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In vitro analysis of aesthetic properties of a newly-developed simplified resin-based composite system: evaluation of optical behavior, color integration, and color stability of universal single-shade composites

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ABSTRACT

The shade selection in restorative dentistry is one of the major challenges for clinicians when aiming to obtain restorations with optimal aesthetic results. This difficulty arises from the complex optical properties of enamel and dentin, and their interaction with surrounding tissues and light. The optical properties of dental hard tissues include hue, chroma, value, translucency, opalescence, and opacity.

Traditional composite resins are available in several degrees of translucency and opacity (enamel, body, and dentin composites) and a range of shades (A, B, C, D) and chromas (A1, A2, A3, A3.5, A4, etc.). Nowadays, the state of the art for accurately reproducing the appearance of a natural tooth consists of selecting and applying multiple layers of these multi-shade different composite masses in varying thicknesses, depending on the specific area of the tooth being restored. While this layering technique can yield excellent aesthetic results, it requires considerable clinical expertise and is often time-consuming. In recent years, to simplify this subjective process, most manufacturers have introduced so-called universal composites. These resins, with a limited number of shade masses, are designed to replicate all the necessary colors for a natural tooth.

Among this innovative family of universal composites are single-shade resins, which are characterized by high translucency and advanced structural technology. These materials allow a single shade to blend seamlessly with the surrounding natural tooth, creating a "chameleon" effect, also named blending effect.

The primary objective of this PhD thesis was to evaluate color matching and integration capabilities of single-shade composites in relation to surrounding dental tissues. A secondary goal was to assess the behavior of restorations made with single-shade composites following professional tooth bleaching, to determine whether these composites could adapt to match a newly altered substrate color. Additional objectives included the evaluation of color stability of single-shade composites after immersion in staining substances, compared to multi-shade resins.

As a future perspective, it will be valuable to assess the clinical color integration of these composites in restorations performed in vivo and to monitor their color adaptation over longer follow-up periods.

The results obtained showed how the single-shade composites achieved excellent chromatic integration both before and after professional teeth whitening, particularly following visual analysis.

RIASSUNTO

La scelta del colore di un restauro al fine di ottenere un'estetica ottimale rappresenta una delle maggiori sfide per i clinici in odontoiatria conservativa estetica.

Questa difficoltà è correlata alle specifiche proprietà ottiche dei tessuti duri dentali (smalto e dentina) ed all'interazione che questi hanno con i tessuti circostanti e con la luce. Le proprietà ottiche di smalto e dentina comprendono tinta, croma, valore, traslucenza, opalescenza, opacità.

Le resine composite tradizionali presentano diversi gradi di traslucenza e opacità (compositi smalti, body e dentine) e diverse tinte (A, B, C, D) e cromi (A1, A2, A3, A3.5, A4 ecc). Attualmente, lo stato dell'arte per riprodurre accuratamente l'aspetto di un dente naturale consiste nel selezionare e applicare più strati di masse composite multi-shade in spessori variabili, a seconda dell'area specifica del dente da restaurare.

Questa tecnica di stratificazione del composito permette di ottenere eccellenti risultati estetici ma richiede una certa esperienza clinica e lunghi tempi di realizzazione.

Per cercare di semplificare questo processo decisionale così complesso ed estremamente soggettivo, negli ultimi anni molte aziende hanno prodotto dei compositi cosiddetti universali, cioè resine che con poche masse di colore fossero capaci di includere tutti i colori necessari per riprodurre il dente naturale.

All'interno di questa innovativa categoria di compositi universali sono compresi anche le resine single-shade, ovvero quei materiali compositi dotati di elevata traslucenza e caratterizzati da una particolare tecnologia strutturale in grado, mediante una sola massa, di mimetizzarsi con il dente naturale circostante. L'effetto visivo che si ottiene è definito camaleontico.

Lo scopo principale della presente tesi di dottorato di ricerca è stato quello di valutare l'adattamento dei compositi single-shade al tessuto dentale circostante in termini di corrispondenza di colore e integrazione cromatica.

L'obiettivo secondario è stato quello di valutare il comportamento dei restauri eseguiti mediante compositi single-shade a seguito di sbiancamento professionale del dente restaurato, al fine di valutare se questi compositi fossero in grado di variare il proprio colore per uniformarsi ad un substrato circostante più chiaro.

Ulteriori obbiettivi sono stati quelli di valutare la stabilità cromatica di compositi multi- e single-shade a seguito di immersione in sostanze coloranti.
Sarà poi utile andare a studiare l'integrazione cromatica clinica di questa tipologia di compositi in restauri eseguiti in vivo ed il loro adattamento cromatico con folllow-up più lunghi nel tempo.
I risultati ottenuti hanno mostrato come i compositi single-shade hanno ottenuto un'ottima integrazione cromatica sia prima che dopo sbiancamento dentale professionale in particolare a seguito di analisi visiva.

INTRODUCTION

1. Dental Materials

1.1 History and development of restorative materials

A century ago, dental amalgam was a widely used restorative material, primarily as improved by G.V. Black in the late 1800s. This alloy was mainly composed of argentum and tin (Ag_3Sn), along with some copper and zinc (Greener EH, 1979). Before clinical use, irregular alloy particles had to be mixed with mercury, and the resulting plastic mass was then packed into the cavity. Once set, the material contained two silver-mercury phases, approximately Ag_2Hg_3 (γ_1) and β_1 (with less mercury), as well as a phase of around Sn_8Hg (γ_2), along with remaining alloy particles (Marshall SJ et al., 1992 (a-b); Mahler DB, 1997). This technique and material remained largely unchanged until the 1960s when spherical alloy particles were introduced to reduce the amount of mercury needed. Traditional amalgam was prone to corrosion over time, particularly in the Sn_8Hg phase, which led to the formation of tin- and chlorine-containing corrosion products, causing visible discoloration of the tooth (Holland GA et al., 1974; Marshall SJ et al.,1980). It was believed that the corrosion processes and the oxidation of zinc helped to "seal" the edges of restorations, reducing the risk of secondary cavities. However, the formation of the Sn_8Hg phase also caused amalgam creep, leading to deterioration at the margins (Mahler DB et al., 1969).

Despite these issues, amalgam restorations presented high compressive strength and long-lasting clinical success. Further advancements were largely halted due to efforts to phase out amalgam because of its mercury content.

Resin-based composites (RBCs) have become the most widely utilized materials for dental restorations, primarily due to their aesthetic appeal, favorable properties, cost-effectiveness, versatility, and reliable clinical performance. Although improvements are still necessary, particularly in enhancing their clinical durability, there is no denying that the innovation and subsequent refinement of these materials have significantly transformed dental practices (Demarco FF et al., 2023; Thyvalikakath T et al., 2024).

Before the development of dental composites, esthetic restorative options were limited to the front teeth, initially employing silicate cements. By the early 1950s, polymethylmethacrylate (PMMA) resins, made from pre-polymerized PMMA powder mixed with methyl methacrylate (MMA) liquid monomer, became available. These were cured through an amine-peroxide reaction first developed by German scientists in the 1940s (Söderholm KJ et al., 1999). However, these early materials exhibited several drawbacks, including marginal staining, discoloration from significant polymerization shrinkage, poor adhesion to dental structures, and a large thermal expansion mismatch with natural teeth. Additionally, the toxicity of MMA often caused adverse pulp reactions, and the inherent weakness of the material further limited its applications (Paffenbarger GC et al., 1953; Sweeney WT et al., 1954; Coy HD, 1958; Gilmore HW, 1970).

Attempts to improve these materials included the incorporation of inorganic fillers into the resin to decrease thermal expansion and reduce shrinkage and water absorption (Rose EE et al., 1955). Despite these efforts, the need for more advanced materials was evident, and Dr. Rafael Bowen made a significant breakthrough by introducing epoxy resins reinforced with crushed fused quartz particles (Bowen RL, 1956). Although epoxies could bond well to various surfaces, they were not ideal for use in moist environments and required chemicals for rapid polymerization that were irritating to tissues. Dr. Bowen's further research led to the creation of a hybrid molecule by reacting a methacrylate with an epoxide, resulting in the Bis-GMA monomer (bisphenol A glycidyl methacrylate), commonly known as Bowen's resin. This innovation was patented in the United States (patent number 3, 066, 112) in 1962 (Bowen RL, 1962), and was introduced to the dental community in 1963 (Bowen RL, 1963).

Dr. Bowen's innovation laid the foundation for contemporary RBC materials. Compared to the acrylics used at the time, these new composites were significantly stronger and more rigid, exhibited reduced polymerization shrinkage, had a thermal expansion coefficient closer to that of natural teeth, and offered better esthetics.

Equally critical was the introduction of the acid etch technique by Dr. Michael Buonocore, which allowed for better adhesion of the acrylic restoratives to the tooth surface (Buonocore MG, 1955). The use of phosphoric acid etching enabled mechanical bonding and effective sealing of the enamel margins in restorations. Initially, the application of these materials was primarily restricted to anterior restorations, where aesthetics was paramount, while most posterior restorations continued to rely on dental amalgam. However, as the properties of dental composites improved, along with advancements in their adhesive capabilities, their use expanded to posterior restorations as well.

As mentioned earlier, the initial commercial dental composite materials were two-part paste systems, where one paste contained a peroxide initiator and the other an amine activator. When these pastes were mixed, they initiated a polymerization process within minutes through an auto- or self-curing mechanism (Kwon T et al., 2012).

A significant advancement in the application of composites was brought about by the introduction of light-curing technology (Stansbury JW, 2000; Ikemura K et al., 2010; Hadis M et al., 2011). Initially, ultraviolet (UV) light was employed as an activator for sealants and composites that included benzoin methyl ether or similar UV-sensitive compounds in the early 1970s, eliminating the need for mixing two pastes and allowing the material to be set within the confines of a defined working time. Although UV light produced acceptable results in terms of clinical trials (Wilder AD et al., 1999), its use was limited by its poor penetration (wavelengths below 400nm) and concerns over exposure to relatively high-intensity UV radiation.

This led to the replacement of UV light with visible light activation technology for curing dental composites in the late 1970s and early 1980s. The switch to visible light-curing was made possible by incorporating camphorquinone (CQ) as a photoinitiator. CQ is a light-sensitive molecule that most effectively absorbs photons at approximately 468nm within the blue region of the electromagnetic spectrum, raising it to a higher energy state. The amine component then reacts with CQ, generating a radical species that initiates polymerization by reacting with and breaking the carbon-carbon double bonds of the monomer. The activated monomer then polymerizes with other monomers, propagating the polymerization process. However, CQ is a very bright yellow compound, and if it is not adequately bleached during the polymerization process, it can leave an undesirable residual color in the material, particularly in unfilled adhesives. As a result, alternative photoinitiators with less intense coloration were sought to either supplement or replace CQ, such as 1-phenyl-1,2-propanedione (PPD), bisacylphosphine oxides (BAPO), triacylphosphine oxide (TPO), and the germanium-based Ivocerin (Topa M et al., 2020;

Kowalska A et al., 2021). These photoinitiators primarily absorb light within the UV spectrum, with their absorption range extending into the visible region up to around 400–410nm.

The evolution of light curing continued with the development of lights that provided higher power over the light tip's diameter, known as irradiance (W/cm^2), which further reduced the time needed to achieve the same degree of polymerization (Hadis MA et al., 2024). Initially, operators exposed composite increments for 40 seconds, but with more powerful lights, curing times were shortened to 10–20 seconds and even down to 1 to 3 seconds for extremely high-powered lights (3000–4000mW/cm^2). While the theory of reciprocity, which suggests that the total energy delivered (energy = irradiance × time, in $Joules/cm^2$) is the most critical factor in curing, has been questioned (Musanje L et al., 2003), it still provides general guidance for adjusting curing times when using lights with lower emissions.

As previously mentioned, Bis-GMA (a methacrylate monomer) was the primary component in the first successful dental composites. These materials were formed by adding ground quartz or glass particles to the resin, typically in sizes comparable to human hair, often greater than 50nm. The larger size of Bis-GMA (512g/mol compared to 100g/mol for methylmethacrylate, MMA) allows it to cross-link and form a thermoset polymer network due to its two carbon-carbon double bonds. Despite numerous methacrylate monomers being introduced in both experimental and commercial systems, no specific resin system has consistently outperformed others in clinical settings (Peutzfeldt A, 1997; Fugolin APP et al., 2017; He J et al., 2023).

One of the biggest challenges with resin dental composites has been addressing the negative effects of polymerization shrinkage, which has been extensively studied (Braga RR et al,. 2005; Stansbury JW et al., 2005; Ferracane JL, 2008; Meereis CTW et al., 2018). Although larger methacrylate monomers exhibit less shrinkage than smaller ones, such as MMA, the shrinkage during polymerization was still implicated in creating gaps between the restorative and the tooth surface, leading to microleakage. However, it was eventually found that the shrinkage itself wasn't the primary issue; rather, the internal stress caused by the interaction between polymerization shrinkage and the resin's adhesion to the cavity preparation was the main culprit (Davidson C et al., 1997). One approach to mitigating this problem was developing monomers with reduced polymerization shrinkage (Albeshir EG et al., 2022), achieved by incorporating larger monomers, which reduced the amount of dimensional change during polymerization (Srivastava R et al., 2018).

Ormocers (organically modified ceramics), introduced in the market in the later 1990s, represent another approach, combining inorganic and organic molecules through a sol-gel process to create materials with a silica backbone and polymerizable methacrylate side chains (Ilie N et al., 2011). Cured using conventional light-curing techniques, ormocers exhibit lower polymerization shrinkage due to their large molecular size. However, early commercial products that included traditional dimethacrylate diluents faced challenges, with clinical studies showing slightly lower success rates in posterior restorations and greater tooth sensitivity and marginal degradation (Monsarrat P et al., 2017; Abreu NM et al., 2022).

A significant advancement in the early 2010s was the introduction of bulk-fill composites, designed to be placed in increments of 4–5mm and cured with a single light exposure. These materials required improved light transmission for enhanced depth of cure and low polymerization stress during curing (Boaro LC et al., 2013; Braga RR et al., 2006). Early formulations were flowable, which provided good adaptability but required a capping layer for mechanical support. Newer formulations were designed to fill the entire cavity preparation up to a maximum depth of 4–5mm. Enhanced cure depth was achieved by matching the refractive index of the filler to the resin matrix and reducing light scattering within the composite. Additionally, some materials incorporated more efficient photoinitiators for better polymerization at lower light energy (de Oliveira D et al., 2019). In general, these bulk-fill composites have been shown to perform as well as conventional composites in both in vitro and clinical studies (Boaro LC et al., 2019; Sengupta A et al., 2023).

1.2 Classification of composite resins

Initially, dental composites used relatively large quartz or glass particle fillers as reinforcing agents. These particles were effective in enhancing strength by blunting and deflecting cracks. However, composites containing particles around 10–20μm in size, with the largest exceeding 50µm, faced significant challenges, particularly in terms of poor wear resistance and difficulty in achieving and maintaining a polished surface (Abell AK et al., 1983). The wear process was uneven, beginning with the loss of the softer resin between the harder particles, which loosened and released these particles from the surface, creating large voids and a rougher surface more susceptible to further wear (Bayne SC et al., 1992). To address this issue, composites with smaller-sized reinforcing fillers were developed. A significant advancement at the time was the production and use of aerosol silica nanofillers, with sizes averaging around 40–50nm. These were initially referred to as "microfillers," a term that, while not technically accurate, was more understandable at the time. "Microfilled" composite became popular because it could produce and maintain a high gloss in the mouth. The particles were small enough to wear at a rate similar to the adjacent resin matrix, resulting in a smooth surface (Amaya-Pajares SP et al., 2022). Although microfilled composites exhibited superior wear resistance against abrasive forces like toothbrushing, they tended to lose material more rapidly under heavy occlusal forces (Leinfelder KF, 1987). The wear resistance of composites was found to be proportional to mechanical properties such as flexural strength and fracture toughness, which are influenced by the amount of reinforcing fillers present (Heintze SD et al., 2016). Due to their small size, filler loading in microfilled composites was limited to below 50% by volume, which also limited their physical properties. To maximize filler content, manufacturers created agglomerates of particles in resin, which were pre-polymerized into blocks and then ground into particles 50µm or larger in size. Because the individual inorganic particles remained nanoscaled, these microfilled composites retained excellent polishing characteristics (Dennison JB, 1982).

The following innovation was the development of "hybrid" composites, which combined larger reinforcing fillers with smaller nanoparticles. These nanoparticles filled the spaces between the larger particles, maximizing filler loading and improving properties such as wear resistance (Bayne SC et al., 1992). However, the large particle sizes in the original hybrid composites continued to be a wear issue, leading to improved processes for grinding glass particles into smaller sizes, resulting in new hybrid formulations called minifilled (Bayne SC et al., 1994), later known as microhybrids (Ferracane JL, 2011). Some manufacturers also incorporated pre-polymerized resin fillers similar to those in microfilled composites, leading to materials known as nanohybrids (Ferracane JL, 2011). Other formulations are referred to as supra-nanofilled because they contain uniform spherical particles in the 100–300nm range and show excellent polishing ability (Can Say E et al., 2014).

1.3 Single-shade composites

In modern dentistry, the aesthetic demands of patients are increasingly high, with particular emphasis placed on the ability to replicate the natural appearance of teeth in restorative procedures. Achieving a seamless color match between restorative materials and natural dentition is one of the greatest challenges faced by clinicians, as the optical properties of dental tissues are highly complex. In recent years, to simplify the choice of composite masses, most manufacturers have introduced so-called universal composites, resins designed to replicate all the necessary colors for a natural tooth.

So-called group-shade (or cloud-shade) composites are a collection of resin composites available in a limited number of shades (3-5), with each shade designed to cover a specific range of VITA Classical shades (Iyer et al., 2021).

Among this innovative family of universal composites is a newly developed resin-based simplified system, named single-shade resins. They allow a unique shade to blend seamlessly with the surrounding natural tooth, creating a "chameleon" effect, also named blending effect. These are single-mass composites that, once placed in the cavity, have the ability to integrate perfectly with the color of the surrounding tooth.

Single-shade composites were developed to streamline restorative procedures by eliminating the need for color selection and reducing the use of multiple composites with varying translucencies (Kobayashi S et al., 2021; Iyer RS et al., 2021). These composites offer an improved ability to adjust to surrounding colors, known as color adjustment potential (CAP). CAP refers to a material's capacity to adapt its color, and it is assessed both visually (CAP-V) and instrumentally (CAP-I), using color measurement devices. The color-blending properties of these innovative materials are attributed to a combination of color shifting and enhanced translucency (Trifkovic B et al., 2018; Ismail EH et al., 2022). For example, the inclusion of well-distributed round filler particles, approximately 260 nm in diameter, produces red-to-yellow hues. This phenomenon, known as "structural color," depends on the angle of light hitting the material (Yamaguchi S et al., 2021).

Ideally, a single-shade composite should possess a high CAP, meaning it can shift its shade toward the surrounding tooth colors. The composite's color blending capability is also closely related to its translucency, with the color of the underlying tooth structure playing a significant role in determining the final restoration shade. (Paravina RD et al., 2006 (a-b); Trifkovic B et al., 2018).

The introduction of restorative materials with chameleon-like properties, which can blend and mimic the surrounding tooth color, significantly eases the clinician's workload and reduces operator-dependent variability in achieving natural-looking restorations. These materials enable clinicians to deliver high-quality aesthetic outcomes more efficiently, even in complex cases. Single-shade composites are suggested to restore class I (Anwar et al., 2024), class III (with palatal surfaces not involved) (de Abreu et al., 2021), and class V cavities (Miranda et al., 2024).

There are few articles in the literature on single-shade composites. Most focus on resin blocks (Iyer et al., 2021; Saegusa et al., 2021; El Rashidy et al., 2022; Altınışık & Özyurt 2023), some on extracted teeth (Cruz da Silva et al., 2023; Cubucku et al., 2023; Rosa et al., 2024), and only a very limited number on patients (Anwar et al., 2024; Miranda et al., 2024; Porwal et al., 2024). Despite being recommended by manufacturers for Class II restorations, no studies have evaluated their use for this purpose.

In cases where the palatal wall is absent, the dark background can negatively affect the composite's ability to blend seamlessly with the natural tooth (Durand LB et al., 2021). To address this issue, some manufacturers have introduced "blocker" composites, designed to be applied beneath single-shade composites to prevent light transmission in cases of through-and-through cavities.

However, beyond the immediate color-matching capabilities, the long-term color stability of these materials is of utmost importance. Patients are increasingly exposed to substances that can stain teeth, whether through dietary habits—such as the consumption of coffee, tea, or red wine—or through the use of oral care products like mouthwashes. Furthermore, with the rising popularity and demand for dental bleaching procedures, it is essential that restorative materials not only blend with the natural tooth color initially but also maintain their aesthetic integrity over time. Materials that are resistant to discoloration, even after exposure to these factors, provide significant value in ensuring long-lasting results that meet patients' aesthetic expectations. As such, the development and use of composite resins with high color stability and chameleon-like blending potential mark a crucial advancement in meeting both the immediate and long-term aesthetic needs in restorative dentistry.

In summary, single-shade composites offer the advantage of blending with the surrounding natural tooth color using just one shade, thereby eliminating the challenges of layering typically required with multi-shade composites. This approach reduces the time needed for both shade selection and restoration. By adapting to the color of the surrounding tooth, single-shade composites are expected to maintain a good color match over time, even in cases of changes to the dental substrate (e.g., whitening or staining). In contrast, multi-shade composites age differently from the natural tooth over time, often leading to noticeable discolorations. Single-shade composites, however, cannot be used in all clinical cases. Therefore, it is essential to carefully select cases where their performance is optimal.

2. Color in Dentistry

Color is a visual perception phenomenon that results from light being reflected or transmitted by an object (Rosenstiel SF et al., 2006).

Achieving accurate shade matching remains one of the key factors in esthetic success and patient satisfaction (van der Burgt TP et al., 1990) and requires accurate shade selection and replication (Rosenstiel SF et al., 2006). The optical properties of the hard tissues of the tooth (enamel and dentin) make shade selection challenging. Factors such as surface texture, translucency, and the surrounding environment influence tooth color. When light interacts with an object, it can be reflected, absorbed, scattered, or transmitted. The layering effect, caused by varying levels of enamel translucency and dentin opacity, adds complexity to shade selection (O'Brian WJ, 1985).

More dependable and effective color-measuring devices are necessary to improve the accuracy of individual measurements (Chen H et al., 2012).

Color perception occurs when the spectrum of visible light enters the human eye, stimulating the three types of color receptors in the retina (Williamson, 1983; Hecht E, 2002). The color of teeth is influenced by both the tooth's intrinsic color and external stains on the surface (Watts A et al., 2001; Joiner A, 2004). Light scattering and absorption within the enamel and dentin largely dictate the intrinsic color of teeth (Muia PJ, 1985). Stains from substances like tea or red wine adhere to the enamel surface, affecting the extrinsic color (Macpherson LMD et al., 2000).

Tooth color measurement methods are generally divided into two categories: visual and instrumental (Brewer JD et al., 2004).

While widely used, traditional visual shade matching is often regarded as inconsistent and subjective. Variables like age, gender, eye fatigue, years of shade-matching experience, and color vision deficiencies can all impact the accuracy of visual shade selection (Culpepper WD, 1970; Horn DJ et al., 1998; Okubo SR et al., 1998; Hammad IA, 2003). Spectrophotometers are instruments used to measure color by detecting the amount of light reflected by an object at intervals of 1 to 25nm across the visible spectrum (Khurana R et al., 2007; Kielbassa AM et al., 2009). On the other hand, colorimeters assess tristimulus values by filtering light into the red, green, and blue regions of the visible spectrum (Chu SJ et al., 2010).

Previous research has demonstrated that spectrophotometers offer greater reliability and accuracy compared to colorimeters (Paul SJ et al., 2004; Judeh A et al., 2009; Chu SJ et al., 2010).

The CIE L*a*b* color system, created by the Commission Internationale de l'Eclairage (CIE, International Commission on Illumination) in 1931, defines a specific shade based on three coordinates: L*, a*, and b*. The value and L* are related to lightness, while a* and b* represent the color's chromatic characteristics; a* refers to the red-green axis, and b* to the yellow-blue axis. CIE Lab* color system is used to calculate the color differences between two objects using Delta E formula (ΔE) (Kim-Pusateri S et al., 2009). ΔE_{ab} formula was developed in 1976 as CIELAB color difference formula (International Commission on Illumination, 2004):

$$\Delta E_{ab} = ([\Delta L^*]^2 + [\Delta a^*]^2 + [\Delta b^*]^2)^{1/2}$$

In an effort to enhance the correlation between calculated and perceived color differences in the CIELAB formula, three advanced color difference formulas have been developed: CMC (Clarke FJJ et al., 1984), CIE94 (Commission Internationale de l'Eclairage, 1995), and CIEDE2000 (Luo MR et al., 2001; Commission Internationale de l'Eclairage, 2001; Commission Internationale de l'Eclairage, 2004). Currently, the CIE (Commission Internationale de l'Eclairage, 2004) recommends using the CIEDE2000 color difference formula. The CIEDE2000 formula addresses the non-uniformity in the CIELAB color space incorporating specific corrections: weighting functions (SL, SC, SH), a rotation term (RT) to reduce the interaction between chroma and hue differences in the blue region, a modification of the a* axis of the CIELAB for the correction of neutral colors, and parametric factors (KL, KC, KH) which are correction terms for variations of experimental conditions (Luo MR et al., 2001).

The calculations for the CIEDE2000 color difference (ΔE_{00}) metrics are based on the following equation (Sharma G et al., 2005):

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)\right]^{1/2}$$

ΔE is critical in quantifying color differences between specimens. Under controlled conditions, a ΔE value of 1 or higher is noticeable to the human eye. When two objects are compared side by side in controlled conditions, the smallest detectable color difference by human vision corresponds to a ΔE value of 1 (Kuehni RG et al, 1979). Thresholds for visible color mismatches are generally lower than those for acceptable differences (Douglas RD et al., 1998).

3. Dental bleaching procedures

The color of a tooth is determined by the optical properties of both enamel and dentin (Demarco FF et al., 2009), but it can also be affected by external or internal stains. Internal, or intrinsic, staining can result from factors such as genetics, aging (as enamel wears down, revealing the yellower dentin beneath), antibiotic use, high fluoride levels, and developmental issues. This type of staining can occur even before the tooth eruption. External staining instead, also known as extrinsic staining, is mainly caused by environmental factors like smoking, pigments in food and drink, antibiotics, and metals such as iron or copper (Joiner A, 2006; Alqahtani MQ, 2014; Alkahtani R et al., 2020; Dioguardi M et al., 2022).

Dental bleaching is a treatment that causes a modification of the tooth's color by using whitening products to interact with the pigments within the tooth (Kwon SR et al., 2015). The primary active ingredients in bleaching products are hydrogen peroxide (HP) and carbamide peroxide (CP) (Faus-Matoses V et al., 2019). Hydrogen peroxide (H_2O_2) is unstable and breaks down into water and reactive oxygen radicals. It dissolves easily, forming an acidic solution, with pH depending on its concentration. Carbamide peroxide ($CH_6N_2O_3$), on the other hand, is a stable compound that breaks down into HP and urea when it reacts with water. Its stability allows for a slower breakdown, resulting in a longer-lasting whitening process compared to HP (Kwon SR et al., 2015; Alkahtani R et al., 2020). The whitening agents penetrate the enamel and dentin to react with organic chromophores. Oxygen radicals from HP interact with the stain molecules through oxidation, breaking the strong double bonds and destabilizing the chromogenic compounds, ultimately reducing the discoloration. These reactions convert the stains into simpler forms or alter their optical properties, producing compounds with higher polarity and lower molecular weight than the original stain (Kwon SR et al., 2015; Alkahtani R et al., 2020).

Professional dental bleaching can be carried out either in-office or at home (Demarco FF et al., 2009; Naidu AS et al., 2020). During in-office bleaching, a gel containing the whitening agent (HP 30%-40%) is applied to the teeth after the soft tissues have been protected, and the active ingredient may or may not be activated using a light source (Joiner A, 2006; Lo Giudice R et al., 2016; Maran BM et al., 2018).

At-home bleaching involves an initial evaluation of the patient and the delivery of an intraoral custom-made tray to hold the whitening product in contact with the teeth. Patients apply the treatment themselves at home, usually overnight, and are supervised during periodic check-ups, where the dentist adjusts the treatment based on the results achieved.

This method typically uses lower concentrations of the product (CP 10%-16%) for a variable duration (ranging from 2 to 8 hours per day). (Hasson H et al., 2006; Alqahtani MQ, 2014; Alkahtani R et al., 2020).

Regardless of the technique used, whitening procedures have adverse effects that depend on the method employed, the type and concentration of the material, and the duration of the treatment. The most common side effects may include temporary sensitivity, gum irritation, oral tissue erosion, and changes in taste (Goldberg M et al., 2010).

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AIM OF THE STUDY

The primary aim of this research project was to evaluate the color integration of restorations customized with single-shade composites to the surrounding tooth through instrumental and visual color analysis. The secondary objective was to analyze whether, by changing the color of the surrounding dental substrate through professional dental bleaching, the restorations would be able to adapt and blend with the lighter tooth color. Additional objectives were to investigate: the comparison between instrumental and visual color match of single-shade and group-shade composites, the effect of curing time on the discoloration of single-shade and multi-shade composites, and the effect of staining substances on the color variations in single-shade, multi-shade, packable, and flowable composites.

The results obtained during the 3-year PhD, which are published or under review in peer-reviewed journals, are here below organized into 8 main chapters, as follows:

- **Chapter 1**: Visual and instrumental color match evaluation of single shade composites before and after bleaching procedures: a pilot study;
- **Chapter 2**: Effect of bleaching on the color match of single-shade resin composites;
- **Chapter 3**: Color match of single-shade restorations after professional dental bleaching: an in vitro study;
- **Chapter 4**: Color match of single-shade vs. multi-shade resin composites: a systematic review with meta-analysis;
- **Chapter 5**: Color stability assessment of single- and multi-shade composites following immersion in staining food substances;
- **Chapter 6**: Assessment of colour modifications in two different composite resins induced by the influence of chlorhexidine mouthwashes and gels, with and without anti-staining properties: an in vitro study;
- **Chapter 7**: Single- and group-shade composites color-match evaluation through visual, instrumental, and vision-algorithm analysis;

- **Chapter 8**: Instrumental and visual evaluation of the color correspondence between universal composite resins and teeth treated with direct restorations.

CHAPTER 1

RESEARCH ARTICLE

Visual and instrumental color match evaluation of single shade composites before and after bleaching procedures: a pilot study

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Keywords: universal composites, color match, blending effect, pilot study, VITA scale.

ABSTRACT

Background: One of the major challenges in restorative dentistry is to obtain an adequate color match between composite restorations and the surrounding tooth. This match depends on several chromatic variables related to the composite itself but also to the teeth. Bleaching procedures are not to be able to modify the shade of composite restorations to a lighter color as it does on natural teeth.

Objective: The objective of this study is to evaluate the visual and instrumental color match of two single-shade resin-based composites in human-extracted teeth before and after bleaching treatment.

Materials and Methods: Six extracted human posterior sound teeth were used. Round-shaped V-class cavities (2x2x4mm) were prepared buccally 2mm away from the CEJ. Two single-shade resin composites (OM-Omnichroma and VE-Venus Diamond One) were used for the restorations. Tooth color was measured using an intraoral spectrophotometer. Visual analysis was carried out by 16 calibrated observers, and the differences were graded from 0 (excellent match) to 4 (huge mismatch). Teeth were then bleached using 40%H_2O_2 (Opalescence Boost PF, Ultradent), and visual and instrumental evaluations were performed after 24 hours.

Results: Before bleaching, visual analysis showed a mean value of 0.16 for OM and 0.24 for VE. After bleaching, the color match showed a mean value of 0.14 for OM and 0.22

for VE. Regarding the instrumental analysis, each restoration matched the tooth VITA scale grade before bleaching and followed the natural tooth VITA scale grade after bleaching procedures.

Conclusion: Within the limits of this pilot study, both composites seem to have excellent color-match properties with the surrounding tooth structure.

INTRODUCTION

Resin composites are the restorative materials of choice due to their aesthetic and handling properties, for being able to show good mechanical characteristics, and for their good adhesion performance [1].

One of the most complex challenges in restorative dentistry is being able to achieve a correct color match between composite restorations and the surrounding teeth [2]. In fact, color matching depends on various chromatic variables related to both composites and teeth, which are responsible for the difficulty to obtain this match [3].

The variability of the color of natural teeth led to the development of different composite systems that include many different shades, following as a reference, in most cases, the VITA Classical shade guide [4]. Composites present several opacities (Enamel = translucent, dentin = opaque/body) that are useful to obtain similar optical properties to natural enamel and dentin [1]. These different composites opacities and chromas are clinically employed in several layers through a layering technique, in order to achieve a restoration with the same optical properties of the natural tooth [5]. This technique is able to obtain acceptable results in color matching but is complex, it requires increased operative timing and is much more skill–dependent than other one- or two-shade procedures [1].

The potential of a resin to take on the color of the surrounding tooth structure via reflection is called Blending Effect (BE). This effect is the basis of the latest generation composites, designed to blend with the surrounding tooth, using the lowest possible number of shades [4,6]. Furthermore, composites blending effect contributes significantly to achieve a proper shade match and improve the aesthetics [4]. Recently, innovative single-shade resins have been introduced, being supposedly able to match all VITA Classical shades, from A1 to D4 [1,7].

The choice of using filler morphology for shade matching is a modern technological innovation, named “structural color”, where shade matching is obtained by resin composite light absorption and emission [4].

The structural color phenomenon is based on the discrimination of different wavelengths by the interaction of incident light with nanostructures like diffraction gratings, photonic crystals, or thin films. As structural colors are the result of fundamental optical processes of interference, scattering, and diffraction, they do not fade, if compared to conventional colors which originate from light absorption by pigments [8].

The match between teeth and composite becomes of fundamental relevance when performing the reconstruction of a tooth in the aesthetic area. In this clinical situation, it is not possible to endure aesthetic compromises and the reconstruction must perfectly blend with the surrounding dental structures [2].

It has been shown that composite resins suffer from intrinsic or extrinsic staining over time, caused by pigments from drinks or food, or smoking habits [9,10]. Whitening procedures for bleaching teeth at home or in the office are often proposed to modify the color of natural teeth towards a desired aesthetic appearance [11,12]. These products are sometimes able to remove stains from composites but seem not to be able to modify the shade of composite restorations to a lighter color, such as can occur with natural teeth [11]. Since composites seem to be unable to change to a lighter shade, bleaching is usually recommended before a new composite filling, in order to obtain a match between the restoration and the new lighter tooth shade [12].

The aim of this pilot study is to evaluate the instrumental and visual color match of two different single-shade resin-based composites with the surrounding tooth, before and after professional bleaching procedures on human extracted teeth. The null hypotheses were that (1) there is no color match between single-shade composites and the surrounding tooth; and (2) that single-shade composites are not able to follow tooth color after bleaching.

MATERIALS AND METHODS

Six human extracted posterior sound teeth (molars) without caries, restorations, and endodontic treatment, stored for 24 hours in distilled water at 37°C in specific individually sealed compartments were used in this pilot study [13,14]. Extracted teeth were used according to the Ethical Committee of the University of Bologna approval (protocol N°:71/2019/OSS/AUSLBO).

On the tooth buccal side, 2mm above the cemento-enamel junction (CEJ), a standardized V class cavity (2mm depth, 2mm high, and 4mm width) was performed using a water-cooled dedicated round-shaped diamond burr (#6801314029, Komet Dental, Lemgo, Germany) [15].

Two different one-shade resin composites were selected: Omnichroma (OM) (Tokuyama Dental, Tokyo, Japan), and Venus Diamond One (VE) (Kulzer, Hanau, Germany), with their correspondent adhesive systems: Universal Bond (Tokuyama), iBond Universal (Kulzer). Details about the tested resin composites are given in **Table 1**.

Table 1. Details about resin composites composition.

Material	Monomer	Filler Type
Omnichroma	UDMA, TEGDMA	SiO2, ZrO2 & CF (68 vol.-%; 79 wt%; 0.2 µm – 0.4 µm in ø)
Venus Diamond One	UDMA, TCD-DI-HEA, TEGDMA	BaAlF, SiO2 (64 vol.-%; 81 wt%; 5 nm – 20 µm in ø)

The six extracted teeth were randomly divided into two groups, with three teeth in each group. Group OM included teeth restored with OM (teeth OM1, teeth OM2, and teeth OM3), while group VE included teeth treated with VE (teeth VE1, teeth VE2, and teeth VE3).

Teeth were restored through a single increment of the correspondent one-shade composite resin. Bonding procedures were performed according to the manufacturer. Composite restorations were then polymerized at 1400mW/cm^2 with a middle-intensity blue-led light-curing unit (Mectron Starlight Pro, Italy) for 40 seconds, as indicated by the manufacturer.

After curing procedures, the restorations were dry polished with a dedicated composite finishing and polishing system (Clearfil Twist DIA, Kuraray), using a slow-speed handpiece at 4000rpm for 30 seconds per step and were stored in distilled water at 37°C for 24h

[13] (Figure 1). Instrumental and visual color measurements were performed after the restoration, as described further.

Bleaching procedures

Teeth were bleached through a 40% hydrogen peroxide (Opalescence Boost PF 40%, Ultradent, South Jordan, USA). Teeth were fixed on a wax plate before the application of the bleaching gel [11]. This gel was applied to cover the whole tooth surface except the composite restoration because bleaching agents at high concentrations can promote a physical deterioration on the surface roughness of composite resins [16,17]. Two consecutive simulated bleaching sessions, 20 minutes each, were performed for each specimen according to the manufacturer [18].

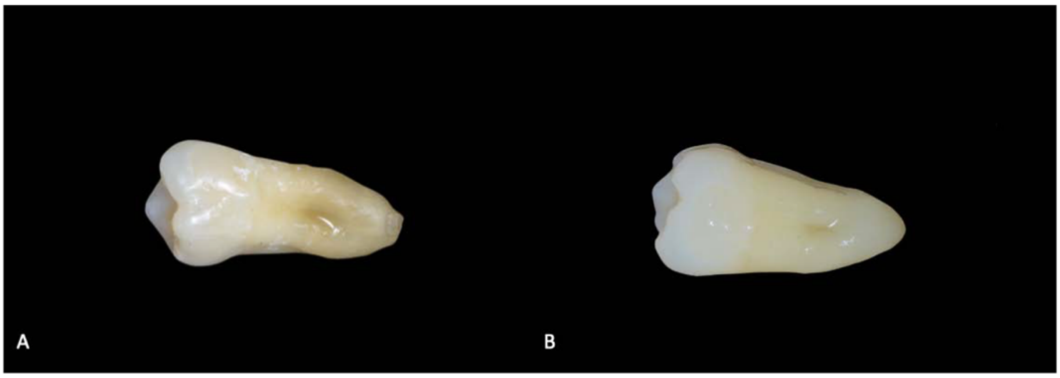

Figure 1. Final aspect of two restorations after 24h (a: OM, b: VE).

After both applications, the bleaching agent was gently removed using gauze soaked in distilled water, and then the specimen surfaces were washed out and dried with absorbent paper. Samples were not air-dried with any system that could dehydrate the samples [11].

Instrumental and visual color measurements were performed after bleaching, as described further.

The specimens were always stored separately in distilled water at 37°C [11].

Instrumental color measurements

Using an intraoral spectrophotometer (VITA Easyshade V, VITA Zahnfabrik, Bad Sackingen, Germany), by placing its measuring tip perpendicular to the vestibular side, VITA color was evaluated. A neutral grey paper was used as a background during the measurements [6,18]. Measurements were taken (24 hours after the restoration, T_0, and 24 hours after professional bleaching, T_1) in the center of the restoration and on the teeth, 1mm away from the margin of the restoration [13] **(Figure 2)**.

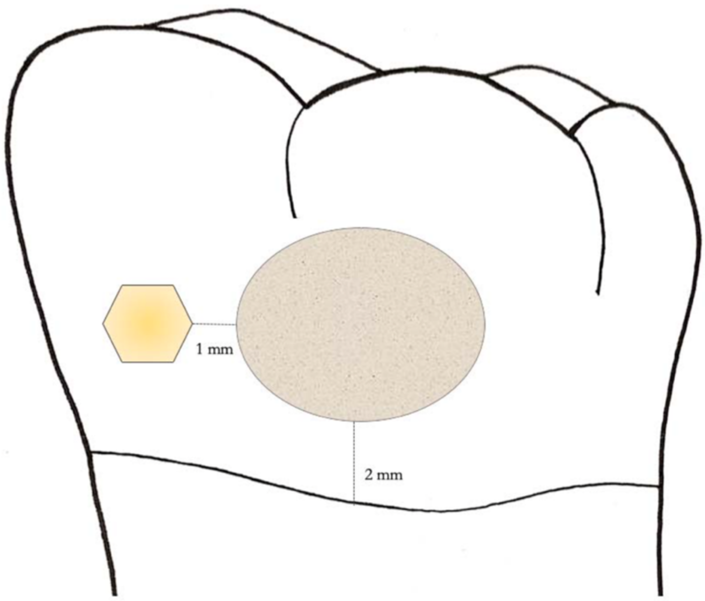

Figure 2. Color measurements areas (0.5x0.5mm) on the restored tooth.

Visual color measurements

After instrumental evaluation, visual color assessments were carried out by 16 dental professionals [6]. These observers were both male and female dentists, with at least 5 years of experience in restorative dentistry, attending the Restorative Department of the Dental School of the University of Modena & Reggio Emilia between January and June 2022. All evaluators passed the test for color-matching competence in dentistry according to ISO/ TR28642 [19].

Under the illumination of a D65 light source and using a 0°/45° viewing geometry, the observers performed blind visual evaluations of all specimens [1] before (T_0) and after bleaching (T_1). The color differences between teeth and restorations were graded from 0 to 4, using the scale based on a previous study where a level “0” means excellent match;

1, very good match; 2, not so good match (border zone mismatch); 3, obvious mismatch; and 4, huge (pronounced) mismatch [1]. Mean values of these observations were calculated.

RESULTS

At baseline (T_0), OM1 and OM3 showed the same VITA color registration both on teeth and on the restorations (OM1: A3, OM3: A3.5). OM2 showed an A3 tooth VITA color grade and A3.5 on the restoration. At T_1, after bleaching procedures, OM1 and OM3 showed the same VITA color registration both on tooth and restoration (OM1: A2, OM3: A2). OM2 showed a B2 VITA color grade on the tooth and A2 VITA color grade on the restoration.

At T_0, VE2 showed the same VITA color registration (A3) both on teeth and on the restorations, whereas VE1 e VE3 showed a tooth VITA color grade of A3.5 and a restoration VITA color grade of A3. At T_1, VE3 showed the same VITA color registration (A2) both on teeth and restoration. VE1 and VE2 showed an A2 VITA color grade of the tooth and a B2 VITA color grade of the restoration (Table 2).

Table 2. VITA color values before and after bleaching and mean values of the visual analysis of single OM and VE specimens.

Resin Composites	VITA Tooth (T0)	VITA Composite (T0)	VITA Tooth (T1)	VITA Composite (T1)	Visual Analysis (T0)	Visual Analysis (T1)
OM1	A3	A3	A2	A2	0.18	0
OM2	A3	A3.5	B2	A2	0.18	0.25
OM3	A3.5	A3.5	A2	A2	0.12	0.18
VE1	A3.5	A3	A2	B2	0.3	0.25
VE2	A3	A3	A2	B2	0.18	0.25
VE3	A3.5	A3	A2	A2	0.25	0.18

The visual analysis showed a mean value of 0.16 (±0.02) for OM and 0.24 (±0.05) for VE at T_0. After bleaching (T_1), the color match showed a mean value of 0.14 (±0.1) for OM and 0.22 (±0.03) for VE **(Table 3 and Figure 3)**.

Table 3. Mean values of the visual analysis (with SD).

Resin Composites	Visual Analysis (T0)	Visual Analysis (T1)
OM	0.16 (± 0.02)	0.14 (± 0.1)
VE	0.24 (± 0.05)	0.22 (± 0.03)

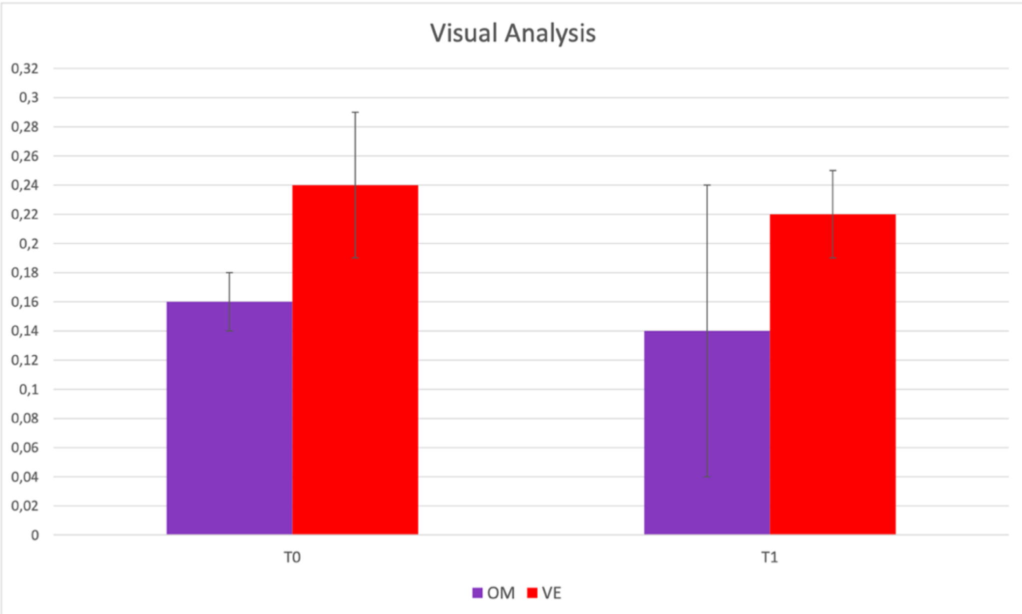

Figure 3. Column graph of the visual analysis results.

DISCUSSION

Blending effect in dentistry is helpful since it neutralizes or minimizes color mismatches and/or the absence of adequate shade in the selected restorative material [20]. Recent research focused on filler morphology in order to influence the color match between teeth and composites. This structural color technology is based on the interaction of reflection from supra-nano particles and light refraction. This phenomenon leads to single-shade universal composites which intend to match all shades of the VITA color guide [7].

In 2021, Iyer et al. used three different composites (Tetric EvoCeram, TPH Spectra ST, and Omnichroma) to restore 15 occlusal cavities on resin teeth [6]. Color differences between composites and teeth (ΔE_{00}) were calculated for all reconstructions with the VITA Easyshade V spectrophotometer, and 30 evaluators gave their consideration regarding the color match using a visual scale from 1 (best match) to 3 (poor match). Tetric EvoCeram showed similar values in all cases, independently from the VITA color of the resin teeth. Omnichroma and TPH Spectra ST instead showed lower values on teeth with brighter VITA colors. The visual analysis showed the best color matches of TPH Spectra ST with brighter resin teeth, and of Tetric EvoCeram with darker resin teeth (VITA C2 and D3) [6]. These visual analysis results are difficult to compare with those of the present pilot study since in Iyer's study the visual scale is divided into three points (best, intermediate, and poorest match), while in this case a more precise and detailed scale, made up of 5 evaluation degrees, was used [1].

Another recent in vitro study tested 120 resin teeth, with shades A1 to A4, that were filled with occlusal restorations performed with three different composites (Supra-nano-filled, Micro-hybrid filled, and Clustered-nano-filled). Differences in color between teeth and resins appeared significantly lower when the supra-nano-filled composite was used to restore A2, A3, and A4 teeth shades [4].

In order to improve aesthetics, dental bleaching has become a common treatment [10]. Bleaching is not able to change the shade of composite restorations to a lighter color as it does on natural tooth structures; however, it can sometimes remove stains on composites and return them to their original shade [12,21].

Pecho et al. in 2019 evaluated the influence of a professional bleaching gel on the color changes of resin composites. Ten discs were created from three different composite resins (Durafill, IPS Empress Direct, Amelogen Plus), and differences between tooth and resin color were obtained before bleaching, and after the first and second bleaching application through a spectrophotometer (VITA Easyshade). Lightness values of all resins did not change after bleaching and there were no statistically significant differences in color variations among all tested materials. This study showed that bleaching with 35% hydrogen peroxide is able to influence restoration color, but that this influence is not perceived clinically [11].

Another study investigated color variations after bleaching using a universal one-shade composite (Omnichroma). Ten extracted sound teeth were prepared with a cervical cavity and then restored with Omnichroma. Instrumental analysis was carried out through a spectrophotometer on 5 points of the composite restoration, and visual analysis was performed by two examiners. After professional bleaching, lightness and color coordinate values were registered after 24 hours, 1, 2, and 4 weeks after bleaching procedures, and then compared to the initial ones. There was no significant difference between these coordinates between restorations and teeth at each time interval, and the examiner's scores showed a perfect match between teeth and composites at all intervals [12]. This article showed interesting visual analysis results but also in this case they are difficult to compare with those of the present pilot study. In Mohamed et al. study, the visual scale is divided into three not very specific points (complete match, somewhat match, and non-match), while in this pilot study a more impartial and detailed scale, made up of 5 evaluation degrees (excellent, very good, not so good match, and obvious and huge mismatch), was used [1].

Recently, a manuscript by Kobayashi et al. tried to evaluate the effect of the structural color phenomenon on the color adjustment of restorations, by investigating their color reproduction performance in cervical cavities of human incisors of various shades. Cavities were filled with Omnichroma, Estelite Σ Quick, Clearfil AP-X, and two experimental resin composites. The first (R1) was characterized by 5-50nm fumed silica fillers, and the second (R2) with 100nm spherical fillers. Color parameters (L, C, h) were measured along the centreline of the restorations and registered using a CIE camera. These data were used to calculate the color difference (ΔE_{00}) between the restoration and the intact tooth. Omnichroma resulted the material which exhibited significantly lower ΔE_{00} than other tested composite resins. Moreover, Omnichroma showed a higher color adjustment potential [8].

CONCLUSIONS

Within the limitations of this pilot study, it can be concluded that with both tested composites an excellent color match between restoration and teeth can be obtained, both before and after tooth bleaching. The positive trend obtained in this pilot study should work as an incentive for the development of a more well-structured study, with a greater number of samples and tested materials.

If these results could be generalized and applied to all single-shade composites, we would be in front of an essential clinical breakthrough. In fact, by using these types of composites, the operative timing could be shortened by avoiding the stratification of several composite masses, costs could be reduced, and the final result would be less skill-dependent than a layering technique. Furthermore, these composites seem to follow the physiological aging of natural teeth, and there could be the possibility of performing tooth bleaching without issues related to the aesthetic discomfort caused by the discoloration of previous restorations.

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CHAPTER 2

RESEARCH ARTICLE

Effect of bleaching on the color match of single-shade resin composites

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Keywords: color perception, composite resins, dental restorations, tooth bleaching.

ABSTRACT

Objective: To evaluate the color match of single-shade resin composites before and after bleaching procedures, through instrumental and visual analyses.

Materials and Methods: Class V cavities were created on the buccal surfaces of 80 extracted human molars, restored with 4 single-shade composites (Omnichroma; Clearfil Majesty ES-2 Universal; Essentia Universal; Venus Diamond One). A spectrophotometer (VITA Easyshade V) was used to evaluate the tooth/resin color match before (T_0), and 24h (T_1) and one week (T_2) after dental bleaching (Opalescence Boost PF 40%). Color variations (ΔE_{00}) were calculated and statistically analyzed ($p<0.05$). Visual analysis was performed before and after tooth bleaching.

Results: Spectrophotometric evaluations revealed statistically significant differences between materials at T_0, T_1, and T_2 ($p<0.05$). Visual analysis reported excellent and very good grades (0 and 1, respectively), irrespective of the materials and time points.

Conclusion: Data seem to indicate that single-shade composites are able to shift their color when the surrounding tooth undergoes bleaching effects. Single-shade composites seem to achieve a good color match with the surrounding tooth structure, before and after professional bleaching.

INTRODUCTION

Among restorative materials, resin composites are widely used for their enhanced esthetics and improved handling properties, as well as presenting reliable mechanical characteristics [1].
Currently, restorative dentistry is linked indissolubly with esthetics, and composite materials should perform perfectly in terms of color match with the shades of the restored tooth [2].
Many parameters are involved in obtaining an accurate color match, and these can be related to teeth or to the resin composite. Characteristics such as value, chroma, hue, opalescence, translucency, transmission and diffusion of light, and surface texture are mainly called into question when dealing with color correspondence analysis [3].
The match between composite and tooth is of fundamental importance when carrying out the reconstruction of an anterior tooth or in the smile region. In this case, it is not possible to accept esthetic compromises and the reconstruction must blend perfectly with the surrounding dental tissues [2].
It is not always easy to uniquely determine the color of a tooth, due to the structural variability of the tooth substrate. Accordingly, composite materials have undergone several improvements over time to minimize these inherent tooth variations, and currently, dentists dispose of materials with different shades, mostly by referencing the VITA Classical shade guide. These shades are mainly characterized by pigments and dyes incorporated into the resin matrix [4]. In addition, resin composite presents different opacities (Enamel = translucent, Dentin = opaque/body) that are useful to reach optical properties similar to that of natural dental substrates [1]. Both opacities and chromas of resin composites are clinically used in multiple layers according to the layering technique, in order to create a restoration with the same optical properties as the natural tooth [5]. This technique has made it possible to obtain excellent esthetic restorative results, but it is highly time-consuming and requires an experienced and skilled operator [1].
The ability of a resin to match the color of the surrounding tooth structure via reflections is called Blending-Effect (BE) or the Chameleon-Effect. This phenomenon represents the innovation of the latest generation of resin composites that are supposed to perfectly blend with the surrounding tooth while minimizing the number of shades [4,6]. According

to a recent study, the blending ability of recent resin composites significantly contributes to achieving a proper shade match with the tooth and improving the esthetics [4]. Very recently, innovative single-shade composites have been introduced in the market, that are supposedly able to match all VITA Classical shades, from A1 to D4 [1,7-9].
Dental bleaching is an increasingly frequent aesthetic request from patients, either for purely aesthetic needs or for discolorations due to intrinsic or extrinsic factors (drinks, foods, or smoking habits) [10-13]. Although composite resins are subjected to staining during functions, it is noteworthy that the same dental bleaching procedures adopted for natural teeth are ineffective to modify the shade of resin composites [12]. As a consequence, bleaching is usually performed before restorative procedures to obtain the maximum match between the restoration and the newly achieved, lighter tooth shade [13].
To the author's best knowledge, no studies have focused on the evaluation of the color match between different single-shade resin composites with the surrounding tooth before and after professional dental bleaching procedures.
Therefore, the aim of this in vitro study was to evaluate the instrumental and visual color match of four different single-shade resin-based composites with the surrounding tooth, before and after professional bleaching procedures performed on extracted human teeth. In particular, the null hypotheses tested were that 1) there is no color match between single-shade composites and the surrounding tooth; and 2) that single-shade resin composites cannot match the tooth shades after dental bleaching.

MATERIALS AND METHODS

Eighty sound, human molars extracted for periodontal or orthodontic needs were stored at 4°C until use [14], no longer than 1 month. Extracted teeth were used according to Ethics Committee of the University of Bologna approval (protocol N°:71/2019/OSS/AUSLBO). In order to be eligible for this research, the teeth had to be free of caries, restorations, and endodontic treatment.
A standardized class V cavity (2mm depth x 2mm high x 4mm width) was performed on each buccal side of the teeth, 2mm above the cemento-enamel-junction (CEJ). The cavities were prepared using a water-cooled dedicated round-shape diamond bur

(#6801314029, Komet Dental, Lemgo, Germany) that was discarded and replaced every 2 teeth [15], and beveled with a finishing bur (#8390314016, Komet Dental).

The teeth were randomly distributed in 4 groups, according to the single-shade resin composite/adhesive system used for the restorations (n=20): Omnichroma/Universal Bond, OM (Tokuyama Dental, Tokyo, Japan); Clearfil Majesty ES-2 Universal/Clearfil Universal, CL (Kuraray Medical Inc., Tokyo, Japan); Essentia Universal/G2 Bond Universal; ES (GC Corp, Tokyo, Japan); Venus Diamond One/iBond Universal, VE (Kulzer, Hanau, Germany). The details of the materials employed in the study are given in **Table 1**.

Table 1. Details of resin composites used in the study.

Code	Composites	Manufacturer	Matrix	Filler system
OM	Omnichroma	Tokuyama Dental (Tokyo, Japan)	UDMA TEGDMA	SiO_2, ZrO_2, CF (68 vol.-%; 79 wt%; 0.2 µm – 0.4 µm in ø)
CL	Clearfil Majesty ES2 Universal	Kuraray Medical Inc (Tokyo, Japan)	Bis-GMA hydrophobic aromatic dimethacrylate	SBG, PPF (40 vol.%; 78 wt.%; 0.37 µm – 1.5 µm in ø)
ES	Essentia Universal	GC Corp. (Tokyo, Japan)	UDMA	Sr, LaF_3, SiO_2, FAISi glass, Fumed silica (81 wt.%; 16 µm – 16 nm)
VE	Venus Diamond One	Kulzer GmbH (Hanau, Germany)	UDMA TCD-DI-HEA TEGDMA	BaAlF, SiO_2 (64 vol.-%; 81 wt%; 5 nm – 20 µm in ø)

UDMA, urethane dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; TCD-DI-HEA, 2-propenoic acid; (octahydro-4,7-methano-1H- indene-5-diyl) bis(methyleneiminocarbonyloxy-2,1-ethanediyl) ester; SiO_2, silica; ZrO_2, zirconia; CF, composite filler; BaAlF, barium-aluminum-fluoride glass; PPF, pre-polymerized filler; Sr, strontium Glass; LaF_3, Inthanoid fluoride; SBG, silanated barium glass; ø = diameter

The sequence in which the restorations were performed was previously randomized and the operator was blinded to the resin composites. Bonding procedures were performed according to their manufacturers and then a single increment of the resin composites was applied. Composite restorations were then polymerized at 1,400mW/cm^2 with a middle-intensity blue LED light-curing unit (Mectron Starlight Pro, Genova, Italy) for 40s, as indicated by the manufacturer.

After curing procedures, the restorations were dry polished with a dedicated composite finishing and polishing system (Clearfil Twist DIA, Kuraray Medical Inc.), using a slow-speed handpiece at 4,000rpm for 30s **(Figure 1)**. Teeth were then stored in distilled water at 37°C for 24h [14,16].

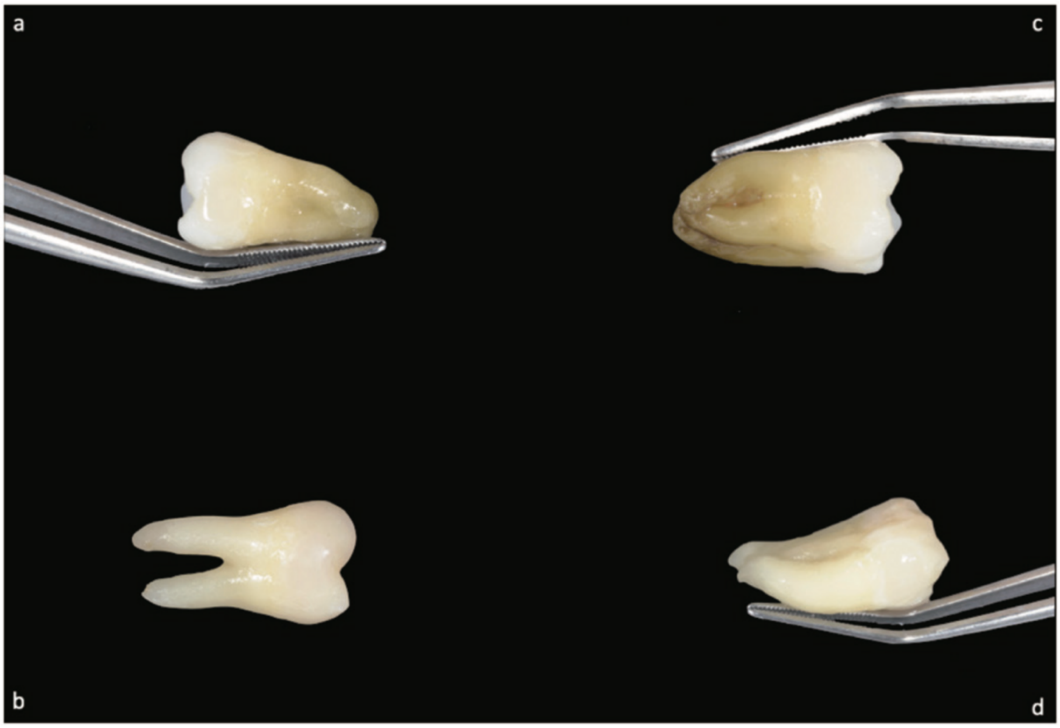

Figure 1. Class V restorations after polishing procedures (a= OM, b= CL, c= ES, d=VE).

Bleaching procedures

After restorative procedures, the teeth were fixed on a wax support [12]. A 40% hydrogen peroxide gel (Opalescence Boost PF 40%, Ultradent, South Jordan, UT, USA) was applied to cover the whole tooth surface except for the composite restoration. Two consecutive simulated bleaching sessions, 20min each [16], were performed for each tooth according to the manufacturer's instructions.

After bleaching, the gel was gently removed using gauze soaked in distilled water and then the specimen's surfaces were washed out and dried with absorbent paper [12].

Instrumental color measurements

An intraoral spectrophotometer (VITA Easyshade V, VITA Zahnfabrik, Bad Sackingen, Germany) was used for color evaluations. The following variables were evaluated: CIELAB color coordinates (L*: lightness, a*: green-red coordinate and b*: blue-yellow coordinate), chroma (C*), and hue (h°) of the teeth (measurement 24h after the restoration, T_0). A neutral gray paper was used as a background during measurements [6,17], and the device was calibrated after every 3 measurements [6]. Measurements were taken at the center of the restoration and on the tooth, 1mm away from the margin of the restoration **(Figure 2)** [14]. The tip of the device, 0.5mm in diameter, was placed perpendicularly in contact with the surfaces, as indicated by the manufacturer, and the time of exposure was given by a spectrophotometer.

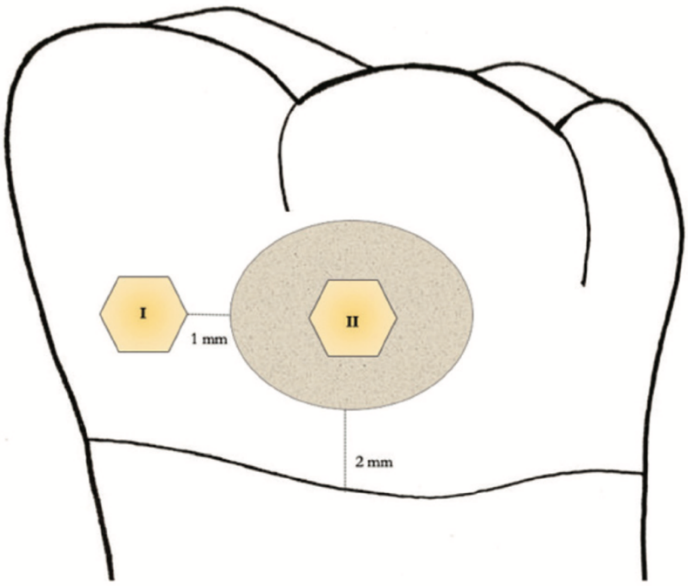

Figure 2. Color measurement areas (0.5mm x 0.5mm) on the restored tooth.
Area I: tooth area of 1mm away from the border of resin composite restoration;
Area II: resin composite area of the center of resin composite restoration.

The CIEDE2000 color differences (ΔE_{00}) between tooth and restoration were calculated using an Excel spreadsheet for implementing the CIEDE2000 color difference formula as suggested by Sharma [6,18]:

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L} \right)^2 + \left(\frac{\Delta C'}{K_C S_C} \right)^2 + \left(\frac{\Delta H'}{K_H S_H} \right)^2 + R_T \left(\frac{\Delta C'}{K_C S_C} \right) \left(\frac{\Delta H'}{K_H S_H} \right) \right]^{1/2}$$

The parametric factors of the formula were set to 1 [1,6,18]. Color match evaluations were performed before (T_0), after 24h (T_1), and after one week (T_2) of the bleaching procedures.

Visual color measurements

After instrumental evaluation, visual color assessments were carried out by 16 dental professionals, 50% males and 50% females, with at least 5 years of experience [6]. A viewing booth was used for this evaluation, and the observation time was controlled during visual analysis, not exceeding 25s [6]. All evaluators passed the test for color-matching competence in dentistry according to ISO/ TR28642 [19].
Under the illumination of a D65 light source and using a 0°/45° viewing geometry, the observers performed blind visual evaluations of all specimens in random order [1]. The color differences between each tooth and restoration were graded from 0 to 4, using the scale based on a previous study where level "0" means excellent match; 1, very good match; 2, not so good match (border zone mismatch); 3, obvious mismatch; and 4, huge (pronounced) mismatch [1,20].

Statistical analysis

Statistical analysis was performed using STATA program version 14 (StataCorp LLC, College Station, TX, USA). The statistician was blinded to the groups when performing the analysis. Means, standard deviations, counts, and percentages were used to summarize the data. The mean effect of the groups was determined using analysis of variance (ANOVA). Prior to the ANOVA test, Levene's Test for Equality of Variances was performed. If the Levene test is positive ($p<0.05$) then the variances in the different groups are different (the groups are not homogeneous) and it may be necessary to apply a logarithmic transformation to the data or use a non-parametric statistic. In the present data, the Levene test was $p>0.05$ and no logarithmic transformation was needed. Data from color coordinates (CIE L*, a*, b*, C*, and h°) were statistically analyzed using one-way analysis of variance (one-way ANOVA) and Tukey's multiple comparison test with Bonferroni correction. The Cronbach's alpha test was used to analyze the reliability between the evaluators. The Pearson correlations test was used to analyze the coefficient of correlation (r) between data from tests. One-way ANOVA was performed to compare the effects of color differences ΔE_{00} value among the materials. Paired t-tests were used to compare continuous measurements between groups. A p-value of ≤ 0.05 was considered statistically significant.

RESULTS

Mean color differences (ΔE_{00}) and standard deviations (SDs) between the tooth and restored composite at baseline (T_0), 24h (T_1), and 1 week (T_2) after bleaching for each of the composite materials are presented in **Table 2**.

Table 2. Mean and standard deviation values of color differences (ΔE_{00}) between tooth and restoration for different periods (T_0, T_1, and T_2).

Group ΔE_{00}	T_0	T_1	T_2
OM	7.6 ± 2.4 (3.3-13.8)^{abAB}	4.7 ± 1.9 (1.4-8.8)^{eA}	4.3 ± 1.9 (1.5-9.1)^{hiB}
CL	7.3 ± 2 (2.6-9.8)^{cdCD}	3.9 ± 1.4 (1.2-6.2)^{fC}	4.0 ± 1.1 (1.5-5.9)^{lD}
ES	4.2 ± 1.9 (0.9-8.5)^{acE}	4.3 ± 2.1 (1.6-11.3)^{gF}	2.9 ± 1.6 (1.1-8.2)^{hlEF}
VE	3.8 ± 1.5 (1.5-6.2)^{bdG}	2.7 ± 1.2 (1.5-5.4)^{efgG}	3.2 ± 1.9 (1.2-9.1)^{i}

ΔE00-T_0: statistically significant difference between OM^a vs. ES^a ($P < 0.001$), and OM^b vs. VE^b ($P < 0.001$); difference between CL^c vs. ES^c ($P < 0.001$), and CL^d vs. VE^d ($P < 0.001$); T_1: statistically significant difference between OM^e vs. VE^e ($P = 0.001$), and CL^f vs. VE^f ($P = 0.001$), and ES^g vs VE^g ($P = 0.015$); T_2: statistically significant difference between OM^h vs ES^h ($P = 0.026$), OM^i vs VE^i ($P = 0.044$), and CL^l vs ES^l ($P = 0.009$); statistically significant difference between for OM^A between T_0 vs T_1 ($P < 0.001$) and OM^B between T_0 vs T_2 ($P < 0.001$); CL^C between T_0 vs T_1 ($P < 0.001$) and CL^D between T_0 vs T_2 ($P < 0.001$); ES^E between T_0 vs T_2 ($P = 0.012$) and ES^F between T_1 vs T_2 ($P = 0.031$); VE^G between T_0 vs T_1 ($P = 0.008$).

The statistical analysis revealed a significant difference between materials ($p<0.05$) at T_0, T_1, and T_2.

In detail, at T_0, OM and CL showed higher ΔE_{00} values than ES and VE, with statistically significant differences between OM and ES ($p<0.001$), OM and VE ($p<0.001$), Cl and ES ($p<0.001$), and CL and VE ($p< 0.001$).

At T_1, OM CL and VE showed a ΔE_{00} decrease compared to T_0 values, whereas ES remained stable. Statistically significant differences were recorded between OM and VE ($p=0.001$), CL and VE ($p=0.001$), and ES and VE ($p=0.015$).

Finally, at T_2, all materials showed a further ΔE_{00} decrease and these values appeared more aligned between each other. OM appeared to be the composite with the highest ΔE_{00} values. Statistically significant differences were recorded between OM and ES ($p=0.026$), OM and VE ($p=0.044$), and CL and ES ($p=0.009$).

Table 3 shows how the 16 observers evaluated the match between reconstruction and natural tooth after 24h from restorative procedures (T_0) and one week after whitening (T_2).

Table 3. Visual color-analysis differences between T_0 and T_2.

T_0	Excellent match	Very good match	Not so good match	Obvious mismatch	Total
OM	150 (46,9)	136 (42,5)	34 (10,6)		320 (100)
CL[a]	160 (50)	136 (42,5)	24 (7,5)		320 (100)
ES	173 (54,1)	124 (38,8)	23 (7,2)		320 (100)
VE[b]	177 (55,3)	114 (35,6)	29 (9,1)		320 (100)
Total	660 (51,6)	510 (39,8)	110 (8,6)		1280 (100)
T_2					
OM[cd]	165 (51,6)	119 (37,2)	32 (10)	4 (1,3)	320 (100)
CL[aef]	144 (45)	133 (41,6)	38 (11,9)	5 (1,6)	320 (100)
ES[ce]	159 (49,7)	145 (45,3)	14 (4,4)	2 (0,6)	320 (100)
VE[bdf]	176 (55)	130 (40,6)	14 (4,4)		320 (100)
Total	644 (50,3)	527 (41,2)	98 (7,7)	11 (0,9)	1280 (100)

Statistically significant differences were observed between CL[a] T_0 and CL[a] T_2 ($P = 0.029$), and between VE[b] T_0 and VE[b] T_2 ($P = 0.043$). Significant differences were observed at T_2 between OM[c] and ES[c] ($P = 0.016$), OM[d] and VE[d] ($P = 0.008$), CL[e] and ES[e] ($P = 0.003$), difference between CL[f] and VE[f] ($P = 0.000$).

The color mismatch, as graded by the evaluators, is graphically represented in Fig. 3a and b. The majority of results fit into the range 0 and 1 (excellent match and very good match).

The statistical analysis of visual data revealed significant differences for CL at T_0 and T_2 (p=0.029), and for VE at T_0 and T_2 (p=0.043). No significant statistical differences were observed between materials at T_0 (p>0.05), but significant differences were present at T_2 between OM and ES (p=0.016), OM and VE (p=0.008), CL and ES (p=0.003), and CL and VE (p=0.000).

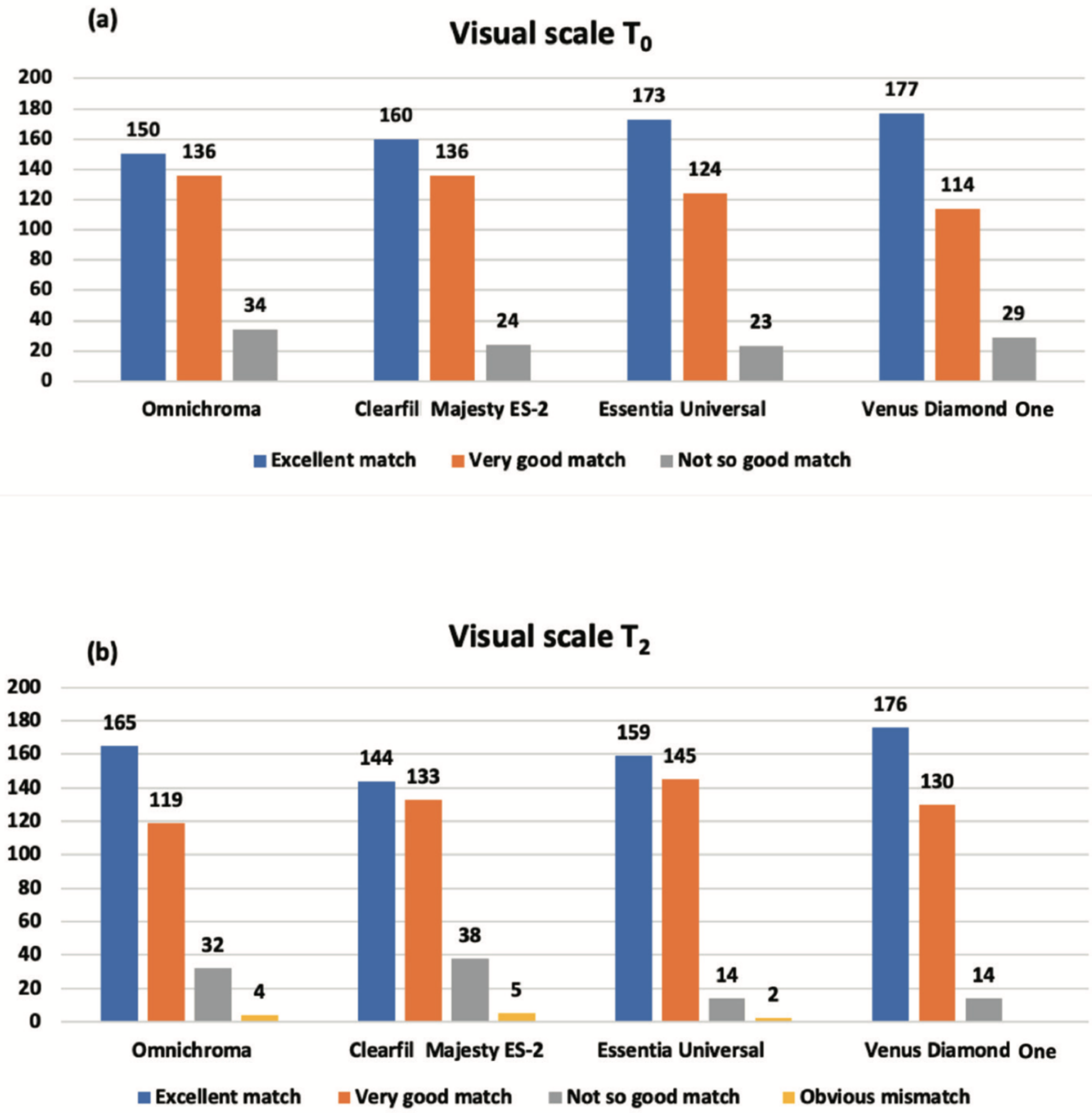

Figure 3. T_0 (a) and T_2 (b) results of the visual analysis. The majority of the evaluations were in the range of values between 0 (excellent match) and 1 (very good match).

DISCUSSION

Recent innovations have focused on the use of filler morphology in order to condition color match between composite and tooth. This "structural color" technology is based on the interaction of light refraction and reflection with supra-nano particles. This phenomenon leads to single-shade resin composites which aspire to match all shades of the VITA color guide [7].

The Commission Internationale de l'Eclairage (CIE) has been traditionally involved in colorimetry for dental materials. It has introduced the main color systems, illumination patterns, and color difference (ΔE) concepts used in color science [16]. When considering CIELAB color space (L*: value axis; a*: red-green axis; b*: yellow-blue axis), ΔE_{ab} has classically been considered the standard parameter for color difference between two objects. In the CIELAB metric, the greater the value, the larger the color difference and, consequently, the more perceptible the difference to the human eye. Aiming to improve the correction between computed and perceived color differences, the CIE recommended the use of CIEDE2000 color-difference formula (ΔE_{00}) [17,21].

In 2021, a research group tested three different composites (Omnichroma, Tetric EvoCeram and TPH Spectra ST) to restore 75 occlusal cavities on resin teeth [6]. ΔE_{00} of all reconstructions was calculated with the VITA Easyshade V spectrophotometer, and 30 evaluators gave their opinion on the color match using a visual scale from 1 (best match) to 3 (poor match). Tetric EvoCeram showed similar ΔE_{00} values in all cases, independently from the VITA color of the resin teeth. Omnichroma and TPH Spectra ST instead showed lower ΔE_{00} values on teeth with brighter VITA colors. The visual analysis showed the best color matches of TE with darker resin teeth (VITA C2 and D3), and of TS with brighter resin teeth. The authors concluded that color match is composite and color dependent [6].

The results of this study, concerning Omnichroma, showed how this material had better results when matching lighter VITA scale tooth shades (A2, B1 and B2). These findings are similar to the results of this manuscript where OM shows a ΔE_{00} reduction after bleaching procedures (T_1 and T_2), therefore on brighter tooth shades.

Another recent in vitro study tested 120 resin teeth, with shades A1 to A4, that were filled with occlusal restorations performed with three different composites: supra-nano filled (Omnichroma), micro-hybrid filled (Essentia Universal), and clustered-nano filled (Filtek Supreme Ultra). Color parameters were registered through ΔE_{ab} and ΔE_{00}. These values appeared significantly lower when supra-nano filled composites were used to restore teeth with A2, A3 and A4 shades, leading therefore to a better color match [4].

In contrast to the findings of the present manuscript and those of Iyer et al. [6], Omnichroma showed lower ΔE_{ab} e ΔE_{00} for all VITA scale tooth shades (A2, A3 and A4) after 24h from the restoration, equivalent to T_1 timing of the present manuscript. Lastly, in the case of A1 tooth shade, the authors found that Essentia Universal had the best match.

Twenty A2-shade extracted premolars were used for another color-match study. Cylindrical cavities 3.0 and 1.5mm in depth were created in the center of the buccal area and were restored with 4 A2-shade composites (Clearfil AP-X, Clearfil Majesty, Tetric N Ceram e Ceram X). The color was measured with a spectrophotometer (Crystaleye) in 4 areas: on the tooth, 1mm from the margin of the restoration; on the tooth, 3mm from the restoration margin; on the restoration, 0.3mm from the margin; on the restoration, 1mm from the margin. ΔE_{ab} was calculated between the different areas and ΔE 2/3 and ΔE 1/4 were used to evaluate color shift between tooth and restoration. For all composites, ΔE 2/3 showed lower values than ΔE 1/4, and ΔE 1 and 2 were higher than ΔE 3 and 4. The authors concluded that all composites showed a color shift at the margin of the restorations [14].

In this article, Tsubone et al. tested Clearfil Majesty, the multi-shade version of Clearfil Majesty ES 2 Universal, and concluded that, after 24h from the restoration, the diffused light transmission property of the composite could produce a chameleon effect due to the reflection of the surrounding tooth.

In order to improve dental esthetics, professional bleaching has become a common treatment in dental clinics [12]. Bleaching can sometimes remove acquired stains on composites and return them to their original shade. However, bleaching is not able to change the shade of composite restorations to a lighter color as it would on a natural tooth structure [13,21,22].

One study evaluated the influence of a professional bleaching gel on the color changes of resin composites. Ten discs were created from three different composite resins (Durafill, IPS Empress Direct, Amelogen Plus), and three sub-groups were obtained for each resin: before bleaching (T_0), after the first (T_1) and the second (T_2) bleaching application. ΔE_{ab} and ΔE_{00} coordinates were obtained through a spectrophotometer (VITA Easyshade) for each period. L* values from all resins did not change after bleaching and there were no statistically significant differences in color variations among all tested materials. The authors stated that bleaching with 35% hydrogen peroxide influences the color of the restoration, but that this influence is not clinically perceived [12].

For this reason, in this in vitro study, a selective bleaching procedure was adopted in order not to influence the color of the composite.

Another study group investigated color variations after bleaching using a universal one-shade composite (Omnichroma). Ten extracted sound teeth were prepared with a cervical cavity and then restored with Omnichroma. Visual analysis was performed by two examiners and instrumental analysis was carried out through a Crystaleye spectrophotometer on 5 points of the composite restoration. After professional bleaching, L*, a*, and b* values were registered after 24h, 1, 2, and 4 weeks after bleaching procedures. These values were then compared to the initial ones. There was no significant difference between L*, a*, and b* values between tooth and restoration at each time interval, and clinicians' scores showed a perfect match between tooth and composite at all intervals [13].

The results of this study agree with the findings of the present manuscript since after bleaching procedures Omnichroma is able to show a very good match with the surrounding structures.

As shown in **Table 2**, color differences at T_0 between tooth and restoration appear to be less perceivable for ES and VE groups (4.2±1.9 and 3.8±1.5) than for OM e CL groups (7.6±2.4 e 7.3±2). However, this difference decreases at T_1 and to a greater extent at T_2, reaching ΔE_{00} values of 4.3±1.9 for OM, 4.0±1.1 for CL, 2.9±1.6 for ES, and 3.2±1.9 for VE. This result could be explained by the fact that OM and CL are particularly capable to adapt themselves to brighter teeth, as stated also by Iyer et al. [6].

In relation to the visual analysis, at T_0, 91.4% of all evaluations ranged between “excellent” and “very good” for all groups, no negative match was graded, and no statistically significant differences were detected between the four tested materials ($p>0.05$). At T_2, one week after bleaching procedures, 91.5% of observers judged the clinical results as “excellent” and “very good”, and only 0.9% evaluated the color match as “obvious mismatch”.

The tendency for different results between instrumental and visual analyses could be explained by the fact that color perception does not provide metric-determined results, and an important role is played by the surrounding structure. This can be explained by the theory that the color perception of a composite resin observed alone is different than the color of the same composite used as a restoration with the whole tooth structure surrounding it [23].

Both initial null hypotheses were rejected, and, within the limitations of this study, it can be concluded that all single-shade resin composites tested showed the best color match with the surrounding tooth after 1 week from the bleaching procedures. Moreover, from a visual point of view, the match between restoration and tooth of all single-shade resin composites tested appeared to be excellent or very good, either before or after bleaching. Based on the significative results of this study, it would be of interest to perform an in vivo instrumental and visual analysis, to determine if single-shade resin composites are clinically able to match the color of the surrounding tooth.

Single-shade composites seem to be a valid clinical option in the restoration of class V cavities, and their clinical management is less time consuming and less skill dependent than traditional multi-layer restorative materials.

The results obtained from the visual analysis were more performant than those obtained with the instrumental analysis. This can be explained by the strong influence that the subjective component has on the perceptive one and by the fact that the perception of color influences the visual result. Therefore, contrary to a purely instrumental and scientific point of view, the most important component for the clinician and the patient is the visual one, i.e. the color perception of the tooth-reconstruction complex.

Following the results of this in vitro study, data seem to indicate that single-shade composites are able to shift their color when the surrounding tooth undergoes bleaching effects.

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CHAPTER 3

RESEARCH ARTICLE

Color match of single-shade restorations after professional dental bleaching: an in vitro study

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Keywords: bleaching; color match; filling materials; restorative dentistry; single-shade composites.

ABSTRACT

Background: Restorative dentistry aims to reproduce natural tooth shades through resin composites that must be layered to obtain colors, opacities, and translucencies, and therefore, clinical success is operator skill dependent.

Objective: The purpose of this study is to evaluate the color shift of single-shade composite restorations before and after dental bleaching.

Materials and Methods: Eighty human extracted posterior teeth were restored with four single-shade composites (Omnichroma OM; Clearfil Majesty ES-2 Universal CL; Essentia Universal ES; Venus Diamond One VE) (n=20 each). Standardized V class cavities were prepared on buccal side. VITA Easyshade V spectrophotometer was used to register VITA color and color coordinates 24h before (T_0), 24h after (T_1), and 1 week after (T_2) dental bleaching (Opalescence Boost PF 40%). Color differences (ΔE_{ab}) and (ΔWI_d) were calculated and subjected to statistical analysis.

Statistical Analysis: Categorical variables were analyzed using Pearson Chi-square, and data from color coordinates were analyzed using one-way analysis of variance and Tukey's multiple comparison test with Bonferroni correction. Paired t-tests were performed to compare continuous measures between groups and treatment time.

Results: Instrumental evaluations revealed statistically significant differences between materials ($p<0.05$) with lower values for ES and VE samples followed by CL and OM at T_0 and T_1. At T_2, OM and CL ΔE_{ab} values decrease getting closer to ES and VE.

Conclusion: Single-shade composites seem to match with the surrounding bleached tooth.

INTRODUCTION

Optical properties of natural teeth are the result of enamel and dentin overlapping and their interaction with the light and the surrounding tissues.[1] One of the biggest challenges in restorative dentistry is to reproduce natural tooth shades using resin composites[2] that must be layered through several increments of different colors, opacities, and translucencies.[3] Therefore, clinical success is still operator-skill dependent, although modern composites seem to be able to assimilate the color of the surrounding structures through a phenomenon named blending effect (BE).[4] In dentistry, the BE concerns the correlation between teeth and dental materials, and it is expressed by a smaller color diversity when viewed together, rather than observed individually: or rather, the detected color of an area changes toward the color of the surroundings. The BE helps the clinician's work since it attenuates or counteracts color mismatches, or/and therefore the lack of suitable shade in selected materials for restorative dentistry.[1] When light enlightens through composites, it disperses at the surface of the filler particles and spreads in several directions. This light conveyance through composite consists of a straight-line dissemination,[5] and the composite filler particles could condition this light conveyance features. Moreover, the restoration BE could be conditioned by the light diffusing refraction and scattering through the composite. Therefore, an assessment of light conveyance of composite having several filler morphologies is essential to foretell shade matching.[5] Recently, single-shade composites have been developed to achieve, through a unique color mass, a color match with all 16 shades of the VITA scale, and with all color shades of natural teeth. This has been possible due to modified optical properties that let single-shade composites be able to acquire the surrounding tooth color.[6] These new composites seem to be very effective in reducing in-chair clinical timing by minimizing the time spent on shade selection.[7,8] In esthetic dentistry, color differences between tooth and restoration can be accurately evaluated through an instrumental analysis using an intraoral spectrophotometer. This device can detect VITA scale values and CIELAB (L*, a*, and b*) coordinates: L* stands for lightness, represented on a scale of 0 (black) to 100 (white); a* represents the hue and chroma values on the red (+) and green (–) axis; b* instead on the yellow (+) and blue (–) one.[9] Data obtained from the spectrophotometer can also be used to calculate the color difference between tooth and composite, through the ΔEab formula developed in 1976 as CIELAB color difference formula.[10] One of the most common esthetic issues in the anterior areas can arise in case of need of professional tooth bleaching. In this clinical situation, previously performed resin restorations are not able to shift their shade following the whitening of the tooth, and often the replacement of the composites is needed.[11]

According to the authors' best knowledge, few previous studies focused on the color match evaluation between several single-shade resins and the surrounding tooth, prior and after dental whitening procedures.[12-14] None of these studies however evaluated the level of white of the restorations using a recently introduced CIELAB-based whiteness index for dentistry (WID).[15] Accordingly, the purpose of this study was to test in vitro the color correspondence of 4 single-shade composite resins with extracted teeth in which they have been applied, and to determine the correspondence of WID between the tooth and the respective restoration after professional bleaching.

The null hypothesis tested were that (1) there is no significant color difference between the 4 tested single-shade composites and teeth shades and (2) that there is no correspondence between WID values of these resins and teeth after whitening procedures.

MATERIALS AND METHODS

Four different single-shade composites were selected to restore eighty extracted sound posterior teeth: Omnichroma (Tokuyama Dental, Tokyo, Japan) (OM), Venus Diamond One (Kulzer, Hanau, Germany) (VE), Clearfil Majesty ES-2 Universal (Kuraray Medical Inc., Tokyo, Japan) (CL), and Essentia Universal (GC Corporation, Tokyo, Japan) (ES). Sound extracted teeth were selected according to the University of Bologna Ethical Committee approval (protocol N°:71/2019/OSS/AUSLBO). Teeth were free of restorations, decays, and endodontic treatment. Following a previously published research protocol,[8] teeth were randomly divided into 4 groups, 20 teeth in each group (n=20), and were stored in distilled H_2O at 37°C in single sealable compartments for 24h.[16,17] Two mm above the cementoenamel junction, on the vestibular aspect of each tooth, a standardized class V cavity (2mm in high and depth, and 4mm width) was performed. A round-shaped diamond bur (#6801314029, Komet Dental, Lemgo, Germany) was used under water cooling to create the cavity and a finishing bur (#8390314016, Komet Dental, Lemgo, Germany) was used to bevel cavity margins, both replaced every 2 samples.[18] Selective etching was performed on enamel with 37% orthophosphoric acid for 30s. The acid was rinsed, and the surface was dried, then adhesive procedures were carried on according to the manufacturer. Each composite was used together with its corresponding universal adhesive system: Universal Bond (Tokuyama), iBond Universal (Kulzer), Clearfil Universal (Kuraray) and G2 Bond Universal (GC). The Universal adhesive system was then gently dried and cured for 10s at 1400mW/cm^2 with a blue-led light-curing device (Mectron Starlight Pro, Italy). Each cavity was finally filled through a single increment of the correspondent one-shade composite resin and polymerized for 40s with the previously used led light-curing unit, placed in contact with the specimens. After polymerization, the restorations were polished with a dedicated finishing/polishing system (Clearfil Twist DIA, Kuraray Medical Inc.), using a slow-speed handpiece at 4000rpm for 30s per step, and were stored in distilled H_2O at 37°C for 24h.[16,17]

Bleaching procedures

Specimens were treated through a 40% hydrogen peroxide bleaching gel (Opalescence Boost PF 40%, Ultradent, South Jordan, USA). Teeth were fixed on a wax plate before the application of the bleaching product,[13] which was placed to cover the entire surface of the tooth other than the restoration, to not alter the mechanical and physical resin properties. According to the manufacturer, two consecutive bleaching sessions, 20min each,[19] were performed for every tooth. After both applications, the bleaching agent was gently removed using gauze drenched in distilled H_2O and then the specimen surfaces were washed out and dried with absorbent paper. They were not air-dried to avoid any system that could cause dehydration.[13]

Instrumental color measurements

Using an intraoral spectrophotometer (VITA Easyshade V, VITA Zahnfabrik, Bad Sackingen, Germany), the following tooth-related color variables were evaluated by a single dental operator with standardized D65 light illumination: VITA color, CIELAB color coordinates (L*: lightness, a*: green-red coordinate and b*: blue-yellow coordinate), chroma (C*), and hue (h°). A neutral grey paper was used as a background during measurements,[9,13] and the device was calibrated after every three measurements.[9] As indicated by the manufacturer, the tip of the device was used perpendicularly in contact with the surfaces, and the adequate exposure time was given by the spectrophotometer. All values were measured on the tooth, 1mm away from the margin of the restoration, and at the center of the restoration.[16] Color differences were calculated using the following CIELAB formula and expressed as
Δ_{ab}:[5] $\Delta E_{ab} = ([\Delta L^*]^2 + [\Delta a^*]^2 + [\Delta b^*]^2)^{1/2}$, where:
$\Delta L^* = L^*rest–L^*tooth$; $\Delta a^* = a^*rest–a^*tooth$; $\Delta b^* = b^*rest–b^*tooth$ (rest=restoration; tooth=treated tooth).
Color match assessments were evaluated before (T_0), after 24h (T_1), and after 1 week (T_2) of the whitening procedures. The whiteness index (WI_d) was calculated using the following equation:[15]

$$WI_d=0.511L^* – 2.324a^* – 1.100b^*.$$

Differences in whiteness index (ΔWI_d) were finally evaluated with the whiteness 50%:50% perceptibility (WPT=0.61 ΔWI_d units) and 50%:50% acceptability (WAT=2.90 ΔWI_d units) thresholds for lay people, and the whiteness 50%:50% perceptibility (WPT=0.44 ΔWI_d units) and 50%:50% acceptability (WAT=2.15 ΔWI_d units) thresholds for dentist population.[15]

Statistical analysis

Statistical analysis was performed using STATA program version 17 (StataCorp LP 4905 Lakeway Drive College Station, Texas 77845 USA). Means, standard deviations, counts, and percentages were used to summarize the data. Categorical variables were analyzed using Pearson Chi-square. Since the normality and homogeneity of variance were satisfied by Levene's test ($p<0.05$), data from color coordinates (CIE L*, a*, b*, C*, and h°) were statistically analyzed using one-way analysis of variance (one-way ANOVA) and Tukey's multiple comparison test with Bonferroni correction. One-way ANOVA
was used to compare the effects of color differences ΔE_{ab} value among the materials. Paired t-tests were performed to compare continuous measures between groups and treatment time. $p\leq0.05$ was considered statistically significant. The statistician was blinded to the groups.

RESULTS

Mean color differences (ΔE_{ab}) and standard deviations (SDs) between the restored composite and the tooth at baseline (T_0), 24h (T_1), and 1 week (T_2) after whitening procedures for each resin are presented in **Table 1**.

Table 1. Mean color differences (ΔE_{ab}) and standard deviations between T_0, T_1, and T_2.

Group	T_0	T_1	T_2
OM	12.5±4.7 (4.1–23.1)^{abAB}	7.7±3.9 (1.5–19.1)^{eA}	6.3±2.6 (2.1–12.2)^{B}
VE	6.9±2.9 (1.8–12.6)^{bdCD}	4.3±2.0 (1.6–8.6)^{efgC}	5.0±2.9 (1.7–13.7)^{D}
ES	7.5±3.9 (1.1–15.6)^{acE}	6.6±3.0 (2.1–14.8)^{gF}	4.4±2.4 (1.7–10.9)^{EF}
CL	12.6±4.1 (4.0–19.1)^{cdGH}	6.2±2.4 (1.6–9.7)^{fG}	6.1±1.8 (2.0–9.3)^{H}

ΔE_{ab} T_0: Statistically significant difference between OM^a and ES^a ($P<0.001$), OM^b and VE^b ($P=0.001$), CL^c and ES^c ($P<0.001$), CL^d and VE^d ($P<0.001$), ΔE_{ab} T_1: Statistically significant difference between OM^e and VE^e ($P<0.005$), VE^f and CL^f ($P<0.001$), VE^g and ES^g ($P=0.023$), Statistically significant difference between OM^A T_0 and OM^A T_1 ($P<0.001$), OM^B T_0 and OM^B T_2 ($P<0.001$), Statistically significant difference between VE^C T_0 and VE^C T_1 ($P=0.003$), VE^D T_0 and VE^D T_2 ($P=0.033$), Statistically significant difference between ES^E T_0 and ES^E T_2 ($P<0.002$), ES^F T_1 and ES^F T_2 ($P=0.016$), Statistically significant difference between CL^G T_0 and CL^G T_1 ($P<0,001$), CL^H T_0 and CL^H T_2 ($P<0.001$). OM: Omnichroma, VE: Venus diamond one, ES: Essentia universal, CL: Clearfil Majesty ES-2 Universal

A significant difference between materials ($p<0.05$) was revealed by the statistical analysis. Statistically significant differences were found at T_0 between OM and VE ($p=0.001$), OM and ES ($p<0.001$), CL and VE ($p<0.001$), Cl and ES ($p<0.001$); at T_1 between OM and VE ($p<0.005$), VE and ES ($p=0.023$), VE and CL ($p<0.001$); any statistically significant differences did not show up among groups at T_2.
Statistical analysis showed significant differences between OM T_0 and OM T_1 ($p<0.001$), and OM T_0 and OM T_2 ($p<0.001$); VE T_0 and VE T_1 ($p=0.003$), and VE T_0 and VE T_2

(p=0.003); ES T_0 and ES T_2 (p<0.002), and ES T_1 and ES T_2 (p=0.016); CL T_0 and CL T_1 (p<0.001), and CL T_0 and CL T_2 (p<0.001).

Due to the heterogeneity of the VITA scale recorded at T_0, it was impossible to carry out a statistical analysis. From a descriptive point of view, ES and VE showed the best color match between the restoration and the tooth at every measurement time (T_0, T_1, T_2). CL and OM showed better color matching especially after bleaching procedures, when the color of teeth became brighter.

However, aiming to categorize into levels the different colors of the VITA scale, three groups were created as follows: light (A1, B1, B2, C1, D2), medium (A2, A3, C2, D3, D4) and dark (A3.5, A4, B3, B4, C3, C4). Following this categorization, **Table 2** shows the relationship between VITA levels, and composite and tooth.

Where significant p values are present, it can be stated that the level of the VITA scale is statistically different between the different composite groups.

Table 2. Relationship between VITA levels, composite and tooth.

Samples	VITA T0 tooth			VITA T0 restoration			VITA T1 tooth			VITA T1 restoration			VITA T2 tooth			VITA T2 restoration		
	Light	Medium	Dark	Light	Medium	Dark	Light	Medium	Dark	Light	Medium	Dark	Light	Medium	Dark	Light	Medium	Dark
OM	1	10	9	19	1	0	5	12	3	17	3	0	11	5	4	14	6	0
VE	3	10	7	20	0	0	12	8	0	19	1	0	16	4	0	18	2	0
ES	3	6	11	3	17	0	9	9	2	7	13	0	11	7	2	9	11	0
CL	2	5	13	3	15	2	13	7	0	4	16	0	8	12	0	6	14	0
Total	9	31	40	45	33	2	39	36	5	47	33	0	46	28	6	47	33	0

Statistically significant differences: T0 R: $P<0.001$, T1 R: $P<0.001$, T2 T: $P=0.019$, T2 R: $P<0.001$. OM: Omnichroma, VE: Venus Diamond One, ES: Essentia Universal, CL: Clearfil Majesty ES-2 Universal, VITA: VITA Classical color scale

Mean Whiteness Index differences (ΔEWI_d) and standard deviations (SDs) were calculated at T_1 and T_2 and are shown in **Table 3**. Statistically significant differences (p<0.05) were found at T_1 between OM and ES (p<0.001), OM and VE (p<0.001), OM and CL (p<0.001), CL and VE (p<0.001); at T_2 between OM and ES (p<0.001), OM and VE (p<0.001), OM and CL (p<0.031), CL and VE (p<0.001), CL and ES (p=0.018). Statistically significant differences were shown between OM T_1 and OM T_2 (p<0.001).

Table 3. Mean color differences (ΔWI_d) and standard deviations between T_1 and T_2.

Group	ΔWI_D T_1	ΔWI_D T_2
OM	11.3±6.7 (0.2–28.9)[abcdA]	7.0±4.2(−0.8–13.8)[efgA]
VE	−2.3±5.4(−11.3–9.1)[cd]	−0.8±5.9(−12.8–9.3.7)[gi]
ES	1.1±7.9(−11.5–14.5)[b]	−0.6±5.9(−11.5–12.5)[fh]
CL	5.4±5.4(−8.4–12.0)[a]	3.6±5.1(−9.0–9.6)[ehi]

ΔEWI_D T_1: statistically significant difference between OM[a] and CL[a] ($P<0.001$), OM[b] and ES[b] ($P<0.001$), OM[c] and VE[c] ($P<0.001$), CL[d] and VE[d] ($P<0.001$), ΔEWI_D T2: statistically significant difference between OM[e] and CL[e] ($P<0.031$), OM[f] and ES[f] ($P<0.001$), OM[g] and VE[g] ($P<0.001$), CL[h] and ES[h] ($P=0.018$), CL[i] and VE[i] ($P<0.001$). Statistically significant difference between OM[A] T_1 and OM[A] T_2 ($P<0.001$). OM: Omnichroma, VE: Venus diamond One, ES: Essentia universal, CL: Clearfil majesty ES-2 Universal

DISCUSSION

Nowadays, dental bleaching is probably the most popular esthetic procedure in dentistry,[20] and it can be performed through two different protocols: In-office (performed by a professional) or at-home (prescribed by a professional but performed by the patient at home).[21] As a result, different agent concentrations (carbamide peroxide or hydrogen peroxide) and different application times can be used for bleaching protocols.[22] Also BE properties of single-shade composites are a current topic in restorative dentistry since these new resins could completely shift the opinion of which material of choice should be used for dental restorations. To evaluate the shade matching ability of an esthetic resin composite, an international research group evaluated in vitro color ΔE_{ab} parameters of three composites, taking into consideration filler morphology and light transmittance characteristics. ΔE_{ab} values of a supra-nano filled composite (Omnichroma) were significantly lower in A2, A3, and A4 VITA scale shades, meaning that a supra-nano filled composite shows better shade matching compared to micro-hybrid filled (Essentia Universal) and clustered-nano filled composites (Filtek Supreme Ultra).[17] Lately published research tested four single-shade composites (Omnichroma, Charisma Diamond One, Vittra Unique, and Essentia Universal) used to restore 40 human incisors. An instrumental evaluation was conducted using VITA Easyshade Compact V spectrophotometer to calculate ΔE_{ab}. Authors concluded that all tested materials had acceptable color-matching potential, with no significant differences between tooth shades and the tested resin composites.[7] These results are partially in contrast with those of the present manuscript, probably due to the different selection of composites and to the different methodology of specimen production. The behavior of the composites used by both studies is very similar, the main difference lies in the fact that Altınışık and Özyurt did not find statistical differences between composites, while our statistical analysis did find some significant differences. One of the major limits of the present manuscript is the choice of posterior teeth. Although this choice has been made for convenience, it must be highlighted that enamel and dentin, as well as the color of posterior teeth, are different from anterior elements.[23] Several previous studies have analyzed the behavior of single-shade resin composites in comparison with traditional materials, but only a few of them have also evaluated the effect of bleaching treatments.[8,12-14] A case series conducted by Mohamed et al. in 2020 investigated instrumental and visual color match on extracted teeth using Omnichroma composite before and after bleaching.[14] The authors concluded that the shade of the filling matched that of the adjacent enamel pre- and post-bleaching. Pecho et al. evaluated the influence of a professional whitening gel on color and whiteness modifications of three multi-shade resins using ΔE_{ab} formula and concluded that bleaching gel had influenced the color and the whiteness of resin-based composites, although color changes were not clinically perceived and whiteness variations were clinically acceptable.[13] Based on these results, the present protocol considered to cover with the bleaching gel only the teeth, avoiding restorations, in order to not influence composites color. Regarding a possible isolation of the restoration during bleaching procedures, a gel bleaching agent was used, so that it would not flow or cover the composite. Authors preferred to avoid using vaseline precisely to avoid the risk that the vaseline could partially cover the tooth, preventing the correct whitening procedure. Moreover, the composite was not covered also to best simulate clinical procedures. More recently, a pilot study on six human extracted teeth evaluated visual and instrumental color match of two single-shade resins (Omnichroma and Venus Diamond One), before and after professional bleaching. Both materials seemed to be able to achieve an acceptable color shift of their VITA color values before and after bleaching procedures, and to reach an excellent match grade with the visual analysis.[12] Based on the positive results of the pilot study, the same study group performed an in vitro study analyzing the BE of four single-shade composites (Venus Diamond One, Essentia Universal, Clearfil Majesty ES-2 Universal and Omnichroma), before and after bleaching, using the CIEDE2000 system. Venus and Essentia composites gave the best color match results after tooth bleaching procedures, but all the tested materials showed a good BE before and after professional bleaching.[8] Even if the color variation analysis system used is different from the one adopted in this manuscript (CIEDE2000 vs. CIELAB), it is curious to note how the tendency of the 4 composites to change color following tooth bleaching is very comparable to that found in the present study. Another potential limitation of the present research could be identified in the selection of the color analysis system. Color science is recently not based only on the CIELAB calculation, because color science associations and researchers suggest studies' report with CIEDE2000 calculation, although very often the two systems have provided overlapping trends and results.[24] The choice to use ΔE_{ab} formula is based on the possibility to compare the present results with further findings from several similar studies that chose the CIELAB calculation to verify the BE of single-shade composites.[5,7,13,17] In a previous study, the color match between tooth and composite restorations was recorded using ΔE_{00} formula.[8] These results are in line with those of the present article, highlighting the fact that regardless of the color analysis system used, the BE results of single-shade composites are extremely performant from an esthetic point of view. Moreover, in the already mentioned previous study, ΔE_{00} formula have been used to verify if single-shade composites were able to match the tooth color also after bleaching procedures. These results were obtained comparing ΔE_{00} values before and after bleaching. In the present study instead, a specific and dedicated index (WI_d) was used to evaluate the level of whiteness of the resin composites.[15] This CIELAB-based whiteness index has been developed specifically for dentistry and has not been used yet to evaluate the BE variation of composites after tooth professional bleaching. A recent paper published by Perez et al. in 2019 studied the whiteness index in dentistry and how to assess the thresholds of whiteness perceptibility and acceptability (WPT and WAT).[15] This study explained that higher values correspond to increasing whiteness mismatches, and therefore poor esthetics and lower patient satisfaction.

Lower values instead correspond to higher whiteness matches. Following these thresholds, the whiteness index differences (ΔWI_d) calculated in the present manuscript at T_1 and T_2 show the lowest values, and therefore the highest whiteness matches, for VE, followed by ES, CL, and OM. Another limitation of this study can certainly be represented by the choice of the spectrophotometer used in this study. The VITA Easyshade V is a clinical device that illuminates the tooth with a 6500K light, and it has been used in several studies.[7,8,12] Even though a bench spectrophotometer could represent the most suitable instrument for an in vitro study,[25,26] following recent data published in the literature,[10-16] a clinical spectrophotometer was chosen for the present manuscript to reproduce in the most precise way a clinical situation. This device provides accuracy and reliability as reported by a study by Dozić et al., which found VITA Easyshade to be, in vitro and in vivo, the most precise among five other similar devices.[27] Based on the findings of the present manuscript, the two initial null hypotheses were rejected.

CONCLUSION

Within the limitations of this in vitro research, the following conclusions can be deduced:

- The four tested single-shades composites showed a good color correspondence with the surrounding tooth
- This correspondence remains effective also after bleaching procedures.

Based on the relevant results of this in vitro research, it would be useful to arrange an in vivo instrumental analysis, better if on anterior teeth, to define if single-shade composites are clinically able to match the color of the surrounding tooth, and therefore to confirm the results obtained in the present study.

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CHAPTER 4

SYSTEMATIC REVIEW AND META-ANALYSIS

Color match of single-shade vs. multi-shade resin composites: a systematic review with meta-analysis

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Keywords: resin composite, direct restoration, color match, single-shade, multi-shade, systematic review, meta-analysis.

ABSTRACT

Objective: To address the following PICOS question: Can single-shade resin composites achieve a color match comparable to multi-shade composites in tooth restoration?

Materials and Methods: A comprehensive search was conducted across multiple electronic databases to identify in vitro and clinical studies evaluating the color match in tooth restoration, in terms of CIELAB (ΔE_{ab}) and/or CIEDE2000 (ΔE_{00}) color differences metric, using single-shade and multi-shade composites. The risk of bias was assessed using the Quality Assessment Tool For In Vitro Studies (QUIN Tool), while the revised Cochrane Collaboration's tool (RoB 2) was employed for randomized controlled clinical trials (RCTs). Meta-analyses were performed using RevMan to compare ΔE_{ab} and ΔE_{00} values between single-shade and multi-shade composites ($p<0.05$).

Results: After initial screening, 15 in vitro studies and 3 RCTs met the inclusion criteria for qualitative synthesis, with 8 in vitro studies selected for quantitative analysis. The majority of in vitro studies were classified as medium risk of bias, while RCTs were ranked as low risk of bias. Meta-analyses performed on in vitro studies revealed that single-shade composites exhibited statistically significant higher color differences with the surrounding tooth structure compared to multi-shade composites, for both ΔE_{ab} and ΔE_{00}

($p<0.05$). However, RCTs usually reported promising outcomes for single-shade materials.

Conclusions: This systematic review concluded that multi-shade composites provide a more accurate color match between tooth and direct restoration than single-shade materials, when evaluated by spectrophotometric analysis in laboratory settings.

INTRODUCTION

The primary objective of restorative dentistry is to restore tooth function while replicating its original shape and color.[1,2] In direct restorations, resin composites are the most commonly used materials due to their excellent mechanical and optical properties.[3,4] To meet the increasing patients' esthetic demands,[5,6] achieving an ideal color match between natural tooth tissues and the restorative material is crucial,[7] so that no difference can be detected by the human eye.[8]

Color is a psycho-physical response to the interaction of light energy with an object and the subjective experience of the observer.[9] In esthetic dentistry, the layering technique for direct composite restorations, first introduced in the 1980s,[10] remains "the gold standard" for mimicking the polychromatic nature of natural teeth.[11] This technique achieves optical matching between tooth tissues and restorative materials through color layering, and the final color of a restoration results from multiple composite masses with varying chromas and opacities.[10] However, attaining perfect color harmony is challenging due to the differing thickness distributions, structures, compositions, and optical properties of enamel and dentin.[12] Thus, traditional multi-shade composites, which vary in shades, chromas, and opacities, require advanced restorative skills, complex shade selection process, and increased cost and chair-side time.[13,14]

In recent years, dental manufacturers have developed optically advanced materials that can reflect the color of surrounding dental tissues, facilitating good esthetic outcomes.[15] These innovative universal single-shade composites are designed to match a wide range of classical shades, thereby reducing restorative procedure time and simplifying the color selection phase in direct restorations.[5] After placement, these composites can reflect specific tooth color wavelengths and adapt chromatically to surrounding tooth structures, providing natural shade adjustment.[16] This optical phenomenon is often referred to as the "chameleon effect" or "blending effect".[17]

Despite the promising clinical implications, the concept of shade simplification has yielded controversial results in laboratory studies when comparing single-shade to multi-shade composites,[7,13,18,19] while few clinical trials have been published only recently.[20,21,22,23]

Therefore, the aim of this systematic review was to evaluate the color match capability of single-shade composites compared to multi-shade composites in direct restorations. Specifically, we aimed to address the following PICOS question: "Can single-shade resin composites achieve a color match comparable to multi-shade composites in tooth restoration?".

MATERIALS AND METHODS

Study protocol and registration

The review protocol was registered in the International Prospective Register of Systematic Review (PROSPERO) database under the number CRD42024501788. The reporting of this systematic review followed the PRISMA 2020 guidelines.[24]

Eligibility criteria and search strategy

The PICOS question[25,26] guided the search criteria and inclusion of articles was as follows:

Population (P): sound extracted human teeth with standardized cavities and/or adult (>18 years old) dental patients in need of direct composite restorations;

Intervention (I): single-shade composite restorations placement;

Comparison (C): traditional multi-shade composite restorations placement;

Outcome (O): instrumental and/or visual evaluation of color match between surrounding tooth structure and direct restorations;

Study design (S): in vitro and in vivo (randomized controlled clinical trials - RCTs) studies.

The search strategy and keywords are listed in Supplementary Table 1.

Supplementary Table 1. Electronic databases and search strategies.

Electronic Database (number of hits)	**Search strategy**
PubMed (n=218) https://pubmed.ncbi.nlm.nih.gov	(tooth restoration OR dental restoration OR "Dental Restoration, Permanent"[Mesh] OR restorative dental material OR tooth filling OR dental filling) AND ("resin composite*" OR "composite resin*" OR "Composite Resins"[Mesh] OR "restorative material*") AND (single-shade OR single shade OR universal shade OR one-shade OR one shade OR multi-shade OR multi shade OR multiple shade) AND (color match* OR shade match* OR color adjustment potential OR color perception OR "Color Perception"[Mesh] OR "Color"[Mesh])
Web of Science (n=170) https://www.webofscience.com	TS=(tooth restoration OR dental restoration OR "Dental Restoration, Permanent" OR restorative dental material OR tooth filling OR dental filling) AND TS=("resin composite*" OR "composite resin*" OR "Composite Resins" OR "restorative material*") AND TS=(single-shade OR single shade OR universal shade OR one-shade OR one shade OR multi-shade OR multi shade OR multiple shade) AND TS=(color match* OR shade match* OR color adjustment potential OR color perception OR "Color Perception" OR "Color")
Scopus (n=105) https://www.scopus.com	("tooth restoration" OR "dental restoration" OR "Dental Restoration, Permanent" OR "restorative dental material" OR "tooth filling" OR "dental filling") AND ("resin composite*" OR "composite resin*" OR "Composite Resins" OR "restorative material*") AND (single-shade OR "single shade" OR "universal shade" OR one-shade OR "one shade" OR multi-shade OR "multi shade" OR "multiple shade") AND ("color match*" OR "shade match*" OR "color adjustment potential" OR "color perception" OR "Color Perception" OR Color)
Cochrane Library (n=25) https://www.cochranelibrary.com	(tooth restoration OR dental restoration OR [mh "Dental Restoration, Permanent"] OR restorative dental material OR tooth filling OR dental filling) AND (("resin" NEXT

	composite*) OR ("composite" NEXT resin*) OR [mh "Composite Resins"] OR ("restorative" NEXT material*)) AND (single-shade OR single shade OR universal shade OR one-shade OR one shade OR multi-shade OR multi shade OR multiple shade) AND (("color" NEXT match*) OR ("shade" NEXT match*) OR color adjustment potential OR color perception OR [mh "Color Perception"] OR [mh Color])
Embase (n=24) https://www.embase.com	('tooth restoration' OR 'dental restoration' OR 'dental restoration'/exp OR 'restorative dental material' OR 'tooth filling' OR 'dental filling') AND ('resin composite*' OR 'composite resin*' OR 'resin'/exp OR 'restorative material*') AND (single-shade OR 'single shade' OR 'universal shade' OR one-shade OR 'one shade' OR multi-shade OR 'multi shade' OR 'multiple shade') AND ('color match*' OR 'shade match*' OR 'color adjustment potential' OR 'color perception' OR 'color vision'/exp OR 'color'/exp)

Study selection and data extraction

After completing the database search, all articles were imported into a web platform (Rayyan ISR, Cambridge, MA, USA).[27] The last systematic literature search was conducted on 2nd November 2024, while the last manual search was conducted on 19th December 2024. Titles and abstracts of each study were independently evaluated by two reviewers (E.F. and C.D.A.).

The exclusion criteria were as follows: (1) reviews (narrative or systematic); (2) case reports; (3) conference abstracts, dissertations, and theses; (4) studies on primary dentition; (5) studies on teeth with enamel defects; (6) studies that included devitalized teeth; (7) cavities made on resin teeth; (8) studies not evaluating color difference; (9) studies involving indirect restorations; (10) studies other than the English language. No date limitation was established during the literature search.

For full-text assessment, articles that appeared to fit the inclusion criteria or lacked sufficient information in the title and abstract were chosen. In case of disagreements, a third reviewer (V.C.) was consulted.
A custom-made spreadsheet (Microsoft Office Word 2019; Microsoft Corporation, Redmond, WA, USA) was used to extract data from the included studies. These details included the study and year of publication, the type and number of single-shade composite restorations (test group), the type and number of multi-shade composite restorations (control group), the aging and storage conditions for in vitro studies, the CIELAB (ΔE_{ab}) and/or CIEDE2000 (ΔE_{00}) color differences metric calculated at various time points, and results. If any data were missing or unclear, the corresponding author of the study was contacted via e-mail to retrieve the missing information.

Risk of bias assessment

Two authors (E.F. and U.J.) independently evaluated each included paper's quality and risk of bias. The parameters were evaluated according to the Quality Assessment Tool for In Vitro Studies (QUIN Tool).[28] This tool involves the evaluation of 12 criteria. For each article, a score was given for each criterion evaluated as adequately specified (2 points), inadequately specified (1 point), not specified (0 point), or not applicable (criteria excluded from the calculation). After the evaluation, the scores for each criterion were summarized to determine the total score for the specific in vitro study. These scores were then used to classify the study as high, medium, or low risk of bias based on the percentage obtained. A score of over 70% indicated a low risk of bias, 50% to 70% indicated a medium risk of bias, and less than 50% indicated a high risk of bias.
The updated Cochrane Collaboration tool for evaluating the risk of bias in RCTs, known as RoB 2,[29] was employed for in vivo studies. The RoB 2 tool[29] features algorithms that interpret responses to specific signaling questions to propose a risk of bias judgment for each outcome assessed in a study. Hence, the evaluation criteria were categorized into five areas: (1) bias from the randomization process; (2) bias due to deviations from the intended interventions; (3) bias due to missing outcome data; (4) bias in outcome measurement; and (5) bias in the selection of reported results. The bias risk judgment for each of these five areas was classified as either "low risk of bias", "some concerns", or

"high risk of bias". The overall bias risk for a specific outcome in a study was determined based on the classification within these assessment domains, as recommended by the RoB 2 tool. If at least one domain was rated as "some concerns" and all other domains as "low risk," the overall bias risk could be "some concerns". If multiple domains were rated as "some concerns," the overall risk of bias could either be "some concerns" or "high", depending on the investigators assessment. Therefore, if any domain was rated as "high risk of bias", the overall bias risk had to be considered "high".

Meta-analysis

Meta-analyses were performed using RevMan (Review Manager 5.4, The Cochrane Collaboration, Copenhagen, Denmark). A random effects model was used to compare the mean difference for ΔE_{ab} and ΔE_{00} between single-shade and multi-shade composites. The level of significance was set to $p<0.05$. Heterogeneity was assessed using the Cochran Q test and the I^2 index.

RESULTS

Study selection

Figure 1 presents a flowchart outlining the procedure for selecting studies in accordance with the PRISMA statement.

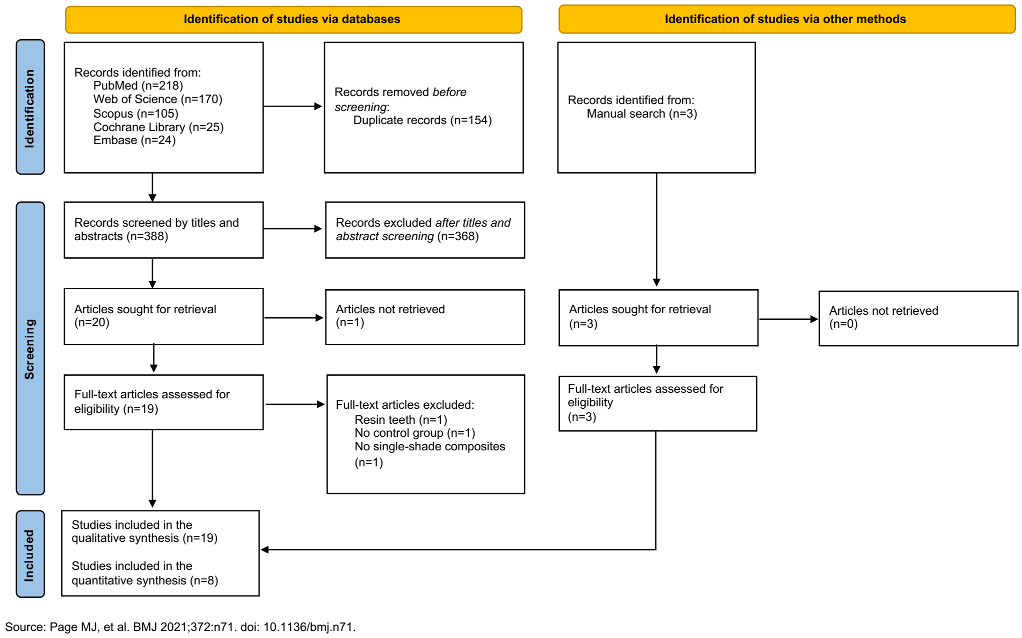

Figure 1. Flowchart according to the PRISMA statement.

A total of 542 articles were retrieved from all databases. After removing duplicates, the title and abstract of 388 papers were screened.

Following the application of exclusion criteria, 20 studies remained for full-text evaluation. From these, the full text of 1 manuscript could not be retrieved,[30] and 3 studies were excluded because of the following reasons (Figure 1): (1) cavities made on resin teeth,[13] (1) no control group,[31] (1) no single-shade composite was used.[32] Two eligible studies were identified from citation searching.[33,34]

Nineteen articles were included in the qualitative analysis: 15 in vitro studies and 4 RCTs. Seven in vitro studies could not be included in the meta-analysis because in 6 studies the mean and SD could not be extracted,[33,35,36,37,38,39] and in 1 study only visual analysis was performed.[40] Consequently, 8 laboratory studies were included in the quantitative analysis.[34,41,42,43,44,45,46,47] RCTs[20,21,22,23] were not included in the meta-analysis due to methodological heterogeneity.

Descriptive analysis of the selected studies

Detailed information about the 19 articles[20,21,22,23,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47] included in this review is shown in Supplementary Tables 2 and 3.

Supplementary Table 2. Characteristics of the in vitro studies that were a part of qualitative analysis.

STUDY	TYPE & NUMBER OF SAMPLES	TOOTH SHADES	MULTI- & GROUP SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	SINGLE-SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	COLOR MEASUREMENT DEVICE	VISUAL SCALE	STORAGE	FOLLOW-UP	MAIN RESULTS
Ahmed et al. 2022	N=60 extracted human maxillary premolars.	A2, A3, B2 and B3 (n=15)	Filtek Z250 (3M ESPE; St. Paul, MN, USA) n=60 V class cavities (5x3x2mm) on the palatal side	Omnichroma (Tokuyama Dental Corporation, Tokyo, Japan) n=60 V class cavities (5x3x2mm) on the buccal side	Vita Easyshade V Compact (VITA, Zahnfabrik, Bad Sackingen, Germany)	N/A	N/A	T_0: after curing	No data at T_0.
Atasayar & Ulusoy 2023	N=120 extracted human anterior teeth	Lighter colored tooth shades (A1, B1, C1, A2, B2) (n=60) Dark colored tooth shades (A3, A3.5, B3, B4, C3) (n=60)	Estelite Sigma Quick (Tokuyama Dental, Japan) N=40 Round shape cavities (7x2mm) on the buccal side n=20 Blocker: ΔE_{00}=3.5±1.7 n=20 Without blocker: ΔE_{00}=3.7±0.9 Neo Spectra ST (Dentsply Sirona, Germany) N=40 Round shape cavities (7x2mm) on the buccal side n=20 Blocker: ΔE_{00}=3.2±1.5 n=20 Without blocker: ΔE_{00}=3.1±1.5	Omnichroma (Tokuyama Dental Corporation, Tokyo, Japan) N=40 Round shape cavities (7x2mm) on the buccal side n=20 Blocker: ΔE_{00}=7.8±1.3 n=20 Without blocker: ΔE_{00}=8.5±2.0	VITA Easyshade Compact (VITA Zahnfabrik, Bäd Säckingen, Germany)	0: complete full up/no difference 1: very good match up/small difference 2: good match up/acceptable 3: bad match up/not very acceptable 4: disharmony/ completely unacceptable	Distilled water 37°C	T_0: 24h	Instrumental evaluation: single-shaded composites exhibited higher ΔE_{00} values compared to multi-shade and group-shade. Visual evaluation: single-shade composites achieved the best color match followed by group-shade and multi-shade composites.
Batista et al. 2023	N=23 extracted human upper and lower molars	A2 (n=1), A3 (n=2), A3.5 (n=2), A4 (n=1), B3 (n=4), B4 (n=3), C2 (n=2), C3 (n=6), C4 (n=1), D3 (n=1)	Admira Fusion (Voco) N=23 I class cavities (4x4mm)	Admira Fusion x-tra (Voco) N=23 I class cavities (4x4mm)	N/A	FDI criteria: Score 1: Clinically excellent/ very good 1.1 Luster comparable to enamel 2a.1 No surface staining 2b.1 No marginal staining 3.1 Good color match, no difference in	Purified water	T_0: 1 week	Visual evaluation: Nonsignificant differences between the composites were observed for all scores. For darker shades (A4, B4, C4) most of the evaluators considered the restorations made with Admira Fusion more esthetic than with Admira Fusion x-tra, For other shades nonsignificant

STUDY	TYPE & NUMBER OF SAMPLES	TOOTH SHADES	MULTI- & GROUP SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	SINGLE-SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	COLOR MEASUREMENT DEVICE	VISUAL SCALE	STORAGE	FOLLOW-UP	MAIN RESULTS
						shade and/or translucency Score 2: Clinically good (after polishing probably very good) 1.2.1 Slightly dull, not noticeable from speaking distance 1.2.2 Some isolated pores 2a.2 Minor surface staining, easily removable by polishing 2b.2 Minor marginal staining, easily removable by polishing 3.2 Minor deviations in shade and/or translucency Score 3: Clinically sufficient/satisfactory (minor shortcomings, no unacceptable effects, but not adjustable w/o damage to the tooth) 1.3.1 Dull			differences were observed.

STUDY	TYPE & NUMBER OF SAMPLES	TOOTH SHADES	MULTI- & GROUP SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	SINGLE-SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	COLOR MEASUREMENT DEVICE	VISUAL SCALE	STORAGE	FOLLOW-UP	MAIN RESULTS
						surface but acceptable if covered with film or saliva 1.3.2 Multiple pores on more than one-third on the surface 2a.3 Moderate surface staining, not esthetically unacceptable 2b.3 Moderate marginal staining, not esthetically unacceptable 3.3 Distinct deviation but acceptable. Does not affect esthetics: 3.3.1 More opaque 3.3.2 More translucent 3.3.3 Darker 3.3.4 Brighter Score 4: Clinically unsatisfactory (but reparable) 1.4.1 Rough surface, cannot be masked by saliva film, simple polishing			

STUDY	TYPE & NUMBER OF SAMPLES	TOOTH SHADES	MULTI- & GROUP SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	SINGLE-SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	COLOR MEASUREMENT DEVICE	VISUAL SCALE	STORAGE	FOLLOW-UP	MAIN RESULTS
						is not sufficient. Further intervention necessary 1.4.2 Voids 2a.4 Unacceptable surface staining; major intervention necessary for improvement 2b.4 Pronounced marginal staining; major intervention necessary for improvement 3.4 Localized clinical deviation that can be corrected by repair 3.4.1Too opaque 3.4.2 Too translucent 3.4.3 Too dark 3.4.4 Too bright Score 5: Clinically poor (replacement necessary) 1.5 Very rough, unacceptable plaque retentive surface 2a.5 Severe surface			

STUDY	TYPE & NUMBER OF SAMPLES	TOOTH SHADES	MULTI- & GROUP SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	SINGLE-SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	COLOR MEASUREMENT DEVICE	VISUAL SCALE	STORAGE	FOLLOW-UP	MAIN RESULTS
						and/or subsurface staining, generalized or localized, not accessible for intervention 2b.5 Deep marginal staining not accessible for intervention 3.5 Unacceptable. Replacement necessary			
Cruz da Silva et al. 2023	N=40 extracted human teeth upper central incisors, upper and lower molars	A1, A2, A3, A3.5, and A4	<u>Filtek Z250</u> (3M ESPE; St. Paul, MN, USA) N=20 cylindrical cavities (4x2mm) ΔE_{ab}=6.8±3.8 ΔE_{00}=4.06±2.3	<u>Omnichroma</u> (Tokuyama Dental Corporation, Tokyo, Japan) N=10 cylindrical cavities (4x2mm) ΔE_{ab}=18.6±8.6 ΔE_{00}=9.8±3.6 <u>Vittra APS Unique</u> (FGM, Joinville, Brazil) N=10 cylindrical cavities (4x2mm) ΔE_{ab}=16.8±4.9 ΔE_{00}=8.7±2.3	Easyshade Advance 4.0 (VITA Zahnfabrik, Bäd Säckingen, Germany)	1: mismatch / completely unacceptable 2: poor match/hardly ac-ceptable 3: good/ acceptable match 4: close match/small diference 5: exact match/no color diference	Distilled water	T_0: 72h	<u>Instrumental evaluation</u>: multi-shade resin presented lower values of ΔE for both CIELAB and CIEDE 2000. <u>Visual evaluation</u>: single- shade composites showed better matching values than the multishade resins, although all groups demonstrated acceptable color matching.
Cubukcu et al. 2023	N=80 extracted human incisors	A3	<u>Clearfil Majesty Esthetic</u> (Kuraray Noritake, Tokyo, Japan) N=40 cavities (3x5x2mm) on the facial surfaces ΔE_{00}=1.9±1.0	<u>Omnichroma</u> (Tokuyama Dental Corporation, Tokyo, Japan) N=40 cavities (3x5x2mm) on the facial surfaces ΔE_{00}=2.3±0.9	Spectro ShadeTM Micro (MHT Optic Research, Milan, Italy)	a: best match b: intermediate match c: poorest match	Distilled water	T_0: 24h	<u>Instrumental evaluation</u>: ΔE values of Clearfil Majesty Esthetic samples were not statistically significantly lower than those of Omnichroma samples ($p>0.05$). <u>Visual evaluation</u>: none of the samples showed poor match.

STUDY	TYPE & NUMBER OF SAMPLES	TOOTH SHADES	MULTI- & GROUP SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	SINGLE-SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	COLOR MEASUREMENT DEVICE	VISUAL SCALE	STORAGE	FOLLOW-UP	MAIN RESULTS
Diab et al. 2023	N=20 extracted human premolars	A3	Filtek Z350 XT (3M ESPE; St. Paul, MN, USA) N=10 V class cavities (6x2x1.5mm) on the cervical third ΔE_{ab}=not specified	Omnichroma (Tokuyama Dental Corporation, Tokyo, Japan) N=10 V class cavities (6x2x1.5mm) on the cervical third ΔE_{ab}=not specified	VITA Easyshade 4.0 (VITA Zahnfabrik, Bäd Säckingen, Germany)	N/A	Distilled water	T_0: 24h	No data at T_0.
Furusawa et al. 2023	N=25 extracted human central incisors	A2	Estelite Universal Flow (Tokuyama Dental Corporation, Tokyo, Japan) N=25 cilindrcal cavities (4x2mm) on the buccal side ΔE_{00}=not specified Filtek Supreme Ultra Flow (3M ESPE; St. Paul, MN, USA) N=25 cilindrcal cavities (4x2mm) on the buccal side ΔE_{00}=not specified	Omnichroma (Tokuyama Dental Corporation, Tokyo, Japan) N=25 cilindrcal cavities (4x2mm) on the buccal side ΔE_{00}=not specified Omnichroma flow (Tokuyama Dental Corporation, Tokyo, Japan) N=25 cilindrcal cavities (4x2mm) on the buccal side ΔE_{00}=not specified EXP101 (Tokuyama Dental Corporation, Tokyo, Japan) N=25 cilindrcal cavities (4x2mm) on the buccal side ΔE_{00}=not specified EXP102 (Tokuyama Dental Corporation, Tokyo, Japan) N=25 cilindrcal cavities (4x2mm) on the buccal side ΔE_{00}=not specified	CIE XYZ digital camera (RC500, PaPaLaB, Shizuoka, Japan)	N/A	100% relative humidity at 37°C	T_0: 24h	Instrumental evaluation: The lowest ΔE_{00} was measured with Omnichroma flow, but it was not significantly different from the others ($p>0.05$). Omnichroma exhibited significantly lower E_{00} adjustment than others ($p<0.05$). When compared with the conventional composites, Omnichroma flow outperformed both Estelite U flow and Filtek S flow ($p<0.05$). Omnichroma performed significantly better than Filtek S flow ($p<0.05$), but the ΔE_{00} of Omnichroma was similar to that of Estelite U flow ($p>0.05$).
Gamal et al. 2022	N=30 extracted	N/A	Fiber-reinforced composite	Omnichroma	Vita Easy shade compact	N/A	Distilled water	T_0: 72h	No data at T_0.

STUDY	TYPE & NUMBER OF SAMPLES	TOOTH SHADES	MULTI- & GROUP SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	SINGLE-SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	COLOR MEASUREMENT DEVICE	VISUAL SCALE	STORAGE	FOLLOW-UP	MAIN RESULTS
	human premolars		N=30 V class cavities (5x3x1.5mm) on the palatal side	(Tokuyama Dental Corporation, Tokyo, Japan) N=30 V class cavities (5x3x1.5mm) on the buccal side	(Vita Zahnfabrik, Bad Sackingen, Germany				
Khayat 2024	N=48 extracted human maxillary premolars	B2, A3, or A3.5 (n=16)	Filtek Z350 (3M ESPE; St. Paul, MN, USA) N=48 round-shaped cavities (3x1.5mm) on the buccal or palatal side ΔE_{ab}=5.3±1.8	Omnichroma (Tokuyama Dental Corporation, Tokyo, Japan) N=48 round-shaped cavities (3x1.5mm) on the buccal or palatal side ΔE_{ab}=7.4±1.8	VITA Easyshade Advanced 4.0 (VITA Zahnfabrik, Bäd Säckingen, Germany)	1=totally unacceptable 2=hardly acceptable 3=acceptable 4=small difference 5=no color difference	Distilled water	T_0: 24h	Instrumental evaluation: The mean ΔE showed statistically significantly higher values for Omichroma than Filtek . The subgroup A3.5-Omnichroma (which recorded the highest mean ΔE among all subgroups) had significantly less color matching than the B2-Omnichroma and A3-Omnichroma subgroups. Visual evaluation: The visual scores of all Omnichroma and Filtek restorations ranged between 4 and 5. The mean VS values of Omnichroma restorations were comparable to the mean values of Filtek restorations in groups B2 and A3 (no statistically significant difference was detected between the types of restorations), but the difference in color matching was statistically significant between Omnichroma and Filtek

STUDY	TYPE & NUMBER OF SAMPLES	TOOTH SHADES	MULTI- & GROUP SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	SINGLE-SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	COLOR MEASUREMENT DEVICE	VISUAL SCALE	STORAGE	FOLLOW-UP	MAIN RESULTS
									restorations in group A3.5, revealing better visual color match for Filtek in A3.5 group.
Kobayashi et al. 2021	N=30 extracted human central incisors	A2	Estelite Σ Quick (Tokuyama Dental Corporation, Tokyo, Japan) N=30 cylindrical cavities (4x2mm) on the labial side ΔE_{00}=not specified Clearfil AP-X (Kuraray Noritake, Tokyo, Japan) N=30 cylindrical cavities (4x2mm) on the labial side ΔE_{00}=not specified	Omnichroma (Tokuyama Dental Corporation, Tokyo, Japan) N=30 cylindrical cavities (4x2mm) on the labial side ΔE_{00}=not specified	CIE XYZ digital camera (RC500, PaPaLaB, Shizuoka, Japan)	N/A	100% relative humidity at 37°C	T_0: 24h	Instrumental evaluation: Omnichroma exhibited the significantly lowest ΔE_{00} value ($p<0.05$), followed by Estelite Quick and Clearfil AP-X.
Koi et al. 2024	N=20 extracted human teeth	Light-tooth shade group: B1, A1, B2, D2, A2, C1, C2, and D4 (n=10) Dark-tooth shade group: A3, D3, B3, A3.5, B4, C3, A4, and C4 (n=10)	Tetric EvoCeram (Ivoclar Vivadent, Schaan, Liechtenstein) N=30 oval-shaped cavities (5x2mm) on the buccal side $\Delta E_{00}=2.6\pm1.3$ Filtek Universal (3M ESPE; St. Paul, MN, USA) N=30 oval-shaped cavities (5x2mm) on the buccal side $\Delta E_{00}=2.8\pm1.1$	Omnichroma (Tokuyama Dental Corporation, Tokyo, Japan) N=30 oval-shaped cavities (5x2mm) on the buccal side $\Delta E_{00}=2.9\pm1.3$ Admira Fusion x-tra (Voco, GmbH, Cuxhaven, Germany) N=30 oval-shaped cavities (5x2mm) on the buccal side $\Delta E_{00}=4.0\pm1.8$ Essentia Universal (GC Corp., Tokyo, Japan) N=30 oval-shaped cavities (5x2mm) on the buccal side $\Delta E_{00}=3.5\pm1.6$	CrystalEye (Olympus, Tokyo, Japan)	N/A	Distilled water	T_0: 24h	Instrumental evaluation: For eight of the ten comparisons, the ΔE00 values were within 1.8 to 3.6, suggesting a mismatch that was moderately unacceptable. In two cases, the ΔE00 exceeded 3.6, suggesting an unacceptable mismatch, with both being for the Dark Shade Group, specifically Admira Fusion x-tra (5.17 ± 2.07) and Essentia Universal (3.74 ± 1.83). There were no composites that achieved excellent or acceptable match. A significant color difference between Light Shade Group and Dark Shade Group in

STUDY	TYPE & NUMBER OF SAMPLES	TOOTH SHADES	MULTI- & GROUP SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	SINGLE-SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	COLOR MEASUREMENT DEVICE	VISUAL SCALE	STORAGE	FOLLOW-UP	MAIN RESULTS
									Omnichroma and Admira Fusion x-tra. Omnichroma and Admira Fusion x-tra showed better color- matching ability in Light Shade Group than in Dark Shade Group. In Light Shade Group, Omnichroma showed better color-matching ability than Essentia Universal. In Dark Shade Group, Admira Fusion x-tra ΔE00 values were significantly higher than Omnichroma and Essentia Universal.
Rosa et al. 2024	N=10 extracted human third molars	A2, A3	<u>Filtek Universal</u> (3M ESPE; St. Paul, MN, USA) N=5 cavities (6x2mm) ΔE_{ab}=10.8±4.3 ΔE_{00}=6.2±2.3	<u>Omnichroma</u> (Tokuyama Dental Corporation, Tokyo, Japan) N=5 cavities (6x2mm) ΔE_{ab}=12.5±3.9 ΔE_{00}=7.2±2.1 <u>Vittra APS Unique</u> (FGM, Joinville, Brazil) N=5 cavities (6x2mm) ΔE_{ab}=19.9±4.7 ΔE_{00}=11.6±2.1 <u>Charisma Diamond One</u> (Heraeus Kulzer, Hanau, Germany) N=5 cavities (6x2mm) ΔE_{ab}=17.1±3.2 ΔE_{00}=9.3±1.8	Easyshade Compact Advance 5.0 (Vita-Zahnfabrik, Bad Säckingen, Germany)	0: perfect match/no difference in color 1: close match/small difference 2: good match/acceptable 3: poor match/hardly acceptable 4: mismatch/not acceptable	Water	T_0: 1 week	<u>Instrumental evaluation</u>: The best color match was observed for Filtek Universal followed by Omnichroma, Charisma Diamond One, and Vittra APS Unique. <u>Visual evaluation</u>: The highest scores were observed for the Filtek Universal, with statistical differences from Omnichroma and Vittra Unique.
Sanad et al. 2022	N=90 extracted human	A2, A3, or A3.5 (n=30)	<u>Filtek Z250</u> (3M ESPE; St. Paul, MN, USA)	<u>Omnichroma</u> (Tokuyama Dental Corporation, Tokyo, Japan)	VITA Easyshade V (VITA Zahnfabrik, Bad Sackingen, Germany)	N/A	N/A	T_0: before restoration	<u>Instrumental evaluation</u>: Filtek™ Z250 XT showed the

STUDY	TYPE & NUMBER OF SAMPLES	TOOTH SHADES	MULTI- & GROUP SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	SINGLE-SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	COLOR MEASUREMENT DEVICE	VISUAL SCALE	STORAGE	FOLLOW-UP	MAIN RESULTS
	anterior teeth		N=30 V class cavities N=15 (3x0.5mm), N=15 (3x1.5mm) ΔE_{ab}=3.3±0.5 Ceram X SphereTEC (Dentsply Sirona, Germany) N=30 V class cavities N=15 (3x0.5mm), N=15 (3x1.5mm) ΔE_{ab}=5.4±0.7	N=30 V class cavities N=15 (3x0.5mm), N=15 (3x1.5mm) ΔE_{ab}=5.8±0.7				T_1: after restoration	best results compared to the other two materials.
Shaalan & El Rashidy 2023	N=40 extracted human premolars	A2, A3 (n=10)	Filtek Z350 XT (3M ESPE; St. Paul, MN, USA) N=20 V class cavities (5x2mm) ΔE_{ab}=2.2±0.4 ΔE_{00}=1.6±0.3	Omnichroma (Tokuyama Dental Corporation, Tokyo, Japan) N=20 V class cavities (5x2mm) ΔE_{ab}=4.1±0.4 ΔE_{00}=2.9±0.3	VITA Easy shade V (VITA Zahnfabrik, Bäd Säckingen, Germany)	N/A	Distilled water	T_0: after polymerization T_1:24h T_2:12 days	Instrumental evaluation: Multi-shade composite showed superior shade matching ability as compared to the single-shade one.
Yamashita et al. 2023	N=30 extracted human central incisors	A2	Filtek Supreme Ultra (3M ESPE; St. Paul, MN, USA) N=30 ΔE_{00}=not specified Estelite Universal Flow (Tokuyama Dental Corporation, Tokyo, Japan) N=30 ΔE_{00}=not specified	Omnichroma (Tokuyama Dental Corporation, Tokyo, Japan) N=30 ΔE_{00}=not specified Omnichroma flow (Tokuyama Dental Corporation, Tokyo, Japan) N=30 ΔE_{00}=not specified Clearfil Majesty ES Flow Universal (Kuraray Noritake, Tokyo, Japan) N=30 ΔE_{00}=not specified	CIE XYZ digital camera (RC500, PaPaLaB, Shizuoka, Japan)	N/A	N/A	N/A	Instrumental evaluation: the universal-shade composites exhibited significantly better adjustment in E_{00}, C* and h* than the conventional-shade composites regardless of thickness ($p<0.05$).

STUDY	TYPE & NUMBER OF SAMPLES	TOOTH SHADES	MULTI- & GROUP SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	SINGLE-SHADE COMPOSITE, NUMBER & TYPE OF RESTORATION & ΔE±DS	COLOR MEASUREMENT DEVICE	VISUAL SCALE	STORAGE	FOLLOW-UP	MAIN RESULTS
				Clearfil Majesty ES Flow Universal dark (Kuraray Noritake, Tokyo, Japan) N=30 ΔE_{00}=not specified					

Supplementary Table 3. Characteristics of the clinical trials that were a part of qualitative analysis.

STUDY	TYPE & NUMBER OF CAVITIES	TOOTH SHADES	MULTI-SHADE COMPOSITE & ΔE±DS	SINGLE-SHADE COMPOSITE & ΔE±DS	COLOR MEASUREMENT DEVICE	VISUAL SCALE	FOLLOW-UP	MAIN RESULTS
Anwar et al. 2024	N=40 2 molars or premolars with occlusal carious lesion in each patient	N/A	Tetric N-Ceram (Ivoclar Vivadent, Schaan, Liechtenstein) N=20	Omnichroma (Tokuyama Dental Corporation, Tokyo, Japan) N=20	N/A	USPHS criteria for a color match and color stability as follows: Alpha: The restoration closely resembles the translucency and color of neighboring dental tissues. Bravo: The color and translucency of the restoration show a minor deviation from adjacent dental tissues, but it falls among the typical range of tooth shades. Charlie: The restoration exhibits a significant discrepancy in shade and translucency when compared to the adjacent teeth structure, and the difference exceeds the typical range of tooth shade and translucency. Marginal discoloration: Alpha: No marginal discoloration observed, Bravo: Marginal discoloration was present but limited in scope and did not extend significantly. Charlie: Noticeable marginal discoloration, penetrating towards the pulp chamber.	Baseline, 1, 3, 6, 9, 12 months	Visual evaluation: At the baseline, all restorations in the two groups revealed Alpha scores. After one, three, and six months, no statistically significant difference between both groups has been noticed. After nine and twelve months, the Tetric N group displayed a statistically significantly higher prevalence of Alpha scores and a lower prevalence of Bravo scores than the Omnichroma group.

STUDY	TYPE & NUMBER OF CAVITIES	TOOTH SHADES	MULTI-SHADE COMPOSITE & ΔE±DS	SINGLE-SHADE COMPOSITE & ΔE±DS	COLOR MEASUREMENT DEVICE	VISUAL SCALE	FOLLOW-UP	MAIN RESULTS
						The Alpha + Bravo score percentage was considered a clinical success.		
Favoreto et al. 2024	N=120 2 non-carious cervical lesions in each patient	N/A	Vittra APS (FGM, Joinville, Santa Catarina, Brazil) N=60 ΔE_{ab}=7.95±4.45 ΔE_{00}=5.95±3.65	Vittra APS Unique (FGM, Joinville, Santa Catarina, Brazil) N=60 ΔE_{ab}=7.3±4.9 ΔE_{00}=5.4±3.8	VITA Easyshade (VITA Zahnfabrik, Bad Säckingen, Germany)	1: color stability and translucency 2: surface gloss/luster 3: surface color 4: anatomical form (aesthetic properties) 5: fracture and retention 6: marginal adaptation 7: marginal discoloration 8: patient perception (functional properties) 9: postoperative hypersensitivity 10: tooth vitality 11: recurrent of initial pathology 12: tooth integrity (enamel cracks) 13: periodontal response (always compared to the reference tooth) (biological properties)	Baseline, 1 week, 6, 12, 18 months	Instrumental evaluation: The single-shade resin composite used achieve the same color match when compared to a multi-shade resin composite after a period of 7 days in NCCLs. Visual evaluation: The restorations scored clinically very good (FDI) at baseline and after 18 months for all outcomes.
Miranda et al. 2024	N=120 2 non-carious cervical lesions in each patient	Distribution of the resin colors used to restore NCCLs with Admira Fusion: non-carious cervical lesions classified as 3rd- and 4th-degree sclerotic dentin were typically restored using A3O (38%) or A2O (12%) as the first layer, followed by a final layer of A3.5 or A3. On the other hand, lesions classified as 1st and 2nd degree of sclerotic dentin were restored using A2 (20%),	Admira Fusion (Voco, GmbH, Cuxhaven, Germany) N=60 ΔE_{00}=6.4±3.9	Admira Fusion x-tra (Voco, GmbH, Cuxhaven, Germany) N=60 ΔE_{00}=6.3±3.9	VITA Easyshade (VITA Zahnfabrik, Bad Säckingen, Germany)	1: color stability and translucency 2: surface gloss/luster 3: surface color 4: anatomical form (aesthetic properties) 5: fracture and retention 6: marginal adaptation/discoloration 7: patient perception (functional properties) 8: postoperative hypersensitivity 9: tooth vitality 10: recurrent of initial pathology 11: tooth integrity (enamel cracks) 12: periodontal response (always compared to the reference tooth) (biological properties)	T_0: before restoration T_1: 1 week after restoration	Instrumental evaluation: No significant difference was observed when Admira Fusion was compared to Admira Fusion x-tra. Visual evaluation: All restorations received the score of clinically very good at baseline and after 7 days.

STUDY	TYPE & NUMBER OF CAVITIES	TOOTH SHADES	MULTI-SHADE COMPOSITE & ΔE±DS	SINGLE-SHADE COMPOSITE & ΔE±DS	COLOR MEASUREMENT DEVICE	VISUAL SCALE	FOLLOW-UP	MAIN RESULTS
		A3.5 (20%), and A3 (10%) as the first layer, followed by either A3 or A2 as the final layer						
Porwal et al. 2024	N=72 At least 2 molars or premolars with occlusal carious lesion in each patient.	N/A	Filtek Z350 (3M ESPE; St. Paul, MN, USA) N=36 ΔE_{00}=5.2±1.2	Omnichroma Blocker and Omnichroma (Tokuyama Dental Corporation, Tokyo, Japan) N=36 ΔE_{00}=5.6±1.2	DSLR Camera (Canon 13D) Images were transferred to a digital adobe photoshop software (adobe Inc.) for color matching analysis using CIELab coordinates; L*, a*, b* coordinates were taken from the surface of the restoration and from intact tooth surface - 1 mm away from the margin of the restoration	USPHS criteria, encompassing various aspects such as marginal discolouration, marginal adaptation, secondary caries, surface texture, colour match, anatomic form, retention, and post-operative sensitivity.	Baseline, 6 months, and 1 year	Instrumental evaluation: no significant difference was observed in the ΔE values between Fitlek and Omnichroma groups. Visual evaluation: Intergroup analysis showed that there was no statistically significant difference between the two groups for all the variables of modified USPHS.

All in vitro studies were conducted in university settings, with the majority of them carried out in Egypt,[33,34,37,44] followed by Brazil,[40,42,47] Japan,[35,38,39] Turkey,[41,43] Saudi Arabia,[36,45] and the USA.[46] The studies were published between 2021 and 2024. A total number of 666 extracted human anterior and posterior teeth were used across the analyzed in vitro studies: 676 cavities were reconstructed using single-shade, while multi-shade composites were applied onto 626 cavities.

Some of the studies included "split tooth design" when evaluating the color match potential of the tested materials.[36,37,45,47] The included in vitro studies evaluated the color match using the CIEL*a*b* system used to calculate color differences through ΔE_{ab} and/or ΔE_{00} formulas. The majority of the studies[33,34,36,37,41,42,44,45,47] used VITA Easyshade (Vita, Zahnfabrik, Bad Sackingen, Germany), 3 studies[35,38,39] used CIE XYZ digital camera (RC500, PaPaLaB, Shizuoka, Japan), 1 study[43] used Spectro ShadeTM Micro (MHT Optic Research, Milan, Italy), 1 study[46] used CristalEye (Olympus, Tokyo, Japan). Solely visual analysis was performed in 1 laboratory study.[40]

The 4 RCTs were conducted in Egypt,[20] Brazil,[21,23] and India.[22] A total of 316 anterior and posterior restorations (140 single-shade and 176 multi-shade) were placed in 161 patients older than 18 years using the split-mouth design. As for cavity configuration, patients with at least two non-carious cervical lesions[21,23] or occlusal carious lesions[20,22] were included. In 1 study,[20] the depths of class I cavities were not specified; however, it was noted that cavities with "considerable depth" were excluded after carious lesion removal. In another RCT,[21] most non-carious cervical lesions had a depth between 1 and 2mm, with only 4 cavities exceeding 2mm. In the third RCT[22], class I cavities in the single-shade group were restored with Omnichroma Blocker applied to the cavity floor to mask discolorations from secondary caries or old amalgam fillings. Two RCTs[20,22] used Omnichroma as single-shade composite, 1 study[21] used Admira Fusion X-tra, while 1 study[23] used Vittra APS unique.

The color evaluation methods used in RCTs were as follows: in 2 of the RCTs,[21,23] VITA Easyshade (Vita, Zahnfabrik, Bad Sackingen, Germany) was used to calculate ΔE_{00} and/or ΔE_{ab}; DSLR Camera (Canon 13 D) and a digital Adobe Photoshop software both registered color coordinates to calculate ΔE_{00} in another RCT.[22] Finally, one RCT[20] performed solely visual analysis - which had also been performed in the above-mentioned RCTs. Modified USPHS[20,22] and FDI[21,23] criteria were used across the studies.

The follow-up period in RCTs ranged from baseline up to 18 months.

Risk of bias of the included studies

Figures 2 and 3 provide an overview of the risk of bias evaluation.[28,29] The majority of in vitro studies were labeled as having a medium risk of bias.[33,35,37,38,39,43,46,47] Seven studies revealed a low risk of bias,[34,36,40,41,42,44,45] and no study showed a high risk of bias. The problematic domains included outcome assessor details,[33,34,35,36,37,38,39,43,44,46,47] operator details,[33,34,35,36,37,38,39,42,44,46,47] blinding,[33,34,35,36,37,38,39,44,46,47] sample size calculation,[35,37,39,40,43,46,47] and randomization.[37,40,42,43,46]

All 4 RCTs[20,21,22,23] were ranked as low risk of bias (Figure 3).

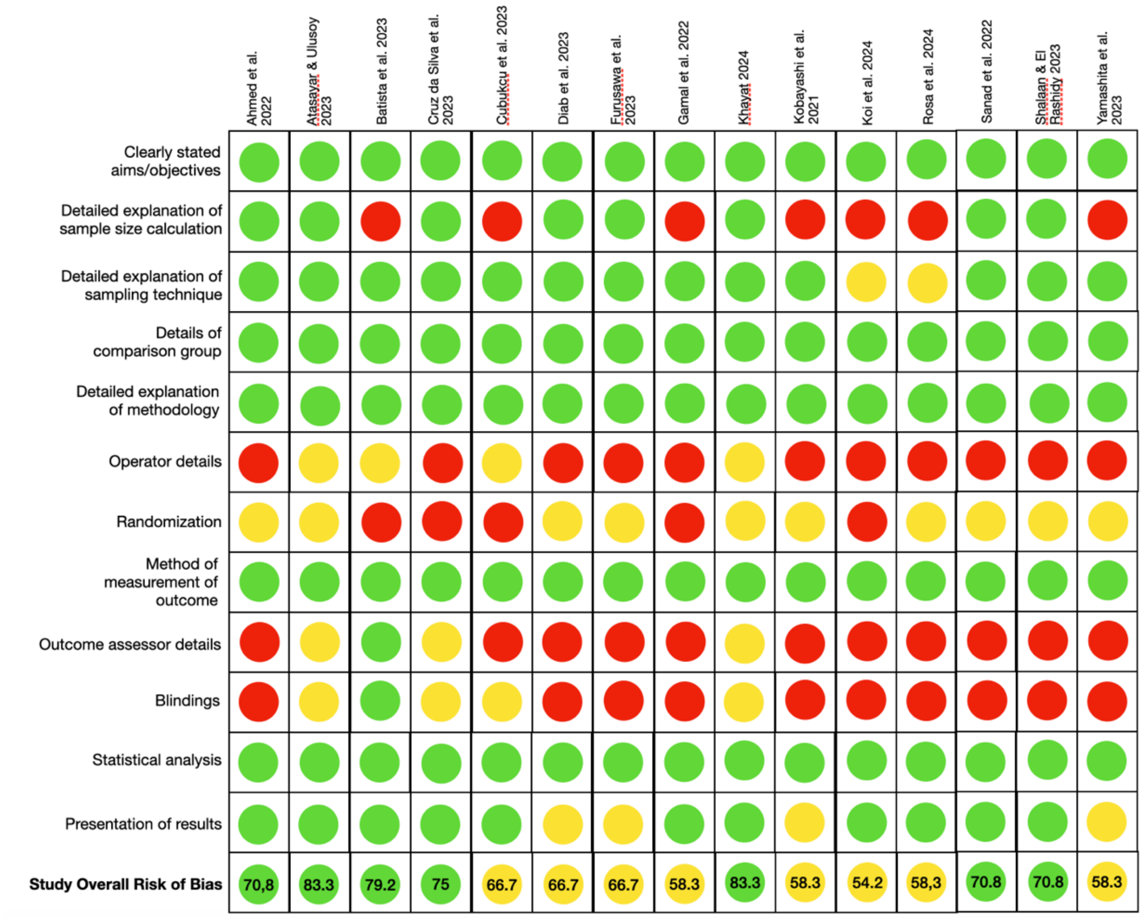

Figure 2. Risk of bias analysis of in vitro studies according to QUIN tool.

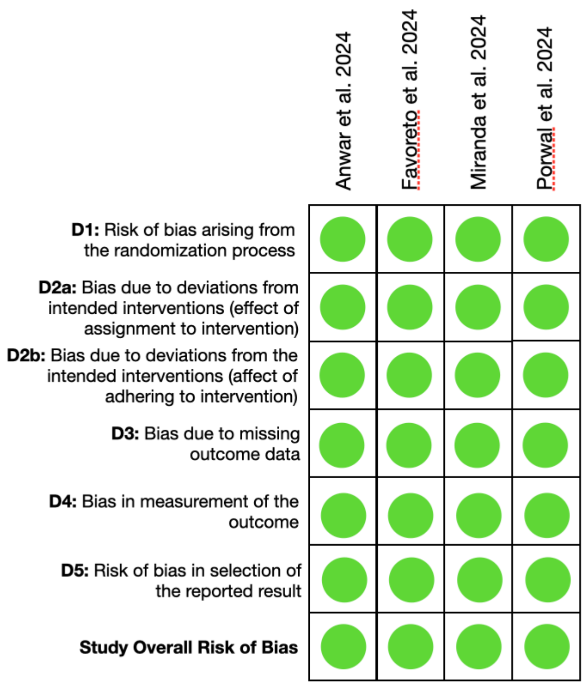

Figure 3. Risk of bias analysis of randomized controlled clinical trials according to RoB 2 tool.

Meta-analysis

Within the first week after restorations' placement and specimens' storage in distilled water, single-shade composites exhibited statistically significant higher color differences with the surrounding tooth compared to multi-shade composites for both ΔE_{ab} ($p<0.00001$; MD=2.88, 95% CI [1.66, 4.10]) and ΔE_{00} ($p<0.00001$; MD=2.37, 95% CI [1.32, 3.41]) formulas. A high heterogeneity index among the studies was found for ΔE_{ab} (I^2=89%) and ΔE_{00} (I^2=96%) (Figures 4 and 5, respectively).

In the forest plot for ΔE_{ab} (Figure 4), the studies by Cruz de Silva et al. (2023)[42] and Rosa et al. (2024),[47] which significantly shift the diamond far to the right, evaluated the color-match potential after 3 and 7 days, respectively, in contrast to other studies that conducted evaluations after 1 day. Sensitivity analysis revealed that, by excluding these two studies with different time-points, the heterogeneity reduced from I^2=89% to 43%. Regarding Figure 5 (forest plot for ΔE_{00}), it was difficult to detect the source of higher heterogeneity, even after running a sensitivity analysis.

	Single-shade			Multi-shade				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Cruz de Silva et al. 2023	17.7	6.75	20	6.8	3.8	20	9.0%	10.90 [7.51, 14.29]
Khayat et al. 2024	7.4	1.8	48	5.3	1.8	48	27.4%	2.10 [1.38, 2.82]
Rosa et al. 2024	16.5	3.9	15	10.8	4.3	5	6.5%	5.70 [1.45, 9.95]
Sanad et al. 2022	5.8	0.7	30	4.35	0.6	60	29.8%	1.45 [1.16, 1.74]
Shaalan et al. 2023	4.1	0.4	20	2.2	1.6	20	27.4%	1.90 [1.18, 2.62]
Total (95% CI)			**133**			**153**	**100.0%**	**2.88 [1.66, 4.10]**

Heterogeneity: Tau² = 1.28; Chi² = 35.75, df = 4 (P < 0.00001); I² = 89%
Test for overall effect: Z = 4.63 (P < 0.00001)

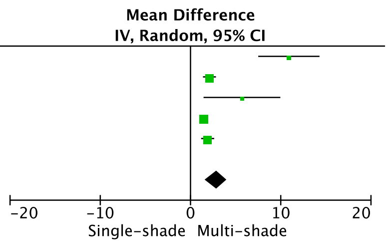

Figure 4. Forest plot of ΔE_{ab} of single-shade and traditional multi-shade composites.

	Single-shade			Multi-shade				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Atasayar & Ulusoy et al. 2023	8.5	2	20	3.4	1.2	40	17.2%	5.10 [4.15, 6.05]
Cruz de Silva et al. 2023	9.25	2.9	20	4.06	2.3	20	13.5%	5.19 [3.57, 6.81]
Cubukcu et al. 2023	2.23	0.87	40	1.88	0.99	40	19.5%	0.35 [−0.06, 0.76]
Koi et al. 2024	3.5	1.6	90	2.8	1.2	60	19.4%	0.70 [0.25, 1.15]
Rosa et al. 2024	9.3	2	15	6.2	2.3	5	10.4%	3.10 [0.84, 5.36]
Shaalan et al. 2023	2.9	0.3	20	1.6	0.3	20	20.0%	1.30 [1.11, 1.49]
Total (95% CI)			**205**			**185**	**100.0%**	**2.37 [1.32, 3.41]**

Heterogeneity: Tau² = 1.41; Chi² = 112.72, df = 5 (P < 0.00001); I² = 96%
Test for overall effect: Z = 4.45 (P < 0.00001)

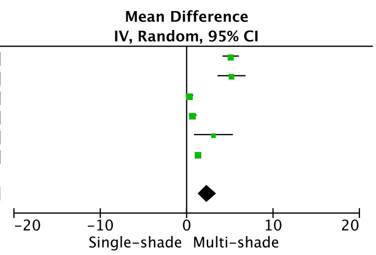

Figure 5. Forest plot of ΔE_{00} of single-shade and traditional multi-shade composites.

DISCUSSION

The dental industry has made significant efforts to develop "universal" materials such as adhesive systems, resin composite cements, and resin composites. These innovative materials aim to allow greater tolerance to technique sensitivity without compromising the functional and esthetic outcomes of restorations.[48,49] Recently, many manufacturers have introduced their own universal or single-shade composite, but only some of these have been tested in in vitro studies. The most frequently used composite in the in vitro studies[33,34,35,36,37,38,39,41,42,43,44,45,46,47] included in this review was Omnichroma - the first product that has been launched to the market - followed by Vittra APS Unique, Charisma Diamond One, Admira Fusion X-tra, and Essentia Universal.[40,42,46,47] While these single-shade composites may exhibit good color adjustment due to high translucency and uniform spectral reflectance,[50] our meta-analyses indicated that traditional multi-shade composites usually achieve a superior color match when in vitro studies were analyzed.

The extent of color change or adjustment can be evaluated visually or by using instruments.[18] Instrumental color analysis can detect VITA scale values and all CIEL*a*b* coordinates: L* (lightness from 0 = black to 100 = white), a* (chroma and hue on the red-green axis), and b* (chroma and hue on the yellow-blue axis).[7] These values allow for calculating color differences between tooth and composite materials using formulas, developed by the Commission Internationale de l'Eclairage (CIE).[51,52] The CIELab formula (ΔE_{ab}), a simplified version of CIEDE2000 (ΔE_{00}), lacks adjustments such as weighting functions (SL, SC, and SH), parametric factors (kL, kC, and kH), and the rotation function (RT) that accounts for chroma and hue interactions, particularly in the blue region.12 Therefore, ΔE_{00} is more precise and computationally demanding than ΔE_{ab}, designed to reduce discrepancies between calculated and perceived color differences.[51,53] Interestingly, the results from our meta-analyses revealed statistically significant differences for both ΔE_{ab} and ΔE_{00} when comparing the color match ability of single-shade to multi-shade composites.

Due to their translucency, single-shade composites reflect the color of the surrounding cavity walls, implying that the cavity depth affects their blending ability. Consequently, the cavity depth and the thickness of the composite restoration influence its color.[47] A recent study[39] explained that single-shade materials are unable to replicate the color of the surrounding tooth structure when the cavity depth reaches 2 mm, as their ability to mirror the underlying substrate is substantially reduced. In most of the studies included in our meta-analysis, the depth of the restored cavities was 2 mm[41,42,43,44,46,47] or 1.5 mm.[34,45] This might explain why we found that single-shade composites were less performant compared to multi-shade materials when their color match was assessed by means of instrumental analysis for both ΔE_{ab} and ΔE_{00} formulas. Our results should, however, be interpreted cautiously due to considerable heterogeneity indices observed among the studies. Although two separate meta-analyses were conducted for data pooled for ΔE_{ab} and ΔE_{00} values obtained from specimens stored in distilled water within the first week after restoration placement, the heterogeneity was high, most likely arising from variations in the materials used (e.g., different single-shade composites utilized across the in vitro studies) and different evaluation time points.26 Indeed, it should be mentioned that color match potential of single-shade composites is reported to be material (or brand) dependent.[39,54,55] This implies that, to achieve the optimal aesthetic outcome, the material should be selected cautiously, taking into consideration also the cement's brand, rather than just the category.[49]

Unlike instrumental evaluations, visual assessments with a shade guide are subjective, influenced by the observer's skills, gender, age, and lighting conditions.56 Despite these subjective influences, it remains the most commonly used procedure in clinical practice. Although the visual method may have drawbacks, it is often decisive in patient acceptance and satisfaction.[42,57] Conversely, instrumental assessments, favored in dental research for their objective results, provide quantifiable data that can detect fine color differences not perceptible to the human eye.[16]

Trained observers use visual analysis to assess the overall aesthetic harmony and integration of restorations, considering factors like translucency, texture, and gloss that instruments might overlook.[58] Human vision adapts to slight color variations, often deeming minor mismatches identified by spectrophotometers as clinically acceptable, emphasizing the restoration's seamless blend with natural dentition.[8,17] This may explain why, in some cases, visual inspection revealed similar or even better color adjustments of single-shade composites in several reviewed in vitro studies.[41,42,43,47] It is noteworthy to mention that visual analysis revealed that multi-shade composites may achieve a better color match than single-shade composites when the tooth color is A3.5, A4, B4, or C4.[40,45]

The RCTs included in this systematic review had no issues regarding the risk of bias assessment and they were all judged as low risk according to RoB 2 tool, implying excellent randomization and blinding technique – factors that can be crucial when evaluating the color of direct restorations. In general, the authors of the analyzed RCTs reported no statistically significant differences between multi-shade and single-shade restorations for all follow-ups (from baseline to 18 months).[20,22] In 1 RCT,[22] after 9 and 12 months, multi-shade composites displayed higher Alpha scores and a lower prevalence of Bravo scores for color match and marginal staining according to the modified USPHS when compared to single-shade materials. Nevertheless, both Alpha and Bravo scores were considered as "clinical success". Interestingly, 1 RCT [23] with the longest follow-up (18 months) reported excellent clinical behavior for both single- and multi-shade composites, and comparable color match of the two materials when evaluated both visually and instrumentally.

A recently published systematic review and meta-analysis of RCTs[59] answered the following PICOS question: "Do single-shade resin-based composites have shade performance comparable to that of multi-shade resin composites in direct restorations?" Four RCTs were included,[20,21,60,61] and no statistically significant differences were found between single-shade and multi-shade composite resins from 1 to 7 days and at 12 months when restorations were assessed by visual inspection. Although some of the RCTs were not included in our systematic review due to exclusion criteria (i.e. studies performed on primary teeth[61]), our findings generally align with those from Leal et al. (2024)[59] and confirm promising potential of single-shade materials to achieve good color match up to 18 months of clinical service.

Lastly, some important observations deriving from this systematic review should be mentioned: in vitro studies should standardize cavity dimensions when preparing samples, improve blinding procedures, and consistently perform sample size calculations. Additionally, better randomization techniques should be employed to minimize bias. Conducting visual analyses alongside instrumental evaluations is crucial for comprehensive assessments of color matching. By addressing these aspects, future in vitro research can provide more accurate and clinically relevant implications. Finally, longer-term studies and more RCTs should provide insights into the effects of aging on single-shade restorations' color, particularly if it adapts to tooth color changes from dietary habits[12] over time.

CONCLUSION

According to the findings of this systematic review, multi-shade resin composites can provide a better color match between tooth and direct restoration compared to single-shade materials when an instrumental analysis is performed in laboratory settings. Nonetheless, the emerging clinical evidence suggests that single-shade composites may be a promising alternative to multi-shade materials in the posterior region, based on visual assessment.

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CHAPTER 5

RESEARCH ARTICLE

Color stability assessment of single- and multi-shade composites following immersion in staining food substances

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Keywords: single-shade composites, color measurement, artificial aging, polymerization, staining agents, spectrophotometer.

ABSTRACT

Background: Composite resins are the material of choice for direct restorations, and their success depends mainly on their color stability since discoloration causes color mismatch, and consequent patient dissatisfaction.

Objective: A single- and a multi-shade resin were compared in order to evaluate their pigmentation after immersion in staining substances and to investigate the effect of the polymerization time on their color stability.

Materials and Methods: Two-hundred-and-forty composite specimens were created, half made of a single-shade (Group ONE, n=120) and half of a multi-shade composite (Group OXP, n=120). Each group was further divided into ONE30 (n=60) and OXP30 (n=60), polymerized for 30′′, and ONE80 (n=60) and OXP80 (n=60), polymerized for 80′′. Randomly, the specimens were immersed in turmeric solution, soy sauce, energy drink, or artificial saliva. By means of a spectrophotometer, ΔE_{00} and WI_d were calculated at 24h (T_0), at 7 (T_1), and 30 (T_2) days.

Results: Single-shade composites showed statistically significant differences in color change from the turmeric solution, energy drink, and soy sauce than the multi-shade composites ($p<0.05$), showing a higher discoloration potential. The polymerization time did not have significative effects on color stability.

Conclusion: Single-shade composites showed more color change than multi-shade systems after immersion in staining substances, and the curing time did not influence color variations.

INTRODUCTION

Tooth color is determined by the ways taken by light inside the tooth defined by light scattering, and the absorption of light along these paths [1]. It has been clinically observed that, after placement, some dental materials take on the color appearance of surrounding hard dental tissues, thus improving esthetics. This optical phenomenon is called Blending Effect (BE) or "chameleon effect" [2]. Single-shaded composites are single-mass resins developed to adapt chromatically to the adjacent tooth structures, irrespective of the shade of the tooth to be restored, since they are capable of simulating all the shades of the teeth color on which they are applied, using one unique mass [3]. These materials have been developed to make easier restorative procedures by eliminating the color selection phase, reducing the need to use different masses of composite and with different translucencies, and therefore expediting the restorative treatment [4]. It appears that these composites are able to match all shades of the VITA classic scale (A1-D4) by reflecting a certain tooth color wavelength [5], and are very promising for use in clinical practice, particularly when compared to traditional multi-shaded composite systems which require several masses of different colors to make a restoration [6].

Multi-shade conventional composites instead present several opacities and hues that mimic the translucency and chromaticity of dentin and enamel [7]. In order to replicate the optical features of a natural tooth, reconstruction procedures establish the use of several composite layers with different chromas and opacities [8,9].

The pigmentation of resin materials can be due to intrinsic and extrinsic causes [10]. The former cause pigmentation of the composite resin by altering the filler–matrix interface and the matrix itself [11], and are mainly associated with the characteristics of fillers, content of organic components, and polymerization degree [12]. Extrinsic factors instead stem from the extended exposure of the restorations to the oral environment, including inadequate oral hygiene and the absorption of colorants contained in beverages and foods [12]. These are typically superficial and are linked to eating habits, smoking, and oral hygiene. Coffee, red wine, and turmeric are considered the foods with the greatest pigmenting capability, followed by mate and tea [13,14].

To obtain great aesthetic composite restorations, it is mandatory that tooth-colored materials preserve resistance to surface staining and intrinsic color stability [15]. Previous studies have demonstrated that traditional composite materials are susceptible to staining in several staining media [15,16]. Multiple in vitro studies have evaluated the pigmentation of composite restorations following exposure, more or less prolonged, to daily drinks [17,18].

Another important factor influencing the esthetic properties and durability of resin composites is the curing efficacy, in other words, the amount of resin that can be converted from monomers to polymers [19]. Polymerization efficiency is mandatory to achieve higher degrees of conversion leading to smaller amounts of residual monomers, which are responsible for the color deterioration [20]. The polymerization depth affects the composite resin's color, translucency, and application thickness, and the distance from the curing device to the material, time after irradiation, filler size, and dispersion [21]. Insufficient light-curing is significantly associated with a decrease in the physical properties of resin composites [22]; insufficient polymerization can make the matrix easily absorb beverages [21] whereas a more efficient polymerization increases resistance to wear and fracture and improves composite resin color stability [23].

In this research project, a single-shade composite resin and a traditional micro-hybrid multi-shade resin were studied, in order to evaluate the pigmentation found following immersion in coloring food substances and the effect of the polymerization time on the color modification of composite resins.

The aim of this in vitro study is to investigate the color differences of a single-shade composite following immersion in staining edible solutions, comparing it to that observed with a traditional multi-shade composite. The effect of the polymerization time of the composites on the color stability was also evaluated.

Particularly, the null hypotheses were that (1) no differences in color variations exist between the two materials, and that (2) curing time does not influence the color stability of the tested materials.

MATERIALS AND METHODS

A total of 240 resin composite blocks (14mm×5mm×4mm) were created using a silicone mold (AGG3549 Flat Embedding Moulds, Agar Scientific, Stansted, UK) to achieve identical samples. Half of them were made of a micro-hybrid single-shade composite resin (ONEshade, OliDent, Poznan, Poland) (Group ONE, n=120), and the other half were made of a micro-hybrid multi-shade composite (OlicoXP A2, OliDent, Poznan, Poland) (Group OXP, n=120). Each group was further divided into two sub-groups: groups ONE30 (n=60) and OXP30 (n=60), polymerized for 30′′, and groups ONE80 (n=60) and OXP80 (n=60), polymerized for 80′′.

The polymerization time recommended by the manufacturer was 30′′, and the descriptions of the tested materials are presented in Table 1.

Table 1. Details of the tested composites.

Composite	Filler Particles	Resin Matrix	Filler	Manufacturer	Lot #
ONEshade	Micro-hybrid	Glass powder, polyurethane dimethacrylate, silicon dioxide, Bis-GMA, tetramethylene dimethacrylate	75% weight, 53% volume. Inorganic filler particles (0.005–3.0 µm)	Olident (Podłęże, Polonia)	2023004852
Olico XP	Micro-hybrid	Glass powder, dimethacrylates, silicon dioxide, Bis-GMA	80% weight, 68% volume. Inorganic filler particles (0.05–0.9 µm)	Olident (Podłęże, Polonia)	52301159C

All the samples were realized through several increments of material (2mm each), each of which was polymerized in contact with the composite surface using a blue-led medium intensity lamp (Starlight Pro, Mectron, Carasco, Genoa, Italy) at 1400mW/cm^2. Before the last curing phase, a Mylar sheet (Mylar, DuPont, Wilmington, DE, USA) was applied on top of the composite to achieve a perfectly glossy and smooth surface with no roughness. Specimens' layers were cured for 30 or 80s depending on their subgroup. Subsequently, samples were stored inside a dark container for 24h in distilled water at 37°C in order to achieve rehydration. Specimens were then air-dried gently and color coordinates were recorded at T_0 using an intraoral spectrophotometer (VITA Easyshade

V, VITA Zahnfabrik, Bad Säckingen, Germany), by positioning the tip perpendicular to the specimens' surface with natural daylight and a grey background [24].

The following CIELAB color coordinates were recorded: L* (lightness), a* (green-red coordinate), b* (blue-yellow coordinate), C* (chroma), and h° (hue). Measurements were taken in the middle of the sample surface (three measurements per unit) after 24h of immersion in distilled water (T_0) [25]. After randomization, the composite blocks were then divided into 16 groups (n=15): ONE30, ONE80, OXP30, and OXP80 specimens were divided to be immersed in 4 different colorant substances.

The following substances were selected for immersion of the samples: turmeric powder–water solution, soy sauce, energy drink, and artificial saliva (Table 2).

Table 2. Description of the food substances used and composition.

LIQUID	CONTENT
Turmeric powder–water solution	Obtained by diluting 1 g of turmeric powder in 1 L of distilled water and boiling for 10 min to obtain a standardized concentration [26].
Soy sauce (Kikkoman®, Kikkoman Trading Europe GmbH, Düsseldorf, Germany)	Water, soy, wheat, salt.
Energy drink (Monster Pacific Punch®, Monster Energy, Corona, CA, USA)	Carbonated water, sugar, glucose, orange concentrate, apple concentrate, taurine, acidity regulators E330–E331, raspberry concentrate, goyava puree, cherry concentrate, preservatives E202–E211, caffeine, natural flavourings, vitamins B3–B6-B2–B12, sweetener E955, pineapple concentrate, passion fruit concentrate, thickener E414, colors E129*–E133, salt, emulsifier E445, inositol, carnitine tartrate. Caffeine: 333 mg/L.
Control	Artificial saliva [27].

Before immersing the samples in the drink formulations, the solution with turmeric was prepared as indicated in Table 2.

The other substances were introduced in their pure form into individual, hermetically sealable plastic containers (FisherbrandTM Screw Top, Fisher Scientific, Hampton, NH, USA).

The drink formulations were replaced every 24h for 30 days, during which the samples were kept in incubation at 37°C in a box away from light. The measurements with the spectrophotometer were carried out against a grey background and natural light [24], calibrating the instrument after every 3 measurements [28], at T_0 (after 24h in distilled water at 37°C), at 7 days (T_1), and 30 days (T_2) [25].

From the data obtained with the spectrophotometer, the ΔE_{00} and WI_d values were calculated:

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L} \right)^2 + \left(\frac{\Delta C'}{K_C S_C} \right)^2 + \left(\frac{\Delta H'}{K_H S_H} \right)^2 + R_T \left(\frac{\Delta C'}{K_C S_C} \right) \left(\frac{\Delta H'}{K_H S_H} \right) \right]^{1/2}$$

$$WI_d = 0.511L^* - 2.324a^* - 1.100b^*$$

Before each measurement, the samples were extracted from the solution, rinsed thoroughly under running water, and dried with a paper towel [29].

Statistical Analysis

Statistical analysis was performed using the STATA program version 17 (StataCorp LP 4905 Lakeway Drive, College Station, TX 77845, USA). According to the RoBDEMAT risk of bias tool for pre-clinical dental research [30], the sample size was calculated depending on a previous study as a reference [31]. According to this research, the response within each subject group was normally distributed with a standard deviation of 1.4. If the actual difference in the experimental and control means is 1.8, the study minimally needed 11 subjects in each group to reject the null hypothesis that the population means of the experimental and control groups are equal with probability (power) 0.8. The type I error probability associated with this null hypothesis test is 0.05. The total sample size increased to 15 subjects per group to compensate for 20% dropout.

Means and standard deviations were used to summarize the data. Data from color coordinates (CIE L*, a*, b*, C*, and h°) were statistically analyzed using analysis of variance (one-way ANOVA) and Tukey multiple comparison test with Bonferroni correction. One-way ANOVA was performed to compare the effects of the color difference ΔE_{00} values among the materials and whiteness index differences (ΔWI_d). Paired *t*-tests were used to compare continuous measures between groups. A p-value of <0.05 was considered statistically significant.

RESULTS

Mean color differences (ΔE_{00}) and standard deviations (SDs) of resin specimens (ONE and OXP) between T_0 (baseline) and the different follow-ups (T_1: 7 days, T2: 30 days), after immersion in various media (artificial saliva, turmeric powder-water solution, energy drink, soy sauce) and at different curing times (30′′ and 80′′) are presented in **Table 3**.

Table 3. Mean color differences (ΔE_{00}) and standard deviations of resin specimens between baseline and the different follow-ups, after immersion in various media and at different curing times.

	Mean ΔE_{00} ± SD					
	T_0–T_1 (7 days)		***p*-Value**	**T_0–T_1 (7 days)**		***p*-Value**
	ONE80	**OXP80**		**ONE80**	**ONE30**	
Artificial saliva	0.7 ± 0.2	0.7 ± 0.1	0.676	0.7 ± 0.2	0.8 ± 0.5	0.630
Turmeric	9.4 ± 0.6	14 ± 1.5	<0.001	9.4 ± 0.6	6.6 ± 2.8	0.004
Energy drink	2.1 ± 0.6	1.4 ± 0.5	0.005	2.1 ± 0.6	1.9 ± 0.7	0.612
Soy	3.7 ± 0.4	3.6 ± 0.9	0.642	3.7 ± 0.4	4.2 ± 0.9	0.171
	T_0–T_2 (30 days)			**T_0–T_2 (30 days)**		
	ONE80	**OXP80**		**ONE80**	**ONE30**	
Artificial saliva	0.7 ± 0.2	0.8 ± 0.1	0.039	0.7 ± 0.2	1.3 ± 1.6	0.184
Turmeric	17.7 ± 0.1	15.1 ± 2.4	-	17.7 ± 0.1	16.0 ± 1.3	-
Energy drink	3.2 ± 1.0	1.8 ± 0.6	0.001	3.2 ± 1.0	2.8 ± 0.9	0.389
Soy	6.7 ± 1.4	6.5 ± 2.4	0.718	6.7 ± 1.4	7.6 ± 1.1	0.095
	T_0–T_1 (7 days)			**T_0–T_1 (7 days)**		
	ONE30	**OXP30**		**OXP30**	**OXP80**	
Artificial saliva	0.8 ± 0.5	0.8 ± 0.7	0.898	0.8 ± 0.7	0.7 ± 0.1	0.071
Turmeric	6.6 ± 2.8	6.6 ± 1.0	0.988	6.6 ± 1.0	14 ± 1.5	<0.001
Energy drink	1.9 ± 0.7	1.2 ± 0.2	0.004	1.2 ± 0.2	1.4 ± 0.5	0.206
Soy	4.2 ± 0.9	3.6 ± 0.7	0.056	3.6 ± 0.7	3.6 ± 0.9	0.967
	T_0–T_2 (30 days)			**T_0–T_2 (30 days)**		
	ONE30	**OXP30**		**OXP30**	**OXP80**	
Artificial saliva	1.3 ± 1.6	0.9 ± 0.3	0.459	0.9 ± 0.3	0.8 ± 0.1	0.005
Turmeric	16.0 ± 1.3	12.1 ± 0.1	0.125	12.1 ± 0.1	15.1 ± 2.4	-
Energy drink	2.8 ± 0.9	1.9 ± 0.5	0.001	1.9 ± 0.5	1.8 ± 0.6	0.740
Soy	7.6 ± 1.1	5.3 ± 1.2	<0.001	5.3 ± 1.2	6.5 ± 2.4	0.145

Statistically significant differences were observed between OXP_80 and ONE_80 at T_1 for turmeric ($p<0.001$) and energy drink ($p=0.005$); at T_2 for artificial saliva ($p=0.039$) and energy drink ($p=0.001$).

Statistically significant differences were observed between OXP_30 and ONE_30 at T_1 for energy drink ($p=0.004$); at T_2 for energy drink ($p=0.001$) and soy ($p<0.001$).
Statistically significant differences were observed between ONE_80 and ONE_30 at T_1 for turmeric ($p=0.004$).
Statistically significant differences were observed between OXP_80 and OXP_30 at T_1 for turmeric ($p<0.001$); at T_2 for artificial saliva ($p=0.005$).
Considering ΔE_{00} (T_0-T_1) and ΔE_{00} (T_0-T_2), statistically significant differences were observed in ONE_80 specimens for turmeric ($p=0.006$), energy drink ($p<0.001$), and soy ($p<0.001$); in OXP_30 specimens for turmeric ($p=0.006$), energy drink ($p<0.001$), and soy ($p<0.001$); in OXP_80 specimens for artificial saliva ($p=0.002$) and soy ($p<0.001$); in ONE_30 specimens for turmeric ($p<0.001$), energy drink ($p<0.001$), and soy ($p<0.001$).
The linear prediction values of ΔE_{00} at baseline and T_2 are shown in **Figure 1**.

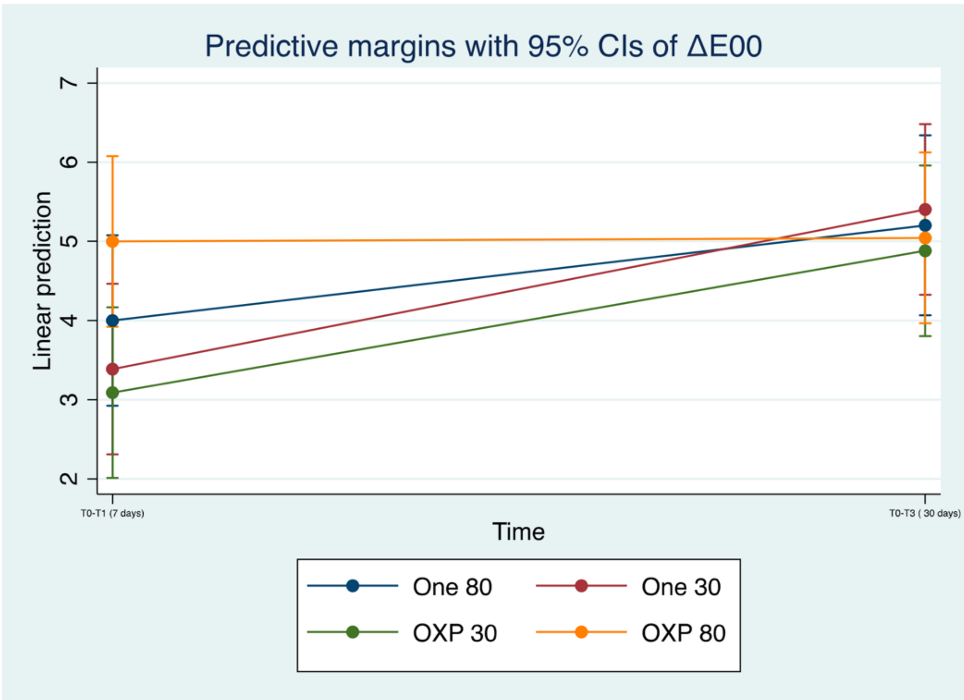

Figure 1. Linear prediction of ΔE_{00}. Means (dots), 95% confidence interval (whiskers), samples at baseline T_0 (time T_0–T_1) and at T_2 (time T_0–T_3).

Mean whiteness index differences (ΔWI_d) and standard deviations (SDs) of resin blocks (ONE and OXP) between T_0 (baseline) and the different follow-ups (T_1: 7 days, T_2: 30 days), after immersion in various media (artificial saliva, turmeric powder–water solution, energy drink beverage, soy sauce) and at different curing times (30′′ and 80′′) are presented in **Table 4**.

Table 4. Whiteness index (WI_d) and standard deviations of resin specimens between baseline and the different follow-ups, after immersion in various media and at different curing times.

Witeness Index ± SD												
	T_0		*p*-value	T_0		*p*-value	T_0		*p*-value	T_0		*p*-value
	ONE80	OXP80		ONE30	OXP30		ONE80	ONE30		OXP30	OXP80	
Artificial saliva	24.7 ± 0.5	22 ± 0.6	<0.001	22.7 ± 1.6	19.7 ± 1.4	<0.001	24.7 ± 0.5	22.7 ± 1.6	<0.001	19.7 ± 1.4	22 ± 0.6	<0.001
Turmeric	23.7 ± 0.7	21.3 ± 3.4	0.015	22.7 ± 1.1	19 ± 0.9	<0.001	23.7 ± 0.7	22.7 ± 1.1	0.003	19 ± 0.9	21.3 ± 3.4	0.021
Energy drink	24.9 ± 0.7	22 ± 0.6	<0.001	23.9 ± 1.5	20.3 ± 0.8	<0.001	24.9 ± 0.7	23.9 ± 1.5	0.015	20.3 ± 0.8	22 ± 0.6	<0.001
Soy	23.7 ± 0.7	21.9 ± 0.5	<0.001	22.5 ± 0.8	20.2 ± 1	<0.001	23.7 ± 0.7	22.5 ± 0.8	0.001	20.2 ± 1	21.9 ± 0.5	<0.001
Total	24.2 ± 0.9	21.8 ± 1.8	<0.001	22.9 ± 1.4	19.8 ± 1.1	<0.001	24.2 ± 0.9	22.9 ± 1.4	<0.001	19.8 ± 1.1	21.8 ± 1.8	<0.001
	T_1			T_1			T_1			T_1		
	ONE_80	OXP_80		ONE_30	OXP_30		ONE_80	ONE_30		OXP_30	OXP_80	
Artificial saliva	24.8 ± 0.7	21.3 ± 0.5	<0.001	22.6 ± 1.4	18 ± 1.1	<0.001	24.8 ± 0.7	22.6 ± 1.4	<0.001	18 ± 1.1	21.3 ± 0.5	<0.001
Turmeric	11 ± 2.3	−0.6 ± 4.3	<0.001	13.4 ± 2.9	8.1 ± 3.4	<0.001	11 ± 2.3	13.4 ± 2.9	0.056	8.1 ± 3.4	−0.6 ± 4.3	<0.001
Energy drink	20 ± 2.1	18.3 ± 1.6	0.013	19.4 ± 1.8	17.4 ± 1	0.001	20 ± 2.1	19.4 ± 1.8	0.351	17.4 ± 1	18.3 ± 1.6	0.075
Soy	17.1 ± 1.3	14.8 ± 2.9	0.011	12.5 ± 2.4	12.5 ± 2	0.947	17.1 ± 1.3	12.5 ± 2.4	<0.001	12.5 ± 2	14.8 ± 2.9	0.027
Total	18.2 ± 5.3	13.5 ± 8.9	<0.001	17 ± 4.8	14 ± 4.5	<0.001	18.2 ± 5.3	17 ± 4.8	0.177	14 ± 4.5	13.5 ± 8.9	0.703
	T_2			T_2			T_2			T_2		
	ONE_80	OXP_80		ONE_30	OXP_30		ONE_80	ONE_30		OXP_30	OXP_80	
Artificial saliva	23.2 ± 0.6	21.2 ± 0.9	<0.001	22.5 ± 1.5	18.9 ± 0.9	<0.001	23.2 ± 0.6	22.5 ± 1.5	0.108	18.9 ± 0.9	21.2 ± 0.9	0.001
Turmeric	−18 ± 2.1	−6.9 ± 5.5	-	−10.9 ± 6.4	−6.3 ± 2.1	0.015	−18 ± 2.1	−10.9 ± 6.4	-	−6.3 ± 2.1	−6.9 ± 5.5	-
Energy drink	17,2 ± 3	17.1 ± 2.1	0.958	16.6 ± 2.6	15.7 ± 1.6	0.191	17.2 ± 3	16.6 ± 2.6	0.675	15.7 ± 1.6	17.1 ± 2.1	0.058
Soy	8.9 ± 3.4	9.5 ± 6.1	0.768	5.6 ± 3.3	10.2 ± 2.4	<0.001	8.9 ± 3.4	5.6 ± 3.3	0.025	10.2 ± 2.4	9.5 ± 6.1	0.722
Total	14.9 ± 9.5	12.1 ± 10.5	0.161	9.5 ± 12.9	13.6 ± 6.5	0.046	14.9 ± 9.5	9.5 ± 12.9	0.017	13.6 ± 6.5	12.1 ± 10.5	0.398

Statistically significant differences were observed between ONE_80 and OXP_80 at T_0 for artificial saliva ($p<0.001$), turmeric ($p=0.025$), energy drink ($p<0.001$), and soy ($p<0.001$); at T_1 for artificial saliva ($p<0.001$), turmeric ($p<0.001$), energy drink ($p=0.013$), and soy ($p=0.011$); at T_2 for artificial saliva ($p<0.001$).

Statistically significant differences were observed between ONE_30 and OXP_30 at T_0 for artificial saliva ($p<0.001$), turmeric ($p<0.001$), and energy drink ($p=0.001$); at T_1 for artificial saliva ($p<0.001$), turmeric ($p<0.001$), and energy drink ($p=0.001$); at T_2 for artificial saliva ($p<0.001$), turmeric ($p=0.015$), and soy ($p<0.001$).

Statistically significant differences were observed between ONE_80 and ONE_30 at T_0 for artificial saliva ($p<0.001$), turmeric ($p=0.003$), energy drink ($p=0.015$), and soy ($p=0.001$); at T_1 for artificial saliva ($p<0.001$) and soy ($p<0.001$); at T_2 for soy ($p=0.025$).

Statistically significant differences were observed between OXP_80 and OXP_30 at T_0 for artificial saliva ($p<0.001$), turmeric ($p=0.031$), energy drink ($p<0.001$), and soy ($p<0.001$); at T_1 for artificial saliva ($p<0.001$), turmeric ($p<0.001$), and soy ($p=0.027$), at T_2 for artificial saliva ($p<0.001$).

Linear prediction of WI_d at baseline, T_1, and T_2 are shown in **Figure 2**.

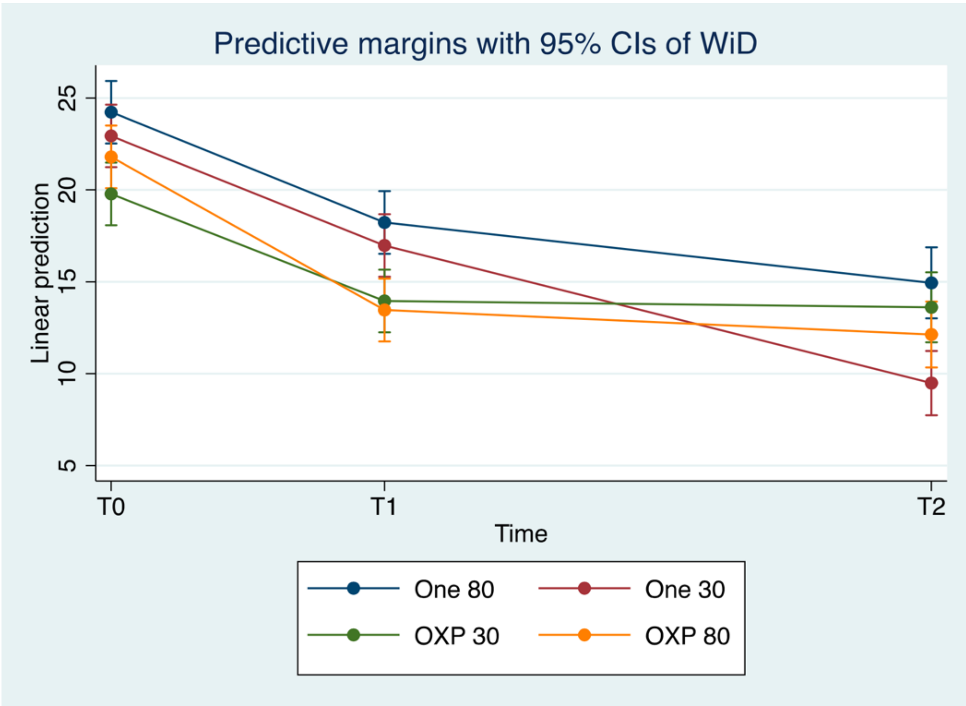

Figure 2. Linear prediction of WI_d. Means (dots), 95% confidence interval (whiskers), samples at baseline T_0, T_1, at T_2.

DISCUSSION

From the achieved results, it can be stated that the null hypotheses formulated were partially rejected, due to the following:

- There were differences in color variations between the two materials;
- Curing time does not influence the color stability of the tested materials.

The primary purpose of this in vitro study was to analyze the color differences of a single-shade composite following immersion in pigmented food solutions, comparing them to the variations observed with a traditional multi-shade composite.

Overall, the results showed that the surfaces of all tested samples underwent a certain amount of color change.

Although there have been scientific publications on the BE of single-shade resin composites [28,32], studies on the color stability of these materials are quite limited [12,25,27,33,34].

A recent study highlighted how these composites were able to show a higher chromatic change compared to traditional multi-shade resins, after immersion in red wine, coffee, and black tea [25].

Similarly, Chen et al. evaluated the color stability of a single-shade composite compared to three multi-shade resins, after immersion in coffee [12]. Although all materials showed different color change degrees, the greatest pigmentation was expressed by the single-shade composite.

Another research group studied the color stability of a single-shade composite compared to a multi-shade one, after immersion in tea and red wine. Although both materials showed a high degree of pigmentation, the color variation of the multi-shade composite was significantly lower than the single-shade composite [27].

Ebaya et al. evaluated and compared the color stability of two single-shade composite restorations after storing them in different staining media (black tea and cola). They concluded that the aging procedure exerted a negative effect on single-shade composite color stability [35].

To our knowledge, no studies have been conducted yet evaluating the color variations of single-shade composites after immersion in the substances tested in the present study: a solution of water and turmeric powder, an orange-colored energy drink, and soy sauce.

Specimens immersed in the water/turmeric solution exhibited the greatest color change, regardless of the type of composite. This result is consistent with previously published studies, where a turmeric-based solution caused the most significant pigmentation in nano-filled and micro-hybrid traditional composite resin samples [26], and high ΔE values in all tested composites, regardless of the initial shade and the composition of the resin matrix [36].

It has been suggested that the absorption of yellow color by these restorative materials could be attributed to the compatibility of pigments with the composites' organic matrix [37]. Furthermore, it has been demonstrated that the pigmented compounds responsible for the color of spices contain polyphenolic structures, and polyphenols are implicated as causal agents in dental pigmentation [38].

It is known that soy sauce contains caramel hydrophilic coloring pigment. Color alterations and microhardness variations of a micro-hybrid composite were evaluated after immersion in various colored foods, investigating the possible correlation between these two variables. According to these authors, the absorption by the hydrophilic component of the organic matrix, especially the characteristic of Bis-GMA, could be responsible for the pigmentation of the composite resin. The ΔE values after 28 days were considered unacceptable from an esthetic point of view, but the greatest color variations in the aforementioned study were caused, in order, by mustard and ketchup [39].

In the present study, soy sauce showed a lower staining capability compared to turmeric in both types of composites investigated, with a statistically significant difference in pigmentation. The samples immersed in the water/turmeric solution and soy sauce showed an incremental color change with increasing immersion time [26].

Regarding the Monster® "Pacific Punch" energy drink, it was shown that there was a pigmentation increase from T_0 to T_2 for the groups ONE30, ONE80, and OXP30, but no statistically significant color variation was recorded for the OXP80 group from T_1 to T_2.

Soft drinks have been widely used to evaluate composite color stability [40], but only a few were tested on single-shade composites [35,41].

In a recent publication, the authors evaluated the color stability of two composite resins after exposure to beverages such as Cola, Pepsi, and Red Bull after 15 days. In all specimens, the tested composites discolored less in the Red Bull energy drink [41].

A recent publication compared the color stability of micro-hybrid composites and nanocomposites after exposure to common soft drinks among adolescents. All soft drinks resulted in clinically unacceptable discoloration of the composite materials with maximum discoloration occurring following the immersion of composite materials in iced tea [40].

De Alencar et al. evaluated the color of nanoparticle and nanohybrid composites after immersion in açaí juice and grape juice. Grape juice produced the greatest color change in nanocomposites after 2 weeks, and açaí juice made the color unacceptable clinically only after 12 weeks [33].

Berber et al. evaluated the color stability of resin composites using different drinks. The authors concluded that when drinks with and without sugar were compared, all groups with sugar demonstrated a higher color difference than without sugar [42].

Unexpectedly, specimens from the OXP80 group immersed in artificial saliva showed a slight color change. Artificial saliva does not contain pigments, and therefore the color change could be due to water absorption of the matrix. This could cause swelling and plasticization of the polymer together with the formation of interstitial spaces between the filler and the resinous matrix, thus allowing the color variation [43]. However, from a clinical point of view, the instrumental color measurements carried out with the spectrophotometer at T_0 and T_2 did not highlight evident chromatic variations when based on the Vita Classical reference scale.

The secondary goal of this research project was to evaluate if different composite polymerization timings could affect resin color, as half of the samples were polymerized for 30′′ and the other half for 80′′. The results showed that all specimens, regardless of the curing time, underwent a certain amount of color change.

This lack of significant differences was found also by Gonder and Fidan in 2022. The authors aimed to evaluate the effect of different polymerization times on color change, translucency parameters, and surface hardness of resin composites after thermocycling. Different curing times did not affect the color change of the composite materials [21].

It is interesting to note that the ΔWI_d showed a greater initial whiteness for the specimens cured for 80′′, in both groups. This could indicate that a longer curing time could have an effect on the initial composites' whiteness.

It is mandatory to highlight that the present research has been conducted in vitro and that the interpretation of the results could present some limitations.

First, the specimens were always in contact with the full concentration of the staining substances. Accordingly, the role of saliva was not simulated.

Second, the specimens were soaked in the food substances at 37°C, but usually some drinks could be consumed cold. Therefore, the amount of discoloration observed in the present study could have been influenced more than what should occur when the immersion is conducted at low temperatures.

An evident limitation of this research protocol could be represented by the choice of the spectrophotometer used for this study. The VITA Easyshade V is a clinical device that has been used in several studies and illuminates the tooth with a 6500K light [6,12,24,28,32,33,40,42]. Even though a bench spectrophotometer could represent the most suitable instrument for an in vitro study [44], based on recently published data [12,24,28,32,33,40,45], a clinical spectrophotometer was chosen for the present study in order to reproduce a clinical situation in the most precise way. A study by Dozic´ et al. found VITA Easyshade to be, in vitro and in vivo, the most precise among five other similar devices, providing good reliability and accuracy [46]. More recently, another publication evaluated the reliability of two clinically applicable spectrophotometers under laboratory and clinical conditions, concluding that both spectrophotometers produced reliable and accurate measurements and can therefore be recommended for clinical and laboratory determinations of tooth color [47].

Additionally, no thermocycling was considered in the present research. Composites aging in the oral cavity and tooth-brushing could modify the extent of discoloration from these staining substances.

Another limit of this research protocol could be that both tested resins are micro-hybrid composites. First-generation conventional composites presented with average particle sizes that exceeded 1μm. These macro-filled materials were very resistant but difficult to polish and impossible to retain surface smoothness. In order to address the important issue of long-term esthetics, which was lacking with the macro-filled composites, manufacturers began to formulate micro-filled materials, until the most recent development of the nano-filled composites, containing only nanoscale particles [48]. For this reason, significant improvements in surface smoothness/polish retention have been reported for nano-filled compared to conventional micro-filled materials [49]. The latest generation of micro-hybrid composites consist of both microscale and nanoscale (~0.02 micron) glass fillers [49]. It may appear that composites featuring smaller filler particles, such as nano-hybrid composite resins, could potentially provide greater color stability. In the literature, however, there is scientific evidence relating to micro-hybrid composite resins that show higher color stability than nano-hybrid ones [41]. A research group, for example, conducted a study to examine the impact of different soft drinks (iced tea, sports drinks, orange juice, and cola) on micro- and nano-hybrid composites. The results indicated that the micro-hybrid composites demonstrated superior color stability after immersion in all the drinks tested [40]. Further studies have shown how increasing the size of the filler particles can lead to a reduction in the pigmentation of the composite, probably due to the lower matrix–filler ratio [33,41].

Therefore, it could be of interest to evaluate the resistance to discoloration of the restorations with thermocycling incorporated, and to establish new in vitro studies that consider the effect of the assessed staining food substances, perhaps in diluted forms, on extracted natural teeth restored with the tested composites.

CONCLUSIONS

According to the results of this in vitro study in which the color stability of two different resin composites were examined, the following conclusions were obtained:

1. Single-shade resin composites in turmeric solution, energy drink, and soy sauce showed more color changes than multi-shade systems;
2. The whiteness index decreased over time, regardless of the type of composite and the staining substance;
3. The curing time did not influence the color variations of both composite groups.

Single-shade composites seem to be more susceptible to discoloration, which may affect their long-term success rate, although the potential discoloration might be limited by dietary adjustments. Patients could be asked about their diet habits and made aware of their potential to discolor composite restorations. At the same time, dentists have to remember the discoloration capability of composite resin restorations.

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CHAPTER 6

RESEARCH ARTICLE

Assessment of colour modifications in two different composite resins induced by the influence of chlorhexidine mouthwashes and gels, with and without anti-staining properties: An in vitro study

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Keywords: chlorhexidine, colour, composites, flowable, in vitro study, stain.

ABSTRACT

Objective: Chlorhexidine (CHX)-based products are the most effective chemical agents used in plaque control and oral disinfection. One of their side effects is tooth and restoration staining. For this reason, CHX products with anti-discolouration systems (ADS) have been developed. The aim of this in vitro study was to compare different CHX-based products (gel and mouthwash) with or without ADS in composite colour modification.

Materials and Methods: Two hundred specimens were created, 100 of which were made of packable composite and 100 of flowable composite. After 24h, colour coordinates (L^*, a^*, b^*, C^*, $h°$) were recorded using a spectrophotometer (T_0). Then, all samples were subjected to a CHX/tea staining model and immersed in human saliva for 2min. Composite specimens were divided in 10 groups (N=20). Control groups (PC, FC) were soaked in distilled water, and test groups (PG, PGads, FG, FGads, PM, PMads, FM, and FMads) were immersed in CHX-based solutions or brushed with CHX gel. Then the cycle was repeated 6 times, and colour differences (ΔE_{ab} and ΔE_{00}) were finally calculated.

Results: Through flowable composites, FC and FG showed the highest colour differences, respectively ΔE_{ab}=3.48±1.0, ΔE_{00}=2.24±0.6 and ΔE_{ab}=2.95±1.3,

ΔE_{00}=1.53±0.6. In the composite groups instead, PM and PMads showed the highest colour differences, respectively ΔE_{ab}=2.78±1.3, ΔE_{00}=1.94±0.8 and ΔE_{ab}=2.71±1.4, ΔE_{00}=1.84±0.9.

Conclusion: CHX-containing products are able to cause stains on restorative composite materials. Discolouration is more likely to occur in flowable composites than packable composites, and ADS-containing products cause fewer pigmentations than CHX products without ADS. Packable composites showed more staining after mouth-wash treatment, whereas flowable composites underwent higher discolouration after treatment with gels.

INTRODUCTION

Chlorhexidine gluconate (CHX) is the most effective chemical agent for plaque control.[1,2] It is classified as a bis-biguanide antiseptic, and is active against Gram-positive and Gram-negative bacteria, including aerobes and anaerobes, and leads to the rupture of the bacterial cell wall.[3]

Following periodontal therapy, rinses or mouthwashes are often suggested as post-therapy care.[1,4] CHX at a concentration of 0.12% is frequently used due to its antibacterial, anti-inflammatory, and anti-biofilm characteristics. It has been shown that rinsing with 0.12% CHX after non-surgical periodontal therapy reduces probing depth to a greater extent compared with non-surgical periodontal therapy alone.[5]

The most common reported side effects of long-term CHX use include taste alteration, irritation of the oral mucosa, and both tooth and restoration (composites and cements) discolouration.[3,6,7] Side effects are reversible upon discontinuation of use but remain a major limitation on patient compliance.[8]

Based on in vitro and in vivo studies, a literature review concluded that the major etiological mechanism of extrinsic dental staining associated with cationic antiseptics was the precipitation of dietary chromogens on dental and oral surfaces.[9]

Three mechanisms are potentially associated with the CHX staining side effect: (1) the Maillard reaction; (2) the formation of pigmented metal sulphides and (3) reactions between tannin and polyphenols from drinks, food, and CHX itself. The Maillard reaction occurs in the biofilm between proteins and sugars, producing glycosylamine that is unstable and rearranged into ketosamines. This reaction is catalysed both by CHX and a series of polymerization reactions, resulting in the brown-coloured pigments also known as 'melanoidins'.[10]

Extrinsic staining factors include coloration by absorption of dyes from exogenous sources, such as smoking, coffee, tea, and red wine assumption. Also, mouthwashes have been reported to stain composite resin restorations in varying degrees.[11] Because of this, daily rinsing with chlorhexidine is not promoted.[2]

In order to counter tooth staining, CHX with an anti-discolouration system (ADS) was developed. The ADS system is made of sodium meta-bisulphite and ascorbic acid, two molecules that seem to be capable of interfering with the main processes that lead to the formation of pigmentation.[12]

Based on a recent literature review, there is moderate evidence from non-brushing studies that the addition of an ADS to CHX- mouthwash does not appear to affect its properties with respect to gingival inflammation and plaque scores and reduces tooth surface discolouration. Also, in brushing studies, there is moderate quality evidence that ADS does not affect the anti-plaque and anti-gingivitis efficacy of CHX. Most comparisons and the meta-analysis including these suggest the absence of a significant effect of ADS on tooth staining when mouthwash is used in addition to toothbrushing.[10]

To date, there is no scientific data available regarding whether a CHX-based liquid product such as mouthwash or a gel product is more effective in staining composite restorations, or which type of composite resin is more sensitive to the phenomenon of CHX-induced pigmentation.

Therefore, the aim of this in vitro study was to evaluate the staining ability of CHX-based mouthwashes and gels on two different composite resins, packable and flowable, compared to the staining caused by the same products with the adjunct of an ADS.

In particular, the null hypotheses tested were that: (1) there is no difference in discolouration between packable and flowable composites after contact with CHX-based products; (2) there is no difference in discolouration on composite resins between CHX-containing gels and mouthwashes; and (3) there is no difference in discolouration on composite resins between CHX-containing products and CHX + ADS-containing products.

MATERIALS AND METHODS

Two hundred resin composite blocks (8mm × 6mm ×5mm) were created using a parallelepiped silicon mold in order to obtain identical samples. Half of them were made of a packable composite (PremiseTM, Kerr Italia Srl) and the other 100 samples were made of a flowable composite (PremiseTM Flowable, Kerr Italia Srl).

All specimens were realized through three different increments of composite, each of which was light-cured with a blue-led medium intensity lamp for 20s (1400mW/cm^2) (Mectron Starlight Pro, Mectron SpA). Before the last curing phase, a Mylar sheet was placed on top of the composite in order to obtain a perfectly smooth surface. Samples were removed from the mold and then polished using a composite diamond-coated polishing kit (TWISTTM DIA for Composite, Kuraray Noritake Dental Inc.).[13] After that, specimens were stored in distilled water at 37° for 24h.[14] Samples were then gently air-dried[15] and colour coordinates (L^*, a^*, b^*, C^*, $h°$) were recorded at T_0 using an intraoral spectrophotometer (VITA Easyshade V, VITA Zahnfabrik, Germany) by placing the tip perpendicular to the sample surfaces with a grey background and natural daylight.[16]

After initial colour measurements, all blocks were subjected to a previously published staining chlorhexidine/tea model,[8] and then immersed in stimulated human saliva (collected from the same experimenter, without food ingestion at least 2h before saliva collection) for 2min.

Subsequently, composites blocks were randomly divided into 10 groups (N=20).[17] Test groups were immersed in CHX-based solutions (Curasept® SPA, Saronno, Italy), or brushed with CHX-based gels (Curasept® SPA), whereas control groups were soaked in distilled water:

1. PG (composite: 2′ CHX gel 0.50%),
2. PG-ADS (composite: 2′ CHX gel 0.50% with ADS),
3. FG (flow: 2′ CHX gel 0.50%),
4. FG-ADS (flow: 2′ CHX gel 0.50%),
5. PM (composite: 2′ CHX mouthwash 0.20%),
6. PM-ADS (composite: 2′ CHX mouthwash 0.20% with ADS),
7. FM (flow: 2′ CHX mouthwash 0.20%),

8. FM-ADS (flow: 2′ CHX mouthwash 0.20%) with ADS),
9. PC (composite: 2′ dH_2O),
10. FC (flow: 2′ dH_2O).

Materials used in the study are described in **Tables 1** and **2**.

Table 1. Description of the tested composite resins.

Composite	Particles	Resin type	Resin matrix	Filler	Producer
Premise™	Nanohybrid	Methacrylate	Bis-GMA, bisphenol-A, ethoxylate dimethacrylate and TEGDMA	Weight 84%, volume 69% Non-agglomerate silice nanoparticles (0.02 μm), pre-polymerised filler (30–50 μm), and barium silicate glass (0.4 μm)	Kerr Italia Srl
Premise™ Flowable	Nanohybrid flowable	Methacrylate	Bis-GMA, bisphenol-A, ethoxylate dimethacrylate and TEGDMA	Weight 72.5%, volume 56% Non-agglomerate silice nanoparticles (0.02 μm), pre-polymerised filler (30–50 μm), and barium silicate glass (0.4 μm)	Kerr Italia Srl

Table 2. Description of the CHX-based products tested.

Product	Composition	Producer
Mouthwash CHX 0.20% with ADS	Aqua, Xilitol, Propylene glycol, PEG-40 Hydrogenated Castor Oil, VP/VA Copolymer, Sodium citrate, Poloxamer 407, Ascorbic acid, Sodium metabisolfite, Sodium DNA, Aroma, Chlorhexidine digluconate, Sodium benzoate, Citric acid, C.I. 42,090	Curasept S.p.A.
Mouthwash CHX 0.20% without ADS	Aqua, Xilitol, Propylene glycol, PEG-40 Hydrogenated Castor Oil, VP/VA Copolymer, Sodium citrate, Poloxamer 407, Aroma, Chlorhexidine digluconate, Sodium benzoate, Citric acid, C.I. 42,090	Curasept S.p.A.
Gel CHX 0.50% with ADS	Aqua, Propylene glycol, Hydroxypropylcellulose, VP/VA Copolymer, PEG- 40 Hydrogenated Castor Oil, Chlorhexidine digluconate, Sodium DNA, Sodium acetate, Sodium citrate, Sodium metabisulfite, Ascorbic acid, Aroma, Acetic acid	Curasept S.p.A.
Gel CHX 0.50% without ADS	Aqua, Propylene glycol, Hydroxypropylcellulose, VP/VA Copolymer, PEG- 40 Hydrogenated Castor Oil, Chlorhexidine digluconate, Sodium acetate, Aroma, Acetic acid	Curasept S.p.A.

After this, every specimen was immersed in a black tea solution (prepared with 5 Lipton tea bags in 1L of hot water for 5min) for 1h.[3] Specimens were then rinsed with distilled water and the cycle saliva/CHX/tea was repeated for six times.[8]
At the end of the last cycle, specimens were rinsed with distilled water, gently air-dried and colour coordinates measured as described previously through the spectrophotometer (T_1).

Colour differences (ΔE) were calculated using CIELAB traditional formula (ΔE_{ab})[17] and CIEDE2000 modified formula (ΔE_{00})[13] as described below:

$$\Delta E^*_{ab} = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$

$$\Delta E^*_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)}$$

Manuscript was prepared following CRIS Guidelines (Checklist for Reporting In-vitro Studies).[18]

Statistical analysis

The statistician was blinded to the groups when performing the analysis. Statistical analysis was performed using STATA program version 17 (StataCorp LP). Means, standard deviations, counts, and percentages were used to summarise the data. Data from colour coordinates (CIE L*, a*, b*, C* and h°) were statistically analysed using one-way analysis of variance (one-way ANOVA) and Tukey's multiple comparison test with Bonferroni correction. A one-way ANOVA was performed to compare the effects of colour differences ΔE_{00} and ΔE_{ab} value among the materials. Paired t-tests were used to compare continuous measures between groups. A p-value of ≤ 0.05 was considered statistically significant.

RESULTS

Colour differences at T_0 and T_1 were calculated using ΔE_{ab} and ΔE_{00} different formulas and are presented in Table 3.

Table 3. ΔE_{ab} and ΔE_{00} mean values and standard deviations.

	ΔE_{ab}	ΔE_{00}
Premise		
PG	1.84 ± 0.7	1.34 ± 0.5
PG ads	1.21 ± 0.5	0.83 ± 0.4
PM	2.78 ± 1.3°	1.94 ± 0.8°
PM ads	2.71 ± 1.4°	1.84 ± 0.9°
PC	1.94 ± 0.7	1.28 ± 0.3§
Premise flowable		
FG	2.95 ± 1.3*°	1.53 ± 0.6°
FG ads	2.79 ± 1.3°	1.47 ± 0.7°
FM	2.63 ± 1.1°	1.46 ± 0.5
FM ads	2.60 ± 1.1°	1.37 ± 0.5°
FC	3.48 ± 1.0*°^	2.24 ± 0.6*°^&$£″

PM samples showed the highest colour change (ΔE_{ab}=2.78±1.3, ΔE_{00}=1.94±0.8), followed by PM-ADS specimens (ΔE_{ab}=2.71±1.4, ΔE_{00}=1.84±0.9). Packable composite brushed with gel showed the least colour modification, especially PG (ΔE_{ab}=1.84±0.7, ΔE_{00}=1.34±0.5) and PG-ADS blocks (ΔE_{ab}=1.21±0.5, ΔE_{00}=0.83±0.4).

Flowable-made specimens instead showed the highest colour change when treated with CHX-based gels, especially FG (ΔE_{ab}=2.95±1.3, ΔE_{00}=1.53±0.6) and FG-ADS (ΔE_{ab}=2.79±1.3, ΔE_{00}=1.47±0.7). Minor colour variations instead were reported with flowable blocks soaked in mouthwashes (FM: ΔE_{ab}=2.60±1.1 and ΔE_{00}=1.36±0.5, FM-ADS: ΔE_{ab}=2.63±1.1 and ΔE_{00}=1.37±0.5).

Concerning the CIELAB traditional formula (ΔE_{ab}), PM-ADS and FG-ADS samples showed a higher colour variation than, respectively, PG-ADS and PG. These differences were statistically significant (p=0.607 and p<0.001).

CIEDE2000 modified formula (ΔE_{00}) analysis instead reported statistically significant differences between PM-ADS and PG-ADS (p<0.001), and between FG-ADS and PG-ADS (p=0.001).

For both CIELAB and CIEDE2000 formulas, the packable composite control group showed similar values compared to samples treated with gels. Whereas the flowable composite control group behaved surprisingly differently, exhibiting dramatic colour changes far superior to all other samples analysed in the study.

DISCUSSION

This study evaluated the effects of four CHX-based products on the colour stability of two composite resins, one packable and one flowable composite. The tested products were CHX-based mouthwashes and gels, with and without the ADS system, and a control solution made of stimulated human saliva. Overall, the results show that both test and control solution produced variable colour changes on the surfaces of all specimens. The ability of CHX-based products to create pigmentation on the surfaces of composite restorations was also recently demonstrated by Ebrahimzade et al.[19] who immersed composite blocks in 0.2% CHX twice a day, for 1min, for 2 weeks. At the end of this period, through a spectrophotometer analysis, the samples showed an increase in a, b, and L values.

Also, Hasani et al.[20] in 2019 soaked different composite specimens in a 0.2% CHX solution, 1 min/day. After 1 month, all the samples presented significant colour changes, although this could also be due to the long-time treatment, not acceptable from a clinical point of view.

Flowable composite showed a greater colour change than packable composite. This is likely due to the fact that resin composites containing fewer filler particles are more prone to colour variations, as they might have higher water absorption which allows penetration of pigmenting agents, resulting in discolouration. This aspect was highlighted in a very recent systematic review, which aimed to investigate whether mouthwashes could affect the colour of direct composite resin restorations and concluded that mouthwashes are responsible of a modification in colour.[11]

Moreover, regarding the colour variation produced by CHX mouthwash compared to that produced by CHX gel, the results were found to be conflicting. Packable composite samples showed greater colour change when treated with mouthwash, while flowable composite samples showed greater colour change when treated with gel. In this regard, a systematic review conducted in 2015, in which the efficacy of a CHX gel compared to a CHX mouthwash was evaluated on plaque, bleeding, gingival inflammation, and tooth colour change scores, highlighted that the CHX mouthwash produces a greater colour change than the gel.[21] Since flowable composites are usually used as liners for cavities and are rarely in contact with the oral environment, the application of CHX gel instead of mouthwash would seem preferable to minimize the pigmentation of composite restorations.

Similarly to what happens on teeth and oral mucosa, products containing the ADS system (G ADS, M ADS) are able to produce less colour variation on composite restorations when compared to the respective products not containing the ADS system (G, M).

This aspect was also confirmed by a recent systematic review in which most of the studies analyzed showed that the ADS system determined a reduction of chlorhexidine-induced pigmentation.[10] This systematic review aimed to investigate whether the addition of an anti-pigmentation system (ADS) to chlorhexidine-based mouthwashes was effective in preventing tooth surface pigmentation, as well as to evaluate whether chlorhexidine combined with ADS maintained its effectiveness in reducing plaque and gingivitis.

Also a recently published paper aimed to assess colour changes in teeth and composite resins under the influence of CHX, with and without ADS. A total of 40 nanoceramic and nanohybrid composite specimens of size 10mm diameter and 0.5mm thickness were prepared, cured for 20s, and polished with a composite polishing kit. Two mouthrinses comprising CHX and CHX with ADS were used. Baseline colour values of composite resins were recorded using an ultraviolet spectrophotometer. After baseline spectrophotometric measurements, all the samples were subjected to the mouthrinses, and the post-immersion colour values of the samples were then recorded using the same spectrophotometer.

Reflectance values showed a statistically significant difference between CHX and CHX with ADS among nanoceramic and nano-hybrid composite samples.[22]

In daily clinical practice, there are several factors that can influence the colour stability of restorative-prosthetic materials. The present research, since it was performed in vitro, only partially simulates the conditions found intraorally, and for this reason, further in vivo clinical studies will be necessary to be able to obtain a more clinically oriented correlation with the clinical aspect.

In particular, contrary to what might have been expected, the control samples, subjected to a saliva/distilled water/tea washing cycle, showed greater colour changes than some test groups subjected to the washing cycle in saliva/chlorhexidine/tea.

These results contrast with those of other studies, which instead found a lower colour change of the control samples compared to the test samples.[9,23]

The study by Addy et al. presented a single-blind randomised design with the aim of determining the in vivo staining potential of a 0.02% chlorhexidine formulation and Listerine phenolic mouthwash compared to a negative control. Fifteen subjects underwent scaling and polishing to make their teeth free of plaque, calculus, and pigmentation, and tongue brushing was performed. Oral hygiene was suspended, and 8 times a day, the subjects rinsed first with the assigned formulation and then with 10mL of black tea. On the fourth day, tongue and teeth pigmentation was assessed. The results showed that the rinse with the 0.02% chlorhexidine formulation produced significantly more pigmentation on the teeth and tongue than that induced by Listerine or the negative control.[9]

Ten years later, the same study group published an in vitro study that aimed to determine whether two 0.2% and 0.12% chlorhexidine-based mouthwashes containing ADS were capable or not of binding the chromogens in the diet. These mouthwashes were compared to a negative control rinse (water). Six acrylic samples were assigned to each group and immersed in saliva for 2min, removed, washed in water and placed in the respective solution for another 2min, then removed and washed again in water, and finally immersed for 60min in tea. After removal from the tea solution, the samples were rinsed in water and allowed to dry and subsequently their optical density was detected using a spectrophotometer. The cycle was repeated until any tested solution produced an average optical density greater than 2.0. All chlorhexidine-based mouthwashes exceeded the optical density of 2.0 at 11 cycles, and significantly less pigmentation was observed for the negative water control.[23]

One of the major differences between the present study and the cited ones concerns the number of samples. It is likely that, having tested 200 composite resin samples, the results obtained from the present research could be considered more plausible than those obtained by analysing a much smaller number of specimens.

Differently from the above-cited studies findings, Carpenter et al.[24] found greater colour change in saliva-pretreated specimens when exposed to tea alone than when exposed to chlorhexidine and tea together. This in vitro study aimed to analyze the role of saliva in the pigmentation mechanism induced by chlorhexidine on hydroxyapatite samples. Using different combinations of tea, chlorhexidine, and saliva, the substances that bound to hydroxyapatite were analyzed by electrophoresis. The results showed that the salivary-acquired biofilm reduced the binding of chlorhexidine and tea when used in combination but, conversely, increased the binding of tea alone or chlorhexidine alone to hydroxyapatite.[24]

Therefore, to date, there is no uniform consensus in the scientific literature regarding this phenomenon.

Based on the findings of the present manuscript, the three initial null hypotheses were rejected.

CONCLUSION

This in vitro study showed how CHX-containing products are able to cause stains on restorative composite materials. In detail, discolouration is more likely to occur in flowable composites than packable composites. ADS-containing products cause fewer pigmentations than CHX products without ADS. It was not clear which material undergoes more likely discolouration processes because packable composites showed more staining after mouthwash treatment, whereas flowable composites underwent higher discolouration after treatment with gels.

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CHAPTER 7

RESEARCH ARTICLE

Single- and group-shade composites color-match evaluation through visual and instrumental analysis

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Keywords: single-shade resin composite, group-shade resin composite, color match, instrumental analysis, artificial intelligence.

ABSTRACT

Objective: The aim of the present randomized controlled trial was to evaluate color-matching properties of single-shade (SS) versus group-shade (OM) composites. Group-shade composites are available in 3 to 5 shades, and each shade is indicated for a limited range of VITA Classical shades.

Materials and Methods: Sixty molars were divided into 3 subgroups, according to the tooth-color correspondence provided for the tested group-shade composite: L including A1, B1, B2, C1 and D2 shaded teeth (n=20); M including A2, A3, C2, D3 and D4 teeth (n=20); D including A3.5, A4, B3, B4, C3 and C4 teeth (n=20). Standardized class V cavities (4x4x2mm) were prepared with each subgroup containing 10 single-shade (OM-Omnichroma) and 10 group-shade composite (SS-SimpliShade) treated specimens. Teeth were restored with Light-shaded SS, Medium-shaded SS, and Dark-shaded SS respectively in L, M and D subgroups. Tooth/restoration ΔE_{00} color differences were calculated at 24h (T_1), and after 7 days (T_2) through the use of a spectrophotometer. A visual analysis was performed after 14 days (T_3) and, another instrumental method to evaluate color differences between tooth and resins by means of a digital camera, named computer vision algorithm (CVA) analysis, was performed at 3 weeks (T_4). Student's t test was used to compare the two groups within each subgroup and time point and an ANOVA test was used to compare the values between subgroups, within each group and time point.

Results: Instrumental analysis at T_1 showed higher mean ΔE_{00} for OM compared to SS ($p<0.05$), within each subgroup. Within OM specimens, significant mean ΔE_{00} differences were found at T_2 between D (8.24±1.85) vs L (5.65±2.24) ($p=0.007$) and vs M (6.49±2.5) ($p=0.03$) respectively. Within SS specimens, significant differences ($p=0.034$) were found between L (4.16±2.19) and M (2.17±1.05) at T_1. Visual analysis reported significant difference ($p=0.0153$) between L-SS (1.03±1.04) and L-OM (1.97±0.78). CVA analysis showed higher value for OM than SS.

Conclusions: Overall, group-shade composites showed lower ΔE_{00} with respect to single-shade composites, independently of the investigation method employed. Nonetheless, both materials seem to be able to achieve satisfactory esthetic performance.

INTRODUCTION

Esthetic restorations, such as direct resin-composite restorations, are considered successful primarily when a precise shade matching between tooth and material is obtained,[1] and the human eye is not able to detect the difference between the two.[2] However, since composites present different color scales, it remains a challenge for the dentist to achieve a perfect color match between the restoration and the surrounding tooth color.[3] A layering technique has always been suggested as the best method to obtain proper color match, but it requires high technical skills, and the color choice is operator-dependent and often time-consuming.[4]

In oral cavity there are several factors able to influence the way in which color match between two structures is perceived, including the morphology of the tooth, the area in which the tooth is restored, and the influence of the surrounding soft tissues. Recently, there has been a tendency to reduce the complexity of restorative dentistry treatments, reducing the number of composite masses to be used and consequently the operator-dependent technical sensitivity.[5]

In restorative dentistry, the terms Chameleon Effect or Blending Effect describe the ability of a material to acquire a color similar to the surrounding tooth structure. This property has enabled the introduction of innovative composite resins that aim to simplify color selection and reproduction.[2,6]

The International Commission on Illumination (CIE) also deals with colorimetry of dental materials, introducing major color systems, lighting schemes and color difference (ΔE) concepts.[7] When considering the CIELab color space (L*: brightness; a*: red-green axis; b*: yellow-blue axis), the formula ΔE_{ab} was used as a standard parameter for the color difference between two objects.[8] Later, in order to obtain a better correlation with visual perception, CIE and the International Organization for Standardization (ISO) jointly recommended the use of the CIEDE2000 color difference formula to calculate the total color difference. While also based on the CIELab color space, several studies have concluded that the CIEDE2000 formula better reflects the color differences perceived by the human eye compared to the previous formula.[7,9,10]

Recently, two different types of universal composite resins have been developed and introduced into the market: single-shade and group-shade (or cloud-shade) composites. These materials can show the so-called blending effect that refers to the ability of a material to acquire a color that is similar to that of its surrounding structures.[11] Moreover, blending effect counteracts or attenuates color mismatches, and therefore the lack of suitable shade in selected restorative dentistry materials.[8,12]

The term "single-shade" is used to indicate a composite material available in one single universal shade, developed to blend with all 16 classic VITA shades, thus providing a shade match for each tooth color.[5] The term "group-shade" instead indicates a composite resin available in few shades (from 3 to 5), with each shade used for a limited range of VITA Classical shades.[5] Finally, the term "multi-shade" refers to traditional composites, available in different shades divided between enamel and dentin, each of which corresponds to a single VITA Classical shade.[13]

Single-shade resins had been firstly introduced aiming to provide a color harmony between tooth and restoration with one single composite shade that is able to reproduce the totality of different colors available.[3,12,14] In a recent study, the technology underlying Omnichroma blending effect ability was defined.[2] This single-shade material incorporates uniformly spherical particles that are evenly arranged and spaced to facilitate the transmission of light through the restoration, which then reflects the color of the surrounding cavity and produces improved mixing. Omnichroma comes in only one shade as its structural color should allow a single shade to match any tooth color. The particle size and structure of Omnichroma are designed such that its translucency increases following photo-polymerization. Moreover, according to the manufacturer, it does not contain pigments or dyes, and its color features are based on its structural properties and smart chromatic technology that controls the optical properties of the composite resin.[11]

Group-shade composites instead were successively developed providing few (usually three to five) shades that have the intent to cover the full range of VITA color shade of natural teeth.[1] These features were obtained thanks to modified optical characteristics that let single-shade and group-shades composites be able to reproduce the surrounding tooth color.[15] These innovative composites aim to be very effective in reducing chair-side time by decreasing the time spent on shade selection.[11,12,14]

In esthetic dentistry, it is possible to precisely evaluate color differences between the restoration and the tooth either visually or through an instrumental analysis. Visual shade assessment by the aid of a shade guide is a subjective procedure and could be affected by several factors such as lighting conditions, observers' skills, age, and gender. Despite this, the visual assessment method is still the most common shade-taking clinical procedure.[16] Taking advantage of the objective outcomes of an instrumental assessment, many instruments have been proposed for shade-taking, such as spectrophotometers, colorimeters, intra-oral scanners, and even digital cameras or smartphones.[17]

Spectrophotometers are able to detect VITA scale values and all CIELab (L^*, a^*, and b^*) coordinates: L^* stands for lightness, represented on a scale of 0 (black) to 100 (white); a^* represents the hue and chroma values on the red (+) and green (–) axis; b^* instead on the yellow (+) and blue (–) one.[5] Selected data provided by the spectrophotometer can also be used to calculate the color differences between tooth and composite, through the ΔE_{00} formula developed by the Commission Internationale de l'Eclairage (CIE) as CIEDE2000 color-difference formula.[7,10,18]

By means of a digital camera, another instrumental method to evaluate color differences between tooth and resins is the Computer Vision Algorithm (CVA). These procedures and techniques are used to enable computers to understand and interpret visual data, such as images and videos, in order to perform tasks like object recognition, image segmentation, and motion detection.[19]

There has been a growing tendency of dental industry to simplify the choice of the correct shade of a restoration, and many universal composites that aim to achieve this goal4 have been launched to the market recently. Consequently, the main aim of the present study was to instrumentally and visually evaluate the color match of a single-shade composite resin placed on simulated cavities within extracted human teeth, compared to a group-shade composite resin. Therefore, the null hypothesis was that there would be no difference in color match between tooth and restorations performed with "single-shade" or "group-shade" composites, from an instrumental and a visual point of view, for each subgroup. Moreover, a comparison between subgroups within each group and at different time points was performed as a secondary aim.

MATERIALS AND METHODS

Sixty human sound molars extracted for periodontal or orthodontic reasons without restorations were selected according to the University of Bologna Ethical Committee approval (protocol N°:71/2019/OSS/AUSLBO) and stored in distilled water at 37° until processing them.[8,12] Teeth with caries, cracks, demineralized surfaces, or opaque lesions were not included. Periodontal ligament and gingival tissues were gently removed using a scalpel and ultrasonic bath. Natural tooth shade was determined on the buccal surface according to the VITA classical A1–D4 shade system in the base shade determination mode, using a VITA Easyshade Compact V spectrophotometer (VITA Zahnfabrik, Bad Sackingen, Germany).[11]

After this first evaluation, according to the tooth-color correspondence provided for the tested group-shade composite, teeth were sorted into three subgroups, each including 20 teeth. Subgroup L (Light) included teeth with shades A1, B1, B2, C1, D2; subgroup M (Medium) included teeth with shades A2, A3, C2, D3, D4; and subgroup D (Dark) included teeth with shades: A3.5, A4, B3, B4, C3, C4.

Specimen preparation

Class V cavities of 4×4mm width and 2mm depth were prepared on the facial surfaces of the selected teeth[3] using a water-cooled dedicated diamond bur (ISO 806 314 001 534 Hager & Meisinger GmbH, Neuss, Germany) by one calibrated operator. A new bur was used for each preparation,[11] and each cavities' width and depth were verified using a CP15 calibrated periodontal probe (Schwert GmbH, Seitingen-Oberflacht, Germany). Each specimen was rinsed with an air–water spray and dried with compressed air.
Within each of the three subgroups, half of the specimen (N=10) were treated with a single-shade resin composite (OM - Omnichroma, Tokuyama, Japan), and the other half (N=10) with a group-shade resin composite (SS - SimpliShade, Kerr, Italy). Specification of the resin composites used are described in Table 1.

Table 1. Composites used in the present study (OM=Omnichroma; L-SS=SimpliShade Light; M-SS=SimpliShade Medium; D-SS=SimpliShade Dark).

GROUP	COMPOSITE	FILLER %	ORGANIC MATRIX	SHADES	LOT N.
OM	Omnichroma, Tokuyama, Yamaguchi, Japan	79.0 wt%/68.0 vol%	UDMA, TEG-DMA	-	113E53, 070EY1
L-SS	Kerr, Scafati, Italy	81.0 wt%/64,5 vol%	BisGMA, BisEMA, TEG-DMA	A1, B1, B2, C1, D2	9216005
M-SS	Kerr, Scafati, Italy	81.0 wt%/64,5 vol%	BisGMA, BisEMA, TEG-DMA	A2, A3, C2, D3, D4	8464865
D-SS	Kerr, Scafati, Italy	81.0 wt%/64,5 vol%	BisGMA, BisEMA, TEG-DMA	A3.5, A4, B3, B4, C3, C4.	9209218

At the end of this procedure, one group (n=30) was made of OM treated specimens and one group (n=30) of SS treated specimens, each containing 10 teeth, according to the initial shade subgroup (Table 2).

Table 2. Specimens' subdivision (L=Light-shaded teeth; M= Medium-shaded teeth; D=Dark-shaded teeth; OM=Omnichroma; SS=SimpliShade).

	VITA A1, B1, B2, C1, D2 L (n=20)	VITA A2, A3, C2, D3, D4 M (n=20)	VITA A3.5, A4, B3, B4, C3, C4 D (n=20)
OM	L-OM (n=10)	M-OM (n=10)	D-OM (n=10)
SS	L-SS (n=10)	M-SS (n=10)	D-SS (n=10)

The OM group cavities were treated with total etching (H_3PO_4 39% Etching Gel HV, Tokuyama, Japan) and a universal adhesive (Universal Bond II, Tokuyama, Japan), then restored using the single-shade composite, and finally cured at 1400mW/cm^2 with a middle-intensity blue LED light-curing unit (Mectron Starlight Pro, Genova, Italy) for 20s, as indicated by the manufacturer (Figure 1).

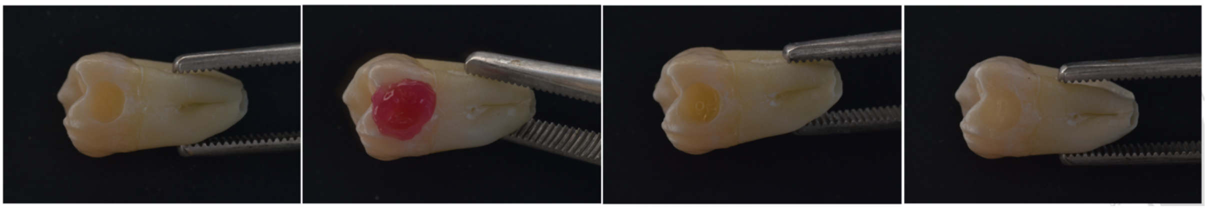

Figure 1. Operative steps performed on a specimen treated with OM (cavity, etching, adhesion procedures, restoration).

On the SS group cavities instead, after total etching (H_3PO_4 37.5% Optibond Gel Etchant, Kerr, Scafati, Italy), a universal bonding agent (OptiBond Universal, Kerr, Scafati, Italy) was applied before performing restoration using the tested group-shade resin composite. Following manufacturer's instructions, L teeth were restored with the Light shaded SS composite resin, M teeth with the Medium shaded SS composite resin (Figure 2), and D with the Dark shaded SS composite resin.

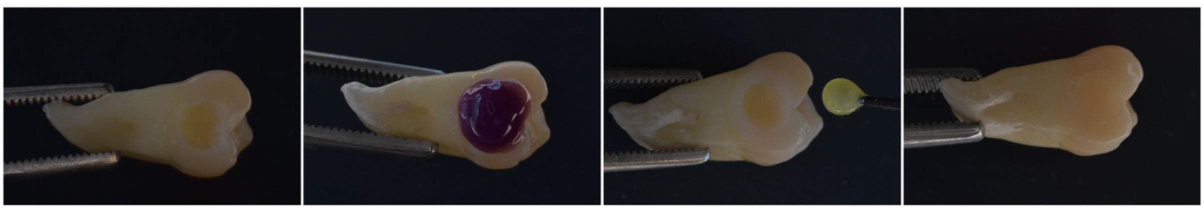

Figure 2. Operative steps performed on a specimen treated with SS (cavity, etching, adhesion procedures, restoration).

All restorations were finally cured for 20s using the previously mentioned LED light device. All specimens were then contoured, finished e polished through finishing discs (OptiDisc Kerr, Scafati, Italy) and brushes (OptiShine Kerr, Scafati, Italy), using a blue ring handpiece at 5000rpm speed.

Instrumental evaluation

Specimens were stored in distilled water at 37°C until instrumental evaluations made at T_1 (24h after the restoration procedures), and at T_2 (7 days after the restoration procedures).[20]

The color match between tooth and restoration was evaluated using a spectrophotometer (VITA Easyshade V, VITA Zahnfabrick, Bad Sackingen, Germany) on a grey neutral background. Color parameters of the restorations were measured placing the spectrophotometer's measuring tip perpendicular to the restoration.[5]

For each specimen, measurements were taken at the center of the restoration and on the tooth surface at a distance of 1mm from the border between tooth remnant and restoration.[8,12,21] The device was calibrated every three measurements.

The CIELab color coordinates (L* = brightness, a* = green-red coordinate, and b* blue-yellow coordinate), defined by the International Commission on Illumination (CIE), chroma (C*), and hue (h°), were obtained with the spectrophotometer.

The CIEDE2000 color differences (ΔE_{00}) between tooth and restoration were calculated using an excel spreadsheet for implementing the CIELab color difference formula as suggested by Sharma.[7]

$$\Delta E_{00}^{*} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)}$$

ΔL', ΔC', ΔH' are the differences in lightness, chroma, and hue between tooth and restoration, respectively. RT is a rotation function that explains the interaction between the chroma and hue differences in the blue region. SL, SC, and SH are the weighting functions, whereas KL, KC, and KH are the correct terms to be adjusted according to the experimental conditions. The parametric factors KL, KC, and KH are the correction terms for variation under experimental conditions and are all set at 1.0, under reference conditions determined by the CIE technical report.[22]

After having calculated ΔE_{00} values of each specimen, also the mean ΔE_{00} for each group was obtained.

Visual evaluation

Specimens were stored in distilled water at 37°C until visual evaluation made at T_3 (14 days after restoration procedures).

Visual color assessments were made by 12 dental professionals—4 each of graduate students, undergraduate students, and faculty.[23] All evaluators were tested for color deficiency using Ishihara's Test for Color Blindness.[24] All evaluators passed the test for color match competence in dentistry according to ISO/TR28642. A viewing booth was used for visual comparisons, with 0/45° optical geometry and D65 illuminant. After a period of adaptation by observing the walls of the light booth, observers compared the color of the specimens, positioned in edge contact on the floor of the viewing booth.[23]

The evaluators were allowed 25 seconds to rank the shade match of the composite restorations with the surrounding tooth structure.[5] Evaluators were blind to all specimens group of belonging. The color differences between each tooth and restoration were graded from 0 to 4, using a scale where level “0” means excellent match; “1”, very good match; “2”, not so good match (border zone mismatch); “3”, obvious mismatch; and “4”, huge (pronounced) mismatch.[4]

Lastly, the mean score for each specimen was calculated and from these data the mean score for each group was obtained.

Evaluation through computer vision algorithm (CVA)

Specimens were stored in distilled water at 37°C until evaluation through CVA made at T_4 (21 days after restoration procedures).

A digital photograph was taken for each sample, using a Nikon D90 reflex camera (Tokyo, Japan) equipped with an AF-S Nikkor 18-105 mm f/3.5-5.6G lens (Nikon, Tokyo, Japan) and a double speedlight flash SB-R1C1 (Nikon, Tokyo, Japan). The camera was mounted on a MK 394-PQ tripod (Manfrotto, Cassola, Italy) to stabilize the camera in a standardized 90° position, and the flashes were positioned at 90° to the ground, each on either side of the camera lens.[4]

The root portion of each sample was fixed on a Protrain support (Simit, Cernusco sul Naviglio, Italy), inside a Godox LST80 photographic softbox (Shenzhen, China), positioning the buccal face of the sample and the restoration perpendicular to the camera lens.

All images were acquired with the same standardized parameters: exposure 1/125 of a second, f(25), ISO (200), flash set in manual mode at an intensity equal to ½ of the maximum capacity, distance (~15cm), 1:1 focus on RAW format. A gray reference-card was used for white balance and all images were saved to an SD drive (Sandisk, Milpitas, CA, USA) and then transferred to a computer.[4]

The acquired images of each sample were refined using Adobe Photoshop. A layer mask was applied to each image to isolate the crown of the photographed sample from the rest of the original image, positioning the image of the coronal portion of the tooth (including the restoration) on a new layer with a PNG-format. This procedure allowed to eliminate the pixels relating to the background of the softbox, Protrain support and root. Using the "Magnetic Lasso Tool" function, the area containing the pixels of the restoration was delimited within each image; after this, a new layer mask was applied. This procedure made it possible to eliminate the pixels related to the dental tissue surrounding the composite resin restoration (Figure 3).

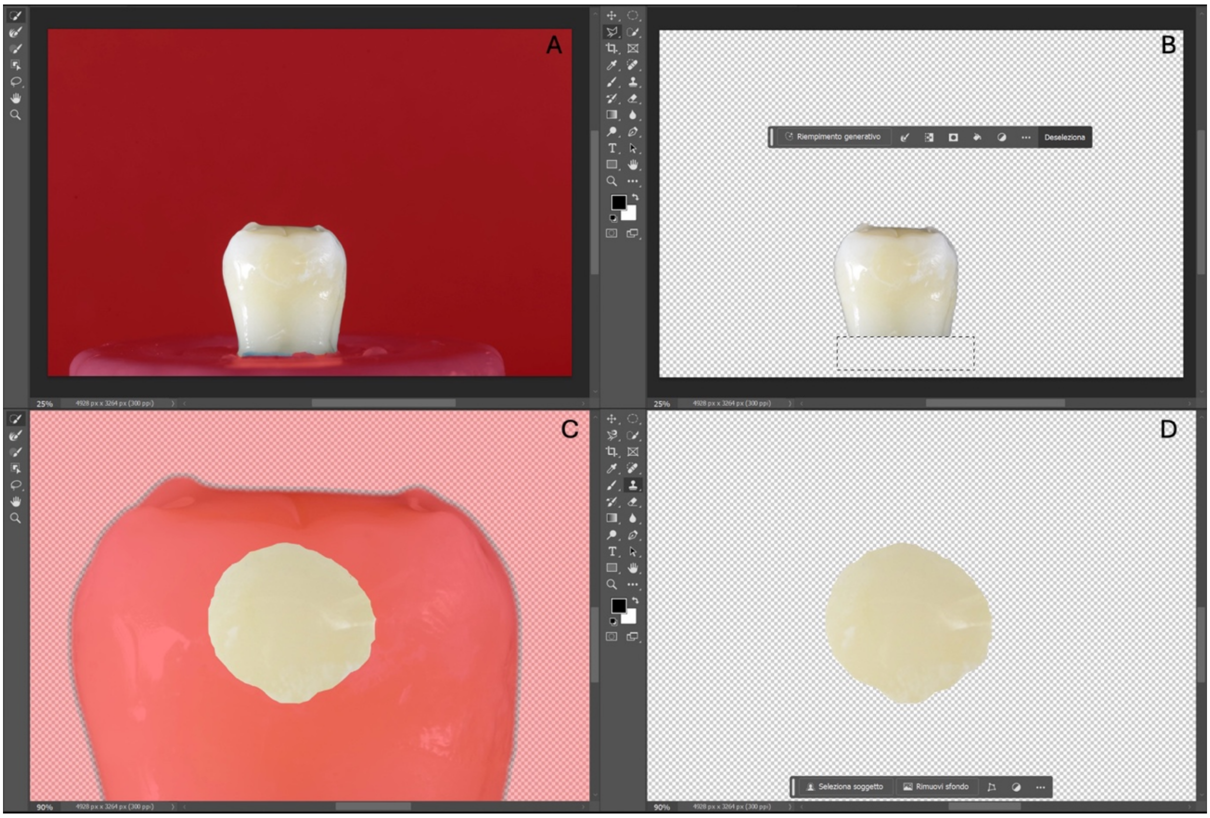

Figure 3. Adobe Photoshop workflow. A: Initial layer mask creation to isolate the whole tooth from the rest of the image; B: Placement of the crown on a new layer with a PNG-format; C: Delimitation of the area containing the pixels of the restoration; D: Elimination of the pixels related to the tooth surrounding the restoration.

Ultimately, from the original image, four images were obtained for each sample: 1) an original image captured with a reflex camera, 2) an image containing the crown of the tooth including the restoration in PNG format, 3) an image of the composite restoration isolated from the surrounding dental tissue in PNG-format, and 4) an image created by the algorithm of the tooth without the restoration (Figure 4).

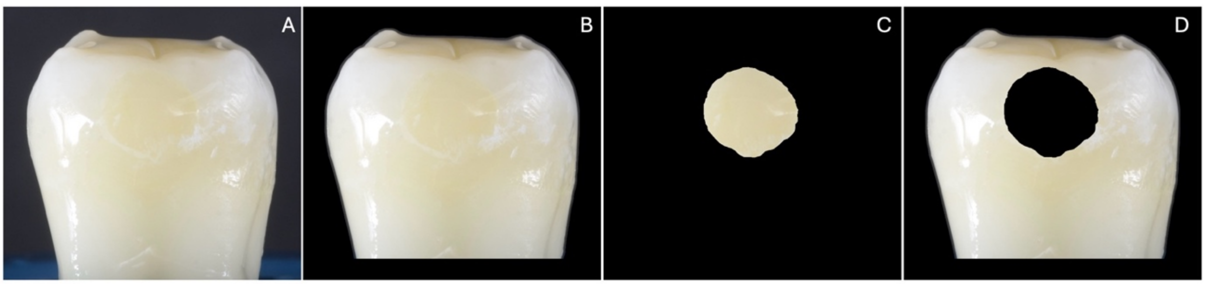

Figure 4. Images used for vision-algorithm analysis. A: Original image; B: PNG-format image of the crown and the restoration; C: PNG-format image of the restoration isolated from the surrounding dental tissue; D: image of the tooth without the restoration created by the algorithm.

Pictures were analyzed by presenting each sample's images to a CVA. A CVA refers to a series of instructions and operations related to images or videos ("vision"), which a machine can autonomously execute. The Python programming language is used to develop AI and other automated algorithms, such as the one used in this study. In this case, the CVA was defined as follow: the data was converted into CIEDE2000 coordinates (L*, a*, b*, C*, h°), measured into the pixels of the restoration and in the residual dental tissue. The input to the algorithm was composed of 3 images: 1) the original RGB image (red, green, blue, the basic color channels in computing), 2) the corresponding tooth layer mask, and 3) the composite resin restoration mask. The data was converted from RGB to CIEDE2000 coordinates (L*, a*, b*), then the average pixel intensity was computed over both restoration and residual dental tissue images. This computation was performed on channels L*, a*, b*. Starting from the average pixel intensities, the average C* and h° value was computed.

Once the CIEDE2000 coordinates were obtained, similarly to what was done for the instrumental analysis, the ΔE_{00} between tooth and restoration was computed for each sample,[7] and the average ΔE_{00} of each subgroup was calculated.

Statistical analysis

According to the RoBDEMAT risk of bias tool for pre-clinical dental research,[25] the sample size (n=10) was chosen according to a previously published study.[26] The normal distribution of data was evaluated with the Shapiro-Wilk test. The comparison of data between OM and SS groups, for each subgroup and time point, was performed with the Student's t test when data were normally distributed, or with the Wilcoxon rank sum test if not normally distributed. Within each OM and SS group and time point respectively, data were compared with the ANOVA test followed by Bonferroni post hoc if normally distributed, or with the Kruskal-Wallis test followed by Dunn post hoc if not normally distributed. Within each OM and SS group, the comparison of data for each subgroup between time T_1 and T_2 was performed with the paired Student's t test if normally distributed, or with the Wilcoxon matched-pairs signed-rank test if not normally distributed. A linear mixed-effect model was also performed, including the group, subgroup and time as fixed effect and the teeth as random. Given the ordinal nature of the evaluations, Gwet's AC and the corresponding 95% confidence interval (CI) were used to measure the inter-rater reliability (IRR) between the 12 examiners.[27] Gwet's AC handles multiple raters, and it also handles chance agreement, especially in the presence of imbalanced marginal distributions, the main cause of the "paradox" of Cohen's Kappa, or small sample sizes.[28] The agreement was classified as poor for values less than zero, slight for 0 to 0.20, fair for 0.21 to 0.40, moderate for 0.41 to 0.60, substantial for 0.61 to 0.80, and almost perfect for 0.81 to 1.29 Stata 18.0 software (StataCorp LLC, Texas, USA) was used for the analysis, all p values <0.05 were considered significant.

RESULTS

Mean ΔE_{00} and standard deviation for each group and subgroup were calculated at T_1 and at T_2 and compared. Results are detailed in Table 3.

Table 3. Mean ΔE_{00} values ± standard deviation at T_1 and T_2 by subgroup (OM=Omnichroma; SS=SimpliShade; L=Light-shaded teeth; M= Medium-shaded teeth; D=Dark-shaded teeth).

T_1		
	OM	SS
L	7.17 ± 1.57*	4.16 ± 2.19[a]
M	7.34 ± 3.16*	2.17 ± 1.05
D	8.05 ± 1.27*	3.27 ± 1.44
T_2		
	OM	SS
L	5.65 ± 2.24*	3.63 ± 1.95
M	6.49 ± 2.50*	3.59 ± 2.80
D	8.24 ± 1.85*[,b]	3.32 ± 0.90

Statistically significant differences between groups ($p<0.05$) were shown at T_1 and T_2. L-OM showed a higher mean ΔE_{00} (7.17±1.57) compared to L-SS (4.16±2.19) (p=0.002), as well as M-OM (7.34±3.16) compared to M-SS (2.17± 1.05) (p=0.0001), and D-OM (8.05±1.27) compared to D-SS (3.27±1.44) (p=0.0000003). At T2 L-OM (5.65±2.24) presented a higher mean ΔE_{00} than L-SS (3.63± 1.95) (p=0.045), as well as M-OM (6.49±2.5) compared to M-SS (3.59± 2.8) (p=0.025), and D-OM (8.24±1.85) compared to D-SS (3.32±0.9) (p=0.00005).

Within the OM group, the comparison of mean ΔE_{00} between subgroups didn't show statistically significant difference ($p>0.05$) at T_1, whereas a statistically significant difference was found for D-OM when compared with L-OM ($p=0.007$) and M-OM ($p= 0.03$), at T_2. On the contrary, within the SS group, only at T_1 a significant difference was found between the L-SS and M-SS subgroups ($p=0.034$).

The paired analysis of ΔE_{00} variation of each subgroup between T_1 and at T_2 for both OM and SS groups didn't show any significant difference ($p>0.05$).

The results from the linear mixed model showed a significant difference between groups, when taking into account the different subgroups and the two time points.

For visual evaluation of color matching, the Gwet's AC was 0.47 (95%CI 0.43 to 0.52), showing a moderate agreement between examiners. Results of the visual evaluation scores for each group and subgroup at T_3 are reported in Table 4.

Table 4. Mean scores ± standard deviation obtained after visual evaluation by subgroup.

T_3	OM	SS
L	1.97 ± 0.78*	1.03 ± 1.04
M	1.35 ± 0.46	1.25 ± 0.64
D	1.36 ± 0.63	1.69 ± 0.72

Only in the L subgroup a statistically significant difference ($p=0.0153$) was found between SS and OM groups, this being the highest (1.97±0.78 vs 1.03±1.04). No significant differences were found in the M and D subgroups between SS and OM.

The ΔE_{00} values detected within each group and subgroup with the evaluation through CVA at T_4 are reported in Table 5 as mean and standard deviation.

Table 5. Mean ΔE_{00} values ± standard deviation obtained after evaluation trough vision-algorithm, by subgroup. (OM=Omnichroma; SS=SimpliShade; L=Light-shaded teeth; M= Medium-shaded teeth; D=Dark-shaded teeth)

T_4	OM	SS
L	4.61 ± 1.81	4.32 ± 1.44
M	4.74 ± 2.64	3.86 ± 1.78
D	3.75 ± 1.33	2.98 ± 1.58

The comparison between groups showed that, for each subgroup, OM had always a higher value than SS; however, no statistically significant differences emerged ($p>0.05$). When comparing the subgroups within each group, the D subgroup for both OM and SS groups showed a lower ΔE_{00} value than M and S subgroups; however, this difference was not significant ($p>0.05$).

DISCUSSION

The instrumental analysis revealed a statistically significant difference between the single-shade composite resin and the group-shade composite resin, which showed lower ΔE_{00} values for each range of VITA Classical values at both T_1 and T_2. Furthermore, a difference in the performance of the two materials emerged when considered individually: in fact, the single-shade composite resins showed better performance when used on teeth with light or medium colors compared to darker colors, while the group-shade composite resins showed better results when used on medium-colored teeth compared to light-colored teeth.

As regards the visual analysis, a difference emerged between the two composites only for the lighter colors of the VITA Classical scale, i.e. in the Light group. This visual analysis was performed by 12 evaluators that could have certainly been influenced by a subjective component, and this influence could have conditioned their answers and therefore the results.[12] For both clinician and patient, the most important component of the final clinical esthetic result is the visual one. An instrumental analysis in addition is meant to compensate the limits of the visual analysis.

Several studies have examined the factors that influence the translucency and the blending effect of composite resins.[11,30-32] In these materials, a positive correlation between translucency and blending effect has been observed: as the former increases, the latter becomes more pronounced.[30]

Several aspects that influence the translucency of a composite resin have been described in a recent article.[11] Relatively to the type of resin used, those based on Bis-GMA demonstrated superior translucency compared to those based on UDMA/TEGDMA. Several studies have in fact confirmed a positive correlation between the amount of Bis-

GMA in the composite resin and its translucency, suggesting that increasing the Bis-GMA content in a resin improves its translucency.[31,32]

Filler content also plays a significant role in the blending effect achievement of a composite resin. Suh et al. found a direct proportional relationship between blending effect and filler, with a notable increase in the former when filler content reached 80%.[33] This is particularly relevant for the group-shade composite resin of the present study (containing Bis-GMA), characterized by a filler percentage of 81% by weight. There would therefore be a particular propensity to obtain a proper blending effect of the "group-shade" of the present study, unlike the single-shade resin based on UDMA and TEGDMA.

A recent in vitro study tested the color match on 40 teeth restored on the buccal side with a standardized cavity using different composite resins: two single-shade (Omnichroma and Vittra APS Unique) and one multi-shade (Filtek Z250).[22] An instrumental analysis was performed using a spectrophotometer (Easyshade Advance 4.0), followed by a visual analysis. The single-shade composite resins showed higher ΔE_{00} and ΔE_{ab} values than the traditional multi shade composite resin.

Curiously, the average ΔE_{00} value detected on the samples restored with Omnichroma was found to be higher when compared with the average value detected on the samples treated with the same material in the present study. The mentioned discrepancies, given the same material used, could be justified by two main differences between the two study protocols. The present study uses a higher number of samples than the study by Da Silva et al, decreasing the standard error, therefore a smaller variability of the data. Furthermore, in the present study a more modern spectrophotometer, released in 2017, was used compared to the one used by Da Silva et al, available on the market since 2014. This difference could have influenced the color detection as a more modern device should ideally be more updated and performing from a technological point of view.

Another group of authors compared the aesthetic performances of single shade and multi shade composite resins, even though the multi shade composite resins were used exclusively in shade A2, despite the restoration being performed on teeth with different shades of color.[34] The results showed a lower average ΔE_{00} value for the single-shade composite resin when compared to that of the multi-shade composite resin. The choice of using a single mass, of a single color, of the multi-shade composites could be the explanation for the higher ΔE_{00} values observed for these resins compared to the single shade ones. It is likely that using only one shade of a multi shade system did not allow the entire VITA Classical shade scale to be replicated.

In a recently published study evaluating the color match of four single shade resins applied to extracted human incisors, ΔE_{00} values detected in samples treated with Vittra APS Unique composite resin were found to be lower than those treated with Omnichroma, suggesting a better esthetic performance of the latter.[11] Since the study did not include a control group, it is somehow challenging to compare the results a direct comparison with group shade or at least multi shade composite resins was not possible.

To date, there are no scientific studies in the literature that have compared the esthetic performance in terms of color-matching of group-shade in relation to single-shade composite resins.

Unlike multi-shade and single-shade resins, group-shade composites represent a compromise between the previous ones: they simplify the choice of color thanks to their blending effect, leaving the clinician to determine a range of VITA Classical values, unlike multi-shade composite resins, which feature different enamel, dentin and opacifying shades.[13] This variability of available shades forces the clinician to adopt layering techniques, having to use numerous composite masses which must blend well with each other.[35]

The fact of being able to pre-determine a range of VITA values to be achieved seems to be able to improve the performance of composite resins that make use of blending effect, such as group-shade resins. In fact, in the present research project, the instrumental analysis showed average ΔE_{00} values of the subgroups treated with group-shade composite resins that were lower when compared respectively to the subgroups treated with single-shade composite resins with the same initial tooth color and at T_1 that T_2.

The instrumental analysis also highlighted different performances of the two systems in relation to the group they belonged to. If the subgroups treated with group-shade were compared with each other, unlike the initial color of the tooth, a lower ΔE_{00} emerged in the samples with medium VITA Classical values (A2, A3, C2, D3, D4) compared to those with lighter VITA Classical values (A1, B1, B2, C1, D2). When the subgroups treated with the single-shade system were compared with each other, unlike the initial color of the tooth, a higher ΔE_{00} emerged in the samples with darker VITA Classical values (A3.5, A4, B3, B4, C3, C4) compared to those with lighter VITA Classical values (A1, B1, B2, C1, D2, A2, A3, C2, D3, D4).

Similarly, other research has also reported better color matching of single-shade resins when used to treat substrates with light shades. For example, one study group tested three different composites: Omnichroma, Tetric EvoCeram and TPH Spectra ST by restoring 75 occlusal cavities on resin teeth.[5] The ΔE_{00} of all restorations was evaluated instrumentally using the VITA Easyshade V spectrophotometer and by visual analysis. Tetric EvoCeram, a traditional "multi shade" composite, showed similar ΔE_{00} values in all cases, regardless of the initial VITA shade of the resin teeth. Omnichroma and TPH Spectra ST, a single shade and a group shade composite respectively, showed lower ΔE_{00} values on teeth with lighter VITA shades. Visual analysis showed the best color matches of Tetric EvoCeram with darker resin teeth (VITA C2 and D3), and of TPH Spectra ST with lighter resin teeth. The authors therefore concluded that color match appears to be composite- and shade-dependent. Regarding Omnichroma, the results of this study showed better esthetic performances when used to treat cavities with light colors of the VITA Classical scale (A2, B1 and B2). This data is partially in agreement with our study, in which Omnichroma esthetic behavior was better when used to treat samples with light and medium VITA Classical shades (A1, B1, B2, C1, D2, A2, A3, C2, D3, D4), compared to when used to treat samples with dark VITA Classical shades (A3.5, A4, B3, B4, C3, C4). However, there was no statistically significant difference between the ΔE_{00} values detected between the light samples (A1, B1, B2, C1, D2) and the medium samples (A2, A3, C2, D3, D4).

In the present study, differently from what was demonstrated by Kobayashi et al in 2021, esthetic performance of OM samples showed inferior ΔE_{00} mean values, regardless of the initial color of the sample.[35] Taking into consideration what was previously stated in relation to the transmission of light through this specific material, the fact that it does not contain any pigments or dyes, and the use of a spectrophotometer whose operation is based on the use of a white LED light, it could be deduced that this light is diffused within the material during the instrumental analysis, causing the detection of CIEDE2000 coordinates which are particularly referable to lighter VITA Classical coordinates. These aspects could determine the lower ΔE_{00} registered in the lighter samples.

On the other hand, group-shade resins are characterized by a Bis-GMA containing filler, that provides the material good properties in terms of translucency, increasing the blending effect. In addition, it contains pigments and dyes, which seems to lower L* values compared to specimens treated with OM. These two features could be responsible for providing these composites a better blending effect ability.

Analyzing ΔE_{00} formula from a mathematical point of view, it is notable how it depends on the CIEDE2000 coordinates L*, a*, b*, C*, h°. In particular, the results of the instrumental analysis of the present study showed statistically significant differences between the values of the L* coordinate detected at the center of the filling of different subgroups with the same color.

Machine learning algorithms can be trained using either supervised or unsupervised methods.[36] In supervised learning, each data point in the training dataset includes input-output pairs, allowing the model to learn from inputs where the corresponding output is already known. The aim of this training process is to understand the relationship between the input and output, enabling the model to predict the output for new test data inputs.[37]

The Python computer language is used to program artificial intelligence and other automated algorithms, such as the one used in this research protocol. The analysis method chosen in this study protocol aims to emphasize a substantial difference with the instrumental analysis: the possibility of comparing each pixel (on average a surface of 0.25mm^2 inside a screen) with all the other pixels belonging to the dental tissue or filling. This comparison allows ΔE_{00} analysis not to be confined only to the two points detected on the surfaces by the spectrophotometer, rather to consider the entire surface of the sample.

CVA evaluation revealed ΔE_{00} values that were significantly higher for the subgroup containing medium color samples treated with the group-shade resin and significantly lower for the subgroups containing dark, medium and light samples treated with single-shade composite, when compared to the values obtained from the instrumental analysis.

A limitation of this study is the choice to use standardized photography in the CVA. Of course, the use of a polarized light could have removed reflections and unregular tooth surfaces, but this decision has been made to replicate more accurately clinical conditions.

The present manuscript has highlighted how group-shade composite restorations present a better color-match than those performed with single-shade resins, for all VITA Classical scale ranges, when measured by means of a spectrophotometer. When evaluated with a visual analysis instead, group-shade restorations seem to perform better on “light” teeth only.

It can therefore be stated that the null hypotheses formulated were partially rejected, as:

- there were color-matching differences in terms of average ΔE_{00} calculated by instrumental analysis, between single-shade and group-shade composite resins, for all VITA Classical scale ranges;
- there were color-matching differences in terms of average score conferred by visual analysis, between single-shade and group-shade composite resins, only for the Light subgroup;

As secondary outcomes, considering the behavior of the different composites within each group, it has been shown that color matching can depend on the color of the tooth, and that after 7 days from the restoration no significant color changes occurred between tooth and composite resin.

CONCLUSIONS

According to the results of the present study, it seems that both types of composites are able to match the color of the tooth on which they are placed. However, the group-shade resins, having a wider choice of masses, seem to be able to obtain a more effective blending effect.

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CHAPTER 8

CLINICAL TRIAL PROTOCOL

Instrumental and visual evaluation of the color correspondence between universal composite resins and teeth treated with direct restorations

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Approved by Area Vasta Emilia Nord Ethics Committee

PROTOCOL

Study type: Non-Profit randomized monocentric clinical study with control group
Objective: This study aims to analyze the behavior of single-shade universal composite resins, evaluating the adaptation (Blending Effect) of these composites to the natural color of the tooth. These instrumental and visual analyses are compared to a traditional composite applied by layering technique.
Study design: Patients requiring cervical restorations (class V) (N=45), treated at the Dept. of Restorative Dentistry of the Structure of Oral-Maxillo-Facial Dentistry and Surgery (University Hospital Polyclinic of Modena) will be included in this study. The study plans to perform cervical restorations using single-shade composite resins (2 test groups) or traditional multi-shade composite resins (control group) applied through layering technique.
Group test A (Essentia Universal, GC Dental, Japan) (N=15)
Group test B (Vittra APS Unique, FGM Dental Group, Brazil) (N=15)
Control group (Harmonize, Kerr) (N=15)
After performing local anesthesia and isolation of the operating field using a rubber dam, traditional cavity cleaning, and adhesion procedures will be performed. Following randomization, it will be chosen which composite to use in that specific case and the reconstructions will be performed with the selected composite.
The tested composite resins (Essentia Universal and Vittra APS Unique) and the related adhesive systems (G-Premio Bond, GC and Ambar Universal, FGM) will be provided by the manufacturing companies free of charge.

The control group will be treated with traditional multi-shade composites and adhesive systems currently in use at the Dept. of Restorative Dentistry of the Structure of Oral-Maxillo-Facial Dentistry and Surgery, University Hospital Polyclinic of Modena: Harmonize composite (Kerr Dental, Italy) and Optibond FL adhesive system (Kerr Dental, Italy).

A visual evaluation will be performed 7 days after therapy by 6 blinded calibrated observers, and an instrumental evaluation will take place, using a digital spectrophotometer (Cobra Rayplicker, Borea Dental, Limoges, France), after 7 days, 6, and 12 months.

FINAL CONCLUSIONS

Nowadays, there is increasing attention to aesthetics, and thanks to the continuous innovation of materials, it has become easier to perform conservative restorations that blend seamlessly with the natural tooth color.

The results of these PhD studies demonstrated excellent color-matching abilities of the single-shade composites tested, both through instrumental analysis using a spectrophotometer and visual evaluation. These findings were corroborated following alterations to the dental substrate, both before and after professional dental bleaching. Instrumental analysis using a spectrophotometer revealed that following dental bleaching, the color difference between the restoration and the surrounding tooth reduced. This leads to the conclusion that, in some cases, single-shade composites adapt better when the surrounding dental substrate exhibits lighter VITA shade colors (A1-A2).

Investigating the color stability of a single-shade resin after immersion in food substances, the tested single-shade composite experienced greater pigmentation than the multi-shade composite, regardless of the curing time.

Additionally, the flowable composite was more susceptible to pigmentation compared to the packable composite. Specifically, the flowable composite shows greater pigmentation after immersion in the gel, whereas the packable composite is more affected by immersion in mouthwash.

Many new scientific articles testing single-shade composites are emerging, although few clinical trials are currently available in the literature. While visual analysis is subjective, it remains the most important evaluation in clinical aesthetics as it takes into account variables that cannot be measured through instrumental analysis.

The introduction of single-shade composites simplifies a complex procedure that has traditionally been time-consuming and highly dependent on the clinician's experience. Currently, the main limitation remains the inability to use single-shade composites in all clinical situations.

Advances in technology will undoubtedly focus increasingly on simplifying procedures to reduce treatment time, lead to the development of materials capable, with a single mass, of adapting to any clinical situation, including anterior restorations with significant substance loss, while also exhibiting the ability to adjust over time to changes in the color of surrounding teeth