IPS e.max®

Lithium Disilicate

SCIENTIFIC REPORT

Vol. 03 / 2001–2017

Chairside CAD/CAM

ivoclar vivadent®

passion vision innovation


IPS e.max® CAD
HT A2 / I 12
ivoclar vivadent
IPS e.max® CAD
LT A2 / C 16
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MO 1 / C14
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IPS e.max®
Lithium Disilicate (LS_2)

in vivo studies
in vitro studies

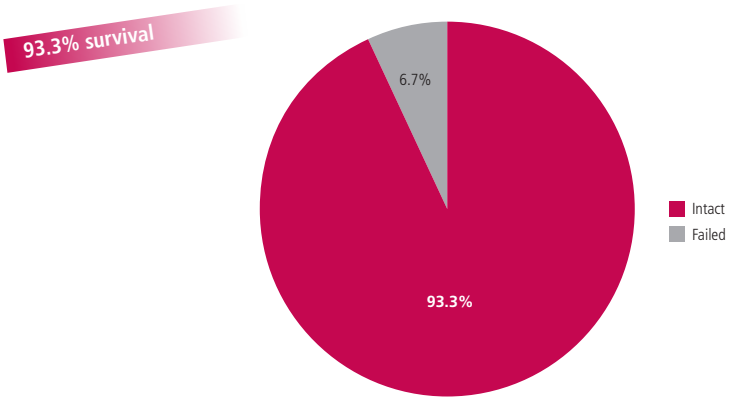
in vivo Studies

Clinical evaluation of a glass ceramic material for chairside CAD/CAM crowns

Study location: School of Dentistry, University of Michigan, Ann Arbor, USA
Study time period: 10 years and 7 years / 2006–2017
Study author(s): D. Fasbinder, G. Neiva, D. Heys, R. Heys

Method:
A longitudinal clinical trial was conducted to assess the performance of monolithic, chairside CAD/CAM fabricated lithium disilicate crowns. 100 IPS e.max CAD crowns were placed in the premolars or molars of 55 patients by one clinician at one-appointment sittings: 62 single IPS e.max CAD crowns were placed in 43 patients from 2006 to 2007 and these restorations could be evaluated over a ten-year period. An extra group of 38 crowns was added to the study in 2009 – for which the 7-year recall has been conducted. This involved an additional 12 patients and some of the original group received a second crown. The first 62 crowns were cemented with the self-etching bonding agent Multilink Automix (n=23) or an experimental self-adhesive cement (n=39). The extra 38 crowns were all cemented with SpeedCem. Two independent evaluators scored the crowns at placement using modified USPHS criteria for various characteristics.

Results:



Clinical performance of chairside IPS e.max CAD crowns after up to 10 years

Summary:
There was an 84% (52/62) recall rate after 10 years for the first group of crowns and 100% (38/38) for the second group. 90 of 100 crowns could be evaluated overall. Mild sensitivity was reported in 15% of the teeth at week 1 but all cases had resolved after 4 weeks and no treatment was required. Two crowns required replacement due to fracture. There was no chipping reported, however one other crown presented with a linear craze line fracture that did not require replacement. Four crowns debonded after 3 years, 3 with the experimental cement and one with Multilink Automix – however all could be re-cemented with Multilink Automix and have remained functional. A further crown debonded after 9 years which had to be replaced as the patient lost it. The diagram depicts the survived (n=84) and failed (n=6) crowns as calculated from the pooled 10 year and 7 year data groups. Failed referring to crowns that required replacement due to fracture (n=2), root canal failure (n=1), core/pin fracture (n=1), secondary caries (n=1), missing crown after decementation (n=1).

Conclusion:
Only 2 crowns fractured requiring replacement, The IPS e.max CAD crowns performed exceptionally well up to 10 years of clinical service.

Reference: Fasbinder et al. (2010), Fasbinder et al. (2017a)

Long-term clinical performance of chairside fabricated IPS e.max CAD LT crowns: 10-year results

Study location: Universität Leipzig, Leipzig, Germany
Study time period: 10 years / 2006/2007–2017
Study author(s): A. Rauch, S. Reich, L. Dalchau, O. Schierz

Method:

Between June 2006 and February 2007 forty-one posterior (31 molars and 10 premolars) full contour lithium disilicate (IPS e.max CAD LT) crowns were placed in 34 patients using a chairside CAD/CAM technique. Thirteen patients were male and 21 female, with an average age of 46.5 years. Twenty teeth were successfully endodontically treated before insertion. Crowns were luted with Multilink Sprint/Ivoclar Vivadent and were evaluated according to modified USPHS criteria at baseline and after 6, 12, 24, 36, 48, 60, 72 and 120 months. Clinical characteristics were rated from A1=1, A2=2, B=3, C=4, D=5 relating to Excellent, Good, Sufficient, Insufficient, Poor respectively.

Results:

86.6% survival *in situ*

Percentage of crowns rated excellent or good after 10 years in situ

Summary:

After 10 years, 33 crowns (80% of the original 41 crowns) could be evaluated in 26 patients. The survival rate *in situ* was reported as 86.6%. Five failures occurred over the time period, involving one crown-fracture at 2 years, an apical infection and a carious lesion under a core build up at 6 years, a lengthwise root fracture at 7 years and a new crown at 10 years due to a carious lesion. When further complications such as decementation were included in the calculation, the survival rate reduced to 76.3% after ten years. As shown in the diagram, the surface of the restorations, colour, crown margin, tooth integrity, crown integrity and compliance (how positively the patient rated the overall treatment experience), were all rated excellent or good.

Conclusion:

Chairside crowns made of IPS e.max CAD LT proved clinically efficient over a period of 10 years and can be recommended. The survival rate (86.6%) was comparable to that recorded with other ceramic materials after ten years.

Reference: Rauch et al. (2017)

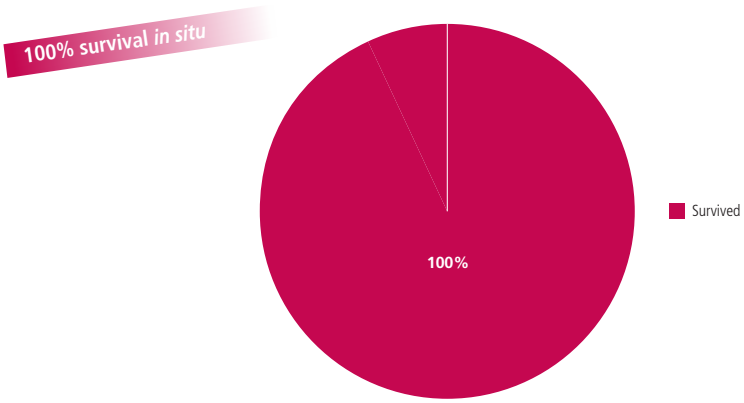
in vivo Studies

8 years' clinical behaviour of adhesively luted all-ceramic single-unit restorations

Study location: Ivoclar Vivadent AG, Schaan, Liechtenstein
Study time period: 8 years / 2007–2016
Study author(s): L. Enggist, A. Peschke, S. Huth, R. Watzke

Method:
Fifty-five single-unit lithium disilicate restorations (IPS e.max CAD / Press) were adhesively luted with Multilink Automix. 33 crowns, 13 partial coverage crowns and 9 inlays were placed by two operators. After a mean observation-time of 7.9 years in clinical function, 49 restorations could be assessed according to selected FDI-criteria.

Results:



Survival of IPS e.max CAD or Press single unit restorations after 8 years

Summary:
Overall, there were 6 drop-outs: 3 patients could no longer be reached, 1 crown fractured because the occlusal minimal thickness was not respected and 2 teeth were extracted due to vertical root fracture or post-endodontic failure. Of the 49 assessed restorations, the longest period in situ was 9 years and 1 month and the shortest was 7 years and 2 months.

After 7.9 years all of the restorations remained in situ, and most exhibited "excellent" to "good" clinical performance. 17% of the total length of all margins showed slight discoloration (FDA grade 2) and 16% of the margins showed minor irregularities.

Conclusion:
After almost eight years of clinical service, most IPS e.max CAD / Press restorations (cemented with Multilink Automix), exhibited outstanding clinical performance.

Reference: Peschke et al. (2013), Enggist et al. (2016)

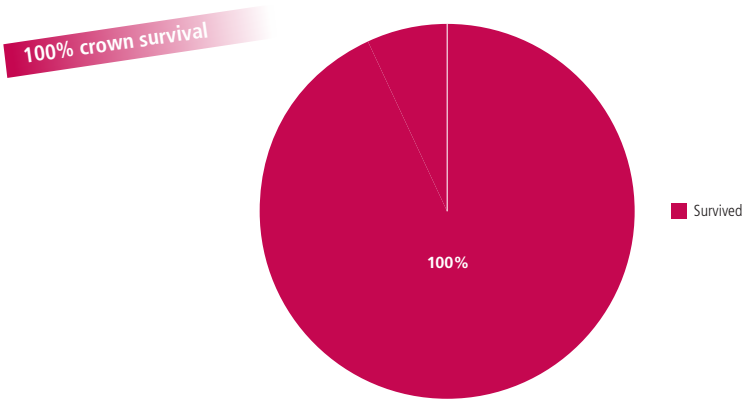
CAD/CAM-fabricated, ceramic, implant-supported single crowns made from lithium disilicate: Final results of a 5-year prospective cohort study

Study location: Department of prosthetic dentistry, University of Freiburg, Germany
Study time period: 5 years / 2017
Study author(s): B. C. Spies, S. Pieralli, K. Vath, R-J. Kohal

Method:

24 patients were included in a study, to evaluate the clinical and patient-reported outcomes of monolithic IPS e.max CAD (LT) crowns on zirconia-implants. All participants received a one-piece ceramic implant in the anterior (n=4) and posterior regions (n= 20). Lithium disilicate crowns were then adhesively luted to the implants using Multilink Automix. Evaluations were carried out at recalls every year for 5 years. Crowns were evaluated as regards survival and clinical performance using modified USPHS criteria. Clinically relevant defects that were repairable intraorally were accepted for survival. Restorations graded alpha or bravo were also considered successful.

Results:



Clinical performance of IPS e.max CAD crowns on zirconia implants after 5 years

Summary:

22 implant supported crowns could be investigated after 55.2 +/- 4.2 months. Two patients dropped out due to death/ moving away. No failures were observed. The survival rate was 100%, however as 2 crowns had to be re-polished (rated Charlie) due to major roughness issues, the Kaplan Meier success rate was calculated as 92%. All the crowns were rated Alpha or Beta for fracture (just one minor chipping = beta), marginal integrity, contour, esthetics and marginal discoloration.

Conclusion:

After 5 years, no implant-supported IPS e.max CAD LT restoration needed to be replaced, resulting in a survival rate of 100%. The Kaplan Meier success rate was calculated as 92%.

Reference: Spies et al. (2017)

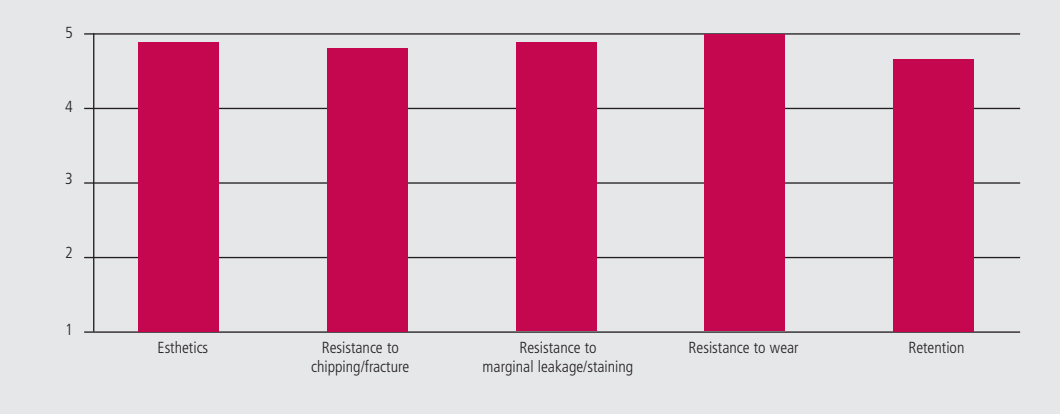
in vivo Studies

IPS e.max CAD: 5 year clinical performance

Study location: The Dental Advisor, Biomaterials Research Center, Ann Arbor, Michigan, USA
Study time period: 5 years / 2006–2015
Study author(s): The Dental Advisor

Method:
To establish the long-term clinical performance of IPS e.max CAD, 1079 IPS e.max CAD restorations were placed between June 2006 and August 2015. Recall data was available for 758 restorations, of which 734 were crowns, 15 inlays and 9 onlays. Overall 48% of the restorations were in service up to 3 years, 30% between 3 and 5 years and 22% were in service for 5 years or more.

Results:



Results for 5-year (or longer) recalled IPS e.max CAD restorations

Summary:
At the 5 year recall, various clinically relevant attributes as shown above, were measured on a scale of 1-5 (1=poor, 2=fair, 3= good, 4= very good, 5= excellent). Esthetics: 96% of the IPS e.max CAD restorations received an excellent rating for esthetics. Chipping/Fracture: 95% received an excellent rating. Two percent of the restorations chipped but did not require replacement. Four crowns fractured and were replaced one of which was due to bruxism. Marginal discoloration: 96% had no visible marginal discolorations and were rated excellent. Wear resistance: No replacements were necessary. Retention: 11 restorations debonded and were recemented – this was not deemed to be due to any particular cement.

Conclusion:
IPS e.max CAD offers excellent esthetics and wear resistance and was rated highly for resistance to chipping/fracture and resistance to microleakage and staining. Retention was excellent and no wear was reported for any restoration. IPS e.max CAD received a clinical performance rating of 98% at 5 years.

Reference: The Dental Advisor (2016)

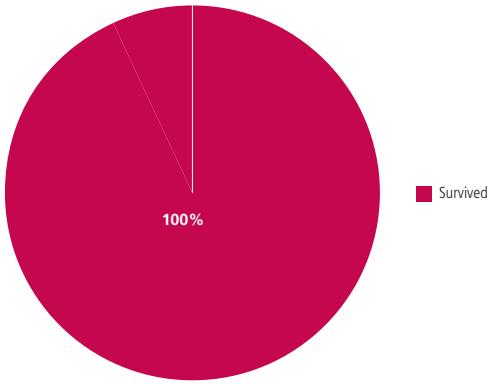
Clinical efficiency of CAD/CAM-fabricated lithium disilicate restorations: 4-year report

Study location: Ludwig Maximillian University (LMU), Munich, Germany
Study time period: 4 years / 2007–2011
Study author(s): F. Beuer

Method:
A total of 38 fully anatomical and partially reduced IPS e.max CAD restorations were fabricated using KaVo Everest (36 crowns, 2 anterior bridges) and veneered with IPS e.max Ceram. The restorations were self-adhesively cemented with Multilink Sprint or adhesively cemented with Multilink Automix.

Results:

100% survival



Clinical performance of IPS e.max CAD crowns and bridges after 4 years

Summary:
No restorative failures were reported, after a mean observation period of 4 years.

Conclusion:
Crowns and anterior bridges made of IPS e.max CAD, proved their clinical efficiency over a period of 4 years.

Reference: Richter et al. (2009), Beuer (2011a)

in vivo Studies

Three-unit CAD-CAM-fabricated lithium disilicate bridges after a mean observation period of 46 months

Study location: Multi-center study in Berlin, Buchholz i. d. Nordheide, Zwickau and Aachen, Germany, under the direction of the RWTH Aachen, Germany

Study time period: 4 years / 2008–2012

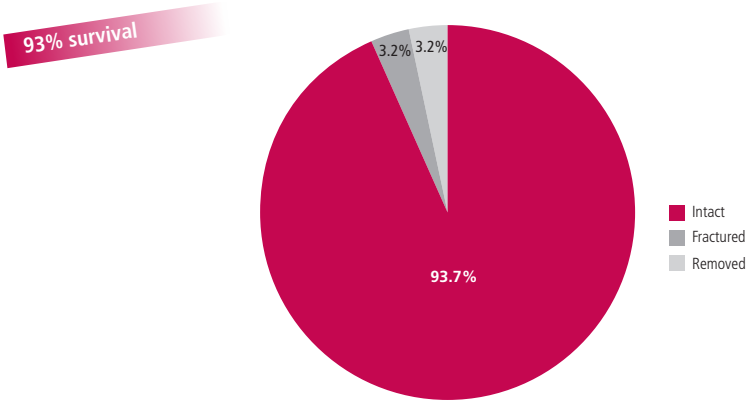
Study author(s): S. Reich, L. Endres, C. Weber, K. Wiedhahn, P. Neumann, O. Schneider, N. Rafai, S. Wolfart

Method:

A total of 38 three-unit bridges, for seating no further back than the second premolar as the last abutment tooth, were fabricated from IPS e.max CAD LT and placed in 33 patients. Fifteen bridges were layered with IPS e.max Ceram after cut-back. Twelve bridges were fabricated chairside. Cementation was performed with Multilink Automix.

Results:

For patients who received more than one bridge, only one bridge was selected at random for evaluation. One female patient also did not appear for the recall because she had moved away. Thus after 48 months, 32 bridges in 32 patients could be evaluated. Two bridges were rated as failures. One of them had fractured in the connector area and the other had to be removed due to unexplained, continuous pain. Two minor cases of repairable chipping were observed after 3 years. Furthermore, three endodontic complications occurred in two bridges after 1.3 and 1.6 years (one of these bridges was removed after 3 years, as described above, due to pain). The survival rate according to Kaplan-Meier was 93%.



Clinical performance of IPS e.max CAD crowns after a mean observation period of 46 months

Summary:

Only one fracture was reported after a mean observation period of 46 months. This fracture occurred within one year after placement and was caused by failing to observe the recommended connector dimensions.

Conclusion:

Bridges made of IPS e.max CAD up to the 2nd bicuspid proved their clinical efficacy over a period of approximately 4 years.

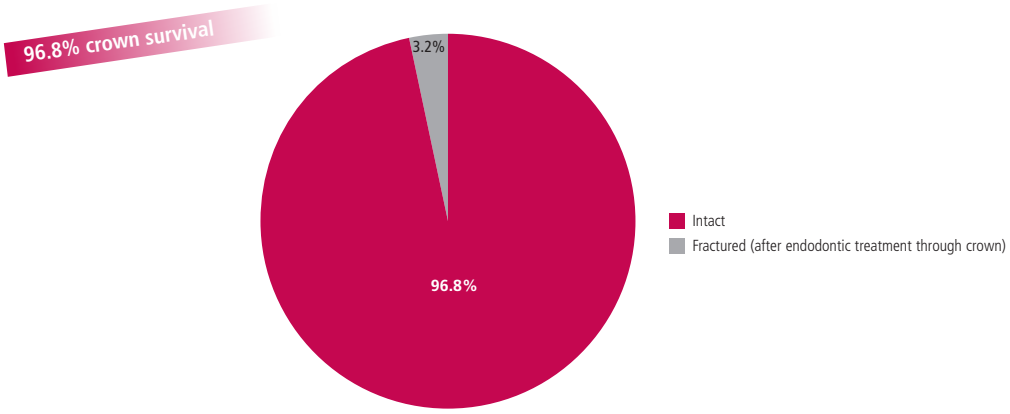
Reference: Reich et al. (2014)

Clinical efficiency and accuracy of fit of milled ceramic crowns

Study location: Boston University, Boston, USA
Study time period: 3 years / 2005–2008
Study author(s): D. Nathanson

Method:
Thirty-one IPS e.max CAD crowns (23 anterior and 8 posterior crowns) were placed in 14 patients by two operators. The restorations were veneered with IPS e.max Ceram and cemented using Multilink or Multilink Automix. Marginal accuracy and clinical performance was assessed at the time of placement and thereafter at 6 months and at yearly recalls.

Results:



Clinical performance of IPS e.max CAD crowns after 3 years

Summary:
Clinical fit was ranked alpha for all restorations. Three anterior single crowns required re-fabrication for improved colour. 17 restorations (55% of total) were evaluated at 2–3 years. One (posterior) restoration fractured after requiring a root canal through the crown after 12 months.

Conclusion:
After an observation period of up to 3 years, only one crown fractured after endodontic treatment through the crown. No other adverse findings were noted throughout the recall process. Crowns made of IPS e.max CAD proved their clinical efficiency over a period of 3 years.

Reference: Nathanson (2008)

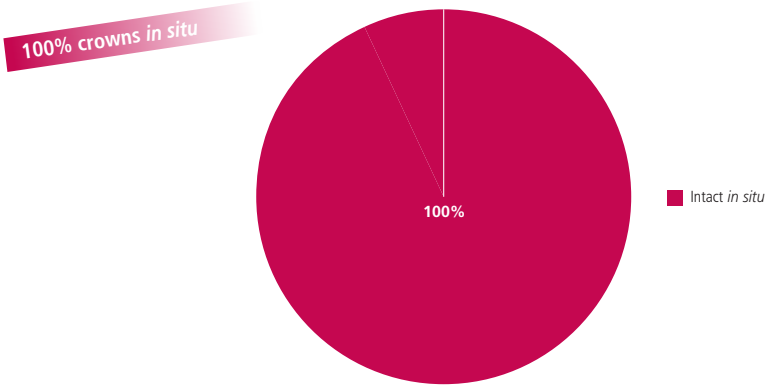
in vivo Studies

Survival rate and clinical quality of CAD/CAM fabricated posterior crowns made of lithium disilicate ceramic. A prospective clinical study.

Study location: University of Zurich, Zurich, Switzerland
Study time period: 3 years / 2007–2011
Study author(s): A. Bindl

Method:
In order to establish the survival rate and clinical quality of self-adhesively luted lithium disilicate CAD/CAM crowns, 42 IPS e.max CAD LT monolithic crowns were placed in 37 patients. Recalls were carried out after 1, 2 and 3 years. At the 3-year recall, 37 crowns in 31 patients could be investigated. Crowns were evaluated according to USPHS criteria.

Results:



Clinical performance of IPS e.max CAD crowns after a mean observation period of 46 months

Summary:
At the follow-up examination after 2 years, 37 crowns were evaluated. Neither fractures nor chipping had occurred, but one crown was affected by decementation. The crown was fully intact and was re-cemented using Multilink Automix. This crown appears amongst the 37 crowns evaluated as part of the 3 year recall – explaining the 100% in situ situation at 3 years. After 3 years all the crowns were evaluated Alpha or Bravo for crown integrity, marginal adaptation, anatomical form, occlusal contact, changes to sensitivity, secondary caries, surface characteristics. With regard to colour, one crown was rated Charlie as it was too light and also due to tooth migration of a neighbouring tooth one crown was rated Charlie regarding approximal contacts.

Conclusion:
Posterior crowns made of IPS e.max CAD proved their clinical efficiency over a period of 3 years.

Reference: Bindl (2011), Bindl (2012)

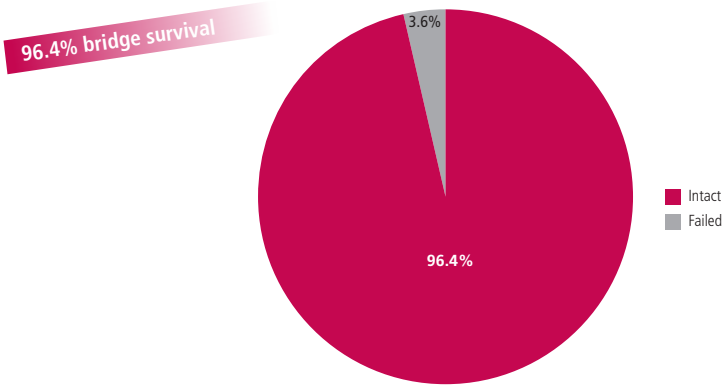
Clinical evaluation of chairside CAD/CAM lithium disilicate fixed partial dentures: 2-year report

Study location: University of Michigan School of Dentistry, Michigan, USA
Study time period: 2 years / 2017
Study author(s): D. J. Fasbinder, G. Neiva, D. Heys, R. Heys

Method:

A longitudinal clinical trial was conducted to assess the performance of chairside fabricated IPS e.max CAD bridges. Patients had a missing premolar or anterior tooth that was appropriate for replacement with a fixed partial denture (FPD)/bridge. Patients received one 3-unit bridge only, which included just one missing tooth. The second premolar was the most distal missing tooth acceptable for inclusion in the study. Abutment teeth had a healthy periodontal status and were asymptomatic prior to treatment. Endodontically treated teeth were acceptable for one of the abutments. Two clinicians placed 30 IPS e.max CAD bridges in 30 patients. Scans were carried out chairside. The digital impression was used in the CEREC 4.3 software program/Dentsply Sirona, for the full contour design of the FPD. The designed FPD was milled in a MCX milling unit/Dentsply Sirona and crystallized in the Programat CS2. The bridges were cemented using Multilink Automix. Clinical evaluation using modified USPHS criteria was carried out at baseline, six months, one year and two years.

Results:



Percentage of intact (n=27) and failed FPDs (n=1) after 2 years

Summary:

After two years, 2 patients could not be contacted and were assigned as drop-outs. One bridge failed after 2 years due to extensive recurrent caries associated with health and medication issues causing xerostomia. The overall survival rate (27/28) was therefore 96.4%. Mild sensitivity was reported in 6 patients after the first week, which had all resolved by 4 weeks. The USPHS scores were overwhelmingly Alpha for all FPDs.

Conclusion:

After 2 years, the survival rate of chairside-fabricated IPS e.max CAD bridges was 96.4% with no structural complications of the material recorded.

Reference: Fasbinder et al. (2017b)

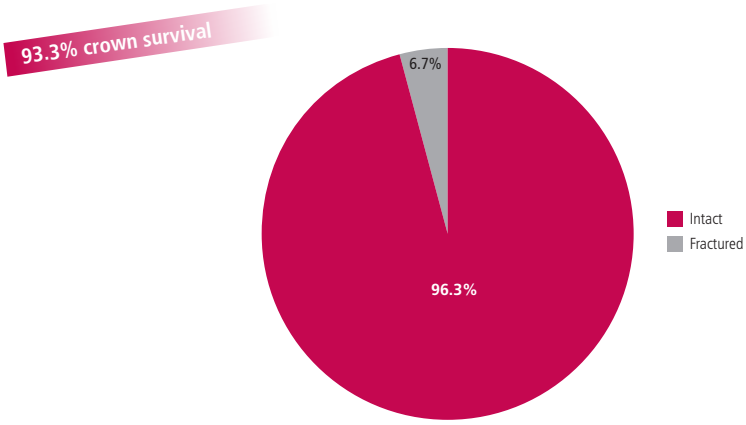
in vivo Studies

Clinical study on IPS e.max CAD posterior crowns

Study location: Pacific Dental Institute, Portland, USA
Study time period: 2 years / 2006–2009
Study author(s): J.A. Sorensen, R. Trotman, K. Yokoyama

Method:
Thirty IPS e.max CAD crowns were veneered with IPS e.max Ceram and placed in 27 patients using an adhesive cementation protocol with Multilink.

Results:



Clinical performance of IPS e.max CAD crowns after 2 years

Summary:
After an observation period of 2 years, two crowns had fractured.

Conclusion:
Lithium disilicate crowns made of IPS e.max CAD proved their clinical efficiency over a period of 2 years.

Reference: Sorensen et al. (2009b)

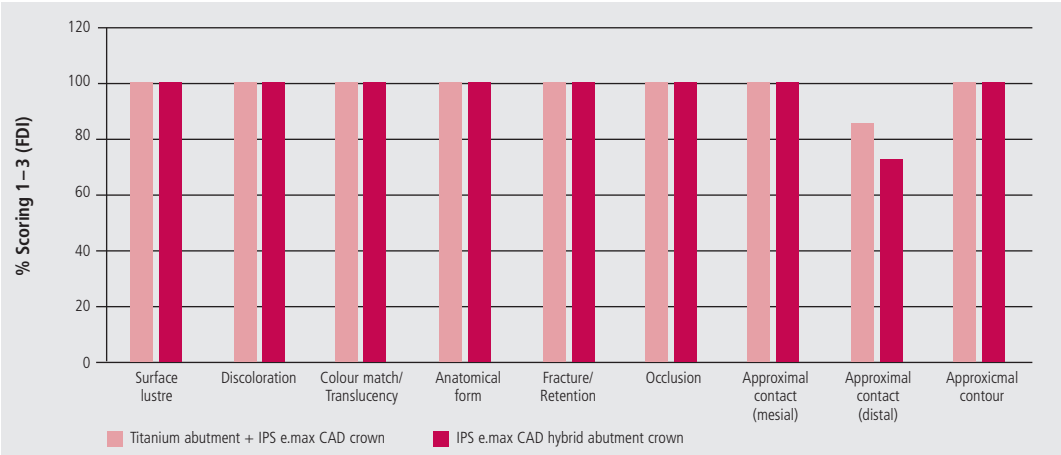
Prospective randomized controlled study of monolithic, chairside, implant-supported crowns made of CAD/CAM lithium disilicate: Baseline Report

Study location: Clinic for dental prosthetics, University Clinic Aachen, Germany
Study time period: Baseline / 2017
Study author(s): S. Reich, S. Wolfart

Method:

In order to evaluate the long-term performance of one-piece hybrid-abutment-crowns for implants, 41 patients received 57 implants/restorations - either a monolithic IPS e.max CAD hybrid abutment crown (Group E/n= 29) or an individualized titanium abutment with a cemented IPS e.max CAD crown (Group A/n=28). The latter group served as a control. 27 patients received 1 implant (A or E), 12 patients received 2 implants (A + E) and 2 patients received 3 implants (A + E + E). The choice of implant type was randomized in each group. FDI grading was used for the clinical evaluation with grades 1-3 considered clinically satisfactory or better.

Results:



Percentage of (Titanium abutment + IPS e.max CAD crown vs. IPS e.max CAD hybrid abutment crown) restorations scoring 1 – 3 (clinically satisfactory) according to FDI criteria, for various characteristics

Summary:

Patient satisfaction, the condition of the peri-implant tissues and the clinical performance of the implant superstructure are to be evaluated. At the baseline stage, patients' satisfaction after the treatment showed no real difference between the IPS e.max CAD hybrid abutment crown group or the titanium abutment plus IPS e.max CAD crown group in terms of perceived strain of the treatment, expectations, satisfaction with the esthetics, colour or form, chewing and speaking. With regard to peri-implant tissues, no significant group differences were noted. The baseline clinical evaluation according to FDI criteria shown in the graph above indicated a clinically satisfactory situation in both groups for all characteristics except distal approximal contacts (in both Group A and E), where in some cases the contacts were slightly too wide.

Conclusion:

At baseline the monolithic, chairside IPS e.max CAD hybrid abutment crown, exhibited similar characteristics to an individualized titanium abutment with a cemented IPS e.max CAD crown.

Reference: Reich et al. (2017)

in vitro Studies

Fracture toughness of five CAD/CAM glass-ceramics

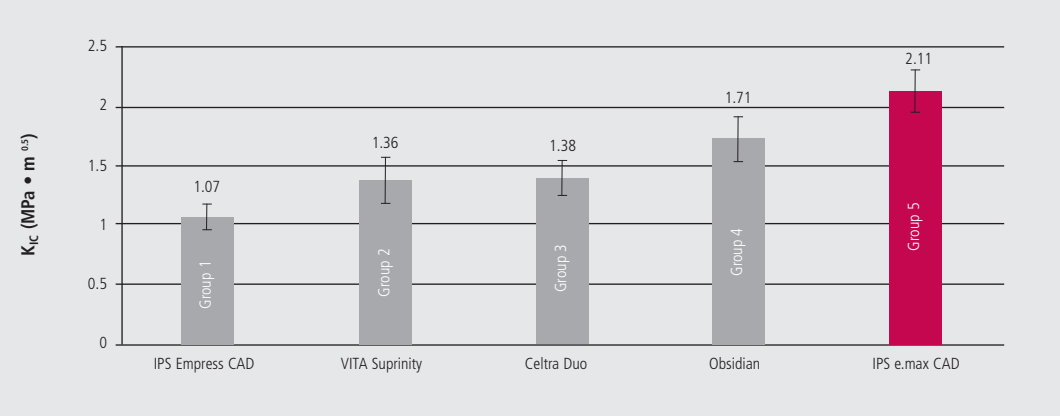
Study location: Ivoclar Vivadent, Amherst NY, USA.
Study time period: 2016
Study author(s): T. Hill, G. Tysowsky

Method:
Using the V-notched beam test, the fracture toughness (K_{IC}) of five commercially available CAD/CAM glass-ceramics was tested. The glass-ceramic materials (n=8) included: Group 1: IPS Empress CAD/Ivoclar Vivadent (leucite), Group 2: VITA Suprinity/Vita (lithium silicate), Group 3: Celtra Duo/Dentsply Sirona (lithium silicate/lithium disilicate), Group 4: Obsidian/Glidewell Dental (lithium silicate), and Group 5: IPS e.max CAD/Ivoclar Vivadent (lithium disilicate). Each material was sectioned into bars (3 mm x 4 mm x 17 mm) using an IsoMet saw. Group 1 was fired using a glaze cycle, groups 2–5 were fired according to the manufacturer's instructions. An initial V-notch was cut into the bars at a depth of 0.5–0.7 mm, using an Amann diamond saw at low speed with copious amounts of water. The V-notch was finished to a depth of between 0.9–1.1 mm, using a razor blade and 6, 3, 1µm diamond paste. After cleaning in an ethanol bath for 10 minutes, the specimens were loaded to failure in a three-point testing fixture (span-15 mm) at a crosshead speed of 0.5 mm/min in an Instron testing machine. Notch depths were measured at three evenly spaced points, using a microscope at 50x magnification. The average and relative depth lengths were calculated and checked that the maximum and minimum values did not vary by more than 0.1mm. The pre-cracked beam method was used to calculate fracture toughness (KIC). Pf is failure load; s is span; t is thickness; w is width; and a is average V-notch depth:

$$K_{IC} = g * [(P_f * Sx10^{-6})/(t * w^{3/2})] * [(3(a/w)^{1/2})/(2(1-a/w)^{3/2})]$$

$$g \text{ is } \{1.99-[(a/w)(1-a/w)]*[2.15-3.93(a/w)+2.7*(a/w)^2]\}/[1+2(a/w)]$$

Results:



Fracture toughness (K_{IC}) of five different glass ceramics

Summary:
Fracture toughness is inherent to a material and can be used to predict other properties such as strength. For the materials examined, fracture toughness increased with increased crystal volume fraction for the lithia based materials. A statistical difference was found between all the groups except Groups 2 and 3.

Conclusion:
IPS e.max CAD exhibited the highest fracture toughness.

Reference: Hill et al. (2016)

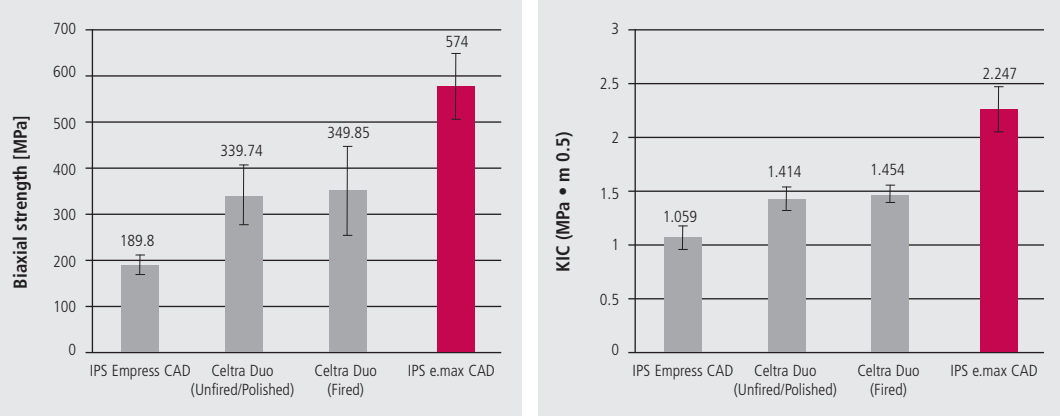
Evaluation of biaxial flexural strength and fracture toughness of a zirconia – reinforced dental ceramic

Study location: College of Dental Medicine, Columbia University, New York, USA/Ivoclar Vivadent, Amherst, New York, USA
Study time period: 2017
Study author(s): W. Randi, A. Randi, T. Hill

Method:

The study compared the biaxial strength and fracture toughness of the lithium disilicate material IPS e.max CAD, the leucite reinforced glass ceramic IPS Empress CAD and the zirconia reinforced lithium disilicate Celtra Duo (fired and unfired/polished)/Dentsply Sirona. 14 disc samples of each material were prepared for biaxial flexural strength testing and 15 of each for the fracture toughness tests. For the biaxial tests, discs radius (12 – 16 mm) and thickness (1.2 mm +/- 0.2 mm) were prepared and polished (30 um grit) according to ISO 6872:2015(E). The specimens were broken over three concentrically supporting balls with the load applied to the centre of the test piece. The single edge V-notched beam method was used for fracture toughness, following ISO 6872:2015(E) guidelines. Bars (3 mm x 4 mm x 17 mm) were fabricated and prepared with a V-notch ranging from 0.8 – 1.2 mm using a razor blade with diamond paste. V-notch depth measurements were made after specimens were fractured using a stereomicroscope. Fracture toughness was calculated using the same formula as detailed in the previous study by Hill et al. (2016).

Results:



Biaxial strength and fracture toughness of various dental ceramics

Summary:

Lithium disilicate (IPS e.max CAD) met the ISO standard recommendation of a minimum fracture toughness of 2.0 for single unit crowns with a value of 2.247 in this study. IPS e.max CAD exhibited the highest biaxial strength and fracture toughness values.

Conclusion:

IPS e.max CAD exhibited significantly higher biaxial strength and fracture toughness values compared to the other materials. There was little difference between the fired and unfired-polished Celtra Duo material and no clinical advantages for zirconia reinforced lithium disilicate over lithium disilicate were found.

Reference: Randi et al. (2017)

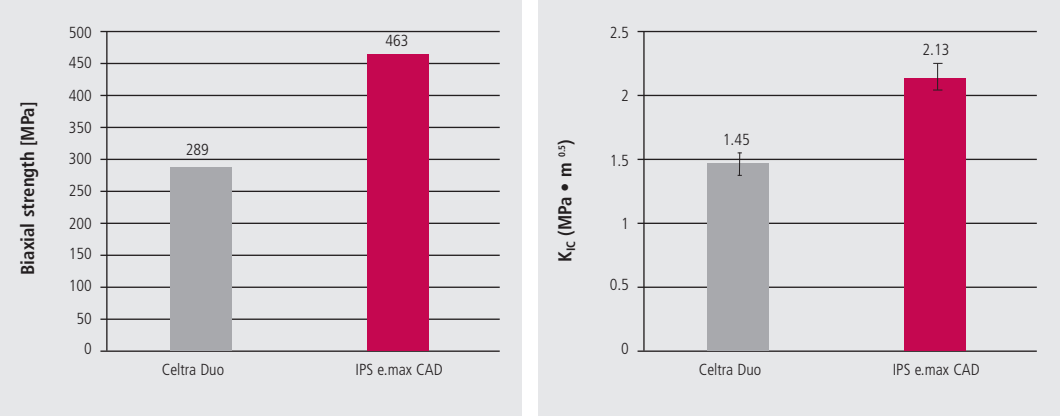
in vitro Studies

Biaxial strength and fracture toughness of IPS e.max CAD and Celtra Duo glass-ceramics

Study location: New York College of Dentistry, New York, USA.
Study time period: 2017
Study author(s): Y. Zhang

Method:
Five samples each of IPS e.max CAD/Ivoclar Vivadent (lithium disilicate) and Celtra Duo/Dentsply Sirona (lithium silicate/lithium disilicate) were tested. Biaxial flexural strength tests were carried out using a piston on 3-ball apparatus. The single-edged V-notched beam method (SEVNB), was used to test fracture toughness (K_{IC}), with each material sectioned into bars (3mm x 4mm x 17mm) using an IsoMet saw. Specimens were polished and an initial V-notch was cut into the bars. Specimens were then loaded to failure in a three-point testing fixture. Notch/pre-crack lengths were measured with optical and scanning electron microscopes.

Results:



Biaxial flexural strength (left) and fracture toughness (right) of two different glass ceramics

Summary:
IPS e.max CAD exhibited higher biaxial strength than Celtra Duo at 463 MPa compared to 289 MPa, and also significantly higher fracture toughness.

Conclusion:
IPS e.max CAD exhibited higher biaxial strength and fracture toughness than Celtra Duo – mainly due to the higher crystalline content of IPS e.max CAD relative to Celtra Duo.

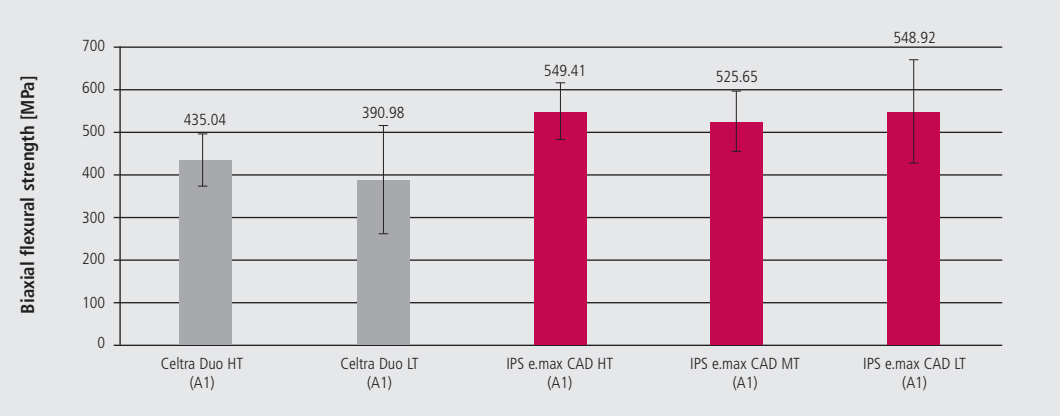
Reference: Zhang (2017/2018), Zhang (2017)

Mechanical characteristics of a zirconia-reinforced lithium silicate CAD/CAM restorative material

Study location: Department of Prosthodontics, Louisiana State University, New Orleans, USA
Study time period: 2017
Study author(s): K. Vu

Method:
Specimens of IPS e.max CAD and Celtra Duo/Dentsply Sirona were sectioned from their CAD/CAM blocs via section saw. Specimens were fired according to manufacturer-instructions then fixed to a metal cylinder whereupon the testing surface was smoothed and polished. The flexural strength and flexural modulus were calculated using the piston on 3-balls configuration according to the ISO standard 6870. Both products were tested in shade A1 and in high and low translucency (HT, LT) for Celtra Duo and high, medium and low translucency (HT, MT, LT) for IPS e.max CAD – creating five (n=10) study groups.

Results:



Biaxial flexural strength of Celtra Duo and IPS e.max CAD in shade A1 with different translucencies

Summary:
The flexural strength of IPS e.max CAD exceeded 500 MPa for all translucencies and was significantly higher than that of Celtra Duo. The two translucencies of Celtra Duo exhibited greater variation in flexural strength than the three translucencies of IPS e.max CAD.

Conclusion:
The flexural strength of IPS e.max CAD exceeded that of Celtra Duo for all translucencies.

Reference: Vu (2017)

in vitro Studies

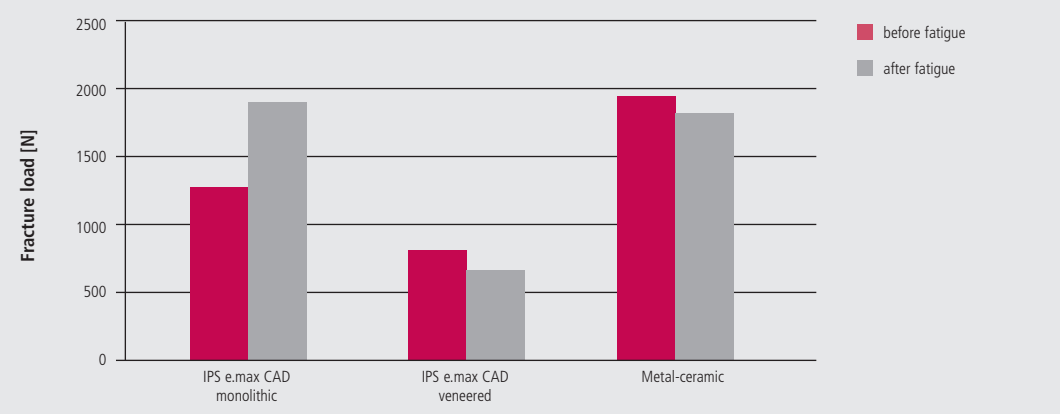
Monolithic and veneered CAD/CAM lithium disilicate bridges vs. metal-ceramic: Comparison of the fracture load values and failure modes upon fatigue

Study location: University Clinic, Freiburg im Breisgau, Germany
Study time period: 2012
Study author(s): S. Schultheis, J.R. Strub, T.A. Gerds, P.C. Guess

Method:

A total of 96 extracted human molars and premolars were divided into 3 groups. Full-contour bridges were milled from IPS e.max CAD using CEREC/Dentsply Sirona and either cemented as a monolithic restoration or manually veneered. Metal-ceramic bridges were used as a control group. The fracture load was determined before and after fatigue tests.

Results:



Mean fracture load of monolithic or veneered bridges made of IPS e.max CAD – compared to metal-ceramic after fatigue testing

Summary:

All bridges survived the fatigue test. Veneered bridges made of IPS e.max CAD fractured at lower forces than monolithic bridges made of IPS e.max CAD, which achieved fracture loads comparable to metal-ceramic. Bridges made of IPS e.max CAD fractured in the connector area. Chipping was not observed in the lithium disilicate bridges, while this was the only type of failure in metal-ceramic bridges.

Conclusion:

Monolithic bridges made of IPS e.max CAD tolerate loads comparable to those of bridges made of metal-ceramic – the gold standard.

Reference: Schultheis et al. (2013)

Monolithic CAD/CAM lithium disilicate compared to veneered Y-TZP crowns: Comparison of the failure types and reliability after fatigue

Study location: New York University, New York, USA
Study time period: 2010
Study author(s): P.C. Guess, R.A. Zavanelli, N.R.F.A. Silva, E.A. Bonfante, P.G. Coelho, V.P. Thompson

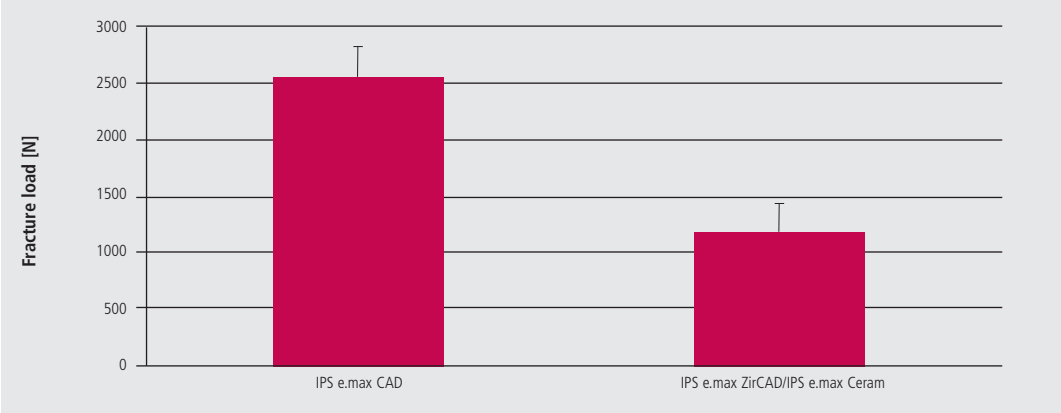
Method:

The fatigue behaviour and reliability of monolithic IPS e.max CAD crowns were investigated.

Method I: 19 fully anatomical crowns were constructed and milled with a CAD/CAM system. The crowns were etched with 5% hydrofluoric acid for 20 seconds, silanated with Monobond Plus, and adhesively cemented onto aged, dentin-type composite dies using Multilink Automix. The test specimens were stored in water for at least seven days prior to the fatigue tests. During the fatigue tests, the crowns were subjected to a tungsten carbide piston that moved from the disto-buccal cusp 0.7 mm in the lingual direction in order to simulate occlusal movements. Three different stress levels were used, with the highest load amounting to 1000 N. After the tests, the crowns were inspected for damage under a stereo microscope with polarized light.

Method II: In the second part of the investigation, the crowns were subjected to a "staircase r ratio fatigue" stress test involving 1 million cycles. The loads varied from 90 to 900 N, 95 to 950 N, 100 to 1000 N and 110 to 1100 N.

Results:



Fracture load of IPS e.max CAD compared to IPS e.max ZirCAD veneered with IPS e.max Ceram

Summary:

Only at rather high forces, did IPS e.max CAD crowns demonstrate fractures with cracks down to the composite die (2576 ± 206 N). In contrast, IPS e.max ZirCAD exhibited fractures exclusively in the IPS e.max Ceram veneering ceramic (1195 ± 221 N).

Conclusion:

Fully anatomical IPS e.max CAD crowns showed to be resistant against fatigue in cyclic fatigue tests. In comparison, crowns made of zirconium oxide failed by fractures in the veneering material at clearly lower loads.

Reference: Guess et al. (2010a)

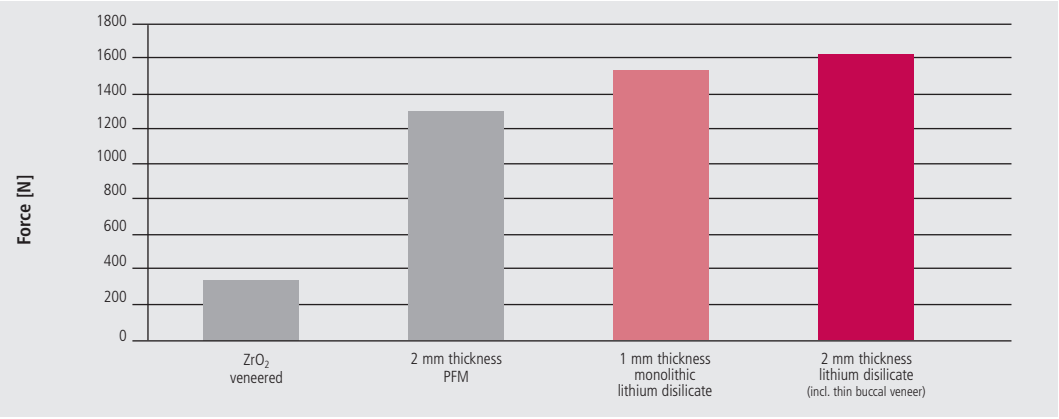
in vitro Studies

Reliability of IPS e.max CAD crowns with thin layer thickness and thinly veneered IPS e.max CAD crowns
Reliability: Crowns with reduced layer thickness and thinly veneered lithium disilicate compared with PFM and Y-TZP crowns

Study location: New York University, New York, USA
Study time period: 2010
Study author(s): N.R.F.A. Silva, V.P. Thompson

Method:
The fatigue behaviour and reliability of monolithic CAD/CAM-fabricated crowns made of IPS e.max CAD were investigated in comparison with veneered crowns made of zirconium oxide (Y-TZP) and conventional porcelain fused to metal-ceramic (PFM). The study included monolithic lithium disilicate crowns with an occlusal thickness of 1 mm and lithium disilicate crowns comprising a 1.5 mm framework plus a thin 0.5 mm buccal veneer i.e. 2 mm thickness overall. Twenty-one crowns per group were constructed, milled with a CAD/CAM system and subsequently glazed. The crowns were adhesively cemented onto an aged, dentin-type composite die using Multilink Automix. The test specimens were stored in water for at least seven days prior to fatigue testing. During the fatigue tests, the crowns were subjected to a tungsten carbide piston that moved from the disto-buccal cusp 0.7 mm in the lingual direction in order to simulate occlusal movements. Three different stress levels were used. After testing, the crowns were inspected for damage under a stereo microscope with polarized light.

Results:



Force upon failure after fatigue testing in masticatory simulator

Summary:
The fracture load of 1 mm monolithic lithium disilicate restorations (IPS e.max CAD) was 1535 N, and 1610 N for 2 mm IPS e.max CAD with a thin veneer. These values are comparable to those of metal-ceramics (1304 N) and higher than those of veneered zirconium oxide (371 N) (see graph). The fractures observed were complete fractures for IPS e.max CAD and chipping for the two other materials. The IPS e.max CAD material was most reliable.

Conclusion:
In this investigation, IPS e.max CAD crowns exhibited values comparable to those of the gold standard – metal-ceramics.

Reference: Martins et al. (2011)

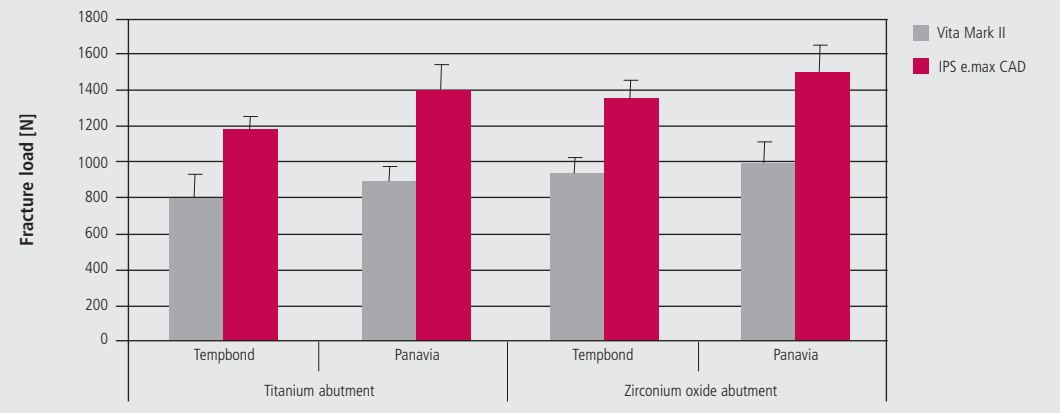
Compressive strength, fatigue and fracture load of implant-retained ceramic crowns

Study location: Ain Sham University, Cairo, Egypt/University of Toronto, Toronto, Canada
Study time period: 2010
Study author(s): A. El-Dimeery, T. Salah, A. Hamdy, O. El-Mowafy, A. Fenton

Method:

A total of 64 implant replicas were divided into 8 groups. Various ceramic materials (VITA Mark II/Vita, IPS e.max CAD), various abutment materials (titanium, zirconium oxide), as well as different cementation materials (Temp-Bond/Kerr Dental, Panavia/Kuraray Noritake) were compared. Molar crowns were cemented to the implant replicas and stored in water at 37°C for 24 hours, before an underwater fatigue test at 55–550 N for 500,000 cycles was conducted. The surviving test specimens were subjected to fracture testing.

Results:



Fracture load of implant-retained crowns made of IPS e.max CAD or Vita Mark II on titanium or zirconium oxide abutments

Summary:

During the fatigue test, two Vita Mark II crowns fractured (1 on a titanium abutment, 1 on a zirconium abutment, both of which were cemented with Temp-Bond). All the other test specimens survived. IPS e.max CAD crowns exhibited higher fracture load values than Vita Mark II in all groups.

Conclusion:

The groups with the IPS e.max CAD crowns achieved statistically significantly higher fracture load values than the groups with Vita Mark II crowns.

Reference: El-Dimeery et al. (2011)

Biocompatibility Definition of Terms Literature

BIOCOMPATIBILITY

Biocompatibility can be defined as the ability of a substance/material to be in contact with a living system without producing an adverse effect. Tests indicate the reactivity or tolerance of cells (often mouse fibroblasts) to soluble compounds of a material. Biocompatibility tests may include in vitro investigations (conducted in artificial environments such as petri/cell culture dishes) such as cytotoxicity, mutagenicity, irritation and sensitivity tests. These tests are useful but have limited significance. Only in vivo investigations (performed in the living organism) i.e. clinical experience, can provide a final and definitive evaluation of biocompatibility.

In order to minimize biocompatibility risks from the outset, Ivoclar Vivadent strives to use well-established raw materials that have already proven safe in vivo – in the development of new products.

The biocompatibility of lithium disilicate glass-ceramic and zirconium oxide has been assessed on the basis of toxicity data from various institutes, plus data found in literature. In these tests, neither lithium disilicate nor zirconium oxide showed excessive solubility, cytotoxicity, genotoxicity or any significant radioactivity.

Chemical durability/solubility

Ceramic materials are highly resistant to acid and corrosion attacks and are therefore regarded as exceptionally biocompatible. The conditions found in the oral cavity (pH and temperature changes) are also not extreme enough to dissolve components from dental ceramics. The standard ISO 6872 prescribes guidelines for chemical solubility testing.

Lithium disilicate

The chemical solubility of IPS e.max lithium disilicate (IPS e.max Press and IPS e.max CAD) was evaluated according to ISO 6872. The values found were clearly below the limit of 100 µg/cm^2. An analysis of ions (dissolved in artificial saliva and acetic acid) from IPS e.max Press and IPS e.max CAD specimens demonstrated a low ion content. Concentrations were in the same range as those of other dental ceramics.

Zirconium oxide

IPS e.max ZirCAD blocks, discs and colouring liquids were similarly tested for chemical solubility according to ISO 6872. All values were also well below the limit of 100 µg/cm^2.

Cytotoxicity

Cytotoxicity refers to the capability of a substance to damage cells. The XTT assay is used to determine whether or not the substance being investigated inhibits cell proliferation or even causes cell death. The resulting XTT_{50} value refers to the concentration of a substance sufficient to reduce the cell number by half. Numerous tests were carried out on both lithium disilicate and zirconium oxide and neither showed cytotoxic potential.

Lithium disilicate

- RCC Report In vitro cytotoxicity test evaluation of materials for medical devices (direct cell contact assay) CCR Project 571100 (28 October 1996)*
- RCC Report In vitro cytotoxicity test evaluation of materials for medical devices (direct cell contact assay) CCR Project 590001 (24 June 1997) *
- RCC Report In vitro cytotoxicity test evaluation of materials for medical devices (direct cell contact assay) CCR Project 590002 (24 June 1997) *
- RCC Report Cytotoxicity Assay in vitro: Evaluation of materials for Medical Devices) RCC-devices with e.max Press (XTT Test) RCC-CCR study number 1165602 (March 2008) *
- NIOM; Test Rep.; #012/04 (4 March 2004) *
- NIOM; Test Rep.; #004/04 (4 February 2004) *
- Grall, F. Toxicon Final GLP Report: 10-1251-G1. Agar Diffusion Test – ISO. April 2010. *

Zirconium oxide

In a "worst case" testing scenario, the in vitro cytotoxicity of the MT O (bleach) discs (immersed in various colouring liquids) was evaluated. None of the samples possessed any cytotoxic potential:

- Roth M. Cytotoxicity assay *in vitro* (XTT-Test). Envigo Report No. 1716001. 2015. *
- Roth M. Cytotoxicity assay *in vitro* (XTT-Test). Envigo Report No. 1716007. 2015. *
- Roth M. Cytotoxicity assay *in vitro* (XTT-Test). Envigo Report No. 1716005. 2015. *
- Roth M. Cytotoxicity assay *in vitro* (XTT-Test). Envigo Report No. 1716003. 2015. *
- Roth M. Cytotoxicity assay *in vitro* (XTT-Test). Envigo Report No. 1734305. 2016. *
- Roth M. Cytotoxicity assay *in vitro* (XTT-Test). Envigo Report No. 1734303. 2016. *
- Roth M. Cytotoxicity assay *in vitro* (XTT-Test). Envigo Report No. 1734301. 2016. *

The *in-vitro* cytotoxicity of the pre-shaded discs: IPS e.max ZirCAD MO4 and IPS e.max ZirCAD MO2, was also examined via XTT test. No cytotoxic potential was determined:

- Meurer K. Cytotoxicity assay in vitro: Evaluation of materials for medical devices (XTT-test). RCC-CCR Report No. 1015500. 2006. *
- Heppenheimer A. Cytotoxicity assay *in vitro*: Evaluation of materials for medical devices (XTT-Test). RCC-CCR Report No. 1120101. 2007. *

Genotoxicity

Genotoxicity refers to the capability of substances or external influences to damage or alter the genetic materials of cells. Ames tests were carried out with lithium disilicate and (deeply coloured) zirconium oxide samples. Neither material showed mutagenicity.

Lithium disilicate

- RCC Report Salmonella Typhimurium and Escherichia Coli Reverse Mutation Assay with e.max Press (Ames Test) RCC – CCR study number 1165601 (May 2008)
- Devaki S, Toxikon Final GLP Report: 10-1251-G3: Salmonella typhimurium and Escherichia coli reverse mutation assay – ISO. April 2010.

Zirconium oxide

- Sokolowski A. Salmonella typhimurium and Escherichia coli reverse mutation assay. Envigo Report No. 1716009. 2015. *
- Sokolowski A. Salmonella typhimurium and Escherichia coli reverse mutation assay. Envigo Report No. 1716015. 2015. *
- Sokolowski A. Salmonella typhimurium and Escherichia coli reverse mutation assay. Envigo Report No. 1716013. 2015. *
- Sokolowski A. Salmonella typhimurium and Escherichia coli reverse mutation assay. Envigo Report No. 1716011. 2015. *
- Sokolowski A. Salmonella typhimurium and Escherichia coli reverse mutation assay. Envigo Report No. 1734313. 2016. *
- Sokolowski A. Salmonella typhimurium and Escherichia coli reverse mutation assay. Envigo Report No. 1734315. 2016. *
- Sokolowski A. Salmonella typhimurium and Escherichia coli reverse mutation assay. Envigo Report No. 1734317. 2016. *

Radioactivity

The standards EN ISO 6872, EN ISO 9693 and IS13356 forbid the use of radioactive additives and stipulate the maximum level of radioactivity permissible in ceramic materials. Tests are made for minute levels of thorium or uranium which may be present in raw materials or pigments. Radioactivity levels in lithium dislocate and zirconium oxide were all far below the allowable threshold of 1Bq/g (ISO 6872).

Lithium disilicate

- Laugs O. Activity measurement of the nuclides 232Th and 238U in dental ceramic with Pulver e.max Press Multi A3.5. Forschungszentrum Jülich. 2014. *
- Küppers G. Activity measurement of the nuclides 232Th and 238U in dental ceramic with IPS e.max CAD MO4. Forschungszentrum Jülich. 2013. *
- Küppers G. Activity measurement of the nuclides 232Th and 238U in dental ceramic with IPS e.max CAD HT C4. Forschungszentrum Jülich. 2013. *
- Küppers G. Activity measurement of the nuclides 232Th and 238U in dental ceramic with IPS e.max CAD LT D4. Forschungszentrum Jülich. 2013. *

Zirconium oxide

- Küppers G. Activity measurement of the nuclides 232Th and 238U in dental ceramic with EAM591. Forschungszentrum Jülich. 2006. *
- Laugs O. Activity measurement of the nuclides 232Th and 238U in dental ceramic with Probe 1298-1 PU ZirCAD LT. Forschungszentrum Jülich Report No. 17-10064. 2017. *
- Laugs O. Activity measurement of the nuclides 232Th and 238U in dental ceramic with Probe 1298-2 PU ZirCAD Schneide. Forschungszentrum Jülich Report No. 17-10065. 2017. *

Conclusion

The IPS e.max lithium disilicate and zirconium oxide ceramics were examined for their toxicological potential with regard to their use as medical products. Dental ceramics are generally known and accepted as highly biocompatible, numerous studies were conducted which confirm this. In addition, the scientific literature and a decade plus of clinical use are testament to the safety of these materials.

It can be concluded that the IPS e.max ceramics pose no health hazard if used correctly, and the benefits of their use outweigh any residual risk.

* Reports of investigations commissioned by Ivoclar Vivadent AG are not published or for distribution

Studies

Studies are conducted to forecast or examine the behaviour of materials when used for the intended application. Aspects of functionality, reliability, safety, compatibility or user-friendliness are often of most interest.

- ***In vitro* studies**
  In vitro means "in glass". These examinations are conducted in a laboratory outside of their normal biological context. Many materials science or toxicological tests are carried out *in vitro*, since they cannot be conducted on human beings for practical or ethical reasons. Moreover *in vitro* studies have the advantage that researchers can work under standardized conditions – plus they are often quicker and less expensive than *in vivo* studies

- ***In vivo* studies**
  In vivo means "in the living object". Such studies are carried out within the biological context i.e. in human beings. The advantage is that results are more meaningful as the investigations are conducted under real conditions. They are however complex due to a wealth of possible influencing factors. They require exact planning, systematic methods and statistically correct evaluation. Randomized controlled studies are considered the gold standard.

- **Prospective study**
  A study planned to be conducted in the future in order to test a certain hypothesis, such as material A is as good as material B. After preparation of a test plan, the patients are recruited and the material used. The test subjects are observed over a certain period of time and the results are subsequently evaluated.

- **Retrospective study**
  Analysis of data collected in the past. For example - all cases of bridge fractures that occurred in a dental office are examined to find out if the fractures happen more frequently with one material than with another.

Clinical Evaluation Techniques for Restorations

Cvar and Ryge/USPHS Criteria

(Cvar & Ryge 1971 and 2005)

Cvar and Ryge developed their much used measurement scale over 40 years ago. This method of evaluation is i nterchangeably referred to as Cvar & Ryge criteria, Ryge criteria or USPHS criteria. The criteria were drawn up for evaluating amalgam or resin based direct restorations. Various authors modified the criteria as restoratives improved over time in terms of longevity. These are referred to as modified Ryge or modified USPHS criteria. The criteria used the Alpha, Bravo, Charlie, Delta evaluation scale. These scores have different meanings depending on the criteria being assessed however in general: Alpha = excellent/optimal, Bravo = acceptable, Charlie = unacceptable/insufficient and Delta = needs replacing.

Hickel/FDI Criteria

(Hickel et al, 2007 and 2010)

Hickel et al as part of the FDI World Dental Federation Science Committee, published a paper in 2007 outlining a proposal for a more modern clinical evaluation of both direct and indirect restorations. They present evaluation criteria related to the original Ryge criteria. These are evaluated as follows: Score 1 = Excellent, Score 2 = Very good but not ideal, Score 3 = Sufficient with minor shortcomings, Score 4 = Unacceptable but repairable, Score 5 = Unacceptable and needs replacing. Hickel et al compare their scoring system with Cvar and Ryge as follows:

Cvar & Ryge	Hickel/FDI
Alpha	Scores 1 & 2
Bravo	Score 3
Charlie	Score 4
Delta	Score 5

In 2010 a number of changes and improvements to the 2007 guidelines were added.

Mechanical properties and in vitro tests

In materials science, there are numerous test methods to determine the mechanical properties of materials. The object of mechanical testing in dentistry, is to make estimates about the clinical efficacy of a material. However, standard test methods frequently test isolated stress conditions, whereas the effects on a material are much more complex in clinical reality. Nevertheless materials science examinations in the laboratory do permit the comparison of different materials when tested in exactly the same way.

Fracture Load

The fracture load indicates the value at which a component fractures. Values are mostly indicated in N (Newton).

Flexural Strength

The flexural strength indicates the flexural stress value that, when exceeded, causes the test specimen to fracture. There are several different methods to determine the flexural strength. Examples of frequently used methods are the biaxial strength (disc-shaped test specimens), 3-point flexural strength, 4-point flexural strength (bar-shaped test specimens). Flexural strength is highly dependent on the measuring method used and the surface texture e.g. polished or ground. Data can only be compared if the methodology is the same. The strength is indicated in MPa (megapascal).

Fracture Toughness

Fracture toughness (K_{IC}) is a unit of measure for the ability of a material to resist crack propagation. K_{IC}, which is also called stress intensity factor or crack toughness, is the critical value at which a catastrophic failure of the component occurs and the stored energy is released in the form of new surfaces, heat and kinetic energy. Various methods can be used to determine the fracture toughness of a material. Similarly to flexural strength values, results of individual measurements can only be compared if the same methods of measurement are used. Typical methods are described briefly below.

IF (Indentation Fracture) method

After the samples have been prepared, different loads are applied to them with a Vickers hardness tester to produce indentation patterns on the surfaces of the samples. The cracks that have formed at the corners of the indentations are measured in an optical microscope. The fracture toughness is calculated as a function of the length of the cracks measured, the indentation load applied and characteristic values of the material (modulus of elasticity, hardness). The material may appear anisotropic under the microscope, depending on the size, shape and orientation of the crystals.

IS (Indentation Strength) method

After the samples have been prepared, different loads are applied to them with a Vickers hardness tester to produce indentation patterns on the surfaces of the samples. Subsequently, the samples are subjected to a strength test (3-point, 4-point or biaxial flexural strength). The fracture toughness is calculated as a function of the strength value measured, the indentation load applied and the characteristic values of the material (modulus of elasticity, hardness).

SEVNB (Single Edge V-Notched Beam) method

Once the specimens are prepared, a defined notch is placed by means of a diamond bur, razor blade and polishing paste. The test specimens are then subjected to a strength test. The KIC value is calculated in accordance with ISO 6872:2008.

Hardness

The hardness of a material is the resistance of a material to the penetration by another body. Various methods can be used to determine hardness, such as Vickers, Knoop, Brinell and Rockwell. In the Vickers method, for example, the surface of a material is loaded with a fine point in the form of a pyramid. The deeper the point penetrates, the less hard the material is considered to be. When indicating hardness, the corresponding method and ideally the load and duration of the load application, should be indicated. Values can only be compared when the method is identical.

Modulus of elasticity

The modulus of elasticity describes the stiffness of the material, that is, its resistance against elastic (temporary) deformation when a stress is applied. The stiffer the material the higher the elastic modulus.

Thermocycling / Chewing simulation / Fatigue

During the development of new materials, it is important to determine how susceptible they are to fracture under the expected stress conditions in the oral cavity. In vitro chewing simulation / fatigue tests are often used, as results are available quickly and materials can be tested and compared under standardized conditions. Test specimens are usually adhesively cemented to standardized PMMA dies and subjected to cyclic, eccentric loading with a pointed steel antagonist in a water bath. The load is increased in steps, e.g. 100,000 cycles with approximately 80 N, then 100,000 cycles with approximately 150 N, followed by 100,000 cycles with approximately 220 N (0.8Hz). Test specimens are simultaneously subject to thermocycling of 105 s each at 5°C and 105 s at 55°C. The number of cycles before fracturing or chipping occurs is measured.

Dynamic stress test

In a dynamic fatigue test, the fatigue behaviour of test specimens is tested in a force- or distance-controlled testing machine. In a test of implants and implant superstructures according to ISO 14801, the test specimens are typically subject to 2 million cycles (2 Hz, water at 37°C).

Cohesive/adhesive delamination

Delamination such as chipping is cohesive if the fracture surface is within a material, e.g. within a veneer. In contrast, a fracture is adhesive, if it occurs between two materials, e.g. at the interface between the framework material and veneer.

Weibull theory / Weibull statistics

Compared to other materials, ceramics exhibit special strength behaviour. Ceramic fractures originate from imperfections in the component. The number of imperfections therefore greatly influences strength values, and can cause relatively wide scattering of the measured data. Strength values also depend on the size of the component, i.e. the smaller the component, the fewer imperfections that are present and consequently - the higher the strength. Weibull statistics take these aspects into consideration.

The Weibull modulus "m" makes a statement about the reliability of a material; the higher "m" is, the more reliable the measured strength values (more narrow scattering).

Weibull strength $\sigma_{63.21\%}$

Strength measurements in ceramic materials tend to yield results that scatter widely. Consequently, the Weibull strength $\sigma_{63.21\%}$ value is often utilized. This indicates the load at which 63.21% of all samples of a test series fail . Other terms used for Weibull strength are "characteristic strength" or "mean strength".

Survival Rates

Kaplan-Meier survival rate

The Kaplan-Meier survival rate is used in studies to present and calculate the probability that a certain (mostly undesired) incident does not occur for a test specimen. In studies involving dental ceramics, the incident is most frequently the failure of the restoration. A special characteristic of these survival curves is that they take dropouts into account which depending on the study may mean patients and/or restorations. These are then represented on the Kaplan Meier curve as a sudden drop.

Cementation / Luting

Dental cements or luting agents are materials used for cementing/luting indirect restorations to the remaining tooth structure/core. Both adhesive and non-adhesive materials are available.

Conventional cementation

Zinc phosphate, carboxlate and glass ionomer cements are all conventional materials. Most consist of a powder plus a liquid component, which are manually mixed. Some are available in mixing capsules. The chemical setting process starts immediately after mixing and does not involve additional initiation. No special pre-treatment of the prepared tooth is needed in conjunction with these materials. Usually, the restoration is simply placed as delivered by the dental laboratory. Complete isolation of the prepared tooth is not required. However, a retentive preparation design is necessary which may entail considerable loss of healthy tooth structure. Conventional cements usually have a grey-opaque appearance and, are therefore visible if the cement joint is exposed. Glass-ionomer cements have been further developed to produce a new group of materials known as hybrid cements. In addition to glass-ionomer components, hybrid cements contain monomers, so that both a cement setting reaction and polymer cross-linking occurs to ensure a complete cure. These luting materials feature better mechanical properties but also lack an adhesive bond to the tooth structure.

Adhesive luting composites

Adhesive composite-based luting materials are resins, composed of monomers and inorganic fillers. These materials can establish a sound chemical bond with the dental hard tissues and allow minimally invasive techniques. They are classified into self-curing, light-curing and dual- curing materials. By carefully selecting the pigments and colour additives, tooth-coloured luting composites are not visible if the cement joint is exposed. Enamel and dentin are pre-treated as prescribed by the adhesive luting protocol and the glass-ceramic material to be luted is usually etched with hydrofluoric acid and treated with a silane coupling agent. The clinical success of glass-ceramic restorations would have been unthinkable without composite luting materials.

Self-adhesive luting composites

These combine the advantages of conventional and adhesive luting materials. Although adhesive luting composites have many advantages, their application involves effort (isolation, application of additional steps and products such as dentin adhesives and primers), whereas conventional cements are simpler to use. Self-adhesive luting composites bond, both to the tooth structure and the restorative material, reducing the number of steps involved in their application and so also eliminating potential sources of error.

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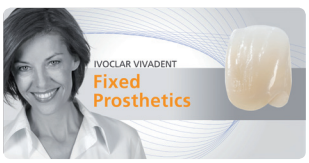

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