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2133 PEPPERRELL ST
JBSA-LACKLAND, TEXAS 78236

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Name of Candidate: Jeremy I. Matis, Maj, USAF, DC
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ARNASON.STEPHEN.C.1296756403 Digitally signed by ARNASON.STEPHEN.C.1296756403 Date: 2022.05.23 11:51:27 -07'00'

Stephen C. Arnason, Maj, USAF, DC
Program Director, Advanced Education in General Dentistry Residency
Travis AFB, CA

SCHILTZ.CHRISTINA.M.1506293665 Digitally signed by SCHILTZ.CHRISTINA.M.1506293665 Date: 2022.05.31 07:53:33 -05'00'

Christina M. Schiltz, USAF, DC
Director of Prosthodontic Training, Advanced Education in General Dentistry Residency
AF Postgraduate Dental School, JBSA-Lackland, TX

VANDEWALLE.KRAIG.STEPHEN.1130663733 Digitally signed by VANDEWALLE.KRAIG.STEPHEN.1130663733 Date: 2022.05.20 09:42:44 -05'00'

Kraig S. Vandewalle, Col (ret), USAF, DC
Director of Dental Research, Advanced Education in General Dentistry Residency
AF Postgraduate Dental School, JBSA-Lackland TX

Optical Properties of Novel Ceramic CAD/CAM Materials

**Maj Jeremy Matis, DDS[1]; Maj Stephen Arnason, DDS, MS[2];
Maj Christina Schiltz, DDS[1]; Col (ret) Kraig Vandewalle, DDS, MS[1]**

[1]USAF Postgraduate Dental School and Clinics, JBSA-Lackland, TX;
[2]60th Dental Squadron, Travis AFB, CA

USU Operational Gap: IV, A

Objective: The purpose of this study was to compare the optical properties of newer all-ceramic CAD/CAM materials to more established materials on the market. Methods: The following ceramic materials were tested: lithium-disilicate/lithium-aluminum silicate (Tessera, Dentsply/Sirona), lithium disilicate (IPS e.max CAD, Ivoclar Vivadent), gradient 4Y-PSZ/5Y-PSZ (IPS e.max ZirCAD MT Multi, Ivoclar Vivadent), gradient 3Y-TSP/5Y-PSZ (IPS e.max ZirCAD Prime, Ivoclar Vivadent), and 4Y-PSZs (IPS e.max ZirCAD MT, Ivoclar Vivadent; Katana STML, Kuraray; YZ ST, VITA). Ten specimens per material were sectioned from blocks or milled from discs with final thicknesses of 0.5, 1.0, 1.5, or 2.0mm after sintering (Programat S1, Ivoclar Vivadent) or crystallization (Programat P500, Ivoclar Vivadent). Specimens were created in the transition zone for the gradient zirconia materials. Tessera specimens were conventionally crystallized (Programat P500) or speed fired (CEREC SpeedFire, Dentsply/Sirona). Translucency and opalescence parameters were determined using a dental spectrophotometer (VITA Easyshade V, VITA). Data were analyzed using ANOVA/Tukey's tests (alpha=0.05). Results: Significant differences were seen in optical properties based on material or thickness ($p<0.05$). In general, the glass-ceramic materials had greater translucency and opalescence than the zirconia materials. IPS e.max CAD had a tendency to have greater translucency than Tessera at greater thicknesses, and lower opalescence at lesser thicknesses. IPS e.max ZirCAD Prime (transition zone) had a tendency to be less translucent than the other zirconia materials at greater thicknesses, and more opalescent at lesser thicknesses. Conclusions: Differences in translucency and opalescence parameters varied based on the type of ceramic material and thickness.

Introduction

The search for more esthetic restorative products is a never-ending quest by dental manufacturers. Updated products are frequently being introduced, even while the products being replaced are still under clinical investigation. As such, in vitro studies are becoming more important for understanding the properties of newer materials, as they will likely provide the most current information for a product before it is replaced by something newer/faster/better.

All-ceramic materials were introduced to provide stronger and more esthetic restorations. Originally, feldspathic porcelain was used to replicate the esthetics of the natural dentition and was fused to a metal substructure to provide strength to the restoration (porcelain-fused-to-metal, PFM). Currently, the two most popularly utilized materials in CAD/CAM dentistry include lithium disilicate and zirconia oxide[1] both of which have the strength to be fabricated without a metal substructure, while providing adequate esthetics. Lithium disilicate is a “glass-ceramic”[2] that is touted for its excellent esthetics, which arises from the similarity of the glassy matrix and the crystal phase, minimizing the refraction and reflection of light as it passes through.[3] Additionally, lithium disilicate has a reported flexural strength as high as 500 MPa[4], which, when combined with its esthetic properties, makes it an adequate material for anterior and posterior restorations. Zirconia, a polycrystalline solid oxide ceramic, exists in three phases: monoclinic, tetragonal, and cubic. Zirconia is stabilized by adding certain molecules, such as yttrium oxide (Y_2O_3), to form tetragonal zirconia polycrystals (TZP).[5] The original zirconia developed for dental use was 3Y-TZP (3 mol% Y_2O_3), which was strong but did not have acceptable esthetics due to its monochromatic opaque white appearance.[5] Efforts to improve the esthetic properties of 3Y-TZP provided 4Y- and 5Y-TZPs (4 mol% and 5 mol%, respectively); as the mol% increased, there was an improvement in esthetics but a decrease in strength.[5]

One of the difficulties in fabricating ceramic restorations that mimic the existing dentition is matching the optical properties, to include color, translucency, and opalescence. The color of an object is dependent on its value, hue, and chroma; whereas translucency is determined by the amount of light that is absorbed, transmitted or reflected.[6] Translucency is defined as the difference between the reflected colors of a material on black and white backgrounds.[7] A recent update to this parameter by the CIEDE2000 introduced TP_{00}, which is a more accurate method of calculating translucency.[8] Opalescence refers to the ability of a material to reflect a blue wavelength when white light hits the object perpendicularly.[9]

Manufacturers continue to introduce new millable ceramic materials. One example is Tessera (Denstply Sirona, Charlotte, NC), a new lithium disilicate material. The manufacturer claims that this new material has a crystallization time of only 4.5 minutes in the CEREC SpeedFire furnace (Dentsply Sirona).[10] Novel zirconia materials have recently been introduced by Ivoclar Vivadent using a unique manufacturing process that uses special powder conditioning to combine 3Y-TZP and 5Y-TZP (IPS e.max ZirCAD Prime) or 4Y-TZP and 5Y-TZP (IPS e.max ZirCAD MT Multi) oxide ceramic powders.

Unlike other multi-layered zirconia dental materials on the market, the gradient technology reportedly offers a seamless progression of strength, with 3Y-TZP or 4Y-TZP in the dentin zone and 5Y-TZP in the incisal or occlusal zone for esthetics. [11, 12] VITA YZ ST (VITA, Bad Sackingen, Germany) is a new 4Y-TZP with a reported flexural strength of 850 MPa and adequate esthetics.[13]

No research has been published evaluating the optical properties of these new glassy ceramic and zirconia materials. The purpose of this study was to compare the optical properties between these newer, all-ceramic CAD/CAM materials to more established materials on the market at different thicknesses. The null hypotheses were that there would be no difference in translucency or opalescence parameters based on (1) type of ceramic or (2) thickness.

Method and Materials

This study evaluated the translucency and opalescence parameters for two lithium-disilicate materials: Tessera (Dentsply Sirona) in both conventional fire and speed fire conditions and IPS e.max CAD (Ivoclar Vivadent); and five zirconia materials: three 4Y-TZP materials (IPS e.max ZirCAD MT, Ivoclar Vivadent; Katana STML, Kuraray America, New York, NY; VITA YZ ST, VITA), a new multi-layer combination of 4Y-TZP and 5Y-TZP (IPS e.max ZirCAD MT Multi, Ivoclar Vivadent), and a new multi-layer combination of 3Y-TZP and 5Y-TZP (IPS e.max ZirCAD Prime, Ivoclar Vivadent) at various thicknesses.

Specimen fabrication

A CAM (computer-aided manufacturing) machine (I-Mes iCore 450i, Eiterfeld, Germany) was used to mill zirconia specimens out of zirconia pucks. The specimens were designed using CAD (computer-aided design) software (DS SolidWorks, SolidWorks, Waltham, MA) and the file was imported into milling software (Sum 3D, iCAM V5, I-Mes, iCore). For the two zirconia materials containing a gradient (IPS e.max ZirCAD MT Multi and Prime), the specimens were centered in the middle of the transition zone. Prior to sintering, the evaluated surfaces of the zirconia specimens were polished using 2,000 grit polishing paper (Sandblaster Pro, 3M ESPE). The final thickness of the specimens was 0.5, 1.0, 1.5, and 2.0 mm after sintering in a furnace (Programat S1 1600, Ivoclar Vivadent) according to the manufacturer's instructions. The IPS e.max CAD and Tessera specimens were sectioned from blocks using a precision saw (IsoMet 5000, Buehler, Lake Bluff, IL) and crystallized in a Programat P500 furnace (Ivoclar Vivadent) or CEREC SpeedFire furnace (Dentsply Sirona), according to the manufacturer's instructions. Ten specimens per thickness were prepared for each ceramic material. The evaluated surfaces of the lithium disilicate specimens were polished using 600 grit polishing paper (Sandblaster Pro, 3M ESPE). Prior to the optical measurements, the thickness of the specimens was measured using a digital caliper (GA182, Grobet Vigor, Carlstadt, NJ) and deemed acceptable if within 0.05 mm of the thickness for that group.

Color measurements

The color of each specimen was determined using a dental spectrophotometer (VITA Easyshade V) in single-tooth mode utilizing techniques outlined in a recent study by Della Bona et al.[14] The spectrophotometer was calibrated using the white calibration plate in the charging base before each series of measurements. Each specimen was placed in direct contact with the aperture of the spectrophotometer and no coupling medium was utilized. The mean value of three sequential measurements of the CIE L*a*b* color parameters was recorded per specimen on white paper and on black paper. Prior to calculating translucency, the L*a*b* values were converted to L*C*H* values according to the protocol proposed by Sharma et al.[15] The three measurements on each colored background were averaged and the values used in calculating the translucency and opalescence parameters.

Calculating translucency

Translucency parameter (TP) was determined by calculating the color difference between readings against black (B) and white (W) backgrounds for the same specimen, with greater TP values indicating a greater ability of light to pass through an object. The following equation was used to calculate TP:[15]

$$TP_{OO} = \sqrt{\left(\frac{L_B - L_W}{k_L s_L}\right)^2 + \left(\frac{C_B - C_W}{k_C s_C}\right)^2 + \left(\frac{H_B - H_W}{k_H s_H}\right)^2 + RT\left(\frac{C_B - C_W}{k_C s_C}\right) * \left(\frac{H_B - H_W}{k_H s_H}\right)}$$

L, C, and H represent lightness, chroma, and hue. The subscript “b” refers to color values over a black background, while “w” refers to color values over a white background.[16, 17] Additionally, RT (rotation function) accounts for the interaction between hue and chroma in the blue region; S_L, S_C, and S_H adjust for variation in the L*a*b* coordinate system; and k_L, k_C, and k_H correct for experimental conditions (k_L = 1.0, k_C = 1.0, and k_H = 1.0 for this study).[18]

Calculating opalescence

Opalescence parameter (OP) was determined using the a* and b* values recorded from the ceramic specimens placed on black (B) and white (W) backgrounds, according to the following equation:[9]

$$OP = \sqrt{(a_B - a_W)^2 + (b_B - b_W)^2}$$

Where: a represents the red-green range, and b represents the yellow-blue range.[3] The subscript “b” refers to color values over a black background, while “w” refers to color values over a white background.[16, 17]

Statistical analysis

A mean and standard deviation were determined for the translucency and opalescence parameter for each of the ceramic materials at each thickness. Data were analyzed using a two-way ANOVA to evaluate the effect of ceramic type and thickness on the translucency and opalescence parameters (alpha=0.05). The translucency and opalescent parameter data were further evaluated using multiple one-way ANOVAs and Tukey’s post hoc tests per material or ceramic thickness (alpha=0.05). All statistical analyses were completed using SPSS software (version 25, IBM, Chicago, IL).

Results

The results of two-way ANOVA found significant differences in translucency and opalescence based on material ($p<0.001$) and thickness ($p<0.001$) with significant interactions ($p<0.05$). When considering translucency, each of the materials lost significant translucency as thickness increased ($p<0.05$). The greatest translucency parameter was found at 0.5mm thickness when Tessera was speed-fired (20.44 ± 0.46), but it was not significantly different from IPS e.max CAD (p=0.38; 19.34 ± 0.76) or Tessera (p=0.29; 19.26 ± 3.01) when conventionally fired. The lowest translucency parameter was found at 2.0mm thickness with IPS e.max ZirCAD Prime (4.16 ± 0.10), which was significantly lower than all other ceramic materials at 2.0mm thickness ($p<0.001$). See Table 1 and Figure 1.

When considering opalescence, each of the materials lost significant opalescence ($p<0.05$) as thickness increased, with the exception of IPS e.max CAD, which had a significantly lower opalescence ($p<0.001$) at 0.5mm than 1.0mm thicknesses, and IPS e.max ZirCAD MT and Vita YZ ST, which had no significant difference ($p>0.113$) in opalescence values between 0.5mm and 1.0mm thicknesses. The greatest opalescence parameter was found with the 0.5mm thick conventionally fired Tessera (16.68 ± 0.54), which was significantly greater ($p<0.03$) than all other ceramic materials at 0.5mm thickness. The lowest opalescence parameter was found at the 2.0mm thickness with IPS e.max ZirCAD Prime (5.05 ± 0.17), which was not significantly different from Katana STML (p=0.98; 5.24 ± 0.09), IPS e.max ZirCAD MT (p=0.20; 5.58 ± 0.20), or IPS e.max ZirCAD MT Multi (p=0.085; 5.66 ± 0.11). See Table 2 and Figure 2.

In general, the glass-ceramic materials had greater translucency and opalescence than the zirconia materials. IPS e.max CAD had a tendency towards greater translucency than Tessera at greater thicknesses, and lower opalescence at lesser thicknesses. IPS e.max ZirCAD Prime (transition zone) had a tendency towards being less translucent than the other zirconia materials at greater thicknesses, and more opalescence at lesser thicknesses.

Discussion

When fabricating an esthetic restoration, it is important to consider translucency and opalescence, as these are two important factors when trying to mimic natural teeth.[19] The translucency of a restorative material provides a more life-like appearance, although a strictly translucent material does not mask the underlying substrate.[20] Opalescence can mask a discolored substrate[21] due to the reflectance of blue light. It has been recommended that a highly opalescent material can be used as a veneer for discolored substrates without the removal of excess tooth structure and without requiring more opacity.[22]

Translucency ranges from 0 to 100, where 0 indicates that a material is opaque and 100 that a material is transparent; therefore, higher translucency parameter values correlate with greater translucency.[19] A new translucency parameter was introduced in 2000 by the International Commission on Illumination (CIE), CIEDE2000 (TP00), in an effort to more accurately assess restorative materials.[18] This formula considers more color attributes and also gives more importance to L, which is critical in dentistry.[23]

For the translucency parameter, the null hypotheses were rejected, as there was a statistically significant difference found in translucency parameter based on the type of ceramic material and for the material thickness.

IPS e.max CAD had significantly higher translucency when compared to the zirconia materials at all thickness, which is consistent with others who found that zirconia materials are less translucent when compared to IPS e.max CAD.[24,25] However, the translucency of the zirconia materials was similar to those of the lithium disilicate ceramic materials at clinically recommended thicknesses,[26] comparing 1.0mm thick lithium disilicate with 0.5mm thick zirconia or 1.5mm thick lithium disilicate with 1.0mm zirconia oxide in the current study.

The translucency parameters for IPS e.max CAD and Tessera were not statistically different at the 0.5mm thickness but were statistically different at the 1.0mm, 1.5mm and 2.0mm thicknesses, with IPS e.max CAD having greater translucency. For the zirconia materials, IPS e.max ZirCAD MT, IPS e.max ZirCAD MT Multi, Katana STML, and VITA YZ ST were all statistically similar at each thickness, with the exception of Katana STML at 2.0mm, which was statistically more translucent than the other materials. IPS e.max ZirCAD Prime was statistically different than the other zirconia materials at all thicknesses. However, translucency significantly decreased for each material at each increase in thickness, which has been confirmed in many studies.[27-28]

Opalescence is an important property of a material, as materials with higher opalescence have a greater ability to mask underlying colors.[19] This is due to the presence of microparticles that are either similar in size or larger than the wavelengths of visible light; causing light scattering/opalescence.[29]

For opalescence parameter, the null hypotheses were rejected, as a difference was found in opalescence parameter based on the type of ceramic material and the thickness of the specimens. All of the tested materials lost opalescence as the specimen thickness increased, with the exception of the following: 1) IPS e.max CAD gained opalescence as thickness increased from 0.5mm to 1.0mm and 2) IPS e.max ZirCAD MT and VITA YZ ST had similar opalescence from 0.5mm and 1.0mm specimens. Additionally, the lithium disilicate materials had greater opalescence than the zirconia oxide materials; with the exception of IPS e.max CAD, which had statistically similar opalescence values to IPS e.max ZirCAD MT Multi and Katana STML at the 0.5mm thickness.

The increase in opalescence from the 0.5mm to 1.0mm thick IPS e.max CAD specimens is unique; it has been proposed that the opalescence of the 0.5mm thick IPS e.max CAD specimens is lower due to the lack of light scattering.[30] This lack of light scattering minimizes the reflectance of blue light, which reduces the opalescence of the material. Once sufficient thickness of the IPS e.max CAD material was achieved, greater blue light reflectance occurred and opalescence increased. As thickness increased from the 1.0mm IPS e.max CAD specimens, and for all of the other evaluated materials starting at the 0.5mm thickness, there was a reduction in translucency. As demonstrated by Arimoto et al,[31] opalescence typically decreases as translucency decreases.

Limitations of this study include: 1. Grain size was not evaluated for the zirconia materials; 2. The optical properties for IPS e.max ZirCAD MT Multi and IPS e.max ZirCAD Prime were measured within the gradient zone; 3. Different shades of each material were not considered. Future research should be conducted with these novel CAD/CAM materials to evaluate how grain size, the transition zone of the gradient materials, and differing material shades affect the translucency and opalescence parameters.

Conclusion

Within the limitations of this study, there was a significant effect of material and thickness on the opalescence and translucency of the evaluated materials. As such, clinicians should be aware of these factors when selecting materials to help improve the esthetics of the restorations they are placing. Additionally, manufacturers should make an effort to continue to improve these two factors to more closely approximate those of natural teeth.

Disclaimer: The views expressed are those of the authors and do not reflect the official views or policy of the Uniformed Services University, Department of Defense, or its Components. The authors do not have any financial interest in the companies whose materials are discussed in this abstract.

Tables and graphs

Table 1. Mean (SD) translucency parameters for each material at each thickness

Material	Translucency Parameter 2000			
	Ceramic Thickness			
	0.5 mm	**1.0 mm**	**1.5 mm**	**2.0 mm**
IPS e.max CAD	19.34 (0.76) Aa	13.25 (0.51) Ba	9.26 (0.51) Ca	7.18 (0.31) Da
Tessera (Conventional)	19.26 (3.01) Aa	12.71 (0.44) Bb	8.46 (1.12) Cb	5.57 (0.30) Db
Tessera (Speed)	20.44 (0.46) Aa	12.58 (0.73) Bb	8.62 (0.41) Cab	5.43 (0.46) Dbc
IPS e.max ZirCAD MT	12.94 (0.11) Ab	9.99 (0.15) Bc	7.32 (0.07) Cc	5.10 (0.06) Dc
IPS e.max ZirCAD MT Multi	14.42 (0.13) Ab	10.05 (0.09) Bc	6.97 (0.23) Cc	5.16 (0.10) Dc
IPS e.max ZirCAD Prime	13.81 (0.35) Ab	9.01 (0.13) Bd	5.87 (0.11) Cd	4.16 (0.10) Dd
Katana STML	14.31 (0.13) Ab	9.63 (0.19) Bc	7.22 (0.18) Cc	5.57 (0.08) Db
VITA YZ ST	13.50 (0.27) Ab	9.54 (0.18) Bc	7.38 (0.13) Cc	5.30 (0.20) Dbc
Groups with the same upper case letter per row or lower case letter per column are not significantly different (p>0.05).				

Figure 1. Translucency parameter for each material at each thickness

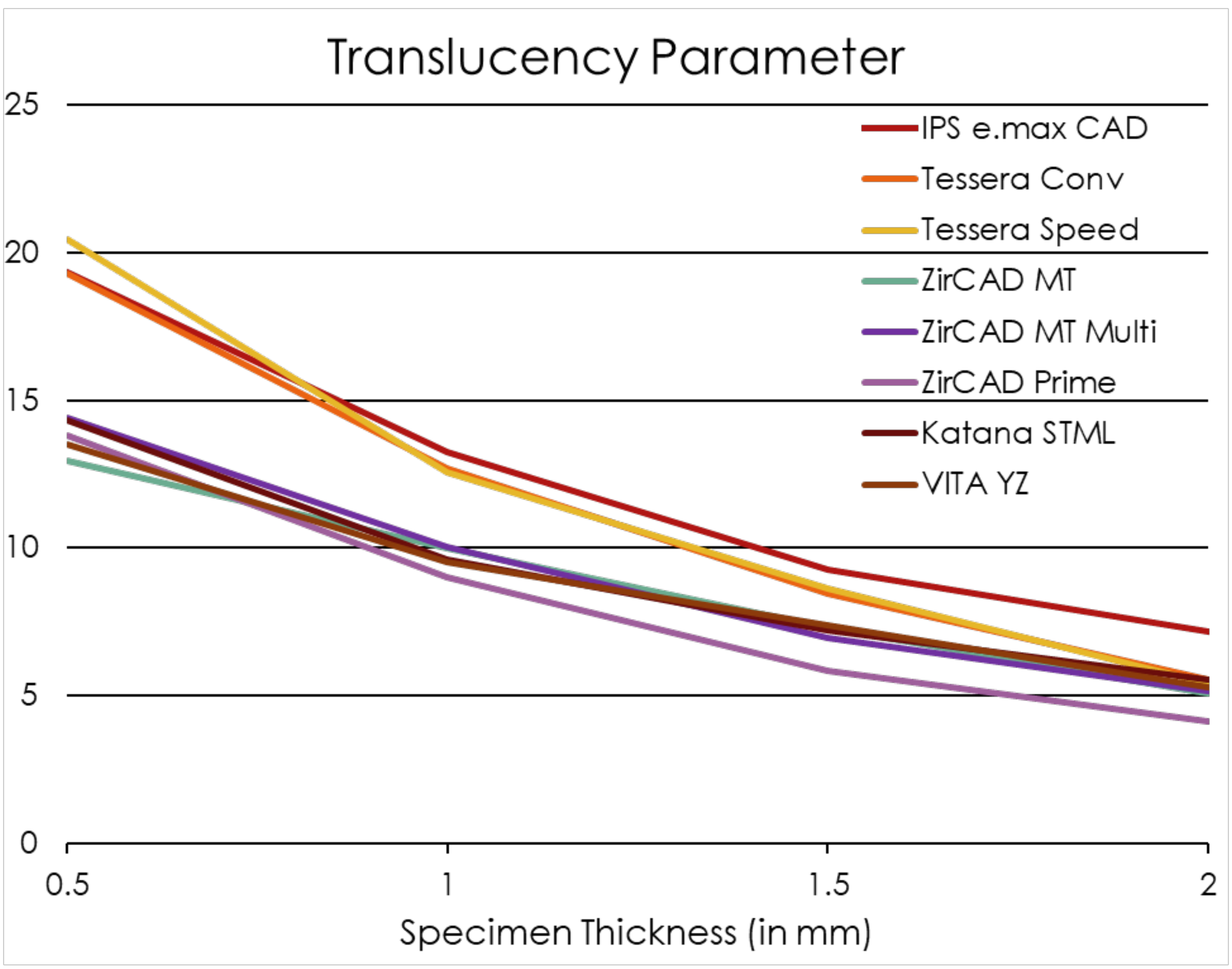
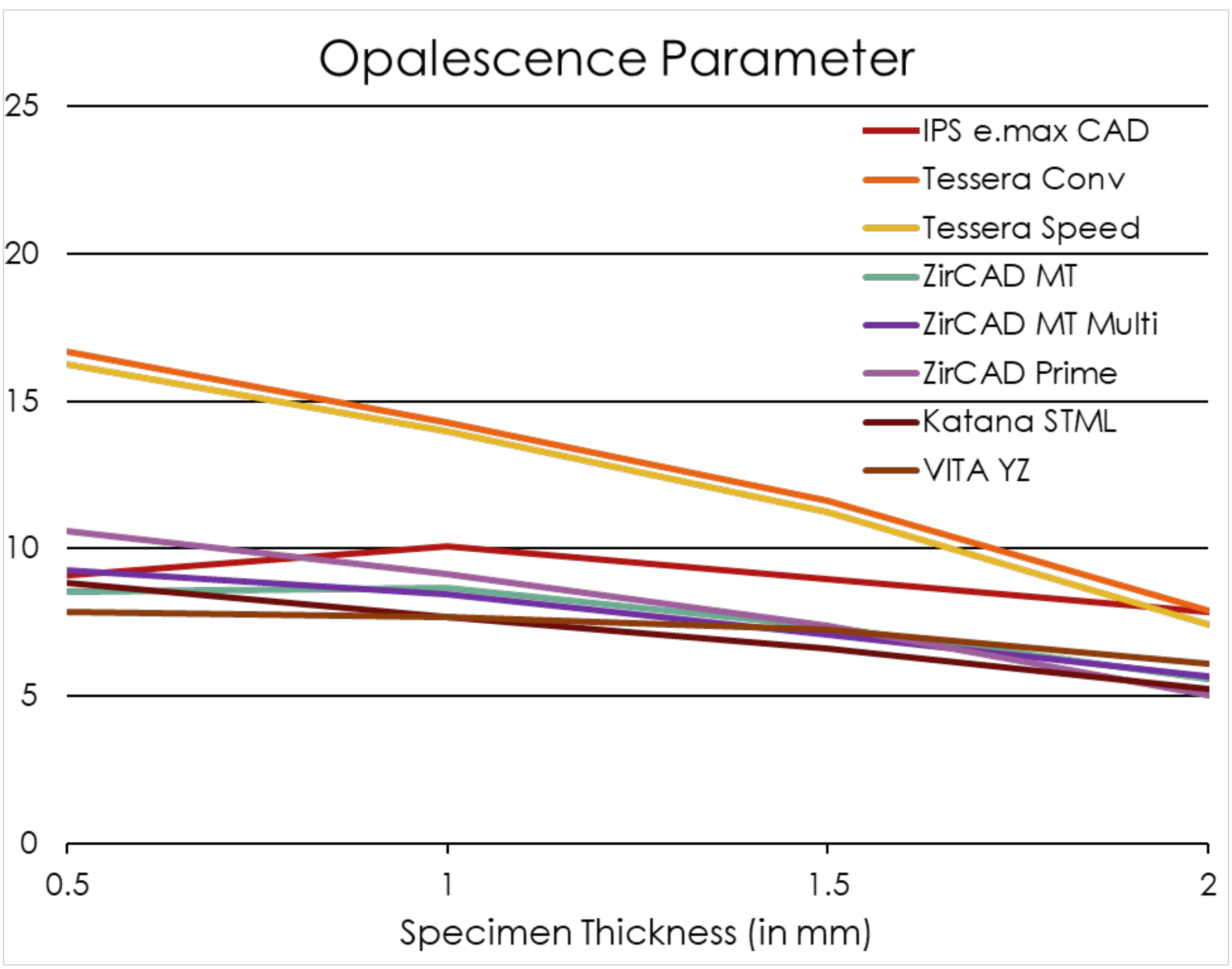


Table 2. Mean (SD) opalescence parameter for each material at each thickness

Material	Opalescence Parameter			
	Ceramic Thickness			
	0.5 mm	**1.0 mm**	**1.5 mm**	**2.0 mm**
IPS e.max CAD	9.12 (0.19) Bde	10.09 (0.19) Ac	8.99 (0.34) Bb	7.85 (0.31) Ca
Tessera (Conventional)	16.68 (0.54) Aa	14.27 (0.54) Ba	11.61 (2.66) Ca	7.91 (0.52) Da
Tessera (Speed)	16.26 (0.36) Ab	13.98 (0.89) Bb	11.24 (0.53) Ca	7.45 (1.11) Da
IPS e.max ZirCAD MT	8.54 (0.09) Af	8.69 (0.16) Ade	7.33 (0.11) Bc	5.58 (0.20) Cbc
IPS e.max ZirCAD MT Multi	9.26 (0.32) Ad	8.47 (0.17) Be	7.08 (0.14) Cc	5.66 (0.11) Dbc
IPS e.max ZirCAD Prime	10.59 (0.02) Ac	9.15 (0.17) Bd	7.40 (0.20) Cc	5.05 (0.17) Dc
Katana STML	8.86 (0.10) Aef	7.68 (0.09) Bf	6.60 (0.21) Cc	5.24 (0.09) Dc
VITA YZ ST	7.88 (0.12) Ag	7.67 (0.18) Af	7.25 (0.26) Bc	6.09 (0.29) Cb
Groups with the same upper case letter per row or lower case letter per column are not significantly different ($p>0.05$).				

Figure 2. Opalescence parameter for each material at each thickness



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