

Mouth Motion Fatigue and Durability Study

Petra C Guess*, Ricardo Zavanelli+, Nelson Silva and Van P Thompson, NYU

Executive Summary:

- Porcelain veneered zirconia crowns and monolithic lithium disilicate crowns were tested
- Mouth-motion-step-stress-fatigue was used to examine reliability and failure modes
- Failure was considered to be chip-off fractures or fracture through the crown
- Three step-stress profiles were used up to failure or up to 900 N and 180K cycles after which a staircase fatigue method was implemented to a load at which 50% of specimens could be expected to survive 1 million cycles
- Veneered zirconia crowns resulted in limited reliability - approximately 90% of specimens would fail from veneer chip-off fracture by 100k cycles at 200 N. These results are similar to previous findings for other veneered zirconia systems (LAVA, Cercon, Vita) tested using this methodology (Coelho PG, Silva NR, Bonfante EA, Guess PC, Rekow ED, Thompson VP. Fatigue testing of two porcelain-zirconia all-ceramic crown systems. Dent Mater. 2009 Apr 21. [Epub ahead of print])
- Approximately 90% veneered zirconia specimens failed by 350 N independent of the number of cycles
- None of the e.max CAD lithium disilicate specimens failed below 900 N and 180k cycles independent of loading profile
- The e.max CAD lithium disilicate specimens survived r ratio fatigue of 1 million cycles at loads of 1000 N. There appears to be a threshold for damage/fracture for the lithium disilicate in the range of 1100-1200 N.

* Visiting Scientist from the Department of Prosthodontics University of Freiburg, Freiburg, Germany

+ Visiting Scientist from the Department of Prevention and Oral Rehabilitation, Federal University of Goias School of Dentistry, Goiania, Brazil.

Background:

While Y-TZP core ceramic exhibits a high stability as a framework material in short- [1] and medium-term studies on fixed partial dentures [2- 3] chip fractures within the veneering ceramic are the most common clinical failure mode of all-ceramic Y-TZP based restorations [4]. Hence attempts have been made to find all-ceramic alternatives for full crown application.

As high survival rates with no chip failures within the veneering ceramic have been reported for lithium disilicate IPS Empress 2 crowns [5, 6] the exploration of the recently developed monolithic CAD/CAM fabricated lithium disilicate crown system IPS e.max CAD is expected to be promising.

Since no study so far has been published on the clinical performance of Y-TZP based or CAD/CAM fabricated lithium disilicate crowns, a preclinical investigation of the vitro longevity and micro-structural fatigue is expected to be most enlightening for the evaluation of long-term behavior of the described all-ceramic systems.

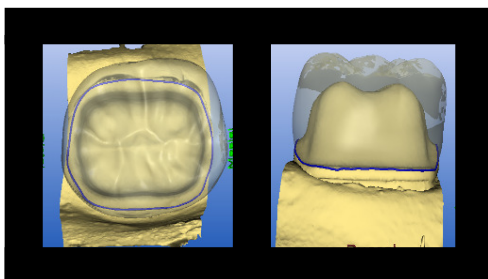
Objective:

To evaluate the effect of on mouth-motion-step-stress-fatigue on reliability and failure modes of monolithic lithium disilicate full crowns (IPS e.max CAD) and to compare these results with hand-layer veneered Y-TZP based crowns (IPS e.max ZirCAD/Ceram).

Methods:

An anatomical correct 3D model of a mandibular first molar full crown was generated. Monolithic lithium disilicate full crowns (IPS e.max CAD, n= 19) and hand-layer veneered Y-TZP based crowns (IPS e.max ZirCAD/Ceram, n= 21) were tested. Full-anatomically shaped IPS e.max CAD and IPS e.max ZirCAD cores were designed and milled with a CAD/CAM system (Cerec InLAB, Sirona, Germany). IPS e.max ZirCAD cores were veneered using the hand-layering technique (IPS e.max Ceram) according to the manufacturer's instruction.

Figure 1: CAD/CAM crown configuration IPS e.max CAD: Full anatomic design (occlusal reduction: 2 mm, axial 1.5 mm, IPS e.max ZirCAD/Ceram (0.5 mm Y-TZP core; 1-1.5 mm veneering ceramic)

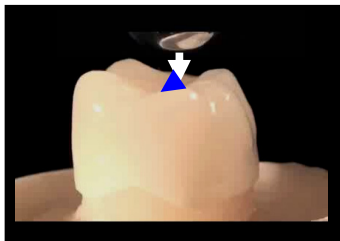


All crowns were cemented to aged resin-based composite dies (Tetric EvoCeram A2) with Multilink Automix. Prior to cementation, a layer of metal primer (Metal/Zirconia Primer) was applied to the internal surface of the zirconia core (no sandblasting or silane coating was employed). IPS e.max CAD crowns were etched

with 5% hydrofluoric acid (IPS Ceramic etching gel) for 20 seconds according to the instructions of the manufacturer.

In order to determine the step-stress profiles three crowns per group were subjected to single load to failure testing. Samples from each group were subsequently exposed to mouth-motion step-stress-fatigue. Mechanical testing was performed by sliding a WC indenter ($r = 3.18 \text{ mm}$) 0.7 mm (lingually) down the disto-buccal cusp (Figure 2).

Figure 2: Mouth-motion fatigue with load application on the disto-buccal cusp of the crown (arrows)

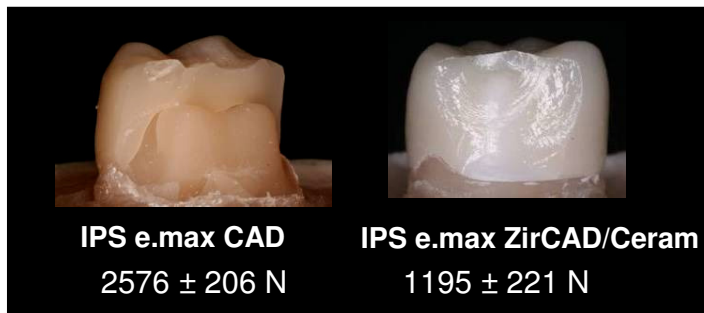


Bulk fractures of the monolithic lithium disilicate IPS e.max CAD crowns and chip-off fractures of the veneering ceramic for veneered IPS e.max ZirCAD/Ceram crowns were considered as failures. Three step-stress profiles (mild, moderate and aggressive) were designed for fatigue testing. The step stress profiles for IPS e.max CAD started with 500 N load based upon preceding experiments and ended at a maximum of 900 N and 180K cycles for the mild profile and 900N and 60K cycles for the aggressive profiles. IPS e.max CAD crown samples ($n=6$) were distributed across the three profiles in a 3:2:1 distribution. If there were no failures it was deemed reasonable based upon the very high loads involved to change the test method. The remaining samples were then used to determine via the staircase fatigue method the load at which 50% of the samples could be expected to survive 1000K cycles with a loading frequency of 5 Hz. An r ratio (1:10) fatigue strategy was employed and failure was designated as a large chip or bulk fracture through the crown.

Results:

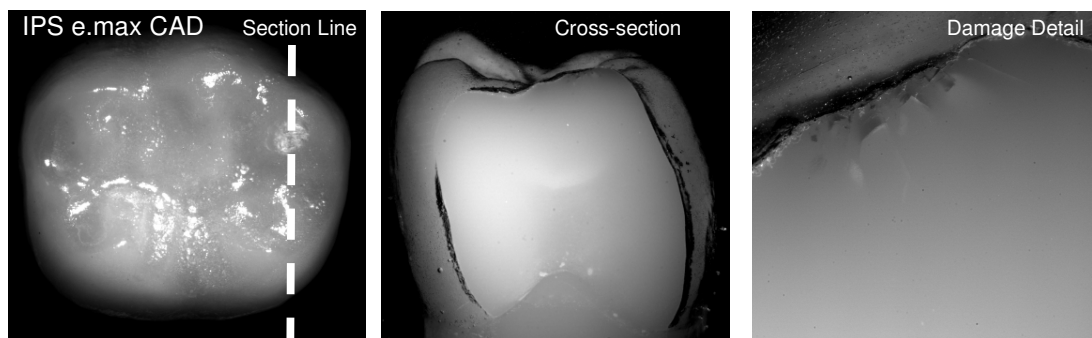
During single load to failure testing IPS e.max CAD crowns showed bulk fractures exposing the resin preparation at a high load level (2576 N, Figure 3). IPS e.max ZirCAD/Ceram crowns revealed fractures limited to the veneering ceramic (1195 N Figure 3).

Figure 3: Single load to failure results and fracture modes (note different failure modes)



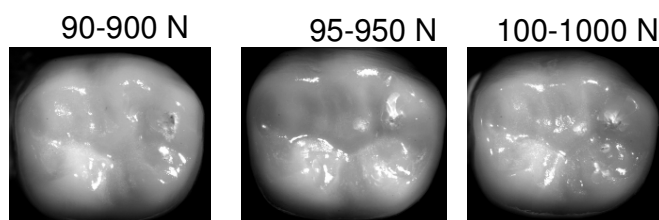
IPS e.max CAD crowns revealed no chip or bulk fractures during mouth-motion step-stress fatigue up to a load level of 900 N. Only superficial surface damage was observed (Figure 4).

Figure 4: Occlusal view (left) and section (middle) of a IPS e.max CAD crown at 900 N load exhibiting only minor occlusal damage (right) at 180K cycles after mouth-motion fatigue.



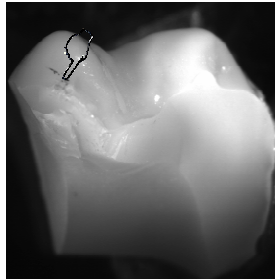
Survival of all IPS e.max CAD mouth motion step-stress fatigue specimens ($n=6$) in the first 3:2:1 distribution grouping resulted in moving to staircase fatigue testing to 1000K cycles. At loads in the range of 900-1000 N cycles no failures at 1000K cycles were observed (Figure 5). Based upon the results of these r ratio fatigued samples ($n=10$) it appeared that fatigue damage had only a minimal effect on the IPS e.max CAD ceramic.

Figure 5: IPS e.max CAD crowns after r ratio 1000K cycles (90-1000 N), no bulk fractures were observed



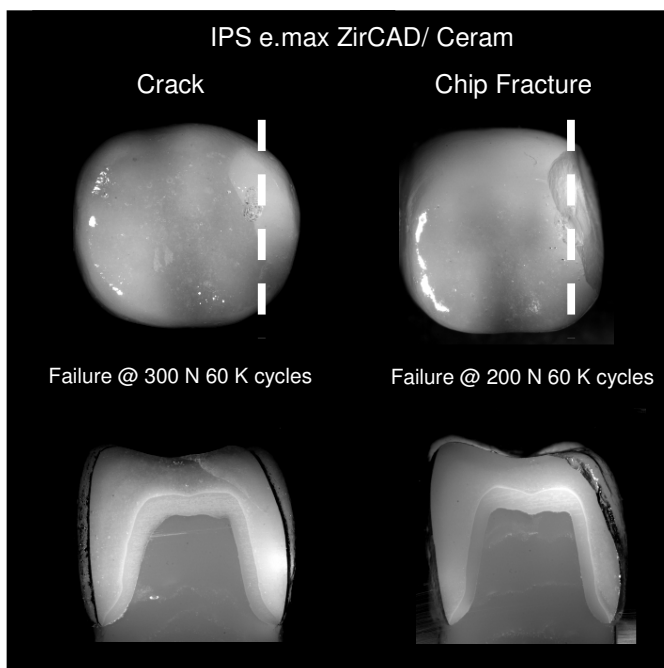
At loads above 1100 N IPS e.max CAD crowns failed by bulk fracture (Figure 6).

Figure 6: IPS e.max CAD crown exhibiting bulk fracture at 800K cycles and r ratio fatigue range of 120-1200 N (black mark/pointer is area of load application).



Hand-layered Y-TZP based crowns (n=18) exhibited a different failure mode during step-stress mouth-motion fatigue compared to monolithic IPS e.max CAD crowns.

Figure 7: Occlusal view (top row) and section (lower row) of IPS e.max ZirCAD/ Ceram crowns exhibiting crack formation (left) and chip fracture (right) after mouth-motion step-stress fatigue

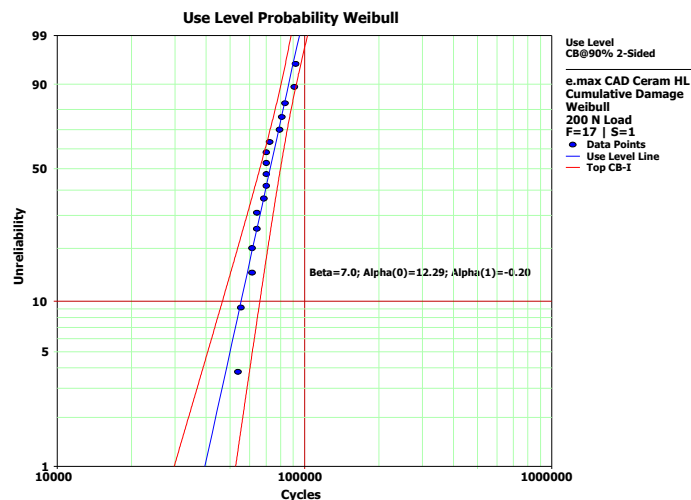


Forty nine percent of the IPS e.max ZirCAD/Ceram crowns revealed crack initiation and propagation before chip-off fractures within the veneering ceramic occurred.

Delamination of the hand-layer veneering ceramic (IPS e.max Ceram) with exposure of the IPS e.max ZirCAD core ceramic could not be observed. None of the IPS e.max ZirCAD/Ceram crown specimens exhibited fractures in the IPS e.max ZirCAD ceramic (Figure 7). The maximum load applied was 500 N.

The hand-layering technique on ZirCAD resulted in limited reliability where at 200 N approximately 90% of the specimens failed by 100K cycles (Figure 8).

Figure 8: IPS e.max ZirCAD/ Ceram unreliability (Weibull distribution) versus time (cycles) at 200 N load



Summary:

- CAD/CAM fabricated monolithic lithium disilicate full crowns (IPS e.max CAD) exhibited no failures at loads of up to 900N and 180,000 cycles in the present standardized crown test model using mouth-motion step-stress fatigue. By contrast the reliability of hand-layering veneered Y-TZP based crowns (IPS e.max ZirCAD/Ceram) would be significantly lower (less than 10% at 200 N and 100,000 cycles).
- IPS e.max CAD crowns survived r ratio fatigue of 1000K cycles at loads of 1000 N. Hence fatigue damage had only minimal effect on the IPS e.max CAD ceramic.
There appears to be a threshold for damage/fracture for monolithic IPS e.max CAD full crowns in the range of 1100-1200 N.
- Improved technology in the manufacturing processes of the IPS e.max CAD ingots, the application of the CAD/CAM fabrication technique as well as the development of a fine-grain lithium disilicate microstructure could be contributing factors for the low fatigue susceptibility of the IPS e.max CAD all-ceramic system in full anatomic crown application.
- In comparison to veneered zirconia systems tested (ZirCAD, LAVA, Cercon, Vita InCeram YZ) under identical conditions, CAD/CAM fabricated monolithic lithium disilicate IPS e.max CAD full crowns are expected to show excellent clinical performance relative to chipping or bulk fracture based upon present fatigue findings. IPS e.max lithium disilicate is the most robust all-ceramic system tested to date. Hence application of this all-ceramic system as a restoration material in implant dentistry seems very promising.
- The reliability of veneered IPS e.max CAD restorations for high aesthetic demands as well as a comparison with the metal ceramic gold standard needs to be explored in future studies.

References:

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