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Effect of Thickness and Shade of Resin and Ceramic-Based Hybrid Materials on Color Masking Abilities and Optical Performance of CAD/CAM Materials

ABSTRACT

Scientific data analysing color masking abilities of chairside CAD/CAM materials is lacking. The purpose of this in-vitro study was to evaluate the thickness and shade influence of three materials on their optical behaviour. Three materials: a) LD: Lithium disilicate glass ceramic (Emax, Ivoclar Vivadent), b) LDS: Lithium-disilicate-strengthened aluminosilicate glass ceramic (N!ce, Straumann) and c) RNC: Resin Nanoceramic (Lava Ultimate, 3M ESPE) were polished in different shades (A1,A2,A3) and thicknesses (0.1-1.2mm). Specimens (N=108; n=36 per group) (12x12x1mm3) were positioned on resin composite base (Clearfil AP-X, Kuraray) in shade A3. Spectrophotometric measurements were performed and the parameters thickness, shade and material were analysed using three-way ANOVA, and pairwise T-tests (P-values < 0.05). Both the shade (p<0.001) and the interaction of material in correlation to thickness (p<0.001) were significant. Shade value A1-A3 comparisons were significant A1 vs. A2 (p=0.045); A2 vs. A3 (p=0.002); A1 vs. A3 (p<0.001)). A significant correlation of the material and thickness was observed when comparing LD and LDS (p=0.007) at the thickness of 0.1-0.4 mm. Masking abilities were influenced by material and thickness choice. Reinforced glass ceramics showed the best results in the smallest thickness tested (0.1-0.4 mm). LDS could be considered as an advantageous alternative in minimal-invasive cases.

INTRODUCTION

The introduction of CAD/CAM technologies in dental medicine enabled the oral rehabilitation with new treatment possibilities such as the restoration with direct chairside ceramic restorations made of newly developed dental materials. Novel dental material classes can nowadays be processed using CAD/CAM technologies, which offer possibilities of designing and manufacturing chairside dental restorations.[1-5] The restorations involve full and partial tooth- and implant-borne single ceramic crowns and fixed dental prostheses (FDP). Comparing digital and conventional workflows, CAD/CAM restorations offer the benefits of reduced labour time, better cost effectiveness, accurate marginal and internal fit, and higher quality control.[1,4,6-9]

Monolithic ceramic systems have been introduced as an alternative to bilayered metal ceramic restorations.[10] Metal ceramic restorations offer high mechanical reliability and satisfying long-term results.[10] However, the demand for aesthetical outcomes, good biocompatibility, lack of gap-corrosion and dark colored crown margins in combination with the digitalisation of dentistry accelerated the widespread use of monolithic ceramic systems.[11,12,13-16]

Since monolithic systems do not necessitate any use of veneering ceramics, less technical preparation is required, and the absence of veneering ceramic could be a solution to veneer-chipping type of failures.[17]

Ceramic materials are divided in three major categories, namely glass ceramics, reinforced glass ceramics such as: leucite-, lithium disilicate-, lithium silicate-, zirconium oxide reinforced and lithium disilicate reinforced lithium aluminosilicate and polycrystalline ceramics.[4,18-20] Newly developed resin-matrix-ceramics (RMCs) include resin based ceramics (RBCs) and polymer infiltrated ceramic network (PICN) resins.[18,20,21]

The recent hybrid materials gain their mechanical resistance thanks to elasticity due to the incorporated resin matrix.[22-24] They seem to be a promising approach to the increasing aesthetic demands from patients in need of prosthodontic treatment and the trend in dentistry towards minimal invasive restorations.[11,22-34]

Although the higher fracture resistance from reinforced glass ceramics compared to conventional glass ceramics and the high resistance of hybrid materials due to elasticity allow thinner wall layers and thereby a minimal invasive restoration,[25,35-38] the aesthetic aspects still must be considered. The wall layers of a dental restoration must be thick enough to cover discolored tooth substance to achieve a satisfying result.

Recently released CAD/CAM processed lithium disilicate reinforced lithium aluminosilicate ceramics can be milled in a full crystallization state without the need of firing before the cementation. Thus, this new material offers a time- and investment-saving alternative to the state of the art lithium disilicate ceramics, which needs a post-milling-crystallisation process to gain its full mechanical performances.

The visual color matching of the shade of the future restoration by comparing patient's tooth with a standardized shade sample is a very common method.[39-42] However, it is highly subjective and dependant on several variables.[39] Studies showed that clinicians cannot reproduce the same shade determination on different days reliabily.[45] Therefore electronic measurement devices, such as spectrophotometers, are successfully applied to support clinicians.[46-50] The Vitapan Classic shade guide is widely used by clinicians to determine the masking abilities of restorative materials regarding various underlying non-human and human substrates.

The correct choice of the material and the best matching shade are prerequisites and eminent regarding the aesthetical outcome and success of the restoration.[51,52] While clinical guidelines are still missing, literature still lacks data regarding optical behaviour and masking abilities of chairside CAD/CAM materials. Especially the influence of material choice, layer thickness, shade and their combinations have not been studied yet.

The purpose of this *in vitro* study was therefore to evaluate the influence of thickness and shade of three different chairside CAD/CAM materials on their optical behaviour. The null hypothesis of this study was that the masking ability of the three different ceramic types is neither affected by the parameters shade, material, and thickness nor by their interaction.

MATERIALS AND METHOD

SPECIMEN PREPARATION

Three different CAD/CAM materials, namely: a) LD: Lithium disilicate glass ceramic (Emax, Ivoclar Vivadent, Schaan, Liechtenstein), b) LDS: Lithium-disilicate-strengthened aluminosilicate glass ceramic (N!ce, Straumann), and c) RNC: Resin Nanoceramic (Lava Ultimate, 3M ESPE) were used to prepare square specimens in different shades and thicknesses *(Table 1)*.

Specimens (N=108; n=36 per group) (12x12x1mm^3) were cut out of CAD/CAM Blocks in the three different shades A1, A2 and A3 using varying thicknesses from 0.1-1.2mm in a 0.1mm interval using an electrical precision diamond wire saw (Well; Walter Ebner) at 250 rpm, with a wire diameter of 0.17 mm and 30μm roughness under constant water cooling. All specimens were manually reduced and polished to the desired thickness (0.1mm -1.2mm) using up to #2400 grit silicon carbid paper (Struers, Willich) under constant water cooling until a plain surface was obtained. The dimensions were sequentially verified with a digital micrometer (Mitutoyo, Kamagawa) until an even thickness was achieved.

One composite specimen (Clearfil AP-X, Kuraray) with a shade of A3 with the same dimension (12x12x1mm^3) was obtained accordingly and served as underlying layer during the measurements. Then all the specimens were cleaned in an ultrasonic bath with distilled water for 10 min. The specimens were positioned above the resin composite layer (1 mm) and spectophotometric measurements (SpectroShade MICRO, MHT) were performed to determine the color change in Vitapan Classic shade guide values using Vitapan Classic shade guide scale A 1-4, B 1-4, C 1-4, D 2-4 *(Figure 1)*.[26,27,48] The measurements were conducted by one calibrated operator.

Table 1. Overview on materials, their composition and mechanical properties (flexural strength, fracture toughness and elasticity modulus) of LD (IPS e.max CAD, Ivoclar Vivadent), LDS (Nice, Straumann) and RNC (Lava Ultimate, 3M ESPE). Information provided by the manufacturers

Material	LD: IPS e.max CAD	LDS: Nice	RNC: Lava Ultimate
Composition (weight %)	57-80 SiO_2, 11-19 Li_2O, < 5 Al_2O_3, < 13 K_2O, < 8 ZnO, < 11 P_2O_5, < 8 ZrO_2, < 5 MgO, < 8 other oxides	64-70 SiO_2, ~11 Li_2O, ~11 Al_2O_3, < 3 K_2O, ~2 Na_2O, < 8 P_2O_5, < 0.5 ZrO_2, < 2 CaO, < 9 coloring oxides	80 % nanoceramic particles bound in the resin matrix, non-agglomerated/ non-aggregated 20 nanometer (nm) SiO_2 fillers, non-agglomerated/ non-aggregated 4 to 11 nm ZrO_2 fillers and aggregated ZrO_2/ SiO_2 cluster (consisting of 20 nm SiO_2 and 4 to 11 nm ZrO_2 particles).
Flexural strength (MPa)	350	360	204
Fracture toughness ($MPam^{1/2}$)	2	1.5	2.02
Elasticity modulus (GPa)	95	80	12.77

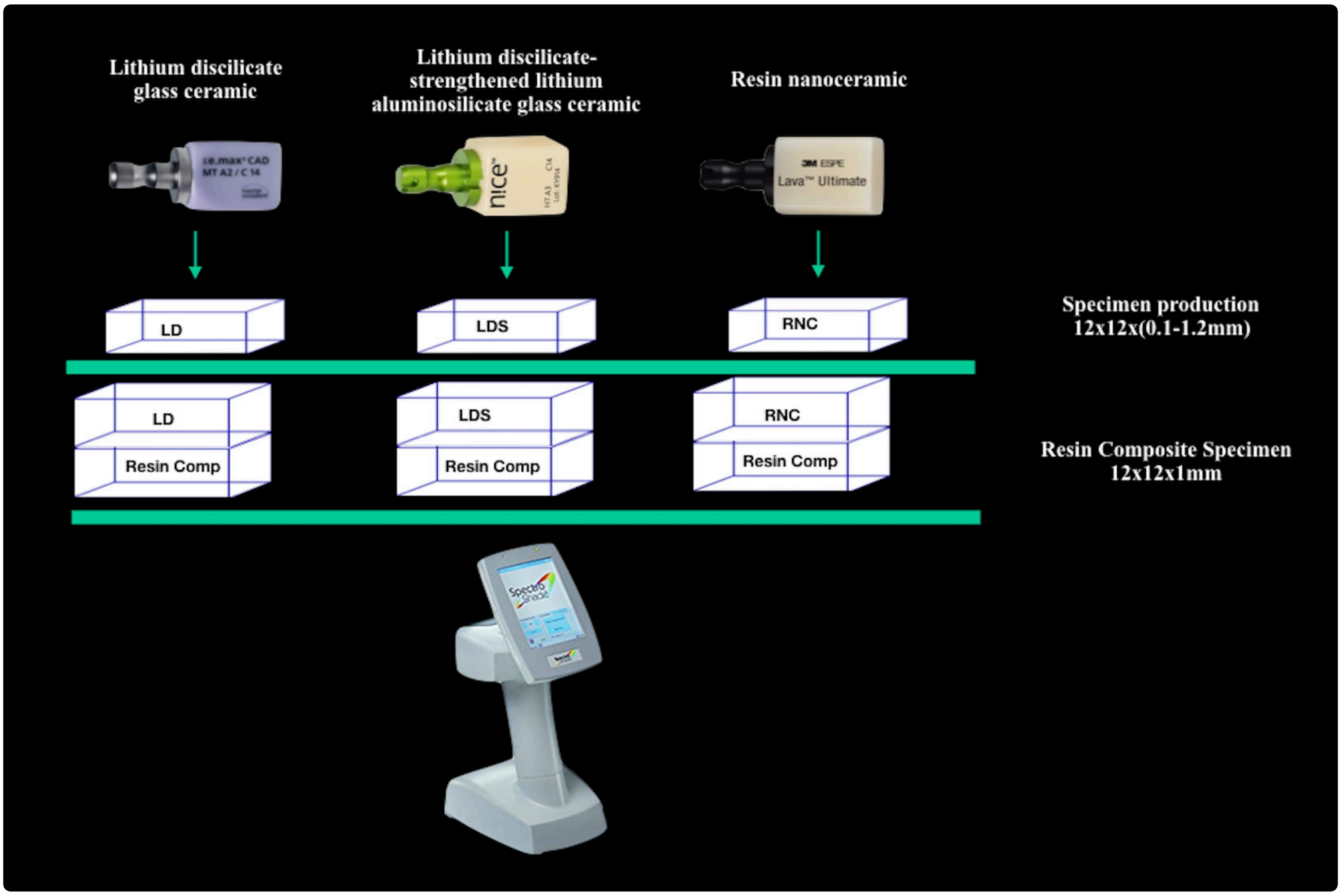


Figure 1: Visualized experimental flow chart.

COLOR TESTING

The calibration of the spectrophotometer took place by following the instruction manual, using the procedure with the white and green calibration tiles. The underlying composite layer (A3, 1mm) was placed over an absolute black background to simulate a more clinically related setup, and the specimens were placed over the composite layer. To avoid irregularities in the measuring procedure, the same operator performed all the color reading and each measurement was repeated three times. The specimens were divided into 3 regions; coronal, middle, apical. For each region the range of color change was recorded according to the Vitapan Classic (Vita Zahnfabrik) shade guide values.

The mean aesthetical successes of all materials with respect to different thicknesses and shades were evaluated using success scores. The success score was defined as 2 in case of consensus of all letters from “Value” among the three regions and in case of consensus of all numbers from “Value” as “1”. If exactly one out of the two conditions was achieved the success score was defined as 1 which was considered as partial success. Otherwise, the success score was defined as 0. Afterwards, the total mean success was defined as the average success score among all three measurements. Thus, a single numerical outcome resulted for each specimen and was further analysed *(Figures 2a-c)*.

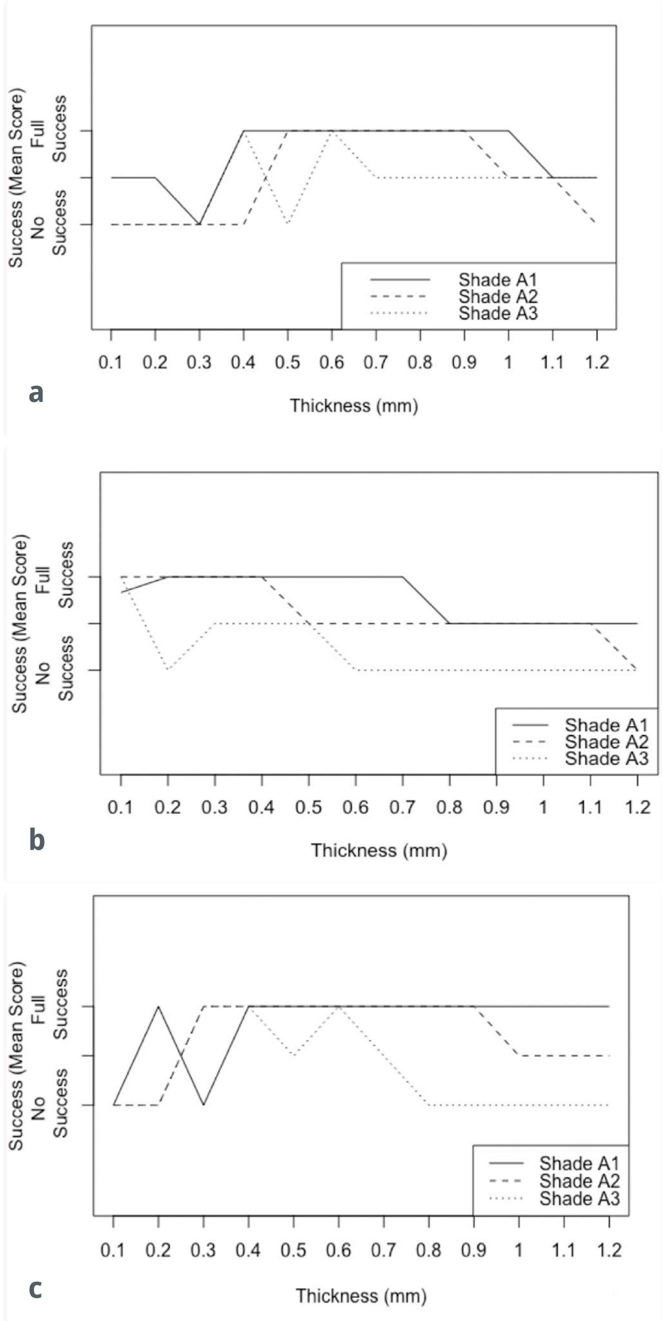
STATISTICAL ANALYSIS

Power analysis was estimated using previous conducted studies, data was analyzed using descriptive analysis, three-way ANOVA, and pairwise t-tests.

For the data analysis the statistics software R, version 3.5.0 (R Development Core Team) was used. A three-way ANOVA test was used as overall test to assess global differences in means. Then pairwise t tests were used as *post hoc* test to assess local differences in means. The reproducibility of the measurements was tested using computing Conger’s weighted Kappa as an index of agreement. 95% confidence intervals were calculated additionally using the Bootstrap method. P values ≤ 0.05 were considered as statistically significant in differences in means. Furthermore, p-values for *post hoc* tests were corrected for multiple testing with “Holm’s method”.

RESULTS

Each of the investigated three parameters thickness, shade and material were evaluated individually and in correlation to each other. The three-way ANOVA showed that the parameters shade and interaction of material in correlation to thickness to material showed both significant p-values (p<0.001) regarding their masking ability *(Table 2)*.



Figures 2a-c: Mean success in background masking abilities of a) LD, b) LDS and c) RNC in respect to thicknesses and shades.

Pairwise t tests compared the different shades and the different materials at fixed intervals of thicknesses. Three different thickness ranges were chosen as 0.1-0.4 mm, 0.5-0.8 mm and 0.9-1.2mm.

Shade A1 lead to the biggest mean success score (mean=1.574±0.645), followed by shade A2 (mean=1.222±0.797) and shade A3 (mean=0.639±0.762). Each comparison of the different shades was significant, A1 vs. A2 (p=0.045), A1 vs. A3 (p<0.001), A2 vs. A3 (p=0.002).

In regard to the correlation of the material and thickness, significant results could be observed when comparing LD (0.5±0.789) and LDS (1.639±0.643) at the thickness level of 0.1-0.4 mm (p=0.007) *(Table 3)*.

Table 2. Three-way Anova overall test results, * significant difference (p<0.5) for the three Groups LD, LDS and RNC regarding to shade and thickness.

Effect	DF	Sum Sq	Mean Sq	F value	P value
Thickness	1	0.135	0.135	0.296	0.588
Shade	2	16.064	8.032	17.623	<0.001
Material	2	0.619	0.310	0.680	0.510
Thickness vs.Shade	2	1.057	0.529	1.160	0.318
Thickness vs.Material	2	9.732	4.866	10.677	<0.001
Shade vs. Material	4	1.665	0.416	0.913	0.460
Thickness vs.Shade: Material	4	2.881	0.720	1.580	0.186

Table 3. Results of post-hoc test for the interaction between the parameters material and thickness, * significant difference (p<0.5) for the three Groups LD, LDS and RNC regarding to shade and thickness.

Thickness (mm)	Tested groups	P value
0.1-0.4	LD vs. LDS	0.007
0.1-0.4	LD vs. RNC	0.157
0.1-0.4	Nice vs. RNC	0.146
0.5-0.8	LD vs. LDS	0.067
0.5-0.8	LD vs. RNC	1.000
0.5-0.8	Nice vs. RNC	0.067
0.9-1.2	LD vs. LDS	0.130
0.9-1.2	LD vs. RNC	0.770
0.9-1.2	Nice vs. RNC	0.170

The reproducibility of the measurements was tested using computing Conger's weighted Kappa as an index of agreement among measurements and among regions. 95% confidence intervals were calculated additionally using the Bootstrap method. Reproducibility among measurements within material resulted for all materials resulted in the following kappa values: LD (1.000); LDS (0.944) and RNC (1.000). Within LD and RNC the agreement is perfect. Nice resulted in high reproducibility, yet significantly lower than in the other two materials (p<0.05). Reproducibility among shades resulted in the following kappa values for all shades: A1:(0.955); A2 (1.000) and A3 (0.975). All agreements were very high without showing significant differences between the three shades.

Reproducibility among each thickness presented in the following kappa values for the different thickness groups 0.1-0.4 mm (0.972); 0.5-0.8 mm (1.000) and 0.9-1.2 mm (0.971). All agreements were very high without any significant differences.

Reproducibility among each region resulted in the following kappa values for the different tested regions coronal (0.934); middle (0.989) and apical (0.990). All agreements were also very high without any significance. In terms of reproducibility among each region within the material was for LD (0.268); LDS (0.090) and RNC (0.253), there were low agreements in all materials. LDS presented the lowest and was significantly lower compared to LD and RNC (both p<0.05).

Reproducibility among each region within the shade was for A1 (0.311); A2 (0.081) and A3 (0.126). The agreements were very low for the shades A2 and A3 and highest for A1. Reproducibility among each region within the thickness was for 0.1-0.4 (0.312); 0.5-0.8 (0.102) and 0.9-1.2 (0.132). The agreement was significantly higher in the thinnest group (0.1-0.4 mm) compared to the other two thickness groups (p<0.05).

DISCUSSION

This study was undertaken in order to evaluate the effect of thickness and shade of various glass and multiphase ceramics on color masking abilities and optical behaviour of CAD/CAM materials. The null hypothesis was not rejected for the influence of masking ability by the parameter "shade" and the two-way interaction of thicknesses and materials for the thickness range 0.1-0.4mm. However, the null hypothesis was rejected for the two parameters "material" and "thickness" as well as all other combinations.

Up to date, the effect of influence of type and thickness of materials on their masking ability has been discussed in the literature controversially. In this study the masking ability was not affected by type and thickness of the chosen material parameters themselves, contradicting one study concluding that material type and its thickness affect the optical properties of monolithic restorative materials significantly.[27] However, in the mentioned study the optical properties were measured by using CIE L*a*b* coordinates of the specimens and evaluated using translucency and opalescence parameter. Other studies showed that thickness,[28,29,33] material[31] or both[27,30,32,34] affect the optical behaviour of dental ceramics significantly. This different outcome compared to this study maybe explained in the differing design of the study, choice of measurement methods and material types investigated.

Instrumental tooth shade analysis is accurate and reproducible compared to visual assessment methods yet has its limitations. Colorimeters have shown good reproducibility. However, shade guides may differ by the brand of the material and may no provide the full optical range observed in a population.[41]

In this study, the masking ability was tested by measuring the color change in Vitapan classic shade guide color values with the spectrophotometer SpectroShade™ MICRO (MHT, 37135 Verona, Italy) working with the CIELab system, whereby geometric attributes of appearance and optical phenomena were not taken into account.[41] No further optical parameters such as translucency parameter or opalescence parameter were evaluated in this study, unlike in a previous study with similar purpose[27] mentioned before.

The specimen shade A1 of the three investigated materials led to highest „mean succes score“, followed by A2 and A3. To achieve the target color, here defined as „1“ according to the Vitapan Classic Shade guide, the shade A1 led to the highest success in masking an A3 colored underground. Therefore, the results of this study suggest that the shade of the restorative material should be chosen close to the intended final color of a restoration.

The aesthetic outcome of a ceramic restoration is not only related to the color match itself, which is accomplished by methods such as determining the color of the teeth with a sample of the dental shade guide. The appearance is also affected by the geometric and aesthetical characteristics such as opacity, transparency, gloss, translucency and optical attributes such as metamerism, opalescence and fluorescence.[41]

Significant differences were found in the two-way interaction of material and thickness between glass ceramics (LD) and glass reinforced ceramics (LDS) in the thickness group of 0.1-0.4 mm, thus in order to obtain the targeted color, glass reinforced ceramics (LDS) showed at very low layer thicknesses better masking abilities compared to glass ceramics (LD). In the both other thickness intervals (0.4-0.8 an 0.9-1.2), glass ceramics (LD) showed higher not statistically significant mean success scores compared to glass reinforced ceramics (LDS).

This result may be explained in the composition of the two ceramic materials. Several studies showed that thickness has a significant influence on the optical behaviour of a ceramic material[27-30,32-34], still it is only one parameter among many others which affect the optical outcome. The micro structure of CAD-CAM ceramics such as content, grain shape and size, homogeneity, particle size distribution, refractive index and porosity for example can affect the optical characteristics.[27] High crystalline content leads to high flexural strength, but decreases translucency,[20] low translucency ceramics are known for poor optical qualities for dental use, but they show better masking abilities of discolored teeth than more translucent ceramics, such as feldspathic ceramics.

Many direct CAD-CAM ceramic systems are available in low or high translucency (LT, HT) options. By varying the crystallization heat treatment in the manufacturing process, the translucency of the ceramics is adjusted, through modifying the crystalline content and crystal size. In the thickness group of 0.5-0.9mm glass ceramics (LD) and resin nanoceramics (RNC) showed identical high mean success values, which indicated a similar masking ability of both materials at this thickness range. There was no significant difference to the resin nanoceramic (RNC) group measured. Previous studies[27,28] with similar purpose showed that resin nanoceramics (RNC) showed significantly higher translucency values than glass ceramics (LD) at similar thicknesses. Higher translucency values of a dental ceramic is reducing its masking ability of underlying discolored tooth substance, abutment or core material shades. Therefore, lower masking abilities of resin nanoceramics (RNC) compared to glass ceramics (LD) can be expected. Regarding the outcome of this study, the previous conclusion that resin nanoceramics (RNC) should show lower masking abilities than glass ceramic (LD) could not be seen as validated.

Nevertheless, direct comparison with the results from previous studies must be made carefully, regarding to different thicknesses compared, different shade taking devices used and different translucency parameters quantified among the three previous studies.[27,28] In the study from Awad *et al.*,[28] the higher translucency from resin nanoceramics (RNC) was explained by the nanoceramic particles. Particles with a diameter smaller than the wavelength of visible light cause less light scattering and absorbance, leading to higher translucency of the material.[28] Resin nanoceramics (RNC) is composed of about 80% mass fraction nanoceramic particles, bound in a resin matrix. The particle size of the ceramic fillers is in a range of 4-20 nm, what is way below the wavelengths of the visible spectrum, going from 380 nm to 780 nm.

The majority of dental studies investigating color change or differences operate with the CIELab to calculate color differences as ΔE,[42] or with the CIEDE200 formula, from the CIE (Commission internationale de l'éclairage) recommended since 2004[43], were color differences are calculated as ΔE_{00} differences in lightness, chroma and hue for a pair of samples in CIEDE2000, and R_T is a function, the so-called rotation function, that accounts for the interaction between chroma and hue differences in the blue region.[44] Weighting functions S_L,S_C,S_H adjust the total color differences for variation in the location of the color difference pair in L´, a´, b´coordinates and the parametric factors K_L, K_C, K_H are correction terms for experimental conditions.[44]

For better comparability of color difference results among dental studies, with the intention of evaluating translucency or masking abilities of dental restorative materials, its advisable to follow the recommendations of CIE from 2004.[42] In order to achieve the predetermined target color of a monolithic direct CAD/CAM ceramic restoration the clinician has to choose the right shade and translucency value for the chosen ceramic material. Most manufacturers offer a high translucency and low translucency version of their ceramic blocks, by varying crystalline content and crystal size through different heat treatment procedures.[34]

Limitation of this study are the possible influence of cutting and polishing procedures on the coloring measurements as such procedures affect the surface topography and light scatering.[53] However, the chosen testing method could be considered more accurate and reproducible compared to other available methods such as visual assessment methods. In summary, the clinician has to decide how much translucency or masking ability is needed in each particular case. The selection is influenced by the remaining tooth structure shade or core build-up material[29] from the translucency level of the remaining adjacent teeth and also by the experience of the clinician and is highly affecting the optical outcome of the final restoration.

For better comparison of color difference measurements among studies, color change should be evaluated with the ΔE_{00} formula, as the CIE (Commission internationale de l'éclairage) recommended the use of CIEDE2000 since 2004, and should be taken as standard for measuring differences in future *in-vitro* studies.

CONCLUSIONS

From this study, the following could be concluded:

Among the tested CAD/CAM materials, masking abilities of direct monolithic CAD/CAM materials were influenced by the choice of shade of the material and by the interaction of thickness and material. Reinforced glass ceramics showed the best results in the smallest thickness 0.1-0.4 mm while presenting similar good results as hybrid ceramics in middle thicknesses 0.5-0.8 mm. To achieve the clinically most aesthetic results with a monolithic direct CAD/CAM ceramic restoration, the clinician has to carefully evaluate the choice of the shade and has to adapt the thickness of the restoration to the chosen material in the given clinical circumstance especially for minimal invasive applications.

DISCLOSURE

The authors declare that they have no conflict of interest.

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