth and access the effect of artificial aging on their fluorescence
Restorative Materials	4 Seasons (Ivoclar Vivadent), Charisma (Heraeus Kulzer), Esthetic X (Dentsply), Opallis (FGMl), Vit-1-escence (Ultradent Products), Filtek Supreme (3M/ESPE).
Optical Properties/parameters discussed	Fluorescence
19. Elgendy *et al.*, 2019.[14]	
Objectives	To compare the light propagation for absorption, transmittance, attenuation and scattering anisotropy coefficient in nano-filled RBCs and dental tissues
Restorative Materials	Filtek Supreme Ultra Universal Restorative (3M/ESPE)
Optical Properties/parameters discussed	Light Absorption, Light Attenuation coefficient, Light Transmittance and Scattering Anisotropy coefficient
20. Perez *et al.*, 2016. [16]	
Objectives	Evaluate and compare optical properties of supra-nano spherical filled RBC, nano-filled, nano-hybrid and micro-hybrid RBCs using Kubelka-Munk theory
Restorative Materials	Estelite Omega (Tokuyama Dental), Estelite Sigma Quick (Tokuyama Dental), Filtek Supreme XTE (3M ESPE), Grandio SO (VOCO) and Herculite XRV (Kerr) and Premise (Kerr)
Optical Properties/parameters discussed	Scattering, Absorption, k/S Ratio, Kubelka-Munk transmittance (T), Direct transmittance (T%)

21. AlSheikh, 2019.[5]	
Objectives	To access IPS Empress Direct ability to mimic tooth colour and appearance and to resist staining
Restorative Materials	IPS Empress Direct (Ivoclar Vivadent)
Optical Properties/parameters discussed	Colour stability
22. Hyun *et al.*, 2016.[18]	
Objectives	To evaluate the effects of bacterial biofilm on colorimetric value and translucency changes of experimental new BAG (bioactive glass)-containing RBCs with different initial surface roughness
Restorative Materials	Experimental RBCs containing BAG or BAG-F and control experimental RBC
Optical Properties/parameters discussed	Colour changes (ΔE) and Translucency parameter (TP)
23. Ozera *et al.*, 2019.[26]	
Objectives	To determine colour changes and gloss of different aesthetic restorative materials after their immersion in different acidic beverages.
Restorative Materials	Filtek Z350 XT (3M/ESPE), IPS Empress Direct (Ivoclar Vivadent) and Charisma Diamond (Heraeus Kulzer)
Optical Properties/parameters discussed	Colour stability
24. Trifkovic *et al.*, 2018.[25]	
Objectives	To access the colour adjustment potential (CAP) of some RBCs
Restorative Materials	Clearfil Majesty ES2 (Kuraray America), HRi ENA enamel (Synca Direct), Herculite Ultra (Kerr Corporation), Renamel Microhybrid (Cosmedent), Venus Pearl (Kulzer), Esthet-X HD (Dentsply Caulk), Gradia Direct (GC America), Filtek Supreme Ultra (3M/ESPE) and used Venus Syringe Refill (Kulzer)
Optical Properties/parameters discussed	Colour adjustment potential and colour changes
25. de Abreu *et al.*, 2020.[2]	
Objectives	To access, using two evaluations methods, the colour matching of universal RBCs restorations performed in anterior teeth
Restorative Materials	Multishade RBCs: Tetric Evoceram (Ivoclar Vivadent), Filtek Universal (3M/ESPE) and TPH Spectra Universal Restorative (Dentsply Sirona) Single-shade RBC: Omnichroma (Tokuyama)
Optical Properties/parameters discussed	Colour matching

26. Condò *et al.*, 2017.[27]	
Objectives	To do an investigation about the morphological and structural characteristics of Giomers in order to compare it with three other restorative materials and to provide information required regarding the processability, mechanical, morphological and optical properties, crystalline nature, colour stability and hardness.
Restorative Materials	Giomer: Beautifil II (Shofu Dental Corporation); Compomer: Dyract Extra (Dentsply); Glass Ionomer cement: Ketac fil plus (3M/ESPE); RBC: Tetric Evoceram (Ivoclar Vivadent)
Optical Properties/parameters discussed	Colour
27. Rauber *et al.*, 2017.[3]	
Objectives	To access the ability of the proposed technique to produce restorations able to mimic tooth structure and to define a clinical protocol
Restorative Materials	IPS Empress Direct (Ivoclar Vivadent)
Optical Properties/parameters discussed	Colour
28. Araujo *et al.*, 2018.[1]	
Objectives	To access the effects of adhesive type used as modelling liquid on colour and opacity stability of RBCs exposed to thermal cycling in staining solutions followed by a bleaching procedure.
Restorative and Coating Materials	RBC: Filtek Z250 (3M/ESPE) Adhesive systems: Adper Universal (3M/ESPE) and Scotchbond Multipurpose (3M/ESPE)
Optical Properties/parameters discussed	Opacity and Colour
29. Cortopassi *et al.*, 2019.[10]	
Objectives	To access coating materials regarding changes of roughness and colour when they are applied over a RBCs restoration
Restorative and Coating Materials	RBC: Filtek Supreme Ultra (3M/ESPE) Adhesive system: Adper Single Bond Plus (3M/ESPE), Scotchbond Universal (3M/ESPE), Clearfil SE Bond (Kuraray Medical Inc.) and Ambar APS (FGM Dental Products) Surface sealants: Bioforty (Biodinâmica), Fortify (BISCO Schaumburg), Permaseal (Ultradent Product Inc.) and G-Coat Plus (GC Corporation))
Optical Properties/parameters discussed	Colour changes

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Orientador Professora Doutora Ana Isabel Pereira Portela

Coorientador Professor Doutor João Ricardo Cardoso Ferreira

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