Optical Properties and Failure Load of Thin CAD/CAM Ceramic Veneers

Keywords

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ABSTRACT

This study aimed to compare optical properties and failure load of leucite (IPS Empress CAD LT) and lithium disilicate glass ceramic (IPS e.max CAD LT) materials in incisor veneers. Four groups of veneers were made on 36 bovine incisors with Cerec 3D milling unit (n=9/group): 0.5 and 0.3 mm thick leucite glass and 0.5 and 0.3 mm lithium disilicate glass veneers. The optical features were measured with CM-700d spectrophotometer using white and yellow try-in pastes. Differences were determined by means of ΔE value and luminance. The bovine teeth with veneers were mounted on acrylic resin blocks (Palapress, Heraeus Kulzer) and static loading test was conducted (LR30K plus, Lloyd Instruments). The color difference of veneers could be noticed with yellow and white cements when the material thickness increased from 0.3 to 0.5 mm (leucite ΔE yellow 4.4, white 6.0; lithiumdisilicate ΔE yellow 2.1, white 4.1). Both materials showed similar failure load with 0.5 mm veneers (leucite 1906 +/-319 N; lithiumdisilicate 2098 +/- 309 N). The failure load of 0.3 mm thick lithium dilisilicate veneers (2002 +/- 427 N) was comparable with the 0.5mm veneers. Ultrathin lithium disilicate glass ceramic veneers (0.3 mm) could be a potential option for clinical use.

INTRODUCTION

Feldspatic glass and leucite based ceramics have been used as veneering materials with metallic crowns and fixed dental prostheses (FDP) for decades.[1] Development of these ceramics have enabled fabrication of monolithic inlay and onlay fillings and crowns. Also the metallic FDP substructures can be replaced with more esthetically favorable materials such as alumina (Al_2O_3) or partially yttrium stabilized zirconia (ZrO_2).[2]

Computer aided design (CAD) and computer aided manufacturing (CAM) have become popular and produced a need for more sustainable ceramic materials. Glass ceramics contain different types of fillers that have a great impact on the strength of the material. Leucite has been the most often used filler material previously. The content of leucite crystals has been around 35-45% depending on the manufacturer.[3] There are many studies on leucite based glass ceramics, and the longest clinical follow up studies have been made with IPS Empress materials (Ivoclar Vivadent AG, Schaan, Liechtenstein). The results have been good. Depending on the location and the type of restoration, a 90-95% success rate has been reported in an 8-year follow-up study.[4] The use of leucite reinforced glass ceramics has decreased after lithium disilicate reinforced glass ceramic was introduced. The high content of lithium disilicate fillers up to 70%, enables the fabrication of stronger restorations. The material can be used in a laboratory for the press technique (IPS e.max Press, Ivoclar Vivadent) or for CAD/CAM (IPS e.max CAD, Ivoclar Vivadent).[3]

Lithium disilicate based ceramics have been studied widely. The durability of the material in large molar restorations has raised some concerns, but according to many clinical studies the material is suitable also for posterior restorations. In their recent 9 year follow-up study, Gehrt *et. al.* (2013) reported that the location of lithium-disilicate crowns did not have any effect on the durability of the restoration. During the follow-up period none of the crowns were lost or fractured.[5] Other follow-up studies have given similar results.[6,7] Also many laboratory studies support the use of lithium disilicate in posterior restorations.[8-10]

These results are promising; lithium disilicate seems to be a widely accepted material for restorative dentistry. The only adverse matter is that ceramic restorations require more space in load bearing areas. Thin ceramic restorations, however, have been used in ceramic veneers. Ultrathin restorations save a considerable amount of sound tooth tissue, but diminishing the layer thickness may affect on the optical properties of the ceramic material.[11] There are a few studies on the use of milled ceramic veneers, but the results are not convergent.[11-13] The aim of this study was to compare the optical properties and failure load of milled ultrathin leucite and lithium disilicate veneers. The study is based on the hypothesis that decreasing ceramic thickness enhances translucency of both glass ceramics. It was also hypothesized that failure load of bonded veneers decreases with decreasing ceramic thickness.

MATERIALS AND METHODS

The materials that were used in this study were IPS Empress CAD LT A2 and IPS e.max CAD LT A2 (Ivoclar Vivadent AG). IPS Empress CAD is a leucite based ceramic that contains leucite crystals $KAlSi_2O_6$ in a glass matrix. IPS e.max CAD is a lithium disilicate based ceramic that contains mainly lithium disilicate crystals $Li_2Si_2O_5$.

Similar sized bovine incisors (n=80) were selected for sample preparation. The teeth were first disinfected in a chloramin solution for one day and after that sterilized in an autoclave. Then the soft tissue remnants were removed from the teeth and they were left in the chloramin solution until used for the substrate preparation. The disinfected bovine teeth were cleaned mechanically and polished and shaped to resemble a human tooth. Finally 36 teeth were chosen for the study based on the following size criteria: mesio-distal width 12.5 ± 0.5 mm and labio-palatinal thickness 2.5 ± 0.3 mm. The selected teeth were then cast in acryl blocks (Palapress, Heraeus Kulzer) to facilitate further preparations.

Veneers were produced using a CAD/CAM technique with a Cerec 3D device (version 3.6, Sirona Dental). CAD requires reference points to work properly, so an artificial gingiva was built around the bovine incisor and acrylic teeth. The "correlate", utility of the CAD program was used to fabricate the veneers, which means that the tooth was scanned before preparation and then the milling program used the scanned shape as a model for the veneer. Besides a predetermined labial reduction of 0.5mm and 0.3mm, which was reached with use of veneer preparation diamonds, the preparation design included a 2 mm incisal reduction with a palatal chamfer. The specimen width was 12.0 mm (SD 0.4 mm) and height 12.0 mm (SD 1.0 mm) *(Figure 1)*.

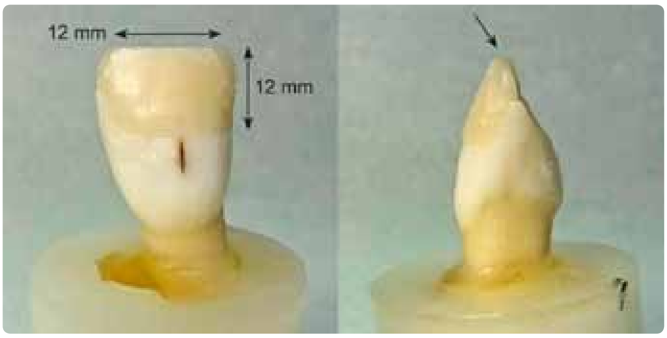

Figure 1a and 1b: a) The dimensions of ceramic veneer cemented on bovine incisor. The image is taken after mechanical testing. b) Thin incisal edge was flattened (arrow) prior to mechanical testing in order to spread the load more equally over the veneer.

Altogether 36 veneers were milled: 9 x lithium disilicate glass 0.5 mm, 9 x leucite glass 0.5 mm, 9 x lithium disilicate glass 0.3 mm and 9 x leucite glass 0.3 mm. After the milling process the restoration was separated from the milling block by using a diamond burr at sprue area which was then polished carefully with ceramic polishing points. The fit of each veneer was checked and possible interferences were eliminated. Lithium disilicate veneers were crystallized according to the manufacturers' instructions. Some veneers broke during the working process: one leucite glass 0.5 mm, one lithium disilicate glass 0.3 mm and three leucite glasses 0.3 mm. These pre-test failures were not included to final statistical analyses in terms of failure load.

Optical properties were determined before mechanical testing. Each veneer was fitted on a prepared tooth with white and yellow try-in pastes. The color values were measured with a spectrophotometer in Lab-Scale (CM-700d, Konica Minolta Sensing Inc) and the spectrophotometer was calibrated according to manufacturers instructions in prior to testing. The following formula (1) was used to calculate the differences in optical properties:

$$\Delta E^*ab = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \qquad (1)$$

L equals luminance, a covers a scale from green to red and b from blue to yellow.[14] The pattern tells the difference of two colors on a scale that starts from zero. A 50:50% acceptability threshold (AT) is reached when ΔE is 2.7 and that stands for a threshold value of clinically acceptable color difference.[15] When ΔE is under 1.2 the difference between two colors is practically impossible to see (50:50% perceptibility threshold (PT)).

After measuring the color values, the veneers were cemented to the teeth. First the veneers were etched with a 9% hydrofluoric acid following the manufacturers' instructions: Leucite glass for 30 sec and lithium disilicate glass for 10 sec. After etching the veneers were conditioned with a silane agent (Monobond). The teeth were kept in water 2-4 days before cementing the veneers. The tooth surfaces were etched with phosphoric acid for 10 sec. Excite DSC dual-curing one component adhesive was then applied both on the tooth and veneer surfaces. Veneers were cemented with Variolink II dual-curing cement and light cured (Elipar S10) for 40 seconds. The irradiance of light curing unit was tested on regular basis according to manufacturers instructions. Veneered teeth were kept in water for 2-4 days before subjected to mechanical testing.

Failure load was measured with a universal testing machine (LR30K plus, Lloyd Instruments). Strength sensor was 2500 N and testing speed was 0.5 mm/min. Results were evaluated with a PC program (Nexygen Plus).

Before the mechanical loading, a flat area was prepared on the incisal edge of each tooth to spread the pressure equally over the veneer. Loading the specimen on pointy incisal edge could have been technically difficult and caused the early failure of thin incisal edge. During the test drying was avoided by keeping the teeth in water as long as possible. Before testing, a small piece of aluminum foil was placed on top of the tooth to spread the pressure evenly. The load was angled incisally. Initial failure load was recorded when there was a notch on a loading curve indicating pre-cracking of the material. Final failure load was recorded when the specimen fractured detrimentally. The fracture modes were evaluated visually.

STATISTICAL ANALYSIS

Statistical analysis was performed with Statistical Package for the Social Sciences (IBM SPSS, Version 22.0). The data were analyzed using analysis of variance (ANOVA) followed by Tukey's post-hoc test. Differences were considered significant at 95% confidence level.

RESULTS

OPTICAL PROPERTIES:

Optical values showed some scattering inside the groups, which may have been a result of the rounded tooth surface (the optical reader could not be tightly pressed on the entire tooth surface).

Lab-scale color values are presented in Table 1. Material thickness had a great impact on the luminosity of the specimen. The luminance value of pure white is 100. The L values presented in Table 1 clearly indicate that more light passes through a thinner material. The difference in L-values between 0.3 and 0.5 mm thick veneers was statistically significant for both materials ($p<0.001$).

The mean color difference between 0.3 and 0.5 mm thick leucite glass veneers and lithium disilicate glass veneers was noticeable with both try-in pastes (*Table 2*). The color difference between leucite and lithium disilicate glass with the same thickness was noticeable in 0.3 mm veneers with both try-in pastes and in 0.5mm veneers with white paste.

Table 1. Mean Lab-scale colour values of the CAD/CAM veneers with yellow and white try-in pastes

Material and thickness	Yellow try-in paste (SD)			White try-in paste (SD)		
Leucite glass 0.3 mm	L= 76.2* (0.5)	a= 0.5 (0.3)	b= 13.8 (1.1)	L= 86.3* (1.3)	a= -0.2 (0.2)	b= 9.9 (0.5)
Leucite glass 0.5 mm	L= 71.6 (1.1)	a= 0.4 (0.4)	b= 13.9 (1.1)	L= 80.2 (3.0)	a= -0.5 (0.2)	b= 11.1 (0.9)
Lithium disilicate glass 0.3 mm	L= 74.0* (0.8)	a= 0.8 (0.5)	b= 14.7 (0.9)	L= 85.7* (0.7)	a= -0.5 (0.2)	b= 11.1 (0.9)
Lithium disilicate glass 0.5 mm	L= 72.2 (0.9)	a= 0.8 (0.3)	b= 14.8 (0.4)	L= 82.4 (0.7)	a= -0.2 (0.1)	b= 13.5 (0.5)

L= Lightness
a= Lab-scale from green to red
b= Lab-scale from blue to yellow
* significant difference between 0.3 and 0.5mm veneers ($p<0.001$)

Table 2. The mean colour difference (ΔE) between leucite and lithium disilicate reinforced glass ceramic veneers according to the material and thickness of the veneer

Material	Veneer thickness	ΔE yellow try-in paste	ΔE white try-in paste
Leucite	0.3 vs. 0.5	4.4	6.0
Lithium disilicate	0.3 vs. 0.5	2.1	4.1
Leucite vs. Lithium disilicate	0.3 mm	2.3	1.5
Leucite vs. Lithium disilicate	0.5 mm	1.1	3.1

Table 3. Labial fracture types of experimental leucite and lithium disilicate reinforced glass veneers

Adhesive fracture[1]			Cohesive fracture[2]	
Small fracture (more than 80% of veneer remains sound)	Medium fracture (more than 50% of veneer fractured)	Total fracture (veneer completely detached)	Fracture inside the veneer (tooth remains intact)	Fracture involves tooth (enamel/ dentin also damaged)
A: 33.3 % B: 25.0 % C: 50.0 % D: 12.5 %	A: 0.0 % B: 12.5 % C: 12.5 % D: 12.5 %	A: 0.0 % B: 12.5 % C: 0.0 % D: 25.0 %	A: 66.7% B: 25.5% C: 12.5% D: 12.5%	A: 0.0 % B: 25.0 % C: 25.0 % D: 37.5 %

A= Leucite 0.3 mm, B= Leucite 0.5 mm, C= Lithium disilicate 0.3 mm, D= Lithium disilicate 0.5 mm.
[1] Fracture has occurred at the veneer-tooth interface exposing the tooth surface.
[2] Fracture has occurred within the tooth (some of the tooth material has come off with the veneer) or within the veneer.

FAILURE LOAD:

The mechanical test revealed that all veneers fractured adhesively on the palatal side. Labial fractures were divided into two different categories: adhesive and cohesive fractures. These two categories were then divided into five different types *(Table 3)*. There was wide variation of fracture types in both the 0.5 mm leucite and lithium disilicate glass veneers. In 0.3 mm leucite glass veneers, most of the fractures took place within the veneer while in 0.3 mm lithium disilicate veneers most of the fractures were small in size.

Two properties were analyzed in failure load test: initial failure load and final failure load. An example of loading curve with initial and final failure load is presented in Figure 2. The initial failure load of 0.5 mm thick leucite and lithium disilicate glass veneers were on a similar level. Furthermore, 0.3 mm thick lithium disilicate glass veneers had comparable strength with 0.5 mm veneers. The mean value of their initial failure load even exceeded the one of 0.5 mm thick leucite glass veneer *(Figure 3)*. The final failure load values were quite similar in all these three groups. Poor results of 0.3 mm thick leucite glass veneers were not surprising, because the material is not recommended to be used in restorations of less than 0.6 mm. One 0.5 mm lithium disilicate glass veneer remained unbroken (maximum strength 2500 N).

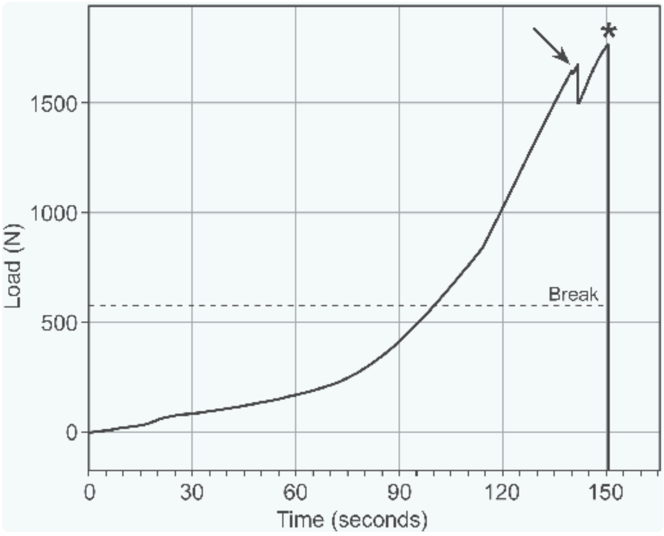

Figure 2: Failure curve of 0.5 mm lithium disilicate reinforced ceramic veneer is showing the appearance initial (arrow) and final (asterisk) failure

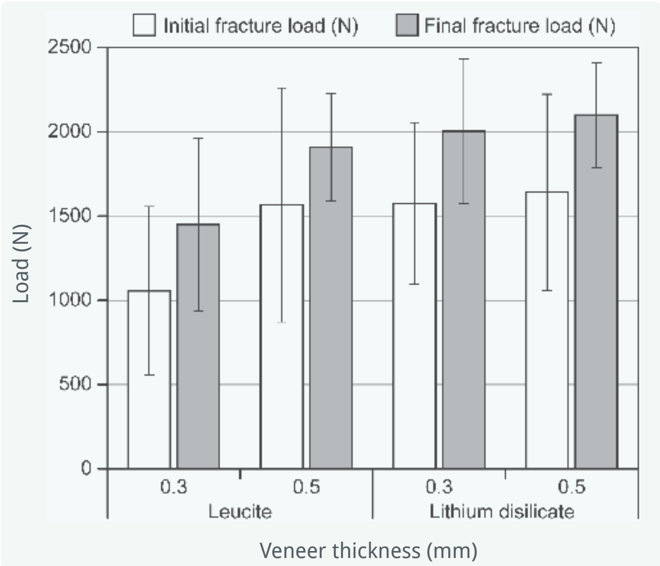

Figure 3: Initial and final failure loads of leucite and lithium dislicate reinforced glass ceramic veneers cemented on bovine incisors with material thicknesses of 0.3 mm and 0.5 mm.

DISCUSSION

Minimally invasive techniques are increasingly needed in restoring tooth in esthetic zones in order to save a patient tooth structures. According to the manufacturer, lithium disilicate reinforced glass ceramic can be used from a material thickness of 0.6 mm and above, which is the same as the minimal thickness for leucite reinforced glass ceramic. This study was conducted in order to explore the optical properties and fracture strength of leucite and lithium disilicate reinforced glass ceramic materials in ultrathin (0.3 and 0.5 mm) CAD-CAM veneers. In the aspect of minimally invasive treatment concept our interest was to test the ultrathin veneers even if the manufacturer does not recommend these structures. Our hypotheses that decreasing the thickness of glass ceramic veneers increases the material's translucency and weakens its failure load, had to be rejected for lithium disilicate reinforced glass ceramic veneers. The results indicated that lithium disilicate glass ceramic could be a potential material even in 0.3 mm CAD/CAM veneers.

In the present study, optical tests revealed that luminance weakened in both materials when material thickness rose from 0.3 mm to 0.5 mm and also the difference in color was visible in both material groups. The greater color changes with leucite reinforced glass veneers suggested that lithium disilicate glass was less of a translucent material than leucite reinforced glass ceramic. This is in agreement with a previous study by Barizon *et al.* (2014).[14] It is possible that leucite reinforced glass looses it's esthetic properties, when used in very thin material layers (0.3 mm).

Leucite and lithium disilicate class veneers of 0.5 mm thickness appears to be quite similar in terms of fracture types and initial fracture load. Although the biaxial strength of leucite reinforced ceramic is much lower,[14] there were not big differences in the fracture strength between the cemented 0.5 mm thick leucite and lithium disilicate glass veneers. Also the fracture types were fairly similar. Apparently cementing strengthens leucite reinforced glass ceramic more than lithium disilicate reinforced glass ceramic. A seven-year follow up study compared posterior lithium disilicate and leucite restorations where the survival rate of lithium disilicate restorations was 100% and that of leucites 97%.[16] These results also suggest that after cementation, leucite reinforced ceramics exhibit almost similar strength with lithium disilicate glass. However the material thickness of leucite reinforced glass ceramics should be at least 0.6 mm to obtain sufficient strength. In our study majority of the fracture types of the 0.3 mm leucite glass veneers were cohesive fractures inside the veneer material. This and the results of the mechanical test support the suggestion that leucite reinforced glass ceramic material is too weak to be used in 0.3 mm thin layers. This material thickness is simply not sufficient to resist fracturing. Also the manageability of 0.3 mm leucite reinforced restorations was poor. From the group of nine veneers, three broke in the processing stage, in other groups only one veneer broke before cementation. These broken specimens were not included to the statistical analyses of the mechanical test. This could cause some overestimation of the results in the group of 0.3 mm thick leucite reinforced restorations and the difference in strength could be in fact larger compared to other study groups.

In prior to mechanical testing, a flat area was prepared on the incisal edge of each specimen to spread the pressure equally over the veneer. This could have been causing flaws on tested specimens. However, loading the specimen on pointy incisal edge could have been technically difficult and possibly caused the early failure of thin incisal edge instead of giving information about the durability of the veneer itself. The specimens in this test had relatively high failure loads and the all veneers fractured adhesively on the palatal side. This supports the methodology used and the fact that the failure did not origin from the flattened incisal surface. However, the fractured surfaces were evaluated visually and no fractographic analysis was done.

In a recent study, Guess *et. al*. (2013) compared the strengths of 0.5 mm, 1 mm and 2 mm thick lithium disilicate onlay restorations and found that there was no significant difference between the fracture resistance of 0.5 mm and 1 mm thick restorations.[17] Our study hypothesis was that decreasing the thickness below 0.5 mm weakens the failure load of both tested materials. However, the hypothesis can be accepted only for leucite reinforced glass ceramics. This is because the mean initial fracture load of 0.3 mm lithium disilicate glass veneers was the same as that of 0.5 mm leucite reinforced veneers. The mean load at break value of 0.3 mm lithium disilicate glass veneers even exceeded one of 0.5 mm leucite glass veneers. Therefore the hypothesis must be rejected for lithiumdisilicate reinforced glass ceramics.

The mechanical properties of leucite or lithium disilicate reinforced glass ceramics are based on the differences in the coefficient of thermal expansion (CTE) of the reinforcing crystals and the glass medium. During the cooling after crystallization firing, compressive stresses are formed around the crystals. This can affect to crack propagation and increase mechanical properties of the material.[18] In the present study the different filler materials and the content of crystal fillers could have a crucial effect on the strength of 0.3 mm ultrathin veneers. Fracture types can also be analyzed through material structures. Most of the 0.3 mm leucite reinforced veneers peeled off (cohesive fracture, tooth remained intact and the fracture took place in the veneer), whereas 0.3 mm thin lithium disilicate reinforced veneers fractured mainly adhesively (clean fracture in the cement line). It might be that the higher content (up to 70%) of lithium disilicate crystals of IPS e.max material prevents fracturing better in thinner layers. Also lithium disilicate glass did not peel off as often as leucite reinforced glass when fractured.

The maximal bite forces of a healthy young adult ranges from 300 to 400 N in the anterior region.[19] The initial fracture load values of both 0.3 and 0.5 mm lithium disilicate veneers and 0.5 mm leucite veneers exceeded 800 N, which is higher than the reported maximal bite forces in the anterior region. However, in the present study the veneers were tested under static loading and no cyclic loading was conducted. It is known that cyclic loading would have given lower fatigue strengths and therefore been a more clinically consequential test setup.[3] Also, clinically during bruxing episodes, bite forces can reach much higher values. This should be taken into consideration when making veneers for bruxers or patients who suffer from occlusal parafunctions.

CONCLUSIONS

Considering the ultrathin material thickness, one should be very careful in choosing the color of the resin cement as it may have a crucial effect on the final esthetic outcome. Within the limitations of this study it can be concluded that ultrathin 0.3 mm lithium disilicate reinforced glass ceramic veneers could be a potential option in CAD/CAM veneer restorations.

MANUFACTURERS DETAILS

- IPS Empress CAD LT A2, Ivoclar Vivadent AG, Schaan, Principality of Liechtenstein
- IPS e.max CAD LT A2, Ivoclar Vivadent AG, Schaan, Principality of Liechtenstein
- Monobond, Ivoclar Vivadent AG, Schaan, Principality of Liechtenstein
- Variolink II, Ivoclar Vivadent AG, Schaan, Principality of Liechtenstein
- Palapress, Heraeus Kulzer, Hanau, Germany
- Cerec 3D 3.6, Sirona Dental, Saltzburg, Austria
- CM-700d, Konica Minolta Sensing Inc., Osaka, Japan
- Elipar S10, 3M ESPE, London, Canada
- LR30K plus testing device, Lloyd Instruments Ltd., Fareham, England
- Nexygen Plus, Lloyd Instruments Ltd., Fareham, England
- IBM SPSS Version 22.0; SPSS. Inc., Chicago, Illinois

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