The effect of translucency of Y-TZP based all-ceramic crowns fabricated with different substructure designs

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Abstract
Purpose: To analyse the effect of translucency of Y-TZP based all-ceramic crowns fabricated with different substructure thicknesses and extensions. The effect of restoration shading is also investigated.

Materials and methods: A maxillary right central incisal typodont tooth was prepared and a die was fabricated with Type IV stone after making impression. Horizontally and vertically reduced substructure extensions were designed at the facial cervical part with 0.3 mm and 0.5 mm thick Lava Y-TZP. Each substructure was fabricated with two different shades, FS1 and FS7. A1 shade veneering porcelain was applied on FS1 shade Y-TZP substructures and D3 shade veneering porcelain was applied on FS7 shade Y-TZP substructures with lost wax and press ceramic technique. Ten specimens were fabricated for a total of 8 groups. The cervical and body colour of specimens were analysed with a spectrophotometer, after placing specimens on the two different coloured abutment teeth using translucent try-in cement. The data were obtained in CIELAB colour coordinates $L^*, a^*, b^*$ and $\Delta E^*$ through the test specimens over ND1 and ND8 shade abutments were calculated.

Results: At the cervical area, there was a significant difference on substructure extension ($P < 0.001$). At the body area, results were borderline on substructure thickness ($P = 0.05$) and there was a significant difference on restoration shade ($P = 0.001$).

Conclusions: Vertical reduction design of Y-TZP substructure could increase $\Delta E^*$ at the cervical area. Decreasing thickness of Y-TZP substructure may increase $\Delta E^*$ at the body area. Increasing the value of Y-TZP based-all ceramic crown shade could increase $\Delta E^*$ at the body area.

Clinical significance: The translucency of a Y-TZP based all-ceramic crowns may influence its esthetic outcome when it is used on a discoloured abutment tooth.

Clinicians should be aware of the effect of substructure design on the translucency of Y-TZP based all-ceramic crowns.

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1. Introduction

The increased demand for esthetic restorations has resulted in the use of all-ceramic crowns especially when anterior teeth need high value shades because they do not require masking the metal substructure with opaque porcelain.\(^1\) The concerns about all-ceramic crowns are their strength and appearance. Among the current ceramics used in dentistry, yttria tetragonal zirconia polycrystals (Y-TZP) is the toughest ceramic material. The flexural strength of Y-TZP is 900–1200 MPa and its fracture toughness is 9–10 MPa/m\(^{1/2}\), twice or more than that of alumina ceramics.\(^2\) Thus, it has become used for the substructure material of single unit or FPD restorations fabricated by computer-aided design/computer-aided manufacturing (CAD/CAM) milling of ceramic block or pre-sintered blocks achieving acceptable marginal fit.\(^3-5\)

However, toughened polycrystalline ceramics have higher opacity due to the polycrystalline structure in the material.\(^6\) Kelly identified the core translucency as one of the primary factors in controlling esthetics and a critical consideration in the selection of materials.\(^7\) The translucency of dental porcelain largely depends on the light scattering.\(^8,9\) If the majority of light passing through a ceramic is intensely scattered and diffusely reflected, the material will appear opaque. The dispersed particle in zirconia has a refractive index different from that of the matrix.\(^10\) In 2002, Heffernan investigated the translucency of six different all-ceramic systems but not Y-TZP material, and reported that there are differences in the translucency of all-ceramic materials fabricated to the manufacturer’s recommended dimensions. There was no translucency on 0.5 mm thick glass-infiltrated alumina with 35% partially stabilized zirconia.\(^11\)

Today’s CAD/CAM technology has been improved to mill out the minimum wall thickness of 0.3 mm Y-TZP substructure for anterior crowns.

A previous study showed a 46.5% contrast ratio on 0.5 mm thick Y-TZP discs and about 8.6% higher translucency on a 0.3 mm one.\(^12\) However, the influence of this difference in the clinically applicable environment with veneering porcelain is unknown.

The following hypotheses are based on the above:

- All-ceramic crowns fabricated with 0.3 mm thick Y-TZP substructure will have stronger effect of translucency than those fabricated with 0.5 mm thick one.
- Y-TZP based all-ceramic crowns which have vertically reduced substructure extension at the facial cervical area will have stronger effect of translucency than those with horizontally reduced substructure extension.

Thus, the purpose of this study is to analyse the effect of translucency of Y-TZP based all-ceramic crowns fabricated with different substructure thicknesses and extensions. The effect of restoration shading is also investigated.

2. Materials and methods

2.1. Tooth selection and preparation

Maxillary right central incisal typodont tooth (ASA-500, Nissin, Kyoto, Japan) was selected to prepare specified designed abutment.

The typodont tooth was prepared to receive crowns with the use of rounded shoulder finishing line following the gingival margin. The amount of tooth reduction on the facial surface of the tooth follow the depth of the preparation at the margin level of 1.3 mm, at the facial body level of 1.5 mm, at the incisal level of 2.0 mm and the palatal level of 1.0 mm was performed in order to achieve adequate thickness of the crown. A high speed handpiece (MSK, Tokyo, Japan), FG fine round end taper diamond burs, S18212 and Fine end taper
diamond burs, S12809 (Brasseler, Savannah, GA, USA) were used for finalizing the preparation.

2.2. Y-TZP substructure fabrication

After making impression of the prepared tooth with additional silicone material (Z dupe, Henry Shine, Ridgeland, MS, USA), dies were fabricated with Type IV stone (Fujirock EP, Alsip, IL, USA) according to ADA classification.

Horizontally and 1 mm vertically reduced substructure extensions were designed on the facial cervical area of the die (Fig. 1).

The dies were scanned by Lava Scanner (Lava, 3M ESPE, St. Paul, MN, USA). Y-TZP Substructures (Lava, 3M ESPE, St. Paul, MN, USA) of 0.3 mm and 0.5 mm thickness were fabricated. Each substructure was fabricated with FS1 and FS7 shade using Lava Form Milling Unit (Ivocler vivadent, Schean, Liechtenstein) and Lava Therm Furnace (Ivocler vivadent, Schean, Liechtenstein).

Eight different groups of substructures were fabricated according to thickness, extension and shade (Fig. 2). 10 specimens were fabricated for each group (Table 1). After fabrication of substructures, each substructure was adjusted by 22 mm/C2 2 mm diamond disc (Diagen Disc, XPdent Corp., Miami, FL, USA) and 3.5 mm/C2 11 mm diamond bar (Diagen Cone, XPdent Corp., Miami, FL, USA) until it had specified thickness of 0.3 mm and 0.5 mm measured by a dial caliper (Calipretto “S” No. 1122-1000, Renfert, Hilzingen, Germany).

2.3. Veneering porcelain application

A1 shade veneering porcelain (IPS e.max ZirPress, Ivocler vivadent, Schaan, Liechtenstein) was applied with lost wax and press ceramic technique on FS1 shaded Y-TZP substructures. A standardized wax pattern was produced for each group by pumping inlay wax (Metalor-ABF Wax Creative, Metalor Dental AG, Switzerland) melted to 195 F. The wax pattern was completed according to the silicon key that had been made for the typodont tooth before preparation; the silicon key allowed the achievement of a final wax thickness of 1.3 mm at facial cervical and 1.5 mm at facial body.

Sprues of 5 mm length and 3 mm diameter were attached to the patterns by using sticky wax. In order to reduce the possibility of distortion, the sprues were attached, at a 45° angle, while the patterns were seated in the dies. The sprued patterns were positioned in crucible former.

The patterns were invested in phosphate-bonded investment (IPS PressVest, Ivocler vivadent, Schaan, Liechtenstein). The powder–liquid ratio was 200 g of powder and 54 ml of liquid (22 ml distilled water and 32 ml special liquid). The investment was mixed under vacuum for 2.5 min with Twister Pro-Renfert-serial no A00211. After stage of wax elimination at 1500 F, pressings were made for each wax pattern by using an IPS e.max ZirPress HT ingot (Ivocler vivadent, Schaan, Liechtenstein) by Programat EF5000 (Ivocler vivadent, Schaan, Liechtenstein) according to the manufacturer’s pressing schedule instruction shown as Table 2.

After divesting, all-ceramic crowns were finished to a uniform facial cervical of 1.3 mm and facial body thickness of 1.5 mm using a dial caliper (Calipretto “S” No. 1122-1000, Renfert, Hilzingen, Germany). Specimens were glazed with IPS e.max Ceram Glaze Paste (Ivocler vivadent, Schaan, Liechtenstein).

2.4. Colored abutment fabrication

After fabricating specimens, colored abutments were fabricated with ND1 and ND8 shade IPS Natural die material

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### Table 1: Eight different groups of substructures, according to thickness, extension and shade.

<table>
<thead>
<tr>
<th>Group</th>
<th>Thickness</th>
<th>Substructure extension</th>
<th>Shade</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3 mm</td>
<td>Horizontal reduction</td>
<td>FS1</td>
</tr>
<tr>
<td>2</td>
<td>0.3 mm</td>
<td>Horizontal reduction</td>
<td>FS7</td>
</tr>
<tr>
<td>3</td>
<td>0.5 mm</td>
<td>Horizontal reduction</td>
<td>FS1</td>
</tr>
<tr>
<td>4</td>
<td>0.5 mm</td>
<td>Horizontal reduction</td>
<td>FS7</td>
</tr>
<tr>
<td>5</td>
<td>0.3 mm</td>
<td>Vertical reduction</td>
<td>FS1</td>
</tr>
<tr>
<td>6</td>
<td>0.3 mm</td>
<td>Vertical reduction</td>
<td>FS7</td>
</tr>
<tr>
<td>7</td>
<td>0.5 mm</td>
<td>Vertical reduction</td>
<td>FS1</td>
</tr>
<tr>
<td>8</td>
<td>0.5 mm</td>
<td>Vertical reduction</td>
<td>FS7</td>
</tr>
</tbody>
</table>

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### Table 2: Pressing and glaze firing chart for IPS e.max ZirPress Porcelain.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Start temperature (°C)</th>
<th>Dry time</th>
<th>Heat rate</th>
<th>Final temperature (°C)</th>
<th>Hold time</th>
<th>Vacuum</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZirLiner firing</td>
<td>403</td>
<td>4.00 min</td>
<td>60 °C</td>
<td>960</td>
<td>1.00 min</td>
<td>Yes</td>
</tr>
<tr>
<td>Pressing</td>
<td>700</td>
<td>N/A</td>
<td>60 °C</td>
<td>910</td>
<td>15.00 min</td>
<td>Yes</td>
</tr>
<tr>
<td>Stain and characterization firing</td>
<td>403</td>
<td>6.00 min</td>
<td>60 °C</td>
<td>770</td>
<td>1.00 min</td>
<td>Yes</td>
</tr>
<tr>
<td>Glazing</td>
<td>403</td>
<td>6.00 min</td>
<td>60 °C</td>
<td>770</td>
<td>1.00 min</td>
<td>Yes</td>
</tr>
</tbody>
</table>
2.5. Tooth color measurements

In order to achieve repeatability of measurements, prior measurement, custom-positioning jig was fabricated for measuring instrument and for the restoration holder: auto-polymerizing custom tray resin (Ivolen, Ivoclar Vivadent, Schaan, Liechtenstein) was used to stabilize the dentiform (D18FE-500A-QF, Nissin, Kyoto, Japan) in one position. The positioning jig ensured repeatable positioning and intimate relation between the instrument’s measuring aperture and the tooth surface. The position was standardized for all the following measurements.

The instruction of the manufacturer was followed. The instrument was placed directly on the tooth (via the positioning jig) ensuring the tip oriented to the target area. The tooth to be measured was centred horizontally and vertically on the display screen. Natural teeth are usually observed in a wet atmosphere. Therefore, all measurements were obtained with the sample in a slightly moist condition. Five measurements of the tooth were recorded in CIELAB color coordinates \( L^*a^*b^* \) in order to reduce the influence of possible misreading.

Standardization areas of 1.5 mm square were positioned at the centre of both the cervical and body regions of maxillary right central incisal typodont tooth to analyse the color (Fig. 4). The custom template was sized so that the image filled the computer screen. The custom template was utilized during all the measurements.

Prior to measurements of color, all crowns were cleaned and visually inspected. The color of the cervical and body areas of specimens were analysed with a chair side spectrophotometer (Crystaleye, Olympus, Tokyo, Japan), and the data were obtained in the CIE LAB color system by calculating \( \Delta E^* \) through the test specimens. The color differences were calculated between the colors obtained on the ND1 and ND8 shade abutments for each crown studied.

Each specimen was measured five times over both ND1 and ND8 shade abutments.

The color difference between specimens was calculated using the equation:

\[
\Delta E^* = \sqrt{|(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2|}
\]

2.6. Statistical analysis

The calculated \( \Delta E^* \) was analysed with three-way analysis of variance (ANOVA). The assumptions of normally distributed residuals and equal variance between groups were assessed via quantile–quantile plots and Levene’s test, respectively. All statistical tests were performed at the 95% confidence level (\( \alpha = 0.05 \)).

3. Results

In this study, the \( \Delta E^* \) of the Y-TZP based all-ceramic crowns on different colored abutments were measured at their cervical area and body area. The average \( \Delta E^* \) between two different colored abutments was 15.215 at the cervical area and 21.871 at the body area.

The mean and 95% confidence interval of \( \Delta E^* \) at the cervical area are presented in Table 3. At the cervical area, quantile–quantile plots of residuals showed no departure from normality. Levene’s test showed no evidence of unequal variances (\( P = 0.313 \)). There was a statistically significant difference between extensions (\( P < 0.001 \)). There were not significant differences for thickness (\( P = 0.792 \)) and shade.

<table>
<thead>
<tr>
<th>Substructure thickness</th>
<th>Substructure extension</th>
<th>Substructure shade and veneering porcelain shade</th>
<th>n</th>
<th>Mean ( \Delta E^* )</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3 mm</td>
<td>Horizontal reduction</td>
<td>FS1 + A1</td>
<td>10</td>
<td>4.656</td>
<td>(4.321, 4.991)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FS7 + D3</td>
<td>10</td>
<td>4.792</td>
<td>(4.457, 5.127)</td>
</tr>
<tr>
<td></td>
<td>Vertical reduction</td>
<td>FS1 + A1</td>
<td>10</td>
<td>5.369</td>
<td>(5.035, 5.704)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FS7 + D3</td>
<td>10</td>
<td>4.888</td>
<td>(4.553, 5.222)</td>
</tr>
<tr>
<td>0.5 mm</td>
<td>Horizontal reduction</td>
<td>FS1 + A1</td>
<td>10</td>
<td>4.592</td>
<td>(4.258, 4.927)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FS7 + D3</td>
<td>10</td>
<td>4.570</td>
<td>(4.235, 4.904)</td>
</tr>
<tr>
<td></td>
<td>Vertical reduction</td>
<td>FS1 + A1</td>
<td>10</td>
<td>5.428</td>
<td>(5.094, 5.763)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FS7 + D3</td>
<td>10</td>
<td>5.241</td>
<td>(4.907, 5.576)</td>
</tr>
</tbody>
</table>
(P = 0.251). The results indicate that a vertical reduction design of the Y-TZP substructure can increase the ΔE* at the cervical area.

The mean and 95% confidence interval of ΔE* at the body area are shown in Table 4.

At the body area, quantile–quantile plots of residuals showed no departure from normality, Levene’s test showed no evidence of unequal variances (P = 0.271). The results were borderline on thickness (P = 0.05) and there was a significant difference for shade (P = 0.001). There was not a significant difference for extension (P = 0.515). The results indicate that decreasing the thickness of the Y-TZP substructure may increase the ΔE* and increasing the value of the Y-TZP based all-ceramic crown can increase the ΔE* at the body area.

Table 4 – Mean and 95% CI of ΔE* at the body area of tested crowns (the color differences calculated between the colors obtained on the ND1 and ND8 abutments).

<table>
<thead>
<tr>
<th>Substructure thickness</th>
<th>Substructure extension</th>
<th>Substructure shade and veneering porcelain shade</th>
<th>n</th>
<th>Mean ΔE*</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3 mm</td>
<td>Horizontal reduction</td>
<td>FS1 + A1</td>
<td>10</td>
<td>5.013</td>
<td>(4.807, 5.219)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FS7 + D3</td>
<td>10</td>
<td>5.021</td>
<td>(4.815, 5.227)</td>
</tr>
<tr>
<td></td>
<td>Vertical reduction</td>
<td>FS1 + A1</td>
<td>10</td>
<td>5.107</td>
<td>(4.901, 5.314)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FS7 + D3</td>
<td>10</td>
<td>4.751</td>
<td>(4.545, 4.957)</td>
</tr>
<tr>
<td>0.5 mm</td>
<td>Horizontal reduction</td>
<td>FS1 + A1</td>
<td>10</td>
<td>4.917</td>
<td>(4.711, 5.123)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FS7 + D3</td>
<td>10</td>
<td>4.545</td>
<td>(4.338, 4.751)</td>
</tr>
<tr>
<td></td>
<td>Vertical reduction</td>
<td>FS1 + A1</td>
<td>10</td>
<td>5.051</td>
<td>(4.845, 5.257)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FS7 + D3</td>
<td>10</td>
<td>4.782</td>
<td>(4.576, 4.988)</td>
</tr>
</tbody>
</table>

4. Discussion

In 2002, Heffernan reported 35% partially stabilized zirconia did not have translucency at the thickness of 0.5 mm.17 Interestingly, our previous study showed a high amount of translucency of 0.5 mm thick Y-TZP (LAVA). It means particle size in the Y-TZP will influence the translucency. Also the translucency of Y-TZP is influenced by the existence of air between disc and background. In the study, petroleum jelly was used to seal the space between specimens and the backgrounds. As a result, 0.3 mm thick Y-TZP had about 8.6% higher translucency than the 0.5 mm one.12 The influence of this difference was examined in the Y-TZP all-ceramic crown study. Thus, this study was designed to achieve a standardized evaluation of different substructure designs in terms of substructure thickness, substructure extension and restoration shade for the translucency of the cervical and body areas of Y-TZP based all-ceramic restorations.

It was indicated that the vertical reduction design of the Y-TZP substructure can increase the ΔE* at the cervical area, decreasing thickness of the Y-TZP substructure may increase the ΔE* at the body area and increasing the value of the Y-TZP based all-ceramic crown shade can increase the ΔE* at the body area. At the cervical area, only substructure extension appeared to affect the masking discoloration of the abutment, and there was no evidence that substructure thickness or restoration shade affect the results. This may be because abutment color from the finishing line to the occluso-axial line angle affects the results at the cervical area, unlike the body area. At the body area, substructure thickness did not appear to affect the result much although there was an 8.6% translucency difference between 0.3 mm and 0.5 mm thick Y-TZP discs in the previous study. It may be because of the different thickness of the veneering porcelain on all-ceramic crowns fabricated with 0.3 mm and 0.5 mm thick Y-TZP substructures and the interaction between the substructure thickness and veneer thickness. According to Shokry, the color appearance of the layered ceramic disc specimens is strongly influenced not only by the core thickness and veneer thickness, but also their interaction.13 Masking discolored abutment becomes more difficult when higher value is needed as a final shade.

Y-TZP has limited masking effect of discoloration. ΔE* of the specimens on two different colored abutments were in the range from 4.570 to 5.428 at the cervical area and from 4.545 to 5.107 at the body area. According to previous studies, the color difference threshold is between 1.6 and 5.5 ΔE* units.14–18 It is not enough to mask a severe discolored abutment only by modifying the design of Y-TZP substructure. In this case, amount of tooth reduction, selection of veneering porcelain and cement would be also important to increase masking ability.19 Considering 0.3 mm thick Y-TZP has a 35% reduction in fracture resistance,20 there seems not much advantage to use 0.3 mm thick Y-TZP substructure for severely discolored teeth. At the cervical area, it may be advantageous to use “zirconia margin” to mask discoloration at the cervical area. However, in this case, the opacity of Y-TZP itself would become problem to achieve shade matching.21

When analysing results obtained from in vitro studies, it is important to keep in mind that oral condition is highly complex and that the actual clinical situation is impossible to mimic to more than a limited extent. It has been concluded that only simple typodont model can provide experimental data of the same quality as more complex ones. Extracted natural teeth could have been used, but the approach chosen was considered valid since performing the same dimension of preparation on two different colored teeth is almost impossible. The procedure of the Y-TZP based all-ceramic crown fabrication was standardized because the color of fabricated crown would be influenced by shade designation, substructure material, substructure thickness, substructure extension design, types of veneering porcelain, veneering porcelain thickness, firing cycles, polishing and cement. Furthermore, comparisons between the results should be made only individually to compare the method or techniques under
study. The color tests used in this study are recognized as valid for clinical testing and have been used in previous studies.

In this study, the effect of types and thickness of veneering porcelain and types of cement on the final shade was not examined. The total masking ability of Y-TZP based all-ceramic crown with different types and thickness of veneering porcelain and different types of cement should be examined in future study.

5. Conclusions

Within the limitations of this study, the following conclusions can be drawn:

- Vertical reduction design of Y-TZP substructure could increase $\Delta E^*$ at the cervical area.
- Decreasing the thickness of Y-TZP substructure may increase $\Delta E^*$ at the body area.
- Decreasing the value of Y-TZP based all-ceramic crown shade could decrease $\Delta E^*$ at the body area.

Conflicts of interest

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