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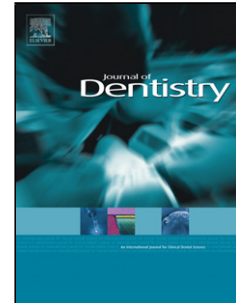
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Title: Transient and residual stresses in a pressable glass-ceramic before and after resin-cement coating determined using profilometry.

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Introduction

Glass-ceramics are routinely used in the manufacture of porcelain laminate veneer (PLV) [1,2] and dentine bonded crown (DBC) [3] dental restorations and are advocated for use in the anterior region of the mouth [1-3]. The results of fractographic studies of clinically failed all-ceramic crowns [4-6] combined with finite-element analysis studies of the stress distribution in all-ceramic crowns [7] have demonstrated that in function, the 'fit' surfaces of these restorations can be subjected to high tensile stresses and frequently become the locus of fracture-failure.

In the last two decades improvements in dental glass-ceramics have been observed with considerable interest by both materials scientists and dental practitioners alike with a view to improving fracture resistance and optimising aesthetics. The introduction of the IPS Empress system in 1990 which was developed by Arnold Woldwend and consisted of 35 vol% leucite crystals, uniformly dispersed into an amorphous glassy matrix [8,9], produced reported mean biaxial flexure strengths (BFS) of 104 ± 23 to 175 ± 32 MPa [10-17] and showed a strength improvement on conventional dental porcelain [18]. In 1998, Empress 2, a lithium disilicate reinforced glass-ceramic was developed by Wolfram Holand in conjunction with Ivoclar-Vivadent and boasted mean BFS ranging from 300 ± 35 to 407 ± 45 MPa [14,16-17]. The increase in the crystalline content to 65 vol% was beneficial by hindering crack propagation as a result of the interlocking microstructure of the elongated lithium disilicate rod-like crystals [16-17]. More recently, IPS emax[®] Press with a similar composition as Empress 2, namely a lithium disilicate reinforced glass-ceramic with a crystalline content of 67 vol% [19], has been available with a reported mean BFS of

440±55 MPa [16]. Accordingly the manufacturer now advocates the use of IPS e.max[®] Press for three-unit bridges from the first premolar to the first molar and for the fabrication of fully anatomical restorations [20].

In service, the flexural strength of a dental ceramic substrate can be modified by the nature and distribution of surface and bulk defects [21], the presence of transient and residual stress states [22,23] and the impact of pre-cementation and cementation processes on these phenomena [23-25]. One of the disadvantages recognised for conventional dental porcelains is that the fabrication of a restoration involves a frit condensation and sintering processing route. Sintering may result in the introduction of thermally induced residual stresses [22] which can result in the deformation of the ceramic body [24] and a modification of the measured BFS [24,26]. It has been suggested that heat-pressing fabrication routes for glass-ceramic materials are advantageous by reducing the likelihood of the formation of large flaws [27,28] and minimising thermally induced residual stresses [22]. A further important clinical influence on restoration fracture resistance is the impact of cementation protocols which may modify surface defect distributions [29-31] and transient and residual stress states [23-25]. Notably, Malament and Socransky reported 14 year [32] and 16 year [33] clinical survival data for 1444 Dicor glass-ceramic dental restorations and demonstrated by employing an adhesive resin-luting cement a reduced fracture rate was observed when compared with conventional luting with acid-base cements such as zinc phosphate or glass-ionomers.

Therefore, the aim of the current study was to investigate the effect of heat-pressing and subsequent pre-cementation (acid-etching) and resin-cementation operative

techniques on the development and magnitude of the transient and residual stresses in different clinically relevant thicknesses of a lithium disilicate glass-ceramic characterised using a profilometric technique [23-25]. The hypothesis tested was that the transient and residual stress state in a heat-pressed lithium disilicate ceramic is modified by acid-etching and resin-cementation but is dependent on the clinically relevant thickness of glass-ceramic employed.

Materials and Method

Specimen preparation

Disc-shaped acrylic resin specimens, 0.83 ± 0.05 , 1.16 ± 0.07 and 1.56 ± 0.06 mm thickness, were prepared by sectioning a solid acrylic resin rod (12.08 ± 0.2 mm diameter) with a diamond saw (IsoMet Low Speed Saw, Buehler, Lake Bluff, IL USA). The acrylic discs were sprued using a 3 mm wax rod and invested by mixing 200 g of phosphate investment powder (IPS Press Vest, Lot No. KL2008, Ivoclar-Vivadent AG, Schaan, Liechtenstein) with 31 mL of special liquid (IPS Press Vest investment liquid, Lot No. KL2059, Ivoclar-Vivadent AG, Schaan, Liechtenstein) and 13 mL of distilled water. The slurry was manually mixed for 20 s before mixing mechanically under vacuum for 60 s (Whip Mix Corporation, Louisville, KY, USA). A large investment ring was filled with the slurry and left to harden over 60 mins. The sprue base was carefully removed and the refractory mould was placed in a burn-out furnace (IPCO 3300, Metrotherm R GmbH, Lilienthal, Germany), heated from room temperature to 250°C at $5^{\circ}\text{C}/\text{min}$ and heat soaked for 30 mins to eliminate the acrylic. The temperature was increased to 850°C at $9^{\circ}\text{C}/\text{min}$ and held for 60 mins before the refractory mould was removed from the furnace. The pressing channel was filled with one large IPS e.max[®] Press ceramic ingot (Lot No. K16275, low translucency shade A2, Ivoclar-Vivadent AG, Schaan, Liechtenstein), the plunger applied and transferred to a pressing furnace (EP 600 Combi, Ivoclar-Vivadent Schaan, Lichtenstein). The pressing procedure involved heating the refractory mould from 700°C to 920°C at a rate of $60^{\circ}\text{C}/\text{min}$ under vacuum, holding for 25 mins and pressing into the mould at 5 bar pressure [34]. At the end of the pressing procedure, the refractory mould was removed from the pressing furnace and allowed to bench cool to room temperature.

The IPS e.max[®] Press disc-shaped specimens were divested by air particle abrasion using 90 µm glass beads (Dentalfarm, Turin, Italy) at 4 bar pressure (Dentalfarm, Turin, Italy) employing an ECO Dry Oxide System (Dentalfarm, Turin, Italy) until the specimens were visible. The air pressure was reduced to 2 bar and the ceramic discs were alumina particle air abraded on both sides with 100 µm particles at a distance of 1 cm. To further remove the reaction layer formed during pressing, the ceramic discs were ultrasonically cleaned for 15 mins in a bath of Invex liquid (<1% hydrofluoric (HF) acid, Lot No. K06662, Ivoclar-Vivadent AG, Schaan, Lichtenstein) [34]. The discs were cut from the sprues using a diamond cutting disc under water lubrication at a low speed under minimal hand pressure and the edges were re-shaped with a conical diamond bur. The ceramic discs were then alumina particle air abraded on both sides from a distance of 1 cm with a pressure of 1 bar with 100 µm aluminium oxide in an alumina particle air abrader. To completely remove the reaction layer the ceramic discs were re-placed in the ultrasonic bath of Invex liquid for 15 mins and alumina particle air abraded on both sides from a distance of 1 cm with a pressure of 1 bar with 100 µm alumina particles.

An Alpha and Beta Grinder-Polisher (Buehler, Lake Bluff, IL, USA) was employed to grind one surface of the disc-shaped ceramic specimens by utilising sequential grinding with ascending grades (P340, P600, P800, P1200 and P2500) of silicon carbide abrasive papers (Buehler, Lake Bluff, IL, USA). Grinding was performed at a speed of 100 rpm under water lubrication with a load of 12 N applied to each specimen which was adhered using super-glue to aluminium stubs to facilitate grinding. The final thickness of the 60 specimens was measured with a micrometer

screw gauge accurate to 10 μm (Digimatic Micrometer, Mitutoyo Corp., Tokyo, Japan). Specimens with thicknesses of 0.61 ± 0.05 , 0.84 ± 0.08 , and 1.06 ± 0.07 mm were allocated to three groups (Groups A-C, respectively) of 20 specimens. The polished surface of the ceramic discs were noted and the area coincided with the centre of the specimens marked at the extremities of the area of interest to ensure repeat profilometric measurements of the selected area, prior to storage in a desiccator before further analysis and testing.

Profilometric evaluation

To produce accurate profilometric measurements the ceramic discs were placed and held for the duration of the profilometric deflection test, in a custom-made metallic multi-axial levelling device [24-25]. Profilometric measurements were performed using an inductive gauge (Talysurf CLI 2000, Taylor Hobson Ltd., Leicester, UK) consisting of a 90° conisphere diamond stylus tip of 2 μm radius on the polished surface of the ceramic discs. Deflection measurements were taken across a 10 mm^2 area (10 mm length and 1 mm width) coincident with the centre of the specimens. In the context of this technique, deflection was defined as the quantifiable difference (μm) in a vertical axis between the most superior and inferior regions of the disc, namely the centre and the periphery of the measurement region, respectively. The deflection measurements were performed at a measurement velocity and applied load of 1 mm/s and 0.75 mN, respectively. The baseline maximum deflection (μm) for each of the ceramic discs was determined by averaging the 251 traces which were profiled at a 4 μm step-size (y-direction) with data points recorded every 10 μm (x-direction) to a 40 nm resolution (z-direction) for the scanning conditions of velocity and load chosen (Figure 1a).

Following baseline quantification of the maximum deflection for each specimen of Groups A-C, the contra-lateral (unpolished) surface was acid-etched for 20 s with <5% HF acid (IPS[®] Ceramic Kit Etching Gel, Lot No. L26132, Ivoclar-Vivadent, Schaan, Lichtenstein), before rinsing thoroughly under running water [34]. The maximum deflection of the ceramic discs following HF acid-etching was re-quantified by re-profiling the defined measurement region on the polished surface of the specimens in accordance with the scanning conditions previously outlined (Figure 1b).

Following profilometric evaluation of the HF acid-etched surface, a thin coat of silane coupling agent (Ceramic Primer S, Lot No. 9YY, 3M ESPE, St. Paul, MN, USA) was applied to the etched surface of the ceramic discs and allowed to air-dry for 15 mins to ensure the silane coupling agent had fully dried. A consistent mass (0.025 g) of Rely-X[™] Veneer Cement (Lot No. 8EB, shade A3, 3M ESPE, St. Paul, MN, USA) was applied to the primed surface, the cement covered with Mylar and a glass-slide used to press the cement until it spread to the edges of the ceramic discs. The cement was light irradiated with an Optilux 501 (SDS Kerr, Danbury, CT, USA) for 20 s at a light intensity of 526 ± 12 mW/cm² delivered through a 13 mm light tip diameter from a distance of 0 mm and stored for 24h at 37°C in a dark temperature controlled environment. The polished surface of the cement coated ceramic discs was re-profiled 24 h after cement coating (Figure 1c), in accordance with the scanning conditions outlined (across the 10 mm² area coincided with the centre of the specimen).

Bi-axial flexure strength (BFS) test

Following profilometric measurements, Groups A-C of cement coated specimens were centrally loaded with the polished surface in contact with a 2.75 mm diameter spherical ball indenter at cross-head speed of 1 mm/min. The cement surface was supported by a thin rubber film placed between the specimen and a 10 mm diameter metallic ring to distribute the load uniformly over the ceramic disc. The bi-axial flexure strength (BFS) of the cement coated specimens was determined from the load at fracture and calculated using equations 1-7 [35].

The position of the neutral plane (t_n) was determined from

$$t_n = \frac{E_1^*(t_1)^2 - E_2^*(t_2)^2}{2(E_1^*t_1 + E_2^*t_2)} \quad \text{Equation 1}$$

where t_1 and t_2 were the ceramic disc and cement thicknesses, respectively and E_1^* and E_2^* were calculated from equations 2 and 3, respectively.

$$E_1^* = \frac{E_1}{1-\nu_1} \quad \text{Equation 2}$$

$$E_2^* = \frac{E_2}{1-\nu_2} \quad \text{Equation 3}$$

where E_1 was the reported elastic modulus of IPS e.max[®] Press [20] and ν_1 was the Poisson ratio (0.23) of IPS e.max[®] Press [16], E_2 was the elastic modulus of the cement (8.2 GPa) [29] and ν_2 the Poisson ratio (0.27) of the cement [36].

The biaxial flexure stress was calculated at axial positions (z) with the bonded interface (at $z = 0$), the porcelain surface (at $z = t_1$) and the resin surface (at $z = -t_2$) as

$$\sigma = \frac{-3P(1+\nu)(z-t_n)}{2\pi(t_1+t_2)^3} \left[1 + 2\ln\left(\frac{a}{b}\right) + \frac{1-\nu}{1+\nu} \left(1 - \frac{b^2}{2a^2} \right) \frac{a^2}{R^2} \right] \left[\frac{E_1^*(E_1^*t_1 + E_2^*t_2)(t_1+t_2)^3}{(E_1^*t_1^2)^2 + (E_2^*t_2^2)^2 + 2E_1^*E_2^*t_1t_2(2t_1^2 + 2t_2^2 + 3t_1t_2)} \right] \quad \text{Equation 4}$$

$(0 \leq z \leq t_1)$ and

$$\sigma = \frac{-3P(1+\nu)(z-t_n)}{2\pi(t_1+t_2)^3} \left[1 + 2 \ln\left(\frac{a}{b}\right) + \frac{1-\nu}{1+\nu} \left(1 - \frac{b^2}{2a^2} \right) \frac{a^2}{R^2} \right] \left[\frac{E_2^*(E_1^*t_1 + E_2^*t_2)(t_1+t_2)^3}{(E_1^*t_1^2)^2 + (E_2^*t_2^2)^2 + 2E_1^*E_2^*t_1t_2(2t_1^2 + 2t_2^2 + 3t_1t_2)} \right] \quad \text{Equation 5}$$

$(-t_2 \leq z \leq 0)$ and

The average Poisson's ratio (ν) [35] of the cement coated specimens was calculated as

$$\nu = \frac{(\nu_1 t_1 + \nu_2 t_2)}{t_1 + t_2} \quad \text{Equation 6}$$

P was the load at fracture, ν was the Poisson's ratio of the cement coated specimens (Equation 6), a and R were the radii of the supporting ring and the specimen, respectively while b was the radius of the loading contact area at the center of the specimen - defined as

$$b = \frac{t_1 + t_2}{3} \quad \text{Equation 7}$$

Statistical Analysis

The deflection data for each ceramic thickness (Groups A, B and C) was explored by testing the observed cumulative distribution functions against theoretical distributions using Kolmogorov-Smirnov tests. Findings from this preliminary analysis identified a parametric statistical approach to be most appropriate. The statistical approach employed was tailored to the testing protocol where the same test (profilometric evaluation to determine the maximum deflection) was performed using repeat measurements across a polishing reference surface (baseline quantification), after HF acid-etching and following resin cementation. As a result, paired sample t-tests were performed at a 95% significance level on the 20 individual samples in each of the groups (Groups A-C) for each comparison. Additionally, the differences between the

magnitude of the mean of the maximum deflection from baseline quantification to resin-cement coating across the polished surface for the three different specimen thicknesses of 0.61 ± 0.05 , 0.84 ± 0.08 , and 1.06 ± 0.07 mm were determined using a one-way ANOVA with post-hoc Tukey tests ($P<0.05$). The statistical significance of resin-strengthening on the BFS of Groups A-C was also determined using a one-way ANOVA and post-hoc Tukey tests ($P<0.05$).

Results

The mean deflection values (μm) characterised across the polished surface ((APol) baseline quantification), after acid-etching (AHf), 24 h after cement coating (AC) and the resultant change in the mean deflection (APol-AC) of the ceramic discs are shown in Table 1. The characterised mean of the maximum deflection after polishing (baseline quantification) the groups of 20 specimens with increasing ceramic thickness (Groups A-C) were 3.2 ± 1.8 , 2.9 ± 1.2 and 3.9 ± 1.4 μm , respectively with no significant differences in the characterised mean of the maximum deflection values (Figure 2) identified between the group means ($p=0.341$).

Since the data was parametric, a paired samples t-test was performed at a 95% significance level on the data sets. Following HF acid-etching of the unpolished (non-reference) surface, a significant increase in the magnitude of the maximum deflection for Group A ($p<0.001$), Group B ($p<0.001$) and Group C ($p<0.001$) specimens was identified compared with the baseline quantification of the mean of the maximum deflection for the individual groups. Additionally, resin-cement coating the HF acid-etched surface significantly increased the characterised mean of the maximum deflection for Group A ($p<0.001$), Group B ($p<0.001$) and Group C ($p=0.001$) specimens compared with the mean of the maximum deflection for the HF acid-etched surface for the individual groups when examined using the paired samples t-test at a 95% significance level. Interestingly, the increase in the mean of the maximum deflection from baseline quantification to resin-cement coating for the three different specimen thicknesses of 0.61 ± 0.05 , 0.84 ± 0.08 , and 1.06 ± 0.07 mm were 4.4,

2.2 and 0.9 μm , respectively and were significantly different ($p < 0.001$) when a one-way ANOVA and post-hoc Tukey test were employed.

The mean thickness of the cement layer was 100.3 ± 23.1 , 94.5 ± 19.7 and 100.1 ± 16.4 μm (Groups A-C, respectively) were not significantly different when a one-way ANOVA and post-hoc Tukey test were employed and the one-way ANOVA and post-hoc Tukey test revealed that the mean BFS values for Groups A-C were also not statistically different.

Discussion

Baseline quantification of the mean of the maximum deflection for the IPS e.max[®] Press disc-shaped specimens necessitated a polished reference surface to enable the magnitude of the transient and residual stresses across the surface defect integral to be characterised using the profilometric technique employed [23]. The divesting procedure for the IPS e.max[®] Press specimens required the removal of the reaction layer formed during pressing [34]. The divesting procedure is extensive and involves bombarding the specimen surfaces with 90 µm glass beads at 4 bar pressure, with repeated alumina particle air abrasion with 100 µm particles at 1 bar pressure at a distance of 1 cm and ultrasonic cleaning for 15 mins in Invex liquid. Previously the authors identified for ceramic discs manufactured to a high geometric tolerance, the requirement for a reference surface containing defects with an amplitude of <4 µm [23] which required polishing of one surface to enable baseline quantification. The extensive and severe divesting abrasion and acid-etching regimes employed produced a surface roughness profile with defect amplitudes of the order of 10 times that required (<4 µm), and was not conducive to characterisation of the mean of the maximum deflection of the disc-shaped specimens using the profilometric technique employed [23].

The authors have shown previously for veneering porcelains (Viadur Alpha [23] and IPS e.max[®] Ceram [25]) that baseline quantification across the polished surface identified the surface form to be convex, indicative of the polished reference surface being in a tensile stress state relative to the unpolished surface. Baseline quantification of the mean of the maximum deflection for Viadur Alpha [23] and IPS

e.max[®] Ceram [25] discs were 8.4 (1.5) and 6.3 (2.3) μm , respectively. In the current investigation, baseline quantification of the mean of the maximum deflection for the IPS e.max[®] Press specimens was markedly lower than the veneering porcelains and ranged from 2.9 (1.2) to 3.9 (1.4) μm . It was suggested previously that the polishing process, which induced surface and subsurface plastic deformation active across the surface defect integral [31,37], and the residual stress state induced on cooling, during specimen processing [22], accounted for the transient and residual stress state manifest as the observed convexity for veneering porcelains. IPS e.max[®] Press is processed by a heat-pressing technique which is reported to minimise thermally induced stress in the glass-ceramic material, as the specimens undergo slow cooling from the pressing temperature to room temperature within the refractory mould [20,34] rather than a conventional sintering processing route [23,25]. Additionally, the extensive and severe divesting (abrasion and acid-etching) regime is applied to both surfaces of the specimens so that processing induced transient and residual stresses should also be minimised [22]. Therefore the authors propose that the lower reported baseline quantification range of the mean of the maximum deflection for the IPS e.max[®] Press specimens was predominantly the result of specimen polishing regime inducing a tensile stress state across the surface defect integral which accounted for the observed surface convexity. The grinding process was multidirectional owing to the rotational spect of the machine during grinding, such that machining induced cracks and residual stresses are difficult to asses so that the nature of the interaction between these opposing factors is unclear in the ceramic literature [38-41]. Interestingly, for the three experimental groups of 0.61 ± 0.05 , 0.84 ± 0.08 , and 1.06 ± 0.07 mm no significant difference in baseline quantification of the mean of the maximum deflection between specimens groups was evident. The polishing procedure

involved the mechanical grinding of one surface of the disc utilising ascending grades of silicon carbide abrasive papers facilitated by adhering the specimens with super-glue to aluminium stubs compatible with the Alpha and Beta Grinder-Polisher. Therefore the specimen thicknesses would not have been expected to produce significant differences in the baseline quantification of the mean of the maximum deflection as the rigidity of the specimens was similar owing to the adhesion to the aluminium stub mediated by the super-glue. In the experimental design chosen by the authors, the IPS e.max[®] Press glass-ceramic discs were not annealed to relieve the polishing-induced tensile stress state in an effort to avoid microstructural changes in the glass-ceramic material [42] and enable a repeat measurements statistical approach to be undertaken for the three different specimen thicknesses of 0.61 ± 0.05 , 0.84 ± 0.08 , and 1.06 ± 0.07 mm.

The conventional wisdom in the dental literature suggests that acid-etching has the potential to modify the crack tip geometry therefore the overall residual stress state [43-44]. The impact of the acid-etching process (acid type, concentration and etching time) varies depending on the type of ceramic material and the ceramic surface topography [43-45]. Acid type, concentration and etching time all impact upon the crack tip geometry and therefore the overall residual stress state [45] although variations to the overall residual stress state differs depending on the ceramic and surface topography. The glass-ceramic investigated was acid-etched with <5% HF for 20 s in accordance with the manufacturers instructions and the paired samples t-test performed at a 95% significance level identified a significant increase in the mean of the maximum deflection for Group A ($p<0.001$), Group B ($p<0.001$) and Group C ($p<0.001$) specimens compared with baseline quantification for the individual groups.

It is suggested that the modification of the flaw geometry and surface topography induced a compressive stress on the acid-etched surface which impacted upon the magnitude of the transient and residual stress characterised across the surface defect integral of the polished surface manifest as an increase in the mean of the maximum deflection for the individual groups.

Resin-cement coating the HF acid-etched surface was identified, using the paired samples t-test at a 95% significance level, to significantly increase the characterised mean of the maximum deflection for Group A ($p < 0.001$), Group B ($p < 0.001$) and Group C ($p = 0.001$) specimens compared with the HF acid-etched surface for the individual groups. This finding was in agreement with previous studies investigating resin strengthening of veneering porcelains (Viadur Alpha [23] and IPS e.max[®] Ceram [25]) conducted using the profilometric technique. The compressive stress state generated by the volumetric shrinkage of the resin-based luting cement during polymerisation [46] is exacerbated due to the shrinkage stress being constrained within the resin-ceramic hybrid layer that is produced by the infiltration of the resin-based luting cement into the surface topography [29-31] induced by acid-etching the ceramic surface [45]. It is suggested that the compressive stress state generated during polymerisation of the resin [46] and constrained within the resin-ceramic hybrid layer [29-31] is less readily dissipated across thinner specimens. The compressive stress is in practice more constrained by the thicker specimens (1.06 ± 0.07 mm) owing to the increased rigidity compared with the thinner specimens (0.61 ± 0.05 mm) manifested as the significantly reduced characterised mean of the maximum deflection on resin-cement coating with increasing specimen thickness. The clinical implications of this finding for PLV or DBC dental ceramic restorations may be difficult to interpret as

the resin is only constrained by the resin-ceramic hybrid layer and the interaction with the tooth structure has not been considered. However, the one-way ANOVA and post-hoc Tukey test revealed no statistically significance differences in BFS group means for Groups A-C which was expected given the marked thickness and elastic modulus differences between the glass-ceramic and resin-cement used to calculate the BFS using Equations 1-7. Additionally the biaxial flexure stress was calculated at axial positions throughout the resin-cement coated specimen and the maximum flexural stress of the resin-cement in the current study was considerably below the elastic limit as reported by Addison et al. [31] further suggesting failure occurred at the resin-ceramic hybrid layer in BFS testing. However despite the resin-cement strengthening mechanism operative in the current study, the mean BFS values are markedly lower than the BFS values quoted by the manufacturers in the Scientific Documentation IPS e.max[®] Press where a values of 440 ± 55 MPa was quoted from the dental literature [16].

Conclusion

The lower reported baseline quantification range of the mean of the maximum deflection for the IPS e.max[®] Press specimens was predominantly the result of specimen polishing regime inducing a tensile stress state across the surface defect integral which accounted for the observed surface convexity. Acid-etching and resin-cementation had a significant impact on the development and magnitude of the transient and residual stresses in the lithium disilicate glass-ceramic investigated.

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Table 1: The mean thickness (mm) and standard deviations (in parenthesis) of the ceramic discs (Groups A-C) and the cement thickness (μm), the mean deflection values (μm) and standard deviations (in parenthesis) of the ceramic discs characterised across the polished surface ((APol) baseline quantification), after acid-etching (AHf) and 24 h after cement coating (AC), the change in the mean deflection (APol-AC) and the mean biaxial flexure strength (BFS) (MPa) and standard deviation (in parenthesis) of the ceramic discs tested 24 h after cement coating. Statistically significant differences within columns (ceramic thickness, cement thickness, mean deflection (APol) and BFS) are highlighted by different lower case letters. A paired samples t-test was performed ($P < 0.05$) on the 20 individual samples in each of the groups (Groups A-C) independently and statistical significance across the mean deflection data (APol, AHf and AC) are highlighted by different lower case letters imply significance difference.

Groups	Ceramic Thickness (mm)	Cement Thickness (μm)	Mean Deflection (μm)				BFS (MPa)
			APol	AHf	AC	APol- AC	
A	0.61 (0.05) ^a	100.3 (23.1) ^d	3.2 (1.8) ^e	4.8 (1.9) ^f	7.6 (2.6) ^g	4.4	288 (29) ^l
B	0.84 (0.08) ^b	94.5 (19.7) ^d	2.9 (1.2) ^e	3.8 (1.3) ^h	5.1 (1.8) ⁱ	2.2	279 (46) ^l
C	1.06 (0.07) ^c	100.1 (16.4) ^d	3.9 (1.4) ^e	4.3 (1.4) ^j	4.8 (1.5) ^k	0.9	273 (38) ^l

Figure Captions

Figure 1: A three dimensional profilometric trace (composed of 251 individual traces) across the polished surface of an IPS e.max[®] Press disc from Group A specimens representing the mean deflection values characterised at: a) baseline quantification, b) after HF acid-etching and c) after 24 h resin-cement coating.

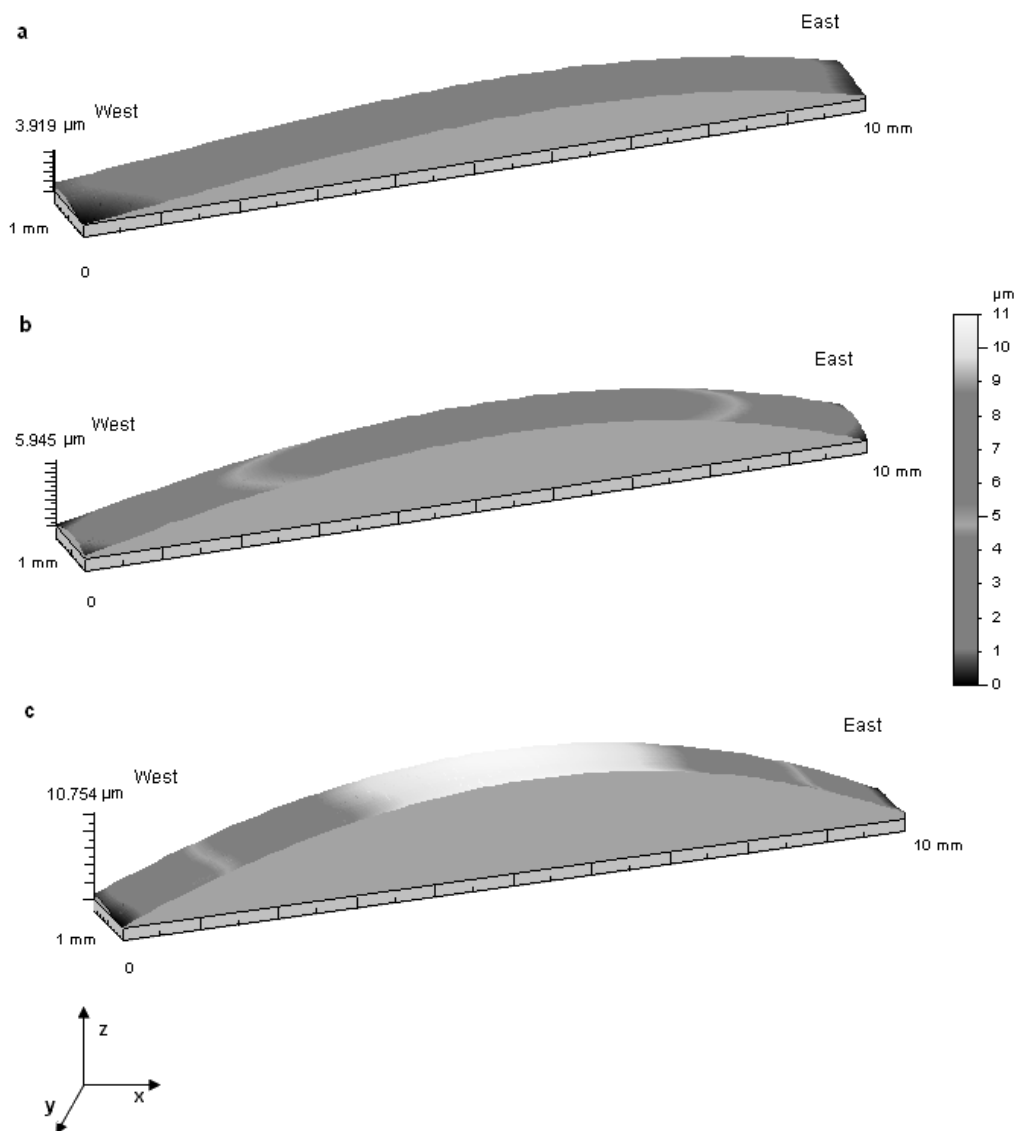


Figure 2: The mean deflection values (μm) for Groups A-C of IPS e.max[®] Press discs profiled across the polished surface ((APol) baseline quantification), after acid-etching (AHf) and after 24 h resin-cement coating (AC) at a $4\ \mu\text{m}$ step-size (y-direction) with data points recorded every $10\ \mu\text{m}$ (x-direction) to a $40\ \text{nm}$ resolution (z-direction) at a measurement velocity and applied load of $1\ \text{mm/s}$ and $0.75\ \text{mN}$, respectively.

