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Effect of Thickness of High-Translucent and Super-Translucent Monolithic Zirconia Restorations on their Translucency Parameter, Color, Internal, Marginal, and Occlusal Adaptation

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Background and objectives: This study assessed the effect of thickness of high-translucent (HT) and super-translucent (ST) monolithic zirconia on its color, translucency, and marginal and internal adaptation.

Materials and methods: Monolithic zirconia restorations were fabricated from HT and ST zirconia blanks (n = 30) with 0.5-, 1- and 1.5-mm thicknesses (n = 10). The color and translucency parameter (TP) was measured by a spectrophotometer, and marginal gap (MG), internal gap (IG), and occlusal gap (OG) were measured by the replica technique.

Results: Zirconia type had no significant effect on TP ($P = 0.362$) but the effect of thickness was significant ($P < 0.001$); 1.5 mm thickness yielded the lowest and 0.5 mm thickness yielded the highest TP. Zirconia type ($P < 0.001$) and thickness ($P = 0.001$) had significant effects on color difference (ΔE); ST yielded significantly higher ΔE, and 0.5 mm thickness resulted in significantly lower ΔE than 1 mm ($P = 0.047$) and 1.5 mm ($P < 0.001$). The MG of both HT and ST increased with thickness ($P < 0.05$). The IG of 0.5 mm thick restorations was significantly higher than 1 mm ($P = 0.005$) and 1.5 mm ($P = 0.003$). In ST restorations, the difference in IG was not significant among different thicknesses ($P > 0.05$). OG was the highest in 0.5 mm thickness. In ST restorations, minimum OG was found in 1 mm thickness. Zirconia type had no significant effect on adaptation ($P > 0.05$).

Conclusion: Zirconia type had no significant effect on TP or adaptation. Increasing the thickness decreased TP. ΔE was lower in lower thicknesses, and ST zirconia yielded higher ΔE. Thickness had a direct correlation with MG and an inverse correlation with IG and OG.

Keywords: Zirconium Oxide, Color, Ceramic, Dental Marginal Adaptation.

1. Introduction

Monolithic zirconia is currently an acceptable treatment option for coronal reconstruction of teeth. This type of restoration has several advantages including the need for less tooth preparation, optimal esthetics, favorable biocompatibility, and high strength, while also causing less wear on the opposing teeth compared to previous generations of zirconia restorations. Such favorable properties have contributed to the increasing popularity of monolithic zirconia restorations (1,2). Although the flexural strength of monolithic zirconia is lower than that of zirconia frameworks in veneered restorations with a comparable thickness the crowns fabricated from monolithic zirconia have higher fracture resistance than zirconia-based crowns due to increased zirconia thickness and absence of a veneering layer (2). However, achieving maximum esthetics is a challenge in using monolithic zirconia.

The esthetic appearance of ceramic restorations depends on their color, translucency, fluorescence, surface texture, and contour (3). Color of ceramic restorations depends on type and thickness of ceramic, color and thickness of the luting cement, underlying tooth/abutment color, and patient's age (4,5). Color of monolithic zirconia is initially affected by the original shade and optical properties of zirconia ceramics dictated by their manufacturing process. Also, the laboratory processes involved in monolithic zirconia production influence its color. In brief, the final color of a restoration is the result of interactions of manufacturing, laboratorial, and clinical parameters (6).
Insufficient translucency is a drawback of full-contour zirconia restorations compared with other all-ceramic systems, such as lithium disilicate and alumina, which is due to the mismatch in the refractive index of different components of the restoration and its matrix (5). Opaque zirconia is commonly used in extensive restorations due to its optimal mechanical properties,

especially when the underlying tooth discoloration needs to be masked. In the recent years, high-translucent (HT) monolithic zirconia was introduced to the market to enhance esthetics while providing high strength. A previous study reported that the final color and translucency of HT monolithic zirconia were affected by the zirconia thickness, such that the translucency significantly increased by decreasing the thickness from 2 to 0.5 mm (7).

Super-translucent (ST) cubic zirconia is the most recent type of zirconia introduced to the market. It is a combination of tetragonal and cubic zirconia phases, which is used in both monolithic and hybrid (with a ceramic veneering) restorations. ST zirconia has exceptional optical properties. It is not white, and is slightly transparent, making it an ideal option for the esthetic zone. In fact, ST zirconia has a translucency comparable to that of lithium disilicate ceramics; however, its mechanical properties are not as favorable as those of previous types (8).

Although it is believed that thickness can affect color and translucency of monolithic zirconia restorations, the pattern and direction of color change as the result of altering the thickness depend on the composition of ceramic (9). Different restoration thicknesses are used in the clinical setting, depending on patient conditions. Thus, knowledge about the relationship of translucency and color with restoration thickness is imperative to obtain favorable results (10). Nonetheless, the effect of zirconia thickness on color and translucency of monolithic zirconia restorations has not been well elucidated (11,12) and is in need of further investigations.

While achieving optimal esthetics is crucial, the success of prosthetic restorations also hinges on factors such as adaptation to prevent issues like cement dissolution, restoration loosening, and development of secondary caries. Secondary caries and retention loss are the main causes of failure of zirconia restorations (13). Also, crowns with poor adaptation of their subgingival margins increase bacterial retention and lead to gingivitis and periodontitis (14,15). The clinically acceptable marginal gap (MG) is reportedly 40 to 120 µm (16). Marginal adaptation of monolithic zirconia restorations is affected by the preparation design, manufacturing process, sintering technique, and type of computer-aided design/computer-aided manufacturing system used (14). Ideal internal adaptation is another important parameter that can improve the mechanical behavior of all-ceramic restorations including their strength, resistance, and retention (17). Poor internal adaptation results in increased cement thickness, compromises retention, adversely affects the occlusion, decreases fracture resistance, and compromises marginal adaptation by impairing the correct seating of restoration (18). Clinically acceptable internal gap (IG) ranges from 200 to 300 µm (19).

Restoration thickness can affect its marginal and internal adaptation (20). Due to its high flexural strength and fracture resistance, manufacturers permit the application of monolithic zirconia in lower thicknesses (21). It has been reported that a minimum wall thickness of 0.4 to 0.5 mm, and a minimum occlusal thickness of 0.5 mm are acceptable for monolithic zirconia restorations (20). Such restorations require less tooth preparation and preserve the tooth structure as such. Also, less tooth preparation is ideal for cases with limited inter-occlusal space or restoration placement on the root surface. Furthermore, monolithic zirconia has higher translucency in lower thicknesses, and restoration esthetics can be improved as such (20).

Zirconia type may affect color, translucency, mechanical properties, and final success of treatment (8). Considering the gap of information on the effect of zirconia type (HT/ST) and thickness on color, translucency, and marginal and internal adaptation of monolithic zirconia restorations, this study aimed to assess the effect of thickness of HT and ST monolithic zirconia restorations on their color, translucency, internal, marginal and occlusal adaptation.

2. Materials and methods

This in vitro, experimental study was conducted on HT and ST zirconia restorations fabricated in 0.5, 1 and 1.5 mm thicknesses on zirconia dies. The study protocol was approved by the ethics committee of the university (IR.SBMU.REC.049/1400 - IR.SBMU.DRC.REC.1400.030).

2.1. Sample size

The sample size was calculated to be 10 for each thickness according to a study by Tabatabaian et al, (11) assuming alpha=0.05 and beta=0.1 for evaluation of color and translucency, and also the study by Boonnithi and Anunmana (22) assuming alpha=0.05, standard deviation of trueness to be 6, and minimum expected difference of 10 µm between the two zirconia types for marginal and internal adaptation .

2.2. Specimen preparation

Three models with A3 shade were designed from HT Plus zirconia blanks (Dechat, China) by DentalCAD 3.0 Galway-Exocad and milled by a milling machine (Roland Dwx51D; Roland, DGA, USA). The models were standardized in terms of surface smoothness and absence of irregularities. Each model had 6-degree occlusal convergence and was designed such that after placement of restorations with 0.5-, 1- or 1.5-mm thickness, the occlusogingival height reached 8 mm, and the diameter reached 6 mm (buccolingually and mesiodistally). Accordingly, the first model had 7.5 mm height and 5.5 mm ferrule diameter, the second model had 7 mm height and 5 mm ferrule diameter, and the third model had 6.5 mm height and 4.5 mm ferrule diameter; the finish line width of the models was 0.5, 1, and 1.5 mm, respectively. The models were scanned by Swing HD scanner (DOF, Korea) and digitized. For the first model, a restoration with a uniform thickness of 0.5 mm was designed. The restoration thickness was 1 mm for the second model, and

1.5 mm for the third model at all points, irrespective of spacer space. The crowns were fabricated from the A2 shade zirconia blanks (HT and ST, Dechat, China) using a milling machine, and were then sintered in a furnace (1650 L; KPF Dental, Iran) at 1500-1600°C temperature for 8 hours. The milled crowns were designed such that they were larger than their original model by 25% to compensate for the sintering shrinkage and reach their original size after sintering (20).

2.3. Assessment of color and translucency parameter (TP):

The crowns were placed on the prepared models, and their color parameters were recorded once against a standard white background (with a* = -1.3, b* = 2.6, and L* = 95.7 according to the CIEL*a*b* color space) and once against a standard black background (with a* = 1.3, b* = -1.5, and L* = 1.8) at their mid-occlusal region. A calibrated spectrophotometer (Xi6X; X-RITE, USA) was used for the color measurements. Considering the color difference (ΔE) against the black and white backgrounds, the TP was calculated using the following formula (23):

$$\text{TP} = \sqrt{(L^*_W - L^*_B)^2 + (a^*_W - a^*_B)^2 + (b^*_W - b^*_B)^2}$$

To calculate ΔE, pre-shaded A2 zirconia restorations were placed on the A3 die, and color measurements were made at the mid-occlusal region. Also, the color parameters of the A2 shade tab of Vita Classic shade guide at the middle third were measured by Ci6X spectrophotometer according to the CIE L*a*b* color space, and placed in the following formula (9):

$$\Delta E = \sqrt{(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2}$$

2.4. Assessment of marginal, internal, and occlusal adaptation :

MG, IG, and occlusal gap (OG) of restorations were assessed by the replica technique. For this purpose, the restorations were filled with low-viscosity addition silicone impression material (Zhermack Elite HD+ Light body, Germany) and seated on their respective models. After complete polymerization of silicone material, the crown was removed from the die, and heavy-body addition silicone material (Zhermack Elite HD+ Tray material, Germany) was injected into the crowns to stabilize the light-body layer inside the copings and support it without distortion. After polymerization of the heavy body, the replica was carefully removed and sagittally sectioned by a #15 scalpel along with the internal silicone support. The thickness of the internal silicone layer in the marginal and axial (distal, buccal, lingual, and mesial) surfaces and the OG were measured under a stereomicroscope (SZX-16; Evident, Olympus, Japan) at x50 magnification (Figure 1). The IG and MG were measured according to Holmes et al, (24) by measuring the vertical distance between a point in the internal surface or at the margin of the casting and the axial and occlusal wall or margin of the model .

2.5. Statistical analysis:

Two-way ANOVA was applied to analyze the effect of zirconia type and zirconia thickness and their interaction effect on color and translucency. Pairwise comparisons were carried out by the Tukey HSD test.
Multivariate ANOVA was applied to compare the MG, IG, and OG among different groups with pairwise comparisons by the LSD test. All statistical analyses were performed using SPSS version 22 (SPSS Inc., IL, USA) at 0.05 level of significance.

3. Results

3.1. TP

Table 1 presents the TP based on zirconia type and thickness. Two-way ANOVA showed that zirconia type had no significant effect on TP (P = 0.362). However, the effect of thickness on TP was significant (P < 0.001). The interaction effect of zirconia type and thickness was not significant on TP (P = 0.275). Restorations with 1.5 mm thickness had the lowest, and those with 0.5 mm thickness had the highest TP, and pairwise comparisons of zirconia thicknesses revealed that all comparisons were statistically significant (P < 0.001).

3.2. Color

Table 2 presents the ΔE values based on zirconia type and thickness. The ΔE values of all thicknesses of both HT and ST zirconia were higher than the clinically acceptable ΔE threshold of 3.3, indicating that both zirconia types in the tested thicknesses caused a significant change in color, compared with the final color. Two-way ANOVA showed significant effects of both zirconia type (P < 0.001) and thickness (P = 0.001) on ΔE, such that ST zirconia yielded a significantly higher ΔE than HT zirconia. Also, different thicknesses had different ΔE values (P = 0.001). Nonetheless, the interaction effect of zirconia type and thickness on ΔE was not significant (P = 0.844). Pairwise comparisons of the thicknesses by the Tukey HSD test showed that 0.5-mm thickness resulted in lower ΔE than both 1 mm (P = 0.047) and 1.5 mm (P < 0.001) thicknesses. However, the ΔEof 1- and 1.5-mm thicknesses was not significantly different (P = 0.223).

3.3.MG, IG, and OG

The overall MG was 48.70 ± 18.29 µm, the overall OG was 58.47 ± 19.16 µm, and the overall IG was 61.72 ± 25.59 µm .

3.3.1. HT restorations

Table 3 presents the mean MG, IG, and OG of HT restorations with different thicknesses. The MG of HT restorations with 1.5 mm thickness was higher than that of HT restorations with 1- and 0.5-mm thicknesses. However, the IG and OG of restorations with 0.5 mm thickness were greater than the corresponding values in restorations with 1- and 1.5-mm thicknesses. Pairwise comparisons of the gaps of HT restorations with different thicknesses (Table 4) by the LSD test revealed significant differences in MG of HT restorations with 1- and 1.5-mm thicknesses (P = 0.000), and 0.5- and 1.5-mm th-

Table 1. ΔE values based on zirconia type and thickness.

Zirconia type	Thickness	Mean	Std. deviation	Minimum	Maximum
ST	0.5	1.7615	0.32546	1.42	2.43
	1	1.2362	0.16855	0.98	1.45
	1.5	1.0651	0.30979	0.59	1.51
HT	0.5	1.7467	0.16093	1.55	2.00
	1	1.2748	0.20785	1.01	1.67
	1.5	0.8773	0.13580	0.73	1.17

Table 1. ΔE values based on zirconia type and thickness.

Zirconia type	Thickness	Mean	Std. deviation	Minimum	Maximum
ST	0.5	6.8857	1.02643	5.40	8.87
	1	7.6053	.64717	6.98	8.86
	1.5	7.9080	.84747	6.41	9.17
HT	0.5	5.7997	.75583	4.73	6.93
	1	6.2495	.40596	5.71	6.95
	1.5	6.7511	.72224	5.90	8.15

Table 2. Mean MG, IG, and OG of HT restorations with different thickness.

Parameter		Thickness (mm)	Mean (µm)	Std. deviation
HT	MG	0.5	31.51	8.201
		1	42.02	13.725
		1.5	64.70	12.340
		Total	46.08	18.029
	IG	0.5	88.40	32.046
		1	55.30	18.148
		1.5	53.30	19.305
		Total	65.67	28.365
	OG	0.5	74.39	23.694
		1	59.23	13.819
		1.5	53.71	13.333
		Total	62.44	19.177

-icknesses (P = 0.000). The difference in IG was significant between 0.5 and 1 mm (P = 0.005), and also 0.5 and 1.5 mm (P = 0.003) thicknesses of HT restorations. However, for the OG, only the difference between 0.5- and 1.5-mm thicknesses were significant in HT zirconia (P = 0.014)

3.3.2. ST restorations

Table 5 presents the mean MG, IG, and OG of ST restorations with different thicknesses. The results showed higher MG and IG of ST restorations in 1.5 mm thickness, compared with 1- and 0.5-mm thicknesses. OG was lower in 1 mm thickness. Univariate ANOVA showed a significant difference among different thicknesses only in MG (P = 0.000) and OG (P = 0.045) with effect size of 45% and 20%, respectively. However, the difference in IG was not significant (P = 0.085). Pairwise comparisons of thicknesses for the MG and OG by the LSD test (Table 6) showed that for the MG, the difference between 1.5 mm and 1 mm (P = 0.006), and also 1.5 mm and 0.5 mm (P = 0.000) thicknesses was significant. However, MG was not significantly different between 1 mm and 0.5 mm thicknesses (P = 0.107). In OG, the difference between 1-mm thickness with both 0.5 mm (P = 0.036) and 1.5 mm (P = 0.026) thicknesses was significant; however, the difference in OG between 1.5 mm and 0.5 mm thicknesses was not significant (P = 0.887).

3.3.3. MG, OG and IG of HT and ST restorations with different thicknesses:

MG and OG of HT and ST restorations with different thicknesses had no significant difference. A small difference was only noted in OG in 1.5-mm thickness. The difference in IG of ST and HT restorations was significant, such that HT zirconia had higher IG in 0.5 mm thickness and ST zirconia had higher IG in 1.5 mm thickness (P = 0.001).

3.3.4. Effect of zirconia type on MG, IG, and OG:

Multivariate ANOVA showed no significant difference in ST and HT restorations in MG, IG, or OG (P > 0.05). The lowest MG was noted in 0.5 mm thickness of HR zirconia, and in both HR and ST zirconia, MG increased by an increase in restoration thickness. The highest IG and OG were noted in 0.5 mm HT zirconia restorations, and by an increase in thickness, IG and OG decreased. However, in ST zirconia, higher thicknesses had higher IG. The lowest OG was noted in 1 mm ST zirconia; 0.5- and 1.5-mm restorations had equal OG.

4. Discussion

This study assessed the effect of thickness of HT and ST monolithic zirconia restorations on their color, translucency, and marginal, internal and occlusal adaptation. The results showed that zirconia type had no significant effect on TP while the effect of thickness was significant and 1.5 mm thickness yielded the lowest and 0.5 mm thickness yielded the highest TP.
Some previous studies reported an increase in TP by reduction in thickness (5,7,12,25-29). In line with the present results, Al-Juaila et al. (28) showed that the TP of ultra-translucent (UT) zirconia was significantly higher than that of HT and ST zirconia; however, the difference between HT and ST was not significant. Sen and Isler (29) demonstrated that 0.5-mm thickness of ST zirconia was more translucent than HT zirconia. Also, ST zirconia has higher mean grain size and Y2O3 content, and lower cubic phase and sintering temperature than HT zirconia. Since the zirconia translucency is influenced by the chemical composition, grain size, phase content, Y2O3 content, density, sintering parameters, and staining, higher translucency of ST zirconia is justifiable considering the other parameters measured in this study (29). Baldissara et al. (30) assessed the TP of 1 and 1.5-mm thicknesses of UT and ST zirconia restorations and reported a reduction in TP by an increase in restoration thickness. Also, TP was generally higher in UT than ST restorations. Harada et al. (31) showed that 0.5 mm UT restorations were significantly more translucent than 0.5 mm ST restorations but the difference between the two zirconia types was not significant in 1-mm thickness. Variations in the reported results can be due to different measurement methods since Harada et al. (31) measured the total transmission percentage (Tt%) at 555 nm wavelength because the human eye is most sensitive to this wavelength of light. Baldissara et al. (30) used a white light source for measurement of Tt% (mainly 460 nm, produced by light-curing units followed by 565 nm wavelength). Since the Tt% of light through UT and ST restorations with 1-mm thickness was higher than that passed through lithium disilicate ceramics in lower wavelengths (unlike 555 nm wavelength) (31), it appears that higher translucency of UT, compared with ST, is due to the dominance of blue light in the composition of the tested light (30). In the present study, translucency was calculated using the TP formula, which uses the ΔE for measurement of TP and is different from the Tt method and may yield different results (32). Different sizes of specimens in the study by Harada et al, (31) and the present study may be another reason for the variations in the reported results. They evaluated zirconia blocks in their study while actual restorations were assessed in the present study to better simulate the optical behavior of restorations in the clinical setting (30).
In the current study, zirconia type and thickness both had significant effects on ΔE such that ST zirconia had significantlyhigher ΔE, and 0.5 mm thickness resulted in significantly lower ΔE than 1 mm and 1.5 mm thicknesses. Unlike the present results, Bayindir and Koseoglu (7) and Malkondu et al. (27) reported a reduction in ΔE by an increase in zirconia restoration thickness. However, they measured the color after cementation of specimens and used zirconia discs, which may explain the difference in the results. In the present study, the ΔE of all thicknesses of both HT and ST zirconia was higher than the clinically acceptable threshold (3.3), indicating that both zirconia types in the tested thicknesses cause a significant change in color, compared with the final color.

Table 3. Pairwise comparisons of different thickness of HT monolithic zirconia restorations regarding MG, IG, and OG.

Parameter	Thickness (I)	Thickness (J)	Mean difference (I-J)	Std. deviation	P value	95CI %	
						Lower bound	Upper bound
MG	0.5	1	10.510-	5.215	0.054	-21.210	0.190
		1.5	-33.190*	5.215	0.000*	-43.890	22.490-
	1	1.5	-22.680*	5.215	0.000*	-33.380	11.980-
IG	0.5	1	33.100*	10.736	0.005*	11.071	55.129
		1.5	35.100*	10.736	0.003*	13.071	57.129
	1	1.5	2.000	10.736	0.854	-20.029	24.029
OG	0.5	1	15.160	7.875	0.065	-0.997	31.317
		1.5	20.680*	7.875	0.014*	4.523	36.837
	1	1.5	5.520	7.875	0.489	-10.637	21.677

Table 4. Mean MG, IG, and OG of ST restorations with different thickness.

Parameter		Thickness (mm)	Mean (μm)	Std. deviation
ST	MG	0.5	38.00	11.951
		1	48.60	15.994
		1.5	67.40	14.439
		Total	51.33	18.475
	IG	0.5	49.90	11.827
		1	53.10	25.675
		1.5	70.30	23.080
		Total	57.77	22.278
	OG	0.5	59.80	16.976
		1	42.80	17.606
		1.5	60.90	17.065
		Total	54.50	18.628

Table 5. Pairwise comparisons of different thickness of ST monolithic zirconia restorations regarding MG, IG, and OG.

Parameter	Thickness (I)	Thickness (J)	Mean difference (I-J)	.Std deviation	P-value	95CI %	
						Lower bound	Upper bound
MG	0.5	1	-10.600	6.362	0.107	-23.654	2.454
		1.5	-29.400*	6.362	0.000*	-42.454	-16.346
	1	1.5	-18.800*	6.362	0.006*	-31.854	-5.746
OG	0.5	1	17.000*	7.700	0.036*	1.201	32.799
		1.5	-1.100	7.700	0.887	-16.899	14.699
	1	1.5	-18.100*	7.700	0.026*	-33.899	-2.301

Table 6. Pairwise comparisons of different thickness of restorations regarding MG, IG, and OG.

Parameter	Thickness (I)	Thickness (J)	Mean difference (I-J)	Std. deviation	P-value	95CI %	
						Lower bound	Upper bound
MG	0.5	1	10.510-	5.215	0.054	-21.210	0.190
		1.5	-33.190*	5.215	0.000*	-43.890	22.490-
	1	1.5	-22.680*	5.215	0.000*	-33.380	11.980-
IG	0.5	1	33.100*	10.736	0.005*	11.071	55.129
		1.5	35.100*	10.736	0.003*	13.071	57.129
	1	1.5	2.000	10.736	0.854	-20.029	24.029
OG	0.5	1	15.160	7.875	0.065	-0.997	31.317
		1.5	20.680*	7.875	0.014*	4.523	36.837
	1	1.5	5.520	7.875	0.489	-10.637	21.677

Tabatabaian et al. (11) reported that the ΔE of 0.7-mm thick Dental Direkt Whitepeaks monolithic zirconia was significantly higher than the clinically acceptable ΔE threshold, and therefore, they suggested a minimum of 0.9 mm thickness for monolithic zirconia restorations. Basso et al. (33) showed that monolithic zirconia restorations masked the C4-shaded underlying structure but could not optimally mask the underlying metal layer. Also, Chang et al. (34) demonstrated that a bleached underlying structure changed the color of Katana monolithic zirconia in the body and cervical part of restorations. Thus, it may be stated that the masking ability of monolithic zirconia depends not only on the thickness and TP of restoration, but also on the cement shade, and material and shade of the underlying structure. Kim et al. (35) indicated that reduction in thickness of zirconia restorations did not change the L* parameter, increased the a* parameter, and decreased the b* parameter. In change of chroma (a* and b*), the sensitivity of the b* parameter to thickness change was higher than that of the a* parameter. According to Douglas and Brewer (36), human eye is more sensitive to change in redness than yellowness .

With respect to adaptation of restorations, the measured MG for both HT and ST zirconia types in all three thicknesses was within the clinically acceptable range of 1 to 165 µm in the present study (20). The highest MG was recorded for 1.5 mm thickness of both HT and ST zirconia. HT zirconia with 0.5-mm thickness had the highest IG while in ST zirconia, thickness had no significant effect on IG. The minimum OG was noted in 1 mm-thick ST zirconia. In HT zirconia, OG was significantly higher in 0.5 mm thickness compared with 1.5 mm thickness. Irrespective of zirconia type, MG was the highest in 1.5 mm, and the lowest in 0.5 mm thick restorations. Restorations with 0.5-mm thickness had the highest OG and lowest MG compared with other thicknesses. Boonnithi and Anunmana (22) reported that in equal axial thickness, MG was lower for restorations with 1 mm occlusal thickness compared with 2 mm occlusal thickness and explained the reason to be the larger OG in 1 mm thick restorations. It appears that less preparation decreases MG and increases OG. Increased OG provides greater cement space (or impression material) and can aid in better vertical seating of crown and reduction of MG (37). In the present study, the difference in IG was not significant among different restoration thicknesses, which was in agreement with the results of Boonnithi and Anunmana (22).

Saker et al. (38) evaluated the effect of finish line width (0.5, 0.8, and 1.2 mm) on marginal and internal adaptation of translucent zirconia restorations for premolar teeth. They reported the highest and the lowest MG in 0.5 mm and 1.2 mm chamfer finish line widths, respectively. Ahmed et al. (39) evaluated the effect of finish line width (0.5, 1, and 1.2 mm) on MG and showed that specimens with a thicker finish line had a smaller MG and found the best marginal adaptation in presence of 1 mm finish line width. It appears that in specimens with non-uniform preparation design, increasing the zirconia volume at the margins decreases the internal stress of restorations and their sensitivity to sintering, and increases their marginal adaptation as such (39). Boonnithi and Anunmana (22) demonstrated equal MG in restorations with similar occlusal thickness, irrespective of axial wall thickness of 1- or 2-mm. Use of titanium models and standard sintering method may explain the difference between the results of Boonnithi and Anunmana (22) with other studies.

Comparison of ST an HT zirconia restorations in this study rev-

-ealed no significant difference in MG, IG, or OG. Al-Hmedat et al. (40) compared three brands of translucent zirconia regarding MG and reported that MG of Whitepeaks crowns was significantly higher than Imes-icor and Dental Direkt crowns, and Dental Direkt crowns had the best marginal adaptation .
This study had some limitations. Measuring the TP allows for visual assessment of translucency; nonetheless, it may be associated with errors for dental crowns due to their complex structure and curved surfaces. Future studies are recommended to calculate Tt%, and contrast ratio for assessment of translucency of zirconia crowns. Final color of zirconia restorations depends on a number of parameters other than thickness, such as cement shade and color of underlying tooth structure, which were not addressed in the present study. Also, only one shade and one brand of zirconia blocks were used. Furthermore, the effect of restoration thickness should be assessed by taking into account different shades of cements and underlying tooth shades.

5. Limitations

In vitro design and no conduction of thermocycling and cyclic loading were among other limitations of this study which affect the generalizability of the findings to the clinical setting. Future clinical studies are required to verify the present findings. Moreover, all restorations had a shoulder finish line, which decreases marginal adaptation. Use of silicone replica technique and its high technical sensitivity and inherent shortcomings was another limitation. Future studies are required to measure the adaptation of restorations after cementation by more accurate 3D or microscopic measurement techniques.

6. Conclusion

Zirconia type had no significant effect on TP while increasing the restoration thickness decreased TP. Also, 0.5 mm restoration thickness had lower ΔE than 1- and 1.5-mm thicknesses. The ΔE of ST restorations was significantly higher than HT restorations. It appears that in absence of cement, zirconia restorations with lower thickness (more translucent) have lower ΔE; presence of cement probably reverses this correlation. MG of both HT and ST restorations increased by an increase in thickness. IG was significantly higher in 0.5 mm thickness of HT restorations compared with other thicknesses. Thickness had no significant effect on IG of ST restorations and OG was the highest in 0.5 mm thickness. In ST restorations, OG was the lowest in 1 mm thickness. ST and HT restorations had no significant difference regarding MG, OG, or IG.

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Authors' contribution
Rambod Varzandeh: Formal analysis, Data curation, Writing – Original draft
Armin Foulad: Formal analysis, Data curation, Writing – Original draft
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Conflict of Interest
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