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Final shade and whiteness: impact of various ultra-thin CAD/CAM veneers and tooth-colored resin substrates

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Abstract

Background Achieving optimal color control in chairside CAD/CAM ultra-thin veneers, remains a significant challenge for dental clinicians and technicians. This study aims to investigate the effect of ultra-thin CAD/CAM medium translucency (MT) lithium disilicate veneers and tooth-colored resin substrates on final tooth shade and whiteness.

Materials and methods Disk-shaped ceramic veneers (IPS e.max CAD MT, Ivoclar Vivadent, Liechtenstein) with a thickness of 0.3 mm were fabricated in BL2, BL3, BL4, B1, A1, A2, and A3 shades. Additionally, 4-mm thick resin substrates (Tetric N-Ceram, Ivoclar Vivadent, Liechtenstein) were prepared in A2, A3, A3.5, and A4 shades to simulate tooth-colored substrates. Veneer-resin composites were prepared by combining veneer specimens and resin substrates. Color coordinates of tooth-colored resin substrates (R), veneer-resin composites (C) and the shade guide tabs (G) were obtained using a spectroradiometer. Color differences of $\Delta E_{00(\text{C-R})}$, $\Delta E_{00(\text{C-G})}$ and $\Delta E_{00(\text{R-G})}$ were then calculated with the CIEDE2000 formula. The initial and final shades were considered matched when $\Delta E_{00(\text{R-G})}$ or $\Delta E_{00(\text{C-G})}$ was clinically acceptable or minimal. Additionally, whiteness differences (ΔWI_D) between R and C specimens were recorded. Two-way analysis of variance (ANOVA) was performed, followed by the Tukey HSD. The significance level was set at $p < 0.05$.

Results Both the shades of resin substrates and veneer shades had significant effects on $\Delta E_{00(\text{C-R})}$ and ΔWI_D ($p < 0.001$), while no interaction effects were observed ($p > 0.05$). They increased with darker resin substrates and lighter veneers, except for no significant differences among BL4, B1, and A1 veneers. The largest color difference was observed for BL2 veneers on A4 substrates ($\Delta E_{00(\text{C-R})} = 6.9 \pm 0.3$, $\Delta WI_D = 19.0 \pm 1.5$), while the smallest occurred with A3 veneers on A2 substrates ($\Delta E_{00(\text{C-R})} = 2.4 \pm 0.6$, $\Delta WI_D = 5.6 \pm 1.0$). Final tooth shades were maximally transformed to lighter shades, with A2, A3, A3.5, and A4 substrates shifting to 2M1, 2L1.5, 2R2.5, and 3L1.5, respectively.

Conclusions Both resin substrates and veneer shades significantly influence final tooth shade and whiteness independently. 0.3-mm thick CAD/CAM MT lithium disilicate veneers produce substantial shade and whiteness transformations, making them effective for shade enhancement.

Keywords Shade, Whiteness, Color difference, Ultra-thin veneer, Lithium disilicate, CAD/CAM

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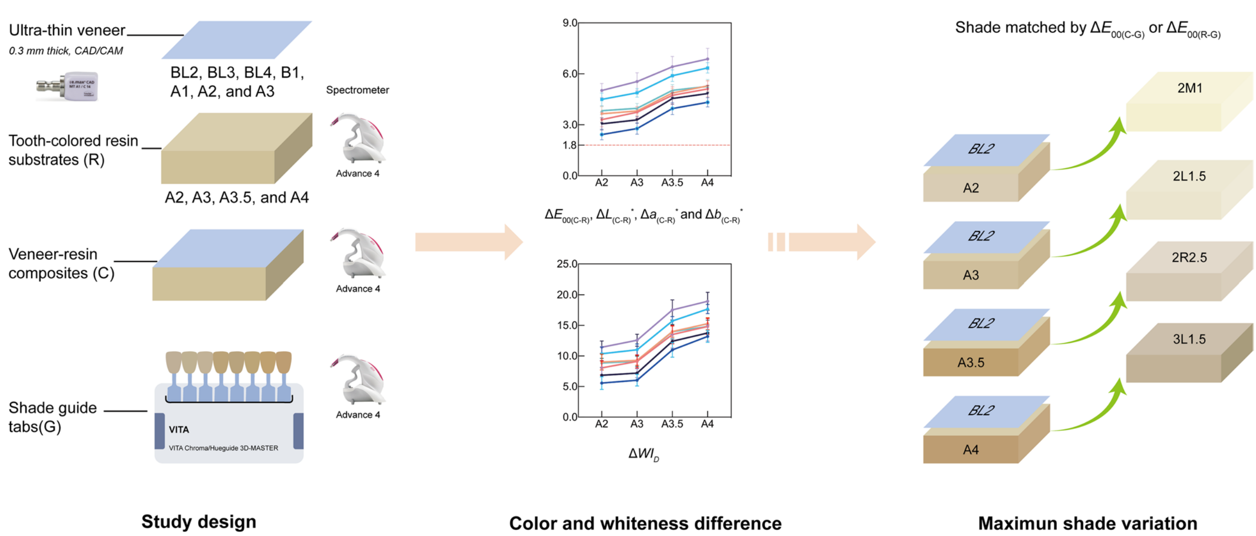
Graphical Abstract



Introduction

The emergence of ceramic veneers offers clinicians a minimally invasive solution for various aesthetic concerns, including morphological defects, diastema closure, and mild tooth discoloration [1, 2]. The integration of chairside CAD/CAM systems enables the fabrication of high-quality, same-day ultra-thin veneers, meeting patients'growing demands for efficient and minimally invasive treatments [1, 3, 4]. Preserving maximal tooth structure, especially enamel, has been shown to reduce risks of fracture and debonding, improve aesthetic and functional outcomes, and enhance long-term survival rates [5–8]. These benefits, particularly with no-preparation veneers as thin as 0.3 mm [9, 10], have made ultra-thin restorations increasingly popular. However, achieving optimal color control in chairside CAD/CAM ultra-thin veneers, remains a significant challenge for dental clinicians and technicians, which is limited by the shade of the chosen block.

There are factors can influence the optical color of CAD/CAM ultra-thin veneers, including ceramic thickness, the shade of the ceramic block, and the color of the underlying tooth substrate [10]. Studies have shown that darker veneers have minimal impact on darker substrates, while lighter substrates are affected by both lighter and darker veneers when using feldspathic ceramics [10]. Many previous [11–13] studies have focused on masking the underlying tooth color to match the shade of the ceramic block used. However, this is challenging with ultra-thin veneers, particularly those that are 0.3-mm thick, as the final color is significantly influenced by the substrate's color [4, 14–16]. It also has been found that the high translucency (HT) lithium disilicate ceramics shown limited color change ability [17, 18], so decreasing ceramic translucency enhance the color change ability over the various substrate [19]. Medium translucency (MT) lithium disilicate ceramic stands out for its superior flexural strength [20, 21] and is optically brighter than its HT counterparts [19]. These properties make it a promising material for ultra-thin veneers and potentially yielding more color change capabilities than HT ceramics [11]. However, the specific impact of ultra-thin MT ceramics on different tooth-colored substrates has not been extensively explored, leaving a gap in the understanding of their clinical application.

In dental practice, color parameters are commonly recorded using the International Commission on Illumination Lab (CIELAB) color space system, which provides a three-dimensional representation of colors [22, 23]. The CIEDE2000 formula, which incorporates not only lightness (L^*) and chroma (a^*, b^*) but also hue weighting functions and an interactive term between chroma and hue differences, has been found to provide a significantly better fit for human observer responses, especially when dealing with small color differences. This is in contrast to the CIELAB formula, which only accounts for lightness and chroma [24]. While ΔE_{00} is widely used to quantify color differences objectively, few studies evaluate final shades by comparing ΔE_{00} values of restorations with the shade guide tabs [23]. Accurate detection of the tooth color and shade is a critical point particularly with aesthetic restoration. Accurate shade detection seems to be subjective, accordingly, there is an agreement that we need a unique formula for calculating differences between colors that most closely match human perception to aid both clinicians and technician. When the color difference between compared different objects can be accurately detected by 50% of observers (there are other 50% that will notice no difference), this could be assigned to what is called the 50:50% perceptibility threshold. Similarly, When the color difference is considered acceptable by 50% of observers (there are other 50% would consider it unacceptable), this could be assigned to the 50:50% acceptability threshold. A perceptible color match in dentistry is a color difference at or below the perceptibility threshold; an acceptable color match is a color difference at or below the acceptability threshold [23]. Additionally, the growing demand for whiter teeth [25–28] underscores patients'preference for evaluating the"degree of whiteness"when comparing restorations to adjacent teeth or shade guide tabs [29]. Although whiteness can be described using three color coordinates, the Whiteness Index for Dentistry (WI_D)—a one-dimensional index—offers a more straightforward and patient-friendly communication tool [29–31].

To address this, it is crucial to integrate shade variation with changes in WI_D to accurately reflect color differences. This in vitro study investigated the impact of various ultra-thin (0.3-mm thick) CAD/CAM MT lithium disilicate veneers and tooth-colored resin substrates on final tooth shade and whiteness. The findings aim to explore the whiteness and shade variation of ultra-thin CAD/CAM lithium disilicate veneers, guide optimal shade selection, and improve communication among clinicians, technicians, and patients. The null hypothesis posited that the shade of both tooth-colored resin substrates and ultra-thin CAD/CAM veneers would not affect the final shade and whiteness.

Materials and methods

Specimen preparation

Thirty-two disk-shaped resin substrates (Tetric N-Ceram, shades A2, A3, A3.5, and A4, Ivoclar Vivadent, Liechtenstein) were fabricated using silicon molds to mimic various tooth substrate colors (n= 8 per shade) [32, 33]. Each disk was light-polymerized on both surfaces (Elipar S10, 3 M ESPE, USA; 20 s per side) [34]. Post-polymerization, specimens were sequentially wet-polished using silicon carbide papers (407Q, 3 M, USA) from 600- to 1200-grit [35] to achieve final dimensions of 8× 8× 4 mm [10, 12]. Dimensional accuracy was verified through five-point measurement using a digital caliper (01412 A, Neiko Tools, USA) [10, 34]. All substrates underwent ultrasonic cleaning in distilled water for 10 min followed by air drying.

Fifty-six lithium disilicate ceramic disks (IPS e.max CAD MT, Ivoclar Vivadent, Liechtenstein) were CAD/CAM-milled in shades BL2, BL3, BL4, B1, A1, A2, and A3 (n= 8 per shade) [11]. Following the same polishing protocol as resin substrates [35], ceramic specimens were processed to final dimensions of 8× 8× 0.3 mm, with dimensional verification using the digital caliper. Crystallization and glazing were performed in a ceramic furnace (Programat P700, Ivoclar Vivadent, Liechtenstein) according to the manufacturer's protocol [36].

Color measurement

Color measurements were performed on the middle third of each shade tab (Linearguide 3D-MASTER, VITA Zahnfabrik, Germany) using an intraoral spectrophotometer (Easyshade advance 4.0, VITA Zahnfabrik, Germany) [37, 38]. All measurements were conducted against a neutral gray background (L^*= 64.1; a^*= 0.3; b^*= −3.4) [39, 40]. For each shade tab, five consecutive measurements were taken to determine mean CIE $L^*a^*b^*$ values (designated as L_0^*, a_0^*, and b_0^*). Similarly, five measurements were obtained from the central region of resin substrates, with corresponding mean values recorded as L_1^*, a_1^*, and b_1^*.

Ceramic specimens were assembled with their corresponding resin substrates using optical gel (Optical Gel, Cargille Labs, USA) as a refractive medium, forming veneer-resin composites [41–44]. Color coordinates (L_2^*, a_2^*, b_2^*) were recorded for each veneer-resin composite. Color differences were calculated using the CIEDE2000 (ΔE_{00}) formula, including:

1. Between veneer-resin composites (C) and resin substrates (R): $\Delta E_{00(\text{C-R})}$, $\Delta L_{(\text{C-R})}^*$, $\Delta a_{(\text{C-R})}^*$, and $\Delta b_{(\text{C-R})}^*$
2. Between shade guide tabs (G) and veneer-resin composites (C): $\Delta E_{00(\text{C-G})}$
3. Between shade guide tabs (G) and resin substrates (R): $\Delta E_{00(\text{R-G})}$

Shade matching was evaluated against the clinically acceptable threshold (AT, ΔE_{00}= 1.8) [23]. Matches were considered acceptable when $\Delta E_{00(\text{C-G})}$ or $\Delta E_{00(\text{R-G})}$ values were below AT. When exceeding AT, the minimal ΔE_{00} value was used for shade determination.

The formula for ΔE_{00} was as follows:

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

- $\Delta L'$, $\Delta C'$, and $\Delta H'$represent differences in lightness, chroma, and hue, respectively.
- S_L, S_C, and S_H are weighting functions for spatial uniformity correction in CIELAB color space [24].

- K_L, K_C and K_H are parametric factors (set to 1 in this study).
- R_T is the rotation function accounting for elliptical non-uniformity in the blue region [45].

Furthermore, the whiteness index for dentistry (WI_D) was calculated for shade guide tabs, resin substrates, and veneer-resin composites, denoted as $WI_{D(G)}$, $WI_{D(R)}$, and $WI_{D(C)}$, respectively. The whiteness difference (ΔWI_D) values between $WI_{D(R)}$ and $WI_{D(C)}$ were determined using the following formula [29]:

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

$$\Delta WI_D = WI_{D(C)} - WI_{D(R)}$$

Statistical analysis

Based on the existing sample size, the power values for the data ($\Delta E_{00(C\text{-}R)}$, $\Delta L_{(C\text{-}R)}^*$, $\Delta a_{(C\text{-}R)}^*$, $\Delta b_{(C\text{-}R)}^*$ and ΔWI_D) were calculated using PASS 15.0 software (NCSS LLC, USA). All the data were also analyzed with SPSS software (SPSS version 22.0; SPSS). The normality was assessed using the Shapiro–Wilk test. Levene's test was applied to check for homogeneity of variances. Two-way analysis of variance (ANOVA) was performed, followed by the Tukey HSD. The significance level was set at $p < 0.05$. To ensure adequate sample size, the power analysis was conducted using PASS 15.0 software (NCSS LLC, USA).

Table 1 L^*, a^*, and b^* coordinates of four tooth-colored resin substrates

	L^*	a^*	b^*
A2	75.15	0.50	20.61
A3	74.19	0.08	23.26
A3.5	70.95	1.60	30.36
A4	66.83	2.81	29.06

Results

The power values for the data ($\Delta E_{00(C\text{-}R)}$, $\Delta L_{(C\text{-}R)}^*$, $\Delta a_{(C\text{-}R)}^*$, $\Delta b_{(C\text{-}R)}^*$ and ΔWI_D) were exceeded 97%. All the data showed normality and homogeneity. Both the tooth-colored resin substrate shade and the ceramic shade significantly affected $\Delta E_{00(C\text{-}R)}$, $\Delta L_{(C\text{-}R)}^*$, $\Delta a_{(C\text{-}R)}^*$, $\Delta b_{(C\text{-}R)}^*$ and ΔWI_D values ($p < 0.001$). No interaction effect was found between the resin substrate shade and the ceramic shade among these variations ($p > 0.05$).

Table 1 displays the L^*, a^* and b^* values of four tooth-colored resin substrates. As shown in Fig. 1, all $\Delta E_{00(C\text{-}R)}$ values surpassed the clinically acceptable threshold (AT, $\Delta E_{00} = 1.8$) [23]. Generally, the $\Delta E_{00(C\text{-}R)}$ values increased as tooth-colored resin substrates became darker and veneers became lighter ($p < 0.05$), except for BL4, B1, and A1 veneers, which showed no significant differences ($p > 0.05$). The highest $\Delta E_{00(C\text{-}R)}$ value was with the BL2 veneer over the A4 substrate (6.9 $\pm$0.3), whereas the lowest value was with the A3 veneer over the A2 tooth substrate (2.4 $\pm$0.6). Figure 1 also presents the color parameters variations from tooth-colored resin substrates to veneer-resin composites. Overall, the a^* values exhibited a slight decrease, the b^* values experienced a dramatic reduction, while the L^* values generally increased. In addition, the $\Delta L_{(C\text{-}R)}$ values showed the similar trend with $\Delta E_{00(C\text{-}R)}$ values, besides that no significant differences were observed among A3 and A2 resin substrates ($p > 0.05$). For $\Delta a_{(C\text{-}R)}^*$ value, the descending order of tooth-colored substrates was A4, A3.5, A2 and A3 ($p < 0.05$). Veneer shades were grouped in descending order as follows: B1, BL2, A1; BL2, A1, BL3; BL3, BL4, A3; and BL4, A3, A2 ($p < 0.05$), with no significant differences within each group ($p < 0.05$). Finally, the $\Delta b_{(C\text{-}R)}^*$ values mirrored the trend of $\Delta E_{00(C\text{-}R)}$ values, except for no significant differences between A4 and A3.5 substrates ($p > 0.05$).

Figure 2 presents a heatmap illustrating the mean values of $\Delta E_{00(C\text{-}G)}$ and $\Delta E_{00(R\text{-}G)}$. The green represents the value lower than AT, blue indicates the lower value,

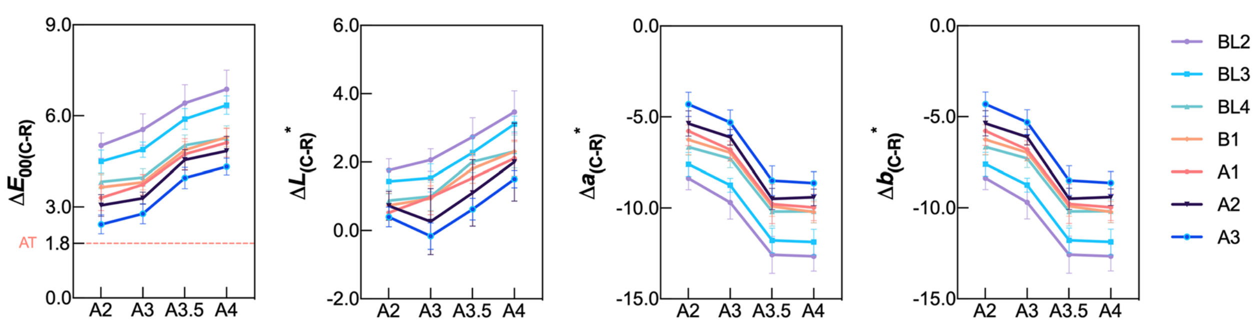


Fig. 1 The results of $\Delta E_{00(C\text{-}R)}$, $\Delta L_{(C\text{-}R)}^*$, $\Delta a_{(C\text{-}R)}^*$ and $\Delta b_{(C\text{-}R)}^*$

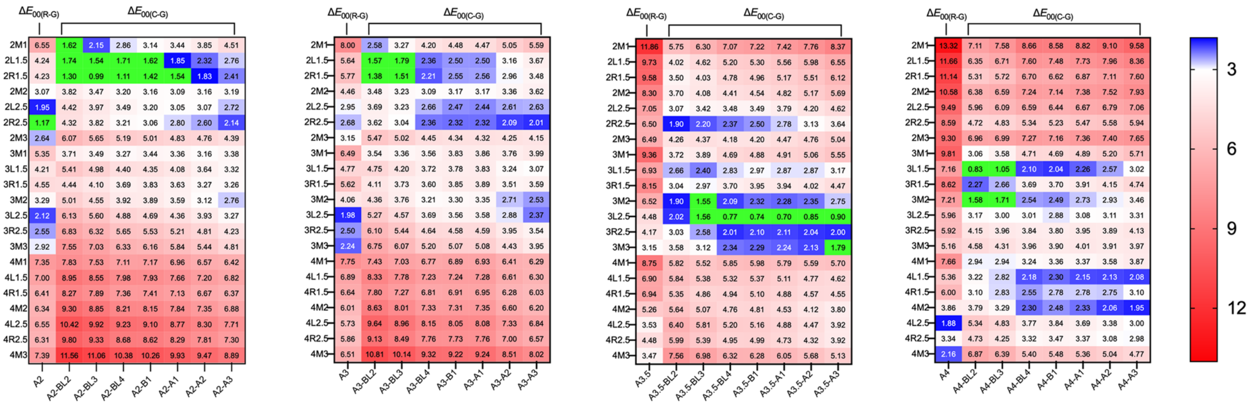


Fig. 2 The heatmap of the mean values of $\Delta E_{00(C\text{-}G)}$ and $\Delta E_{00(R\text{-}G)}$. The green represents the value lower than AT, blue indicates the lower value which close to AT, while the red means the higher value

while the red means the higher value. Table 2 illustrates the shade variation from resin substrates to veneer-resin composites. The result revealed that A2, A3, A3.5 and A4 were shade matched to 2R2.5, 3L2.5, 3M3 and 4L2.5, respectively. The shades of tooth-colored resin substrates were transformed as follows: A2 to 2M1 and 2R1.5, A3 to 2L1.5 and 2R2.5, A3.5 to 2R2.5 and 3L2.5, and A4 to 3L1.5 and 4M2.

As presented in Fig. 3A, the bar graph of showed the whiteness value of tooth-colored resin substrates and veneer-resin composites, while the line graph demonstrated the whiteness value of shade guide tabs. The result presented a near-linear decrease in the $WI_{D(G)}$ values across each lightness group from second to fifth lightness level group. $WI_{D(C)}$ values significantly increased from the $WI_{D(R)}$ and experienced a decrease as the veneers and resin substrates darken. The ΔWI_D values were outlined in in Fig. 3B. It indicated that all the ΔWI_D values exceeded the 50:50% whiteness acceptability threshold (WAT, 2.62 WI_D units) [29]. The trend of ΔWI_D values generally mirrored that of $\Delta E_{00(C\text{-}R)}$. Specifically, ΔWI_D values increased as resin substrates became darker and veneers became lighter ($p < 0.05$), with no significant differences observed among BL4, B1, and A1 veneers ($p > 0.05$). The largest whiteness difference was noted when the BL2 ceramic covered the A4 tooth substrate (19.0 ± 1.5), while the smallest difference occurred with the A3 ceramic combined with the A2 tooth substrate (5.6 ± 1.0).

Discussion

Based on the present findings, the null hypothesis was rejected. The final shade and whiteness were affected by the shade of both tooth-colored resin substrates and veneers. The shades of veneers and underlying resin substrates showed no interaction effect between each other using 0.3-mm CAD/CAM MT lithium disilicate veneers.

Table 2 The shade variation from resin substrates to veneer-resin composites

Resin substrates	Initial shade	Final shade						
		BL2	BL3	BL4	B1	A1	A2	A3
A2	2R2.5[a]	2M1[a] 2L1.5 [a] 2R1.5[a]	2L1.5[a] 2R1.5[a]	2L1.5[a] 2R1.5[a]	2L1.5[a] 2R1.5[a]	2R1.5[a]	2R1.5[b]	2R2.5[b]
A3	3L2.5[b]	2L1.5[a] 2R1.5[a]	2L1.5[a] 2R1.5[a]	2R1.5[b]	2R2.5[b]	2R2.5[b]	2R2.5[b]	2R2.5[b]
A3.5	3M3[b]	2R2.5[b] 3M2[b]	3M2[a] 3L2.5[a]	3L2.5[a]	3L2.5[a]	3L2.5[a]	3L2.5[a]	3L2.5[a] 3M3[a]
A4	4L2.5[b]	3L1.5[a] 3M2[a]	3L1.5[a] 3M2[a]	3L1.5[b]	3L1.5[b]	4L1.5[b]	4M2[b]	4M2[b]

The shades of veneer-resin composites (final shade) and the resin substrates (initial shade) were matched when the $\Delta E_{00(C\text{-}G)}$ or $\Delta E_{00(R\text{-}G)}$ below AT, otherwise the minimal value was used for shade matching

"a"indicating the value of $\Delta E_{00(C\text{-}G)}$ or $\Delta E_{00(R\text{-}G)}$ below AT

"b"indicating the value of $\Delta E_{00(C\text{-}G)}$ or $\Delta E_{00(R\text{-}G)}$ exceeding AT

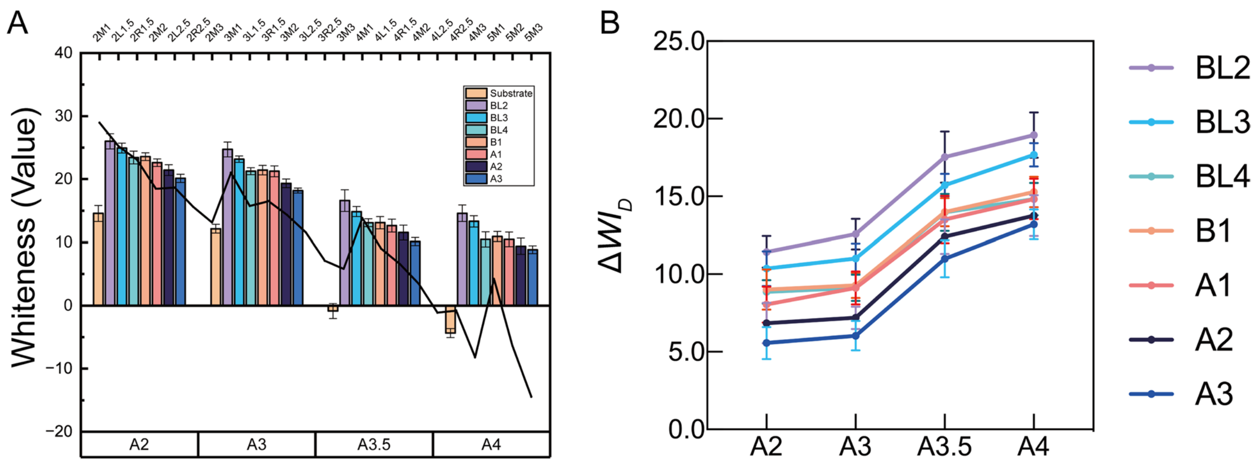


Fig. 3 The result of whiteness value. **A** The results of $WI_{D(C)}$, $WI_{D(R)}$, $WI_{D(G)}$. The bar graph demonstrates the $WI_{D(C)}$ and $WI_{D(R)}$. The line graph outlines the $WI_{D(G)}$. **B** The results of ΔWI_D

Fabricating chairside CAD/CAM ultra-thin lithium disilicate ceramic veneers presents challenges in achieving accurate color matching with adjacent natural teeth and creating lifelike restorations. Minimally invasive veneers, which do not require tooth preparation, are typically 0.3-mm thick [10]. At this thickness, the final color of the veneer restorations can be significantly affected by the underlying tooth substrates [10], not the dentin [12]. Consequently, dental clinicians and technicians may place greater emphasis on the color-changing capacity of ultra-thin veneers rather than their masking ability. Therefore, this study evaluated the color-changing potential of 0.3-mm CAD/CAM MT lithium disilicate veneers over various tooth-colored resin substrates. Specifically, we tested all shades of CAD/CAM MT lithium disilicate ranging from lighter to darker as provided by the manufacturers, including BL2, BL3, BL4, B1, A1, A2, and A3, as well as the common anterior tooth shades A2, A3, A3.5, and A4. Notably, A2 and A3 resins simulated typical tooth colors [32, 33], while A3.5 and A4 represented darker or discolored teeth.

In the present study, the L^*, a^*, and b^* values of the Vita Linearguide 3D-MASTER shade guide tabs, tooth-colored resin substrates, and veneer-resin composites were measured using a spectrophotometer [46–48], a reliable tool for both clinical and research applications [49, 50]. The $\Delta E_{00(\text{C-R})}$ values, which indicated the color differences between resin-veneer composites and tooth-colored resin substrates, were used to assess the color-changing ability of ultra-thin veneers over four tooth-colored resin substrates. Higher $\Delta E_{00(\text{C-R})}$ values suggested a greater ability to alter the substrate color. As shown in the line graph of Fig. 1, all $\Delta E_{00(\text{C-R})}$ values exceeded the clinically acceptable threshold (AT, ΔE_{00}= 1.8) [23], indicating that 0.3-mm CAD/CAM MT lithium disilicate veneers produced significant color differences over the four tooth-colored resin substrates. This capability appears to be enhanced by the veneer shades lighten and the underlying substrate color darken consistently with previous studies, including ultra-thin feldspathic ceramic veneers and 0.5-mm CAD/CAM lithium disilicate restorations [19].

As depicted in Fig. 1, all the L^* values generally increased, indicating enhanced brightness. This may be attributed to the glazed surface of the veneers and the inherent brightness of the MT blocks [11]. The a^* values exhibited a slight decrease, while the b^* values experienced a significant reduction. This suggested that ultra-thin ceramic veneers significantly reduce yellowing (b^* value) but have a minimal attenuating effect on redness (a^* value). In other words, the chroma values, which is coordinated by a^* and b^* value, were reduced after being covered by the ultra-thin CAD/CAM MT lithium disilicate veneers. While darker substrates generally exhibited greater $\Delta E_{00(\text{C-R})}$, $\Delta L_{(\text{C-R})}^*$, and $\Delta b_{(\text{C-R})}^*$ values, some exceptions were noted among specific shade combinations. The lack of significant differences between A3 and A2 substrates in $\Delta L_{(\text{C-R})}^*$ and between A4 and A3.5 substrates in $\Delta b_{(\text{C-R})}^*$ suggests that the initial color parameters of the substrate play a crucial role in determining the final optical outcome (See Table 1).

Previous studies have primarily focused on color differences to assess the color change capabilities of various veneers [51]. However, there is limited knowledge regarding the shade variations produced by these veneers, and a lack of visual presentation for clinicians and technicians. In the present study, the final shade was matched when $\Delta E_{00(\text{R-G})}$ and $\Delta E_{00(\text{C-G})}$ were clinically acceptable [52]. Otherwise, the minimal value was used for shade matching. $\Delta E_{00(\text{C-G})}$ denoted the color differences between veneer-resin composites and the shade guide tabs, indicating the final shade of the veneer restorations. $\Delta E_{00(\text{R-G})}$ pointed to the color differences between tooth-colored resin substrates and the shade guide tabs, enhancing comparability between the substrate shade and the final shade. The results revealed that A2, A3, A3.5, and A4 were shade matched to 2R2.5, 3L2.5, 3M3, and 4L2.5, respectively. Regardless of the resin substrate shade, the BL2 veneer exhibited the most significant shade change, while the A3 veneer showed the least. The BL4, B1, and A1 shades yielded comparable results, suggesting their potential as viable alternatives in clinical settings. The largest shade change capacity was observed when the BL2 veneer covered the A4 resin substrate, with the shade ranging from 4L2.5 to 3L1.5. In clinical practice, if $\Delta E_{00(\text{C-G})}$ exceeds the clinically acceptable threshold from the shade guide tabs, adjustments can be made using resin cements with different colors [53]. However, the 0.1 mm thickness of the resin cement limits the range for color adjustment [11, 12, 15, 54], making the choice of ceramic block shade critical. For example, the color differences of resin cement beneath 0.5-mm CAD/CAM MT lithium disilicate veneers were found to be less than 1.0 [19]. The other way to adjust the final color is to stain, which takes more chairside time. Additionally, the final aesthetic outcome was significantly influenced by the shade of the underlying tooth substrates. Thus, the shade matching of the abutment tooth is crucial to achieve the optimal outcome.

For the Whiteness Index for Dentistry (Fig. 3A), the $WI_{D(\text{R})}$ and $WI_{D(\text{C})}$ values were compared with $WI_{D(\text{G})}$ values to assess whiteness variations. Results revealed a near-linear decline in $WI_{D(\text{G})}$ values within the same lightness groups. $WI_{D(\text{C})}$ values significantly increased compared to $WI_{D(\text{R})}$, by up to one lightness level, but decreased as the veneers and resin substrates darkened. Figure 3B shows that all ΔWI_D values exceeded WAT, indicating that all resin substrates are significantly whitened by applying ultra-thin MT lithium disilicate veneers. This whitening effect was attributed to increased lightness and reduced chroma, consistent with $\Delta L_{(\text{C-R})}^*$, $\Delta a_{(\text{C-R})}^*$, and $\Delta b_{(\text{C-R})}^*$ results [55]. Consistent with the trend in $\Delta E_{00(C\text{-}R)}$, ΔWI_D values also varied depending on the veneer and resin substrate shades. These findings suggest that WI_D values are valuable for dentist-patient communication, enabling an effective evaluation of color changes achieved with ultra-thin veneers.

The findings support the use of ultra-thin MT lithium disilicate veneers (0.3-mm thick) for enhancing the color and whitening of anterior teeth, particularly with BL2 ceramics. Shades such as BL4, B1, and A1 demonstrated similar effects and may serve as viable alternatives in specific cases. These results not only provide guidance for optimal veneer shade selection but also facilitate more effective communication among dental clinicians, technicians, and patients. However, it is important to note that this study was conducted in vitro, which does not fully replicate the complexities of the in vivo environment. Additionally, the study used only four shades of tooth-colored resin substrates, limiting its ability to fully simulate the coloration and optical properties of natural abutment teeth. Furthermore, no resin cement was incorporated, which could influence the final aesthetic outcomes. Future research should address these limitations, including clinical studies to verify the in vitro findings. Additionally, the development of a final color prediction model for CAD/CAM ultra-thin MT lithium disilicate veneers, incorporating the interplay of various factors, could be a valuable direction for further exploration.

Conclusions

Within the limitations of this study, the following conclusions were drawn:

1. The final shade and whiteness are affected by the shade of both tooth-colored resin substrates and veneers, with all 0.3-mm thick CAD/CAM MT lithium disilicate veneers yielding notable shade differences and whiteness enhancement over various tooth-colored resin substrate shade.
2. Both color differences and whiteness differences increase as tooth-colored resin substrates became darker, and veneers became lighter, indicating whiteness values could be used as a crucial evaluation parameter in dentist-patient communication to evaluate color changes with ultra-thin veneers.

Abbreviations

CAD-CAM	Computer-aided design and computer-aided manufacturing
ANOVA	Analysis of variance
LT	Low translucency
MT	Medium translucency
HT	High translucency

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Authors' contributions

H.C., G.H., and Y.W. designed the study. Y.W., X.C., and L.L. conducted the experiments and collected the data. X.W. and L.G. analyzed the data. Y.W., X.W., and Y.P. drafted the manuscript. D.L., L.G. and Y.P. prepared the figures and tables. H.Y., H.C., and G.H. reviewed and edited the manuscript. All authors reviewed and approved the final manuscript.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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