IPS e.max®

SCIENTIFIC REPORT

Vol. 01 / 2001 – 2011

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EDITORIAL

The IPS e.max system is an innovative all-ceramic system that comprises lithium disilicate (LS_2) glass-ceramic and zirconium oxide (ZrO_2) materials for the press and CAD/CAM technologies. Additionally, there is a universally applicable nano-fluorapatite glass-ceramic available for veneering all IPS e.max components.

The most prominent element of the IPS e.max system is the patented lithium disilicate (LS_2) glass-ceramic (IPS e.max Press and IPS e.max CAD). It is a glass-ceramic material distinguished from all previous ceramic systems by four specific features:

- **Optical refractive index:** The refractive index of the lithium disilicate crystals is adjusted to that of the glass matrix. Four levels of translucency and unique opalescent shades were achieved with the help of opacifiers and ion colouring.

- **High strength:** A very high crystalline content of approximately 70% can be included in the glass matrix to increase the strength without compromising the translucency. With entirely mature crystallization, the LS_2 glass-ceramic features a flexural strength of 360–400 MPa (according to ISO 6872). This combination enables the fabrication of monolithic restorations with a highly esthetic appearance.

- **Adjusted coefficient of thermal expansion:** With 10.2x 10^{-6}/K, the CTE of the LS_2 glass-ceramic is in the range of that of zirconium oxide (ZrO_2). Hence, it is possible to use only one veneering ceramic, IPS e.max Ceram, for all the required veneers, characterizations and glaze firings, for both the IPS e.max LS_2 glass-ceramic and the IPS e.max ZrO_2. This is a clear advantage today particularly with regard to simplicity, effectiveness and economic efficiency.

- **Innovative processing technology:** Given the processing in its blue intermediate phase by means of the CAD/CAM technology and a subsequent short crystallization procedure, the IPS e.max CAD lithium disilicate (LS_2) glass-ceramic is the innovative all-ceramic material for all CAD/CAM-fabricated single-tooth restorations. The IPS e.max CAD-on technique is the latest development in the field of digital restorations. It combines the advantage of IPS e.max LS_2 and ZrO_2 in an innovative fashion and thus introduces a new generation of restorations in the bridge technique, which inspires users with regard to the combination of user friendliness, speed and overall strength.

Since the beginning of its development until to today, the IPS e.max system has been monitored by the scientific community, and many renowned experts have contributed to an excellent data base with their studies. The worldwide success story, the ever growing demand, as well as approx. 40 million fabricated restorations are testament to the success and the reliability of the system.

More than 20 clinical in vivo studies to date and even more in vitro studies, as well as the continuously rising number of clinical studies involving the e.max system throughout the world show the long-term success in the oral cavities of the patients. This "IPS e.max Scientific Report Vol. 1" is a compilation of the most important results of the studies conducted between 2001 and 2011.

After all, IPS e.max stands for an all-ceramic system that offers an ideal solution for all indications, which not only works from a material standpoint, but is also backed by a wealth of scientific data.

IPS e.max: all-ceramic – all you need

IPS e.max® System – Clinical Performance

Summary of the IPS e.max® System

There are data on the IPS e.max System that cover a period of up to 5 years of clinical use for ZrO_2 and of up to 10 years of clinical use for LS_2.

The survival rates* of IPS e.max Press (6 studies), IPS e.max CAD (6 studies) and IPS e.max ZirCAD (8 studies) were combined and the overall survival rate for the entire system was calculated. A total of 1071 restorations from 20 clinical studies were included. The resulting overall survival rate for the IPS e.max System was 96.8%.

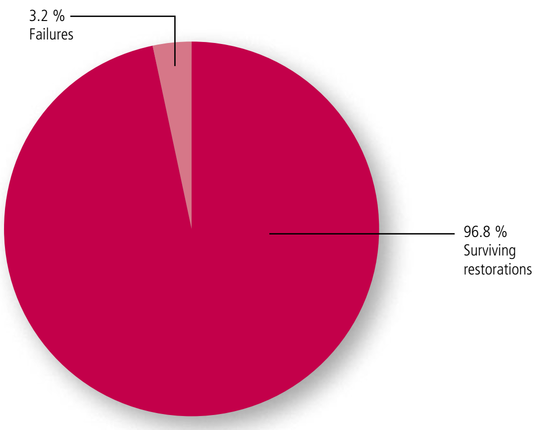

Fig. 1: Summary of the results of 20 clinical studies involving restorations (crowns and bridges) fabricated with IPS e.max materials; the distribution of success cases and failures is presented in per cent.

For more information about the study design and success cases and failures please refer to the detailed descriptions on the following pages of the Scientific Report.

* See Definition of Terms for the definition of survival rate.

Summary of IPS e.max Press

(Lithium disilicate glass-ceramic LS_2)

By now, there are results of clinical studies lasting up to 10 years for IPS e.max Press.

Six clinical studies (Boning et al., 2006; Etman and Woolford, 2010; Guess et al., 2009; Gehrt et al., 2010; Dental Advisor 2010) and an internal Ivoclar Vivadent study with a combined total of 499 restorations (crowns) have shown a survival rate of 98.4% after a mean observation period of 4 years. The failure causes include fracture (0.4%), endodontic failure (0.2%), and secondary caries (0.2%). Moreover, 4 crowns (0.8%) were removed in one study because of crack development. Chipping occurred in 1.4% of the restorations. However, all cases could be repaired in situ. Conventional and adhesive cementation work equally well.

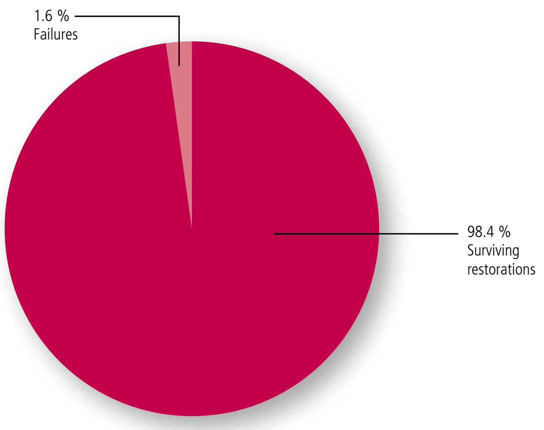

Fig. 2: Summary of the results of 6 clinical studies involving IPS e.max Press restorations (crowns); the distribution of success cases and failures is presented in per cent.

Comparison with the literature:
Systematic reviews of the survival rates of conventional glass-ceramic materials determined fracture rates of 3.8% (Heintze and Rousson, 2010a). The survival rate of metal-ceramic crowns is 95.6% after 5 years (Pjetursson, 2007). Biological or technical failures, such as endodontic failures or chipping, are reported to occur with a frequency of 5 to 10%. With a fracture rate of 0.4% and a survival rate of 98.4%, IPS e.max Press demonstrates a clearly better clinical performance than conventional materials, such as glass- or metal-ceramics.

Summary of IPS e.max CAD

(Lithium disilicate glass-ceramic LS_2)

There are results of clinical studies lasting up to 4 years for IPS e.max CAD.

Six clinical studies (Richter et al., 2009; Nathanson, 2008; Reich et al., 2010; Fasbinder et al., 2010; Bindl, 2011; Sorensen et al., 2009b) with a total of 237 restorations (crowns) showed that 97.9% of the restorations survived after a mean observation period of 2.5 years. The failure rate of 2.1% includes 0.4% irreparable chipping, 0.4% secondary caries and 1.3% fractures. In addition to the above case of irreparable chipping, no further chipping occurred.

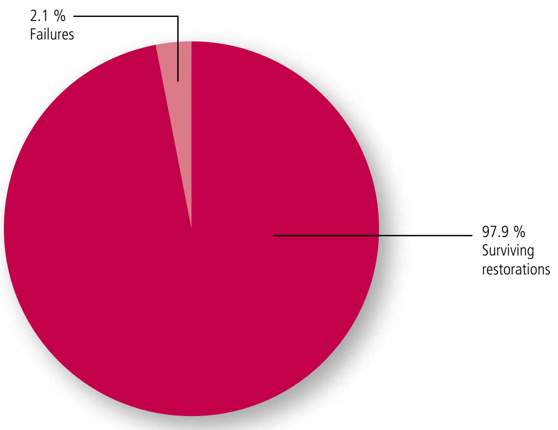

Fig. 3: Summary of the results of 6 clinical studies involving IPS e.max CAD restorations (crowns); the distribution of success cases and failures is presented in per cent.

Comparison with the literature:
All fractures affected restorations in molars. In the literature, fracture rates of 6.7% for molars after 2.5 years can be found (Heintze and Rousson, 2010a) – the fracture rate of IPS e.max CAD molar restorations is 1.0%. With a survival rate of roughly 98% and a fracture rate of only 1.3%, the clinical performance of IPS e.max CAD is also clearly better than that of metal-ceramics and other ceramics (Pjetursson, 2007).

Summary of IPS e.max ZirCAD

(Zirconium oxide ZrO_2)

There are data on IPS e.max ZirCAD that cover a period of up to 5 years of clinical use.

Eight clinical studies (Stanford 2009; Sorensen et al. 2009a; Fasbinder and Dennison 2009; Beuer et al. 2010; Beuer 2011; Tinschert 2008; Christenensen 2008; Munoz 2009; Hicklin et al. 2008) involving a total of 335 restorations (203 crowns, 132 bridges) have shown a survival rate of 93.7%. The failure causes include 2.7% irreparable chipping, 2.4% fractures and 0.9% endodontic failure. Moreover, repeated decementation was rated as failure in one study. Chipping occurred in 12% of the restorations, but required replacement of the restoration in only 2.7% of the cases.

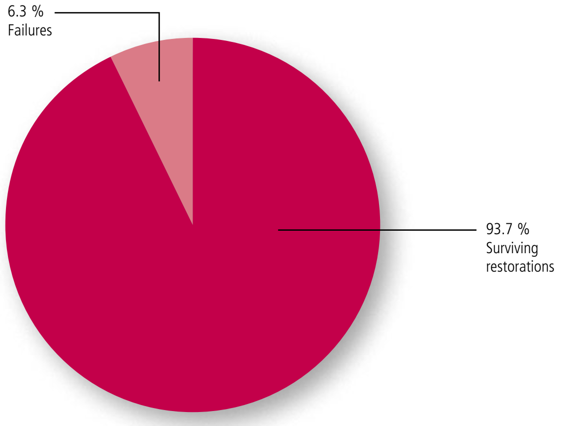

Fig. 4: Summary of the results of 8 clinical studies involving IPS e.max ZirCAD restorations (crowns, bridges); veneered with IPS e.max ZirPress and/or IPS e.max Ceram. The distribution of success cases and failures are presented in per cent.

Comparison with the literature:
Systematic reviews of the survival rate of zirconium oxide restorations determined a fracture rate of less than 1% for three- and four-unit bridges after 3 years (Heintze and Rousson, 2010b) and a survival rate of 94.29% after 5 years (Schley et al., 2010) (i.e. a fracture rate of approximately 6%). Technical complications affected 23.59% of the restorations, whereas chipping represented the most frequent technical problem. Biological complications occurred in 8.28% of all cases.

With roughly 2.4% (or 2.3% for bridges), the fracture rate of IPS e.max ZirCAD is slightly below the value reported in the literature for zirconium oxide bridges (1% after 3 years, approximately 6% after 5 years). Technical and biological complications occurred clearly less frequently with IPS e.max ZirCAD than in the literary references.

Summary of IPS e.max ZirPress

(Fluorapatite glass-ceramic)

There are data on IPS e.max ZirPress that cover a period of up to 3 years of clinical use.

Four clinical studies (Tinschert 2008; Christensen 2008; Hicklin et al. 2008; Fasbinder and Dennison 2009), involving a total of 124 restorations (61 crowns, 63 bridges) made of IPS e.max ZirPress as a veneer on IPS e.max ZirCAD have shown a survival rate of 95.2%. Overall, 4.8% of the restorations were replaced for the following reasons: irreparable chipping 2.4%, fracture 1.6%, endodontic failure 0.8%. Chipping occurred in 19% of the restorations, but was irreparable in only 2.4% of the cases. All other chipping incidents could be repaired in situ by means of polishing or composite.

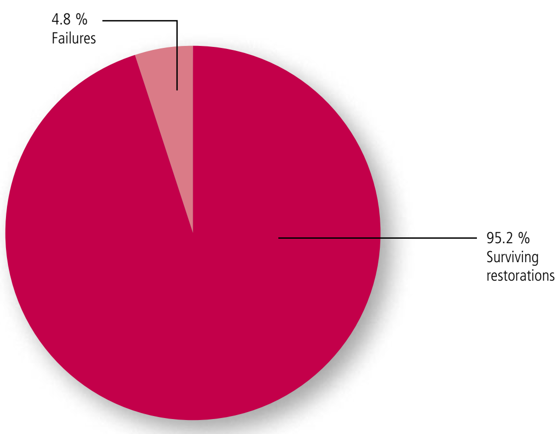

Fig. 5: Summary of the results of 4 clinical studies involving IPS e.max ZirPress on IPS e.max ZirCAD restorations (crowns and bridges); the distribution of success cases and failures is presented in per cent.

Comparison with the literature:
A systematic review showed a survival rate of 90% for zirconium oxide bridges with regard to chipping, which means that chipping occurred in 10% of the restorations. Chipping was non-repairable in 2–5% of the restorations and required replacement of the restoration (Heintze and Rousson, 2010b).
With IPS e.max ZirPress, non-repairable chipping occurs in 2.4% of the restorations, which is at the lower end of the frequency described in the literature.

Summary of IPS e.max Ceram

(Nano-fluorapatite glass-ceramic)

There are data on IPS e.max Ceram that cover a period of up to 4 years of clinical use.

Eight clinical studies (Dental Advisor 2010; Nathanson 2008; Richter et al. 2009; Stanford 2009; Sorensen et al. 2009a; Fasbinder and Dennison 2009; Beuer et al. 2010; Beuer 2011; Hicklin et al. 2008), involving a total of 377 restorations veneered with IPS e.max Ceram have shown a survival rate of 95%. The failures include 2.4% irreparable chipping, 1.9% fracture of the framework (different materials), 0.5% endodontic failure and a decementation rated as failure. Chipping occurred in 5% of the restorations. However, more than half of them could be repaired in situ.

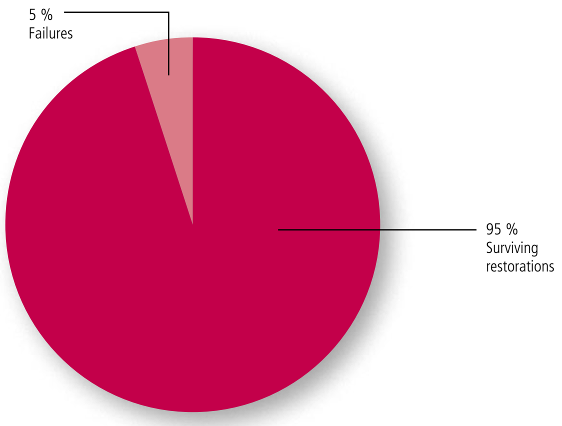

Fig. 6: Summary of the results of 8 clinical studies involving IPS e.max Ceram on IPS e.max ZirCAD or IPS e.max CAD and Crystal Zirconia restorations (crowns and bridges); the distribution of success cases and failures is presented in per cent.

Comparison with the literature:
A systematic review showed a survival rate of 90% for zirconium oxide bridges with regard to chipping, which means that chipping occurred in 10% of the restorations. Chipping was non-repairable in 2–5% of the restorations and required replacement of the restoration (Heintze and Rousson, 2010b).
With IPS e.max Ceram, chipping occurs in 5% of the restorations, thus less frequently than described in the literature. Furthermore, it was non-repairable in only 2.4% of the cases, which is also below the literature data.

IPS e.max®
Lithium Disilicate (LS_2)

in vitro studies
in vivo studies

Title of the study: **Survival rate and fracture resistance of all-ceramic partial crowns with different preparation designs after thermocycling and masticatory simulation**

Place of the study: University Clinic Freiburg, Freiburg i. Br., Germany

Time: 2002, 2006

Author(s): C. Stappert

Method:

The fracture resistance of natural molars with all-ceramic monolithic partial crowns with different preparation designs was determined. Teeth with and without MOD inlay preparation were used as control group. The partial crown preparations included 1 to 4 occlusal cusps (PC-1, PC-2, PC-3, PC-4). The crowns were placed using an adhesive technique (Variolink II). All test specimens were subjected to masticatory simulation and thermocycling (1.2 million cycles, 98 N, 5°/55°C) and subsequently loaded to breaking point in a universal testing machine.

Results:

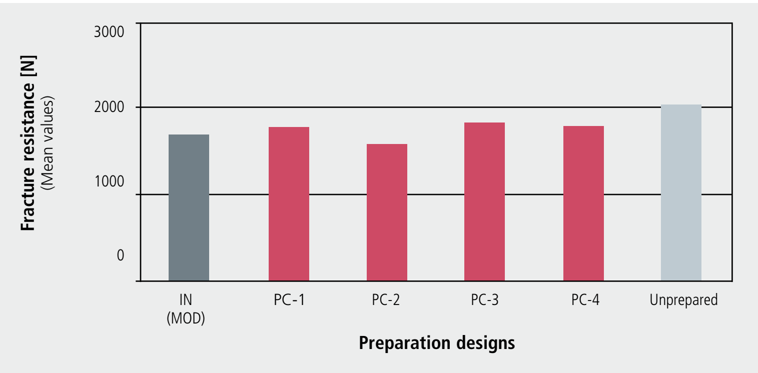

Fig. 7: Fracture resistance of natural molars in conjunction with partial crowns prepared according to various preparation designs

Summary:

All specimens achieved a 100% in vitro survival rate in the masticatory simulator. Irrespective of the size of the ceramic IPS e.max LS_2 restoration, the fracture resistance measured in the posterior region did not significantly differ from that of natural, unprepared teeth.

Reference:

(Stappert et al., 2002; Stappert et al., 2006)

Title of the study: **All-ceramic partial coverage premolar restorations. Cavity preparation design, reliability and fracture resistance after fatigue**

Place of the study: University Clinic Freiburg, Freiburg i. Br., Germany

Time: 2005

Author(s): C. Stappert

Method:

In natural upper premolars, the effect of various preparation designs and layer thicknesses on the fatigue behaviour and fracture resistance was determined in all-ceramic partial crowns and veneers made of IPS e.max Press. Teeth with and without MOD inlay preparation were used as control groups. The partial crowns were adhesively cemented (Variolink II). All test specimens were subjected to masticatory simulation and thermocycling (1.2 million cycles, 49 N, 5°/55°C) and subsequently loaded to breaking point in a universal testing machine.

The following preparation designs were tested (N=16 per design version):
- Unprepared teeth
- MOD inlays
- Partial crowns with the palatal cusp reduced by 2.0 mm, 1.0 mm and 0.5 mm.
- Partial crowns with the palatal (pal.) and vestibular (vest.) cusp reduced by 2.0 mm, 1.0 mm and 0.5 mm.
- Full veneers: Reduction of the entire masticatory surface and veneer preparation of the facial segment
  - Occlusal layer thickness 2.0 mm / facial segment 0.8 mm
  - Occlusal layer thickness 1.0 mm / facial segment 0.6 mm
  - Occlusal layer thickness 0.5 mm / facial segment 0.4 mm

Results:

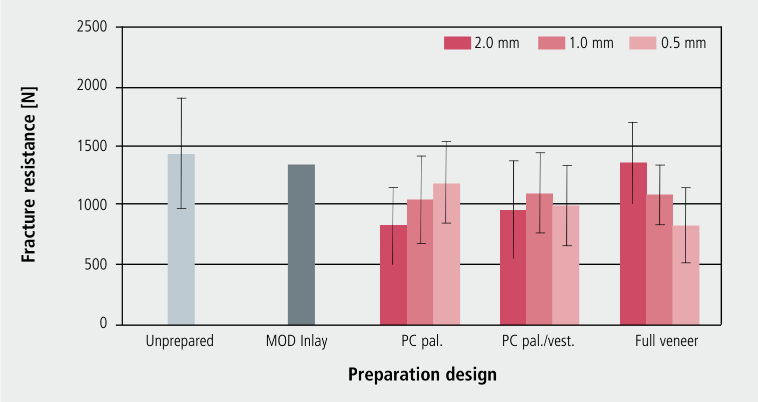

Fig. 8: Mean fracture resistance in upper premolars in conjunction with partial crowns and full veneers with various preparation designs after masticatory simulation

Summary:

- The survival rate after more than 1.2 million cycles in the mastication simulator is 100% for all the partial premolar crowns tested.
- The fracture resistance of the partial palatal crowns (PC pal.) did not significantly differ from that of the partial crowns for which the entire occlusal surface was reduced (PC pal./vest.) .
- The fracture resistance of MOD inlay preparations, as well as full veneers with an occlusal layer thickness of 2.0 mm and a facial segment of 0.8 mm does not significantly differ from that of unprepared natural premolars.
- In crowns with palatal reduction and premolar crowns in which the whole occlusal surface had been reduced (PC pal./vest.), the layer thickness did not significantly influence the fracture load.

Reference:

(Stappert, 2005)

Title of the study: **Monolithic CAD/CAM lithium disilicate versus veneered Y-TZP crowns: Comparison of failure modes and reliability after fatigue**

Place of the study: New York University, New York, USA
Time: 2010
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 CAD/CAM-fabricated IPS e.max CAD (LS_2) crowns were investigated:

Method I: Nineteen 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. 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 the 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 with 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:

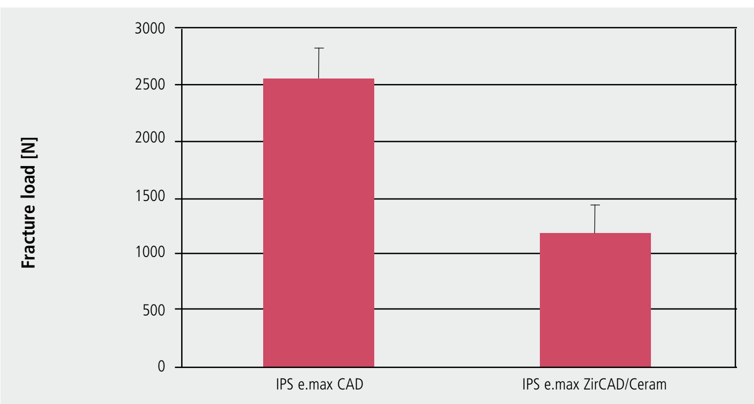

Fig. 9: Fracture load of IPS e.max CAD compared to IPS e.max ZirCAD veneered with IPS e.max Ceram

Summary:

Only with rather high forces did IPS e.max CAD (LS_2) crowns demonstrate fractures with cracks down to the composite die (2576 ± 206 N). In contrast, IPS e.max ZirCAD (ZrO_2) exclusively showed fractures 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, 2010)

Title of the study: **Reliability of reduced-thickness IPS e.max® CAD and thinly veneered IPS e.max® CAD crowns**
Reliability: reduced-thickness and thinly veneered lithium-disilicate vs. MCR and Y-TZP crowns

Place of the study: New York University, New York, USA
Time: 2010
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 (LS_2) were investigated in comparison with veneered crowns made of zirconium oxide and conventional metal-ceramic (MCR). On the one hand, there were crowns with an occlusal strength of 1 mm, and, on the other hand, crowns with a wall thickness of 2 mm, a core of 1.5 mm, and a thin buccal veneer of 0.5 mm. 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 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. After the tests, the crowns were inspected for damage under the stereo microscope with polarized light.

Results:

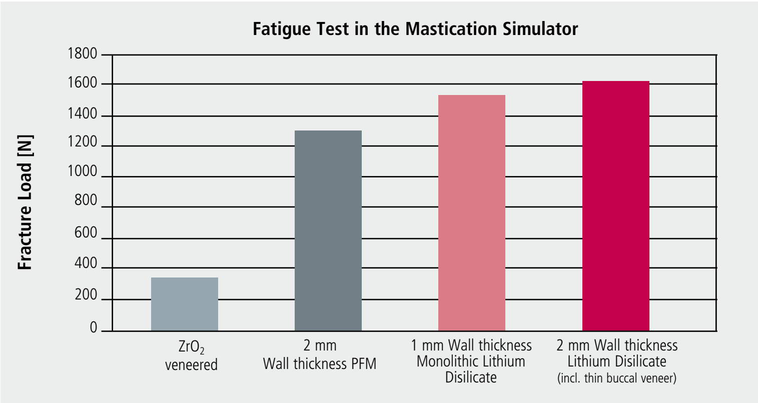

Fig. 10: Fracture load based upon load failure during fatigue.

Summary:

The fracture load of monolithic IPS e.max CAD (LS_2) was 1535 N for IPS e.max CAD 1 mm and 1610 N for IPS e.max CAD 2 mm. These values are comparable to those of metal-ceramic (1304 N) and higher than those of veneered zirconium oxide (371 N) (see Figure 10). The fractures observed were complete fractures for IPS e.max CAD and chipping for the two other groups. The IPS e.max CAD material showed the highest reliability.

Conclusion:

In this investigation, IPS e.max CAD crowns showed good values comparable to those of the gold standard, i.e. metal-ceramics.

Reference:

(Martins, 2011)

Title of the study: **Compressive fatigue resistance and fracture resistance of implant-supported ceramic crowns**

Place of the study: Ain Sham University, Cairo, Egypt / University of Toronto, Toronto, Canada

Time: 2010

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, IPS e.max CAD), various abutments (titanium, zirconia), as well as different cementation materials (Tempbond, Panavia) were compared. The molar crowns were cemented to implants and stored in water at 37 °C (99 °F) 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 a fracture test.

Results:

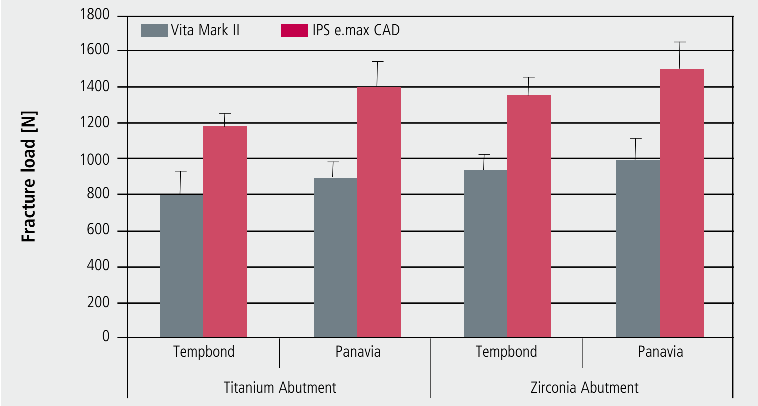

Fig. 11: Fracture load of implant-retained crowns made of IPS e.max CAD or Vita Mark II on titanium or zirconia abutments. Cementation was carried out with either Tempbond or Panavia.

Summary:

During the fatigue test, 2 Vita Mark II crowns fractured (1 on a titanium abutment, 1 on a zirconia abutment, both cemented with Tempbond). All the other test specimens survived.

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

Reference:

(El-Dimeery, 2011)

Title of the study: **Performance of a new press glass-ceramic**

Place of the study: Technical University Dresden, Dresden, Germany

Time: 2003 – 2006

Author(s): K. Böning

Method:

Placement of 39 IPS e.max Press (LS_2) crowns (test group) and 40 metal-ceramic crowns made of the d.SIGN® 96 high-gold alloy and the IPS d.SIGN® fusable ceramic (control group) in a total of 63 patients.
The restorations were conventionally cemented with glass ionomer cement.

Results:

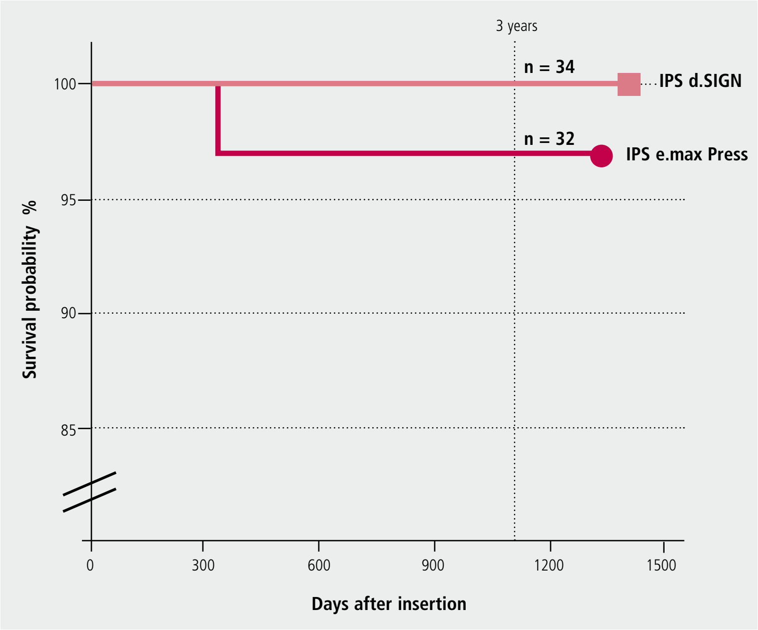

Fig. 12: Survival probability of crowns made of IPS e.max Press and IPS d.SIGN after 3 years.

Summary:

After an observation period of 3 years, a survival probability of 97% for the test group and 100% for the control group was determined. The log rank test did not show any significant difference.

Conclusion:

All-ceramic crowns made of IPS e.max Press were as clinically successful as metal-ceramic crowns.

Reference:

(Böning et al., 2006)

Title of the study: **Clinical examination of two commercially available systems versus an experimental ceramic system**[1]

Place of the study: King´s College, London, United Kingdom
Time: 2001 – 2008
Author(s): T.F. Watson, M. K. Etman

Method:

The clinical behaviour of posterior crowns with regard to abrasion was examined. For that purpose, 3 ceramic and metal-ceramic materials were compared. A total of 90 posterior crowns were placed in 48 patients:
– 30 were fully anatomical IPS e.max Press crowns (LS_2)
– 30 were veneered Procera-AllCeram crowns (Al_2O_3)
– 30 were metal-ceramic crowns (PFM, IPS Classic®)
Impressions were taken in regular intervals during 2 years and the wear determined by means of a new technique.

Results:

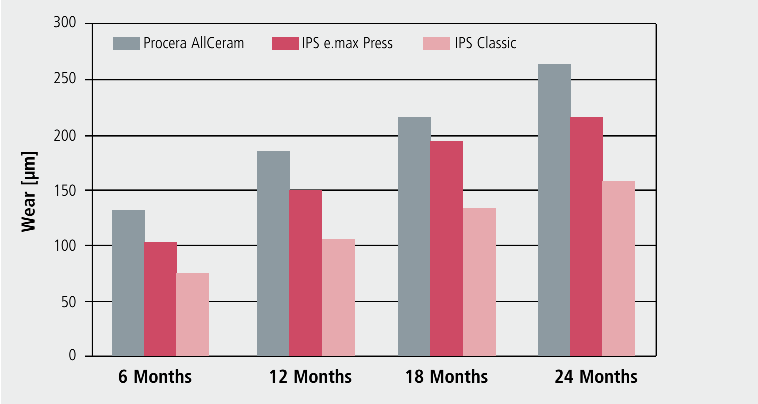

Fig. 13: Abrasion of ceramic crowns in relation to the wear period.

Summary:

Measurements after 2 years showed that IPS e.max Press crowns demonstrated less wear than Procera-AllCeram crowns. The abrasion of the antagonist tooth is also lower. After 7 years, the abrasion of enamel opposing IPS e.max Press crowns is still lower than that of enamel opposing Procera-AllCeram crowns.

Conclusion:

Procera and IPS e.max performed equally well, but IPS e.max Press was superior with regard to abrasion.
Even if wear can be measured it is usually noticed neither by the patient nor the dentist. The phenomenon should therefore not be overrated with normal patients (without bruxism or increased masticatory pressure). If the material is processed correctly, the abrasion of glass-ceramic crowns is so low that the esthetic and biological advantages over metal and metal-ceramic restorations prevail.

Reference:

(Etman et al., 2001; Etman and Woolford, 2010)

[1] at the beginning of the study, IPS e.max Press was not yet commercially available and was, therefore, called an experimental ceramic system.

Title of the study: **Prospective clinical study on IPS e.max® Press and ProCAD® partial crowns**

Place of the study: University Clinic Freiburg, Freiburg i. Br., Germany

Time: 2006–2011

Author(s): C. Stappert, P. C. Guess

Method:

All-ceramic crowns / inlays made of the IPS e.max Press lithium disilicate press ceramic (n=40) and the ProCAD leucite glass-ceramic for CAD/CAM fabrication (CEREC, Sirona) (n=40) were placed. A maximum of 20 non-vital abutment teeth per group were permitted; those were to be stabilized by an all-ceramic post system.

Results:

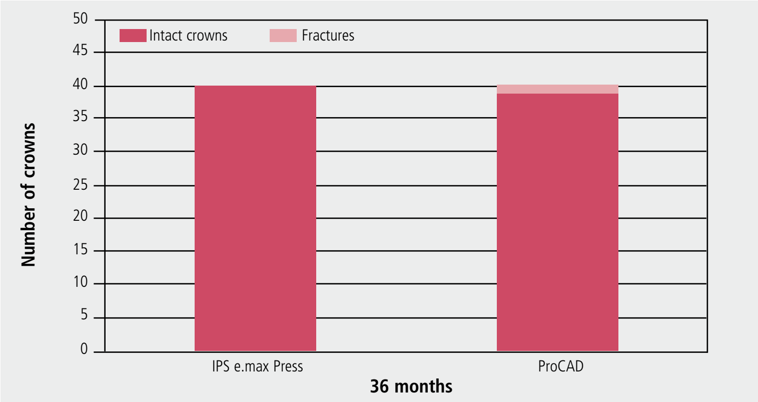

Fig. 14: Clinical efficiency of crowns made of IPS e.max Press and ProCAD after 36 months.

Summary:

A survival rate after 36 months of 100% was reported for IPS e.max Press and 97% for ProCAD.

Conclusion :

All-ceramic partial crowns, either pressed or CAD/CAM-fabricated, represent reliable treatment options for the restoration of larger defects in the posterior region.

Reference:

(Guess et al., 2006; Guess et al., 2009)

Title of the study: **Ten-year results of 3-unit bridges made of monolithic lithium disilicate (LS_2)**

Place of the study: University Clinic Schleswig-Holstein, Kiel, Germany
Time: 2001–2011
Author(s): M. Kern, S. Wolfart

Method:

Thirty-six bridges made of IPS e.max Press (LS_2) were seated in 28 patients. Slightly more than half of the crown-retained bridges were placed using a conventional cementation technique. All the other bridges were adhesively cemented (Variolink® II). As many as 90% of all restorations were placed in the posterior region.

Results:

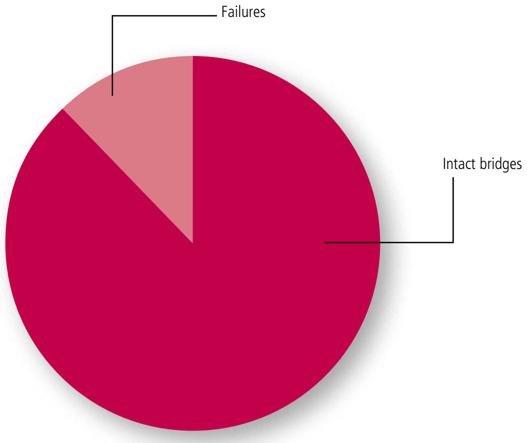

Fig. 15: Clinical efficiency of bridges mad of IPS e.max Press after 121 months.

Summary:

No fractures of the bridges occurred after a mean observation period of 48 months. The 4-year survival rate according to Kaplan Meier is 100%. Two bridges fractured and chipping of the veneering material occurred in two others (6%) after 8 years. The 8-year survival rate according to Kaplan Meier is 93%. With regard to the periodontal parameters, the comparison of the pocket depth, bleeding upon probing and tooth mobility showed no significant differences between the test and the comparison teeth ($P > 0.05$ Wilcoxon rank sum test).

After 10 years, a total of 3 fractures (in the molar region) occurred, and another restoration was lost due to the extraction of a tooth for biological reasons. Chipping occurred in 6.1% of the restorations. The 10-year survival rate according to Kaplan Meier is 87.9%.

Conclusion:

Three-unit bridges made of IPS e.max lithium disilicate glass-ceramic have proved their clinical efficiency in the posterior region (premolars) with both adhesive and conventional cementation. The survival rate is comparable to that of metal-ceramics and bettter than that of other ceramic systems.

Reference:

(Wolfart et al., 2005; Wolfart et al., 2009; Kern et al., 2011)

Title of the study: **Clinical examination of veneered IPS e.max® Press crowns**

Place of the study: University Clinic Aachen, Aachen, Germany
Time: 2002–2010
Author(s): D. Edelhoff

Method:

A total of 104 IPS e.max Press (LS_2) restorations (82 crowns in the anterior region, 22 crowns in the posterior region) were incorporated in 41 patients. The majority of the restorations (69.2%) were cemented using an adhesive technique (Variolink® II) and roughly one third of the restorations (30.8%) were placed using a glass ionomer cement (Vivaglass® CEM).

Results:

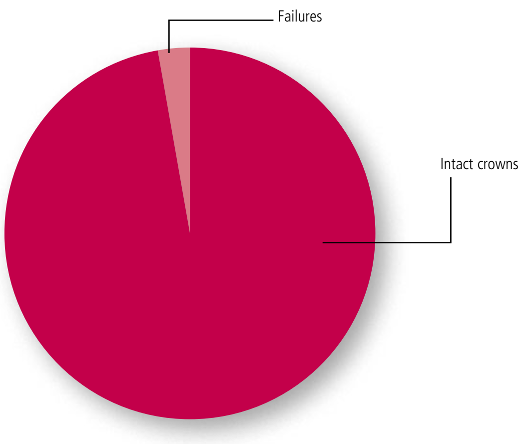

Fig. 16: Clinical efficiency of crowns made of IPS e.max Press after 8 years.

Summary:

The Kaplan-Meier survival rate after 8 years is 92.3%. One failure was caused by secondary caries, another by endodontic complications. Furthermore, 2 crowns (2.1%) showed chipping of the veneering material and one crown (1.1%) demonstrated marginal discolouration.

Conclusion:

Crowns made of IPS e.max lithium disilicate-ceramic have proved their clinical efficiency with both adhesive and conventional cementation.

Reference:

(Gehrt et al., 2010)

Title of the study: **IPS e.max® – 4 year clinical performance**

Place of the study: USA
Time: 2006 – 2010
Author(s): The Dental Advisor

Method:

Four dentists placed 440 IPS e.max Press (LS_2) restorations in 260 patients. Two hundred and thirty-six restorations were examined on the occasion of a recall (the maximum wear period was 4 years). Of these restorations, 42% were molar crowns, 37% premolar crowns, 9% anterior crowns, 7% inlays/onlays and 5% bridges. A self-adhesive or adhesive cement was used for cementation.

Results:

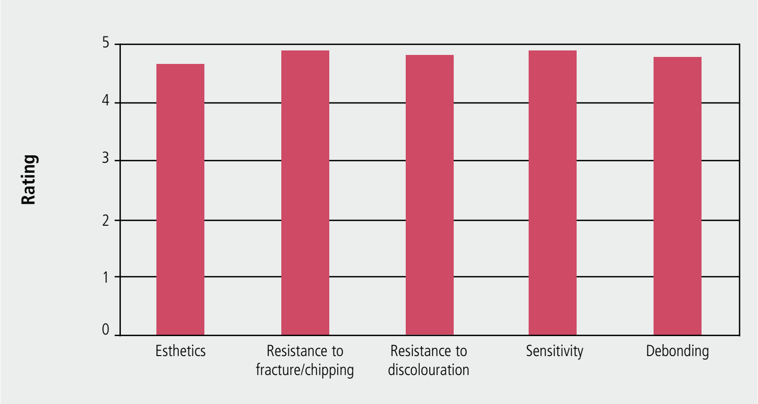

Fig. 17: Assessment of important clinical parameters of restorations made of IPS e.max Press after 4 years.
5: excellent; 4: very good; 3: good; 2: sufficient, 1: insufficient.

Summary:

Only one fracture was reported out of 236 restorations. Chipping was observed in only 2.5% of the restorations. IPS e.max Press was rated excellent also with regard to marginal discolouration and esthetics.

Conclusion:

IPS e.max Press is a highly esthetic material with high strength and excellent clinical performance over 4 years. It is superior to traditional metal-ceramic restorations, as well as to many other all-ceramic materials.

Reference:

The Dental Advisor, 2010

Title of the study: **Clinical evaluation of chairside lithium disilicate CAD/CAM crowns. 3-year report**

Place of the study: University of Michigan, Ann Arbor, USA

Time : 2007–2010

Author(s): J. Fasbinder

Method:

Sixty-two IPS e.max CAD LS_2 crowns (premolar and molar) were fabricated chairside with a CEREC 3D milling unit and adhesively cemented using Multilink® Automix (n=23) and self-adhesively using Multilink Sprint (n=39).

Results:

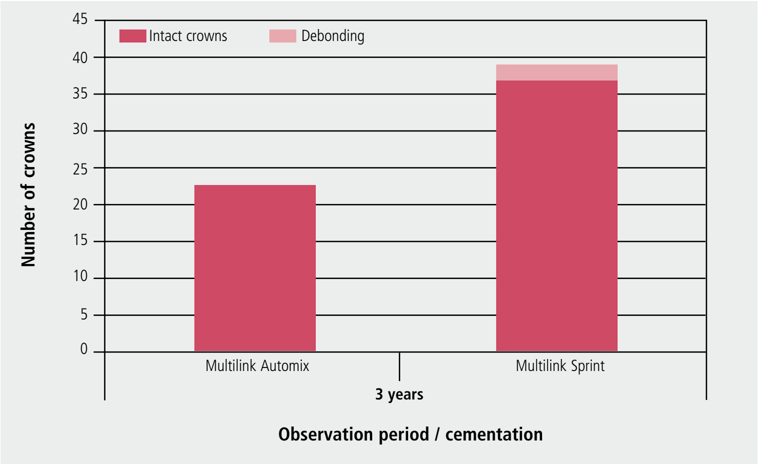

Fig. 18: Clinical efficiency of crowns made of IPS e.max CAD after 3 years.

Summary:

No fractures or chipping of the veneering material were reported after an observation period of up to 3 years. All the crowns seated with Multilink Automix were clinically acceptable; 2 cases of decementation were reported for Multilink Sprint. Those two were re-cemented using Multilink Automix.

Conclusion:

Crowns made of IPS e.max CAD proved their clinical efficiency over a period of 3 years; no fractures or chipping occurred.

Reference:

(Fasbinder et al., 2010)

Title of the study: **A preliminary study on the short-term efficacy of chairside computer-aided design/computer-assisted manufacturing-generated posterior lithium disilicate crowns**

Place of the study: RWTH Aachen University, Aachen, Germany
Time: 2008–2010
Author(s): S. Reich

Method:

Forty-one IPS e.max CAD LS_2 crowns were fabricated using the CEREC 3D milling machine. Self-adhesive cementation was performed with Multilink® Sprint.

Results:

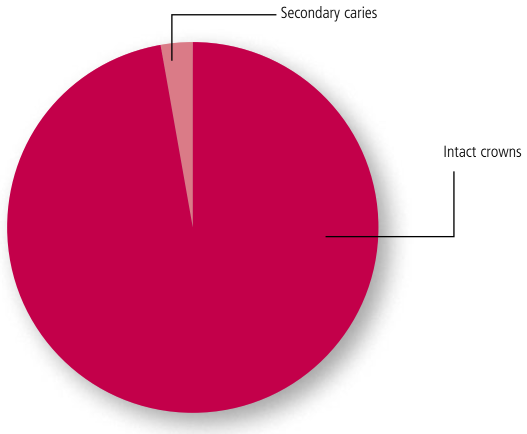

Fig. 19: Clinical efficiency of crowns made of IPS e.max CAD after 2 years.

Summary:

No fractures of the restorations were reported after an observation period of 2 years; merely a case of secondary caries.

Conclusion:

Crowns made of IPS e.max CAD proved their clinical efficiency over a period of 2 years; no fractures or chipping occurred.

Reference:

(Reich et al., 2010)

Title of the study: **Clinical performance and fit of a milled ceramic crown system**

Place of the study: Boston University, Boston, USA
Time: 2005 – 2008
Author(s): D. Nathanson

Method:

Thirty-one IPS e.max CAD LS_2 crowns (23 anterior crowns, 8 posterior crowns) were placed in 14 patients. They were veneered with IPS e.max Ceram and cemented using Multilink® or Multilink Automix.

Results:

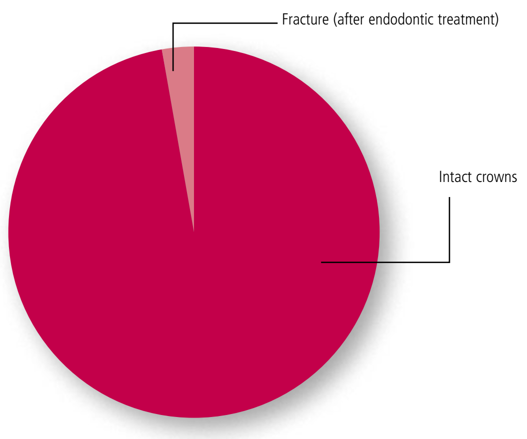

Fig. 20: Clinical efficiency of crowns made of IPS e.max CAD after 3 years.

Summary:

After an observation period of up to 3 years, only one crown placed after endodontic treatment showed a fracture.

Conclusion:

Crowns made of IPS e.max CAD proved their clinical efficiency over a period of 3 years.

Reference:

(Nathanson, 2008)

Title of the study:	**Survival rate and clinical quality of CAD/CAM fabricated posterior crowns made of lithium disilicate ceramic. A prospective clinical study**
Place of the study:	University of Zurich, Zurich, Switzerland
Time:	2007 – 2011
Author(s):	A. Bindl

Method:

Forty-two IPS e.max CAD LS_2 posterior crowns were placed in 37 patients using a self-adhesive cementation protocol.

Results:

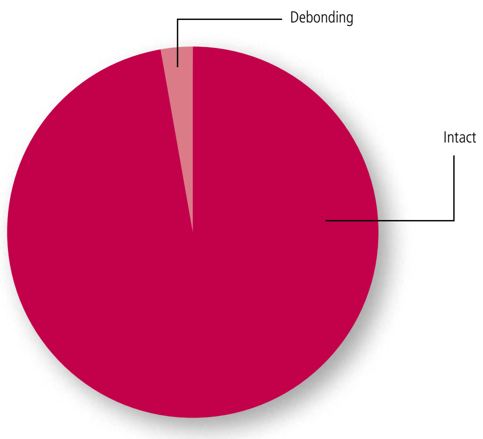

Fig. 21: Clinical efficiency of crowns made of IPS e.max CAD after 2 years.

Summary:

At the follow-up examination after 2 years, 37 crowns were assessed. Neither fractures nor chipping had occurred. Only one crown was affected by decementation. The crown was intact and was recemented using Multilink® Automix.

Conclusion :

Posterior crowns made of IPS e.max CAD proved their clinical efficiency over a period of 2 years.

Reference:

(Bindl, 2011)

Title of the study: **IPS e.max® CAD posterior crown clinical study**

Place of the study: Pacific Dental Institute, Portland, Oregon, USA
Time: 2006 – 2009
Author(s): J. A. Sorensen, R. Trotman, K. Yokoyama

Method:
Thirty IPS e.max CAD LS_2 crowns were veneered with IPS e.max Ceram and placed in 27 patients using an adhesive cementation protocol with Multilink®.

Results:

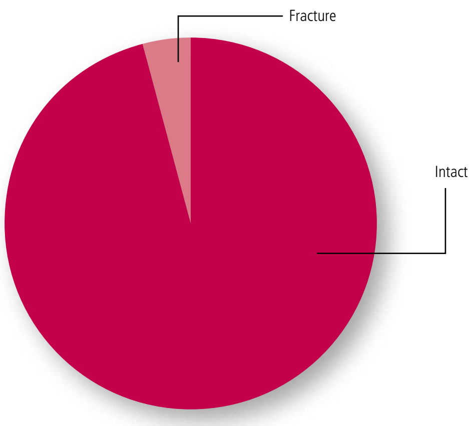

Fig. 22: Clinical efficiency of crowns made of IPS e.max CAD after 2 years.

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

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

Reference:
(Sorensen et al., 2009b)

Title of the study: **Microstructural and in-vivo wear analysis of all-ceramic and metal-ceramic crowns and their enamel antagonists**

Place of the study: University of Florida

Time: 2005 – 2008

Author(s): J.F. Esquivel-Upshaw, K. J. Anusavice, W. Rose, E. Oliveira

Method:

A total of 36 metal-ceramic and all-ceramic crowns were placed in 31 patients. The crowns were classified into three groups:

- Metal-ceramic crowns (IPS d.SIGN; n=12)
- IPS Empress 2 crowns veneered with IPS Eris for E2 (n=12)
- IPS e.max Press crowns glazed (n=12)

The all-ceramic crowns were cemented in place using Variolink® II. The metal-ceramic crowns were placed with RelyX Unicem. Pictures were taken at the baseline and at every recall and impressions were taken using an addition-type vinyl polysiloxane to determine the wear at a later stage.

Results:

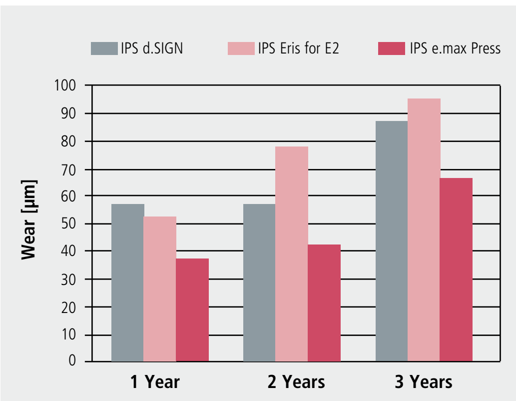

Fig. 23: Abrasion of ceramic crowns in relation to the wear period.

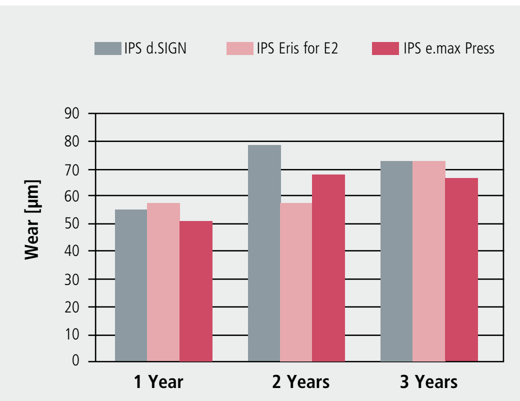

Fig. 24: Antagonist abrasion in relation to the wear period

Summary:

Evaluations of the enamel wear have shown only a weak interrelation between wear and maximum biting force. This indicates that other factors have a dominating influence on wear. The antagonist abrasion was higher that that of natural teeth (enamel/enamel) for all materials. However, the values for IPS e.max Press were comparable to or lower than for other materials (see figure). The wear of the ceramic crowns was lower for IPS e.max Press than for the other ceramic materials (see figure).

Conclusion:

The higher strength of IPS e.max Press does not necessarily mean higher abrasion of the antagonist tooth.

Reference:

(Esquivel-Upshaw et al., 2008)

Title of the study: **Clinical performance of CAD/CAM-fabricated lithium-disilicate restorations**

Place of the study: Ludwig Maximilian University Munich, Munich, Germany
Time: 2007–2011
Author(s): F. Beuer

Method:

Thirty-eight fully anatomical and partially reduced IPS e.max CAD (LS_2) restorations respectively were fabricated using KaVo Everest (36 crowns, 2 anterior bridges) and veneered with IPS e.max Ceram. Self-adhesive cementation was performed with Multilink® Sprint and Multilink Automix.

Results:

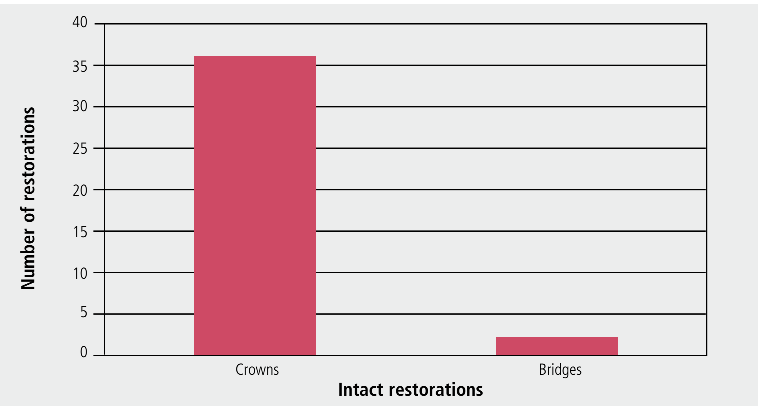

Fig. 25: Clinical efficiency of crowns and bridges made of IPS e.max CAD after 4 years.

Summary:

No failures of the restorations seated thus far 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 2011)

Title of the study: **Twelve months' clinical performance of IPS e.max® CAD-on-restorations (lithium disilicate fused to zirconium oxide frameworks)**

Place of the study: R&D, Ivoclar Vivadent AG, Schaan, Liechtenstein
Time : 2009–2011
Author(s): R. Watzke, A. Peschke, J.F. Roulet

Method:

Twenty-five restorations (20 crowns, 5 3-unit bridges) were fabricated with a new type of CAD/CAM technique. The frameworks were fabricated of IPS e.max ZirCAD (ZrO_2), the veneers of IPS e.max CAD (LS_2). The framework and veneer were fused by means of Ivomix and IPS e.max CAD Crystall./Connect. The restorations were conventionally cemented.

Results:

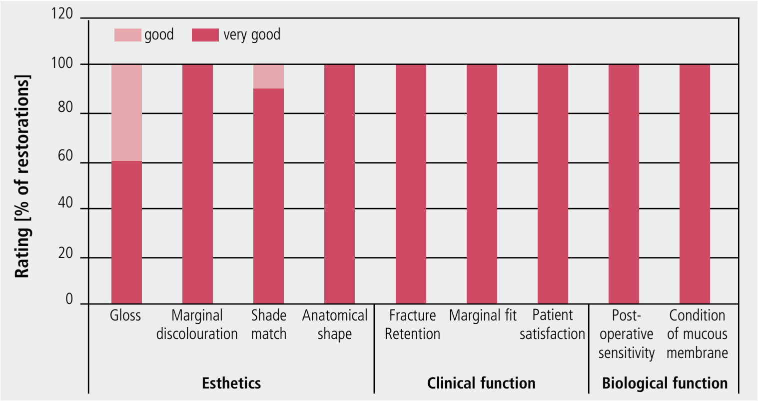

Fig. 26: Clinical efficiency of crowns and bridges made of IPS e.max ZirCAD and veneered with IPS e.max CAD ("CAD-on") after 12 months.

Summary:

The IPS e.max CAD-on restorations were rated very good to good for all clinical parameters (esthetics, function, biological parameters) after 12 months.

Conclusion:

The IPS e.max CAD-on technique permits the fabrication of reliable restorations with high esthetics, which prove their clinical efficiency after an observation period of 12 months. IPS e.max CAD-on restorations are very well suitable for implant-retained crowns and 3-unit bridges.

Reference:

(Watzke et al., 2011)

IPS e.max®

Zirconium Oxide (ZrO_2)

in vitro studies
in vivo studies

Title of the study: **Influence of veneering techniques on the failure behaviour and fatigue strength of Y-TZP three-layer systems**

Place of the study: New York University, New York, USA
Time: 2009
Author(s): P.C. Guess, Y. Zhang, Prof. V.P. Thompson

Method:

CAD/CAM Y-TZP zirconium oxide specimens (12 x 12 x 0.7 mm) were veneered using the lost-wax press technique (IPS e.max ZirPress; test group, n=24) and the layering technique (IPS e.max Ceram, control group, n=24). After the adhesive cementation (Alloy Primer and Panavia 21) onto composite blocks (12 x 12 x 4 mm, Z-100), the test specimens were stored in water for seven days before the fatigue tests. The three-layered test specimens were subjected to a chewing simulation step stress test with a ball-shaped tungsten carbide antagonist (R=3.18) with three different profiles (EL-3300 Bose/Enduratec) until the cracks reached the bonding interface between the veneering and framework ceramics. All test specimens were arranged at a 30° off-axis angle to simulate the cusp inclination in the posterior region. The step stress profiles were determined on the basis of the initial fracture toughness.

Results:

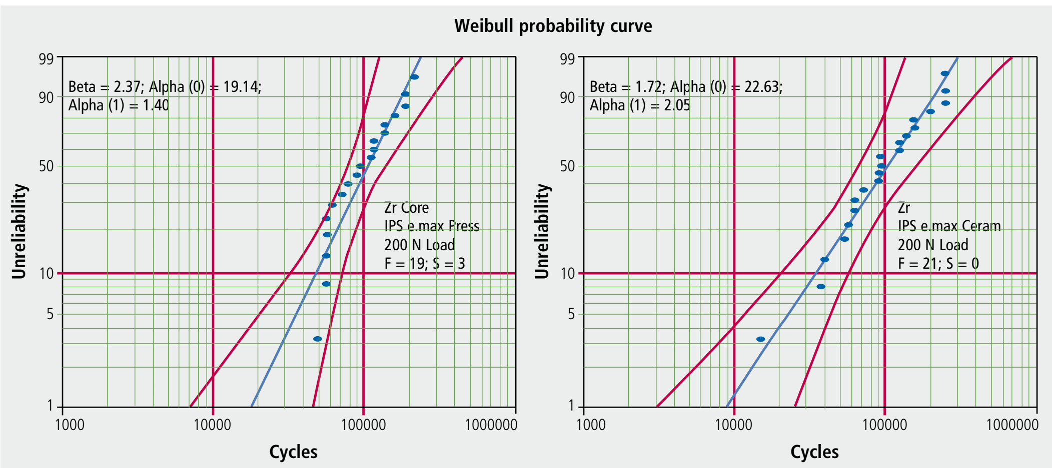

Fig. 27: Weibull probability curve for IPS e.max ZirCAD, veneered with IPS e.max ZirPress (left) or IPS e.max Ceram (right). Blue dots: data dots; red line: tow-sided confidence intervals at 90%. Nineteen (ZirPress) and 21 (Ceram) specimens failed (F).

Summary:

The fatigue strength of veneered zirconium oxide with step-stress material fatigue of pressed and layered veneers is comparable. Only superficial fractures in the veneer were observed. Framework fractures did not occur.

Conclusion:

The fatigue strength of IPS e.max ZirCAD (ZrO_2) does not depend on the type of veneer (pressed-on or layered).

Reference:

(Guess, 2009)

Title of the study: **Fracture resistance of all-ceramic crown systems**

Place of the study: Christian Albrechts University Kiel, Kiel, Germany

Time : 2011

Author(s): M. Steiner, M. Sasse, Prof. M. Kern

Method:

A model die was fabricated, onto which a model crown with a standardized, anatomical occlusal surface with an occlusal layer thickness of 2.0 mm (cusps) and 1.5 mm (fissures) was waxed-up and subsequently scanned. Several identical crown models were milled of an acrylate resin and used for the fabrication of the lithium disilicate press crowns (IPS e.max Press). The CAD-milled ZrO_2 crowns (IPS e.max ZirCAD, Lava Zirconia, Cercon Base) were fabricated in the same manner by scanning and milling them of the respective materials. For the fabrication of veneered crowns, the occlusal thickness of the veneering material was 1.0 mm and 0.8 mm; veneering with LavaCeram and Cercon Ceram / pressing-over with IPS e.max ZirPress were carried out according to the instructions of the respective manufacturer. The crowns were adhesively cemented on metal dies using Multilink Automix. The test specimens were stored in water at 37 °C (99 °F) for 3 days before the stress tests. Eight test specimens per material group were then mounted in the Willytec chewing simulator and subjected to cyclic load. The weight load was increased every 100,000 cycles (3, 5, 9, 11 kg); the total number of cycles was 400,000. All intact test specimens were then loaded in a universal testing machine until complete failure.

Results :

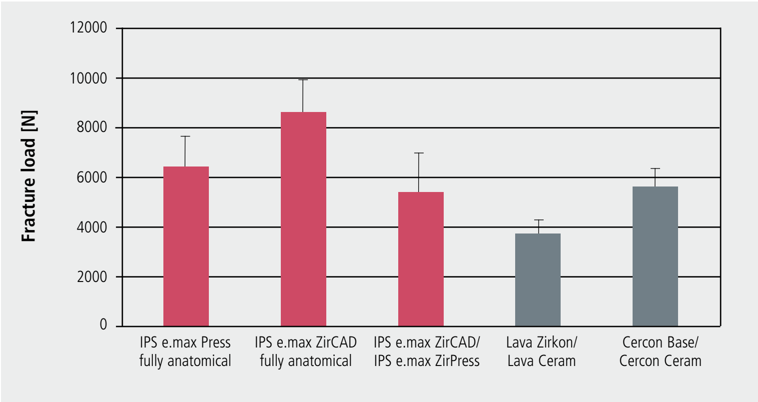

Fig. 28: Fracture load of all-ceramic crowns made of different materials.

Summary:

No chipping occurred during dynamic loading. The fracture load of fully anatomical IPS e.max Press is in the same range as that of veneered zirconium oxide.

Conclusion:

The IPS e.max material not only withstands the physiological forces in the posterior region, which range between 300 and 1000 N, but it also presents a sufficient safety margin to tolerate accidental overload.

Reference:

(Steiner et al., 2011)

Title of the study: **Influence of the veneer on the fracture resistance of zirconium dioxide restorations**

Place of the study: Ludwig Maximilian University Munich, Munich, Germany

Time: 2004

Author(s): F. Beuer, T. Kerler, K. Erdelt, J. Schweiger, M. Eichberger, W.Gernet

Method:

Sixty circular test specimens made of Cercon smart ceramics (ZrO_2) were prepared according to the requirements for biaxial fracture tests. Twelve specimens remained unveneered, 24 each were veneered with a layer thickness of 0.2 mm and 0.8 mm, of which 12 each were veneered with the framework manufacturer's veneering ceramic for ZrO_2 frameworks (Cercon Ceram S) and with IPS e.max Ceram. All specimens were tested in the universal testing machine with the veneer located in the tensile zone.

Results:

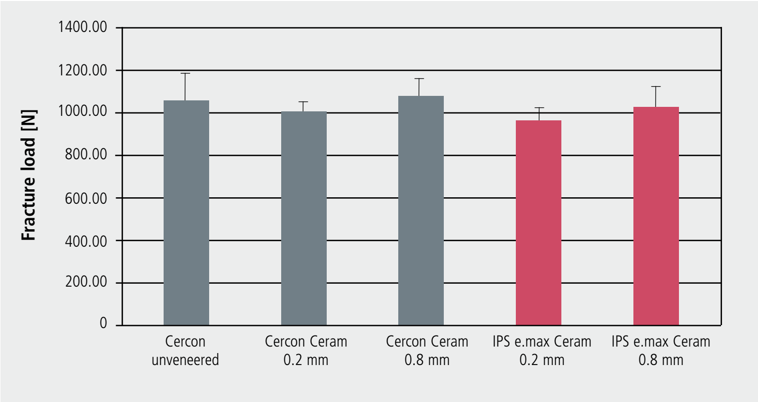

Fig. 29: Fracture load of unveneered and veneered Cercon ZrO_2 test specimens.

Summary:

Unveneered test specimens showed a mean fracture resistance of 1066 N. With a veneer thickness of 0.8 mm, no statistically significant differences were noted between the IPS e.max Ceram and the Cercon Ceram S veneers.

Conclusion:

The IPS e.max Ceram veneering material does not have a negative effect on the fracture load of zirconium oxide frameworks.

Reference:

(Beuer et al., 2004)

Title of the study: **Frachture resistance of three-unit zirconium dioxide posterior bridges**

Place of the study: University Clinic Freiburg, Freiburg i. Br., Germany
Time: 2006
Author(s): K. Stamouli, S. Smeekens, W. Att, Prof. J.R. Strub

Method:

Ninety-six teeth (48 lower premolars, 48 lower molars) were ground and fixed with an artificial periodontal ligament. After impression-taking and model fabrication, 48 three-unit bridges were fabricated of three different ZrO_2 materials (n=16 per material). Group 1: Procera Zirconia, Group 2: DC-Zirkon, Group 3: Vita In-Ceram YZ. All frameworks were veneered with IPS e.max Ceram and conventionally cemented (Ketac Cem). Half of the test specimens were artificially aged. Subsequently, all bridges were loaded to fracture using a universal testing machine (Zwick).

Results:

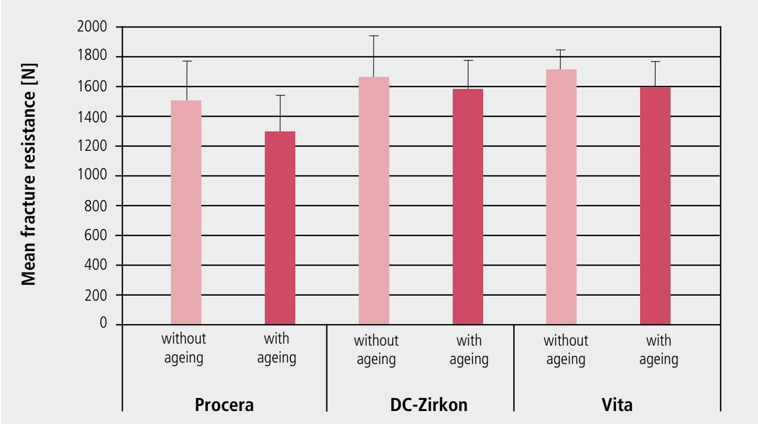

Fig. 30: Fracture resistance of ZrO_2 bridges, veneered with IPS e.max Ceram, before and after artificial ageing.

Summary:

All bridges withstood the dynamic chewing simulation. Neither fractures nor chipping of the veneer were observed. Without ageing, the fracture resistance values of the materials did not differ; however, there were differences in the fracture resistance after ageing (see diagram).

Conclusion:

IPS e.max Ceram enables reliable veneering of zirconium oxide bridges.

Reference:

(Stamouli et al., 2006)

Title of the study: **All-ceramic, titanium or conventional metal-ceramic**

Place of the study: University of Zurich, Zurich, Switzerland
Time: 2008
Author(s): B. Stawarczyk, J. Fischer

Method:

Frameworks of idental shapes were fabricated of titanium and Lava zirconium oxide (11 series of 10 test specimens each) and veneered with suitable veneering ceramics. Among other materials, IPS e.max Ceram was used to veneer the ZrO_2 frameworks. Conventional, veneered gold crowns made of Degudent U / VM13 were used as control group. The veneered crowns were adhesively cemented to a metal die and loaded to fracture at an off-axis angle of 45° in a test assembly.

Results:

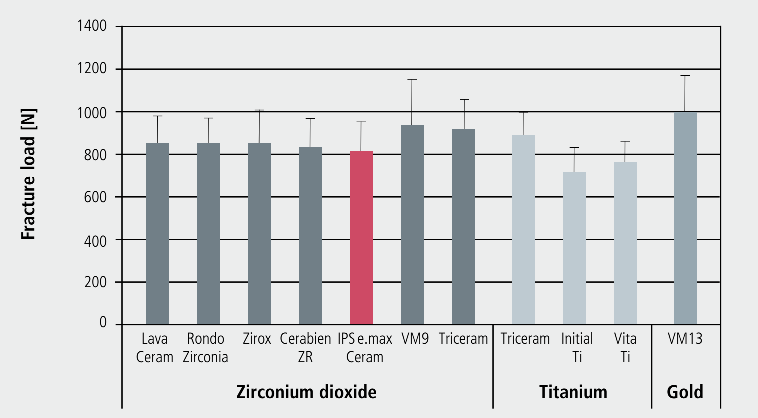

Fig. 31: Fracture load of veneered test specimens made of ZrO_2, titanium or gold.

Summary:

IPS e.max Ceram on ZrO_2 frameworks achieved fracture load values comparable to those of other veneering materials. Veneered zirconium oxide was in the range of conventional metal-ceramic.

Conclusion:

The fracture load of veneered zirconium oxide crowns is comparable to that of veneered metal crowns.

Reference:

(Stawarczyk and Fischer, 2008)

Title of the study: **High-strength CAD/CAM-fabricated veneering material sintered to zirconia copings: a new fabrication mode for all-ceramic restorations**

Place of the study: Ludwig Maximilian University Munich, Munich, Germany

Time: 2009

Author(s): F. Beuer, J. Schweiger, M. Eichberger, H.F. Kappert, W. Gernet, D. Edelhoff

Method:

A 360° chamfer preparation with a shoulder of 1.2 mm was prepared on a second upper molar and doubled 15 times with a cobalt-chromium alloy. Forty-five zirconium oxide copings were fabricated of IPS e.max ZirCAD and divided into three groups. The first group was conventionally veneered using IPS e.max Ceram in the layering technique, the second group was pressed over with IPS e.max ZirPress, while a high-strength, anatomically shaped full veneer was CAD/CAM-fabricated of IPS e.max CAD (LS_2) and fused onto the ZrO_2 (fusion crown). All crowns were conventionally cemented and loaded in a universal testing machine until clinical failure.

Results:

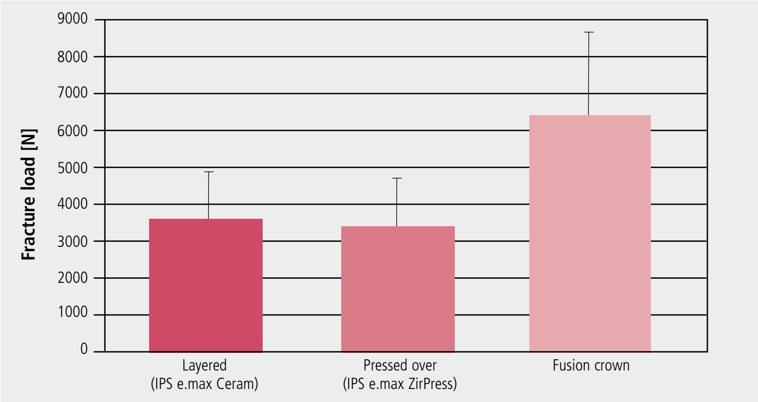

Fig. 32: Fracture load of crowns made of IPS e.max ZirCAD, veneered with IPS e.max Ceram, IPS e.max ZirPress or IPS e.max CAD-on (fusion crown).

Summary:

The fracture load values of the layered and pressed-over crowns were similar, while the values of the fusion crowns (IPS e.max CAD-on) were clearly higher.

Conclusion :

The fusion crowns (IPS e.max CAD-on) were superior to the layering and press-on technique with regard to the fracture load.

Reference:

(Beuer et al., 2009)

Title of the study: **Long-term clinical performance of IPS e.max® Ceram on IPS e.max® ZirCAD**

Place of the study: Dental Clinical Research Center, University of Iowa, Iowa City, USA
Time: 2005–2009
Author(s): C. Stanford

Method:

Incorporation of 50 crowns and 11 bridges made of IPS e.max ZirCAD (ZrO_2), veneered with IPS e.max Ceram.

Results:

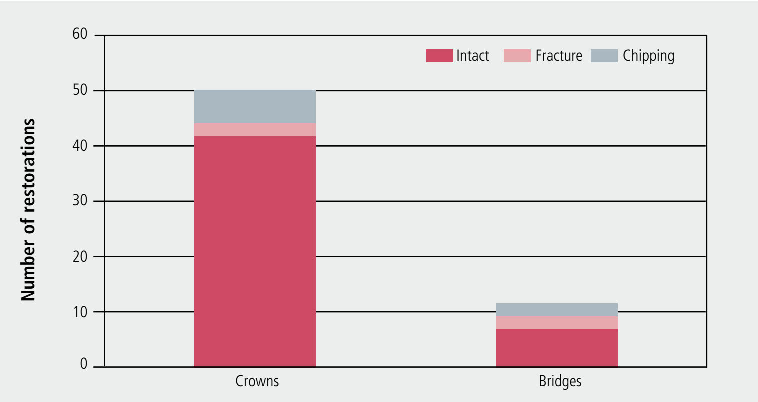

Fig. 33: Clinical efficiency of IPS e.max ZirCAD/Ceram-veneered restorations after 36 months.

Summary:

After an observation period of 36 months, two fractures and 5 cases of chipping of the veneering material occurred in the crowns, which, however, could all be repaired by polishing. For the bridges, two fractures (of which one de-cementation with new fabrication) and two cases of chipping were reported. The chipping was also repairable in situ by polishing and did not require replacement of the restoration.

Conclusion:

Restorations made of IPS e.max ZirCAD and veneered with IPS e.max Ceram have proved their clinical efficiency.

Reference:

(Stanford, 2009)

Title of the study: **Long-term clinical performance of IPS e.max® Ceram on IPS e.max® ZirCAD**

Place of the study: Pacific Dental Institute, Portland, USA
Time: 2004–2009
Author(s): J. A. Sorensen

Method:
Incorporation of 20 bridges made of IPS e.max ZirCAD (ZrO_2) veneered with IPS e.max Ceram.

Results:

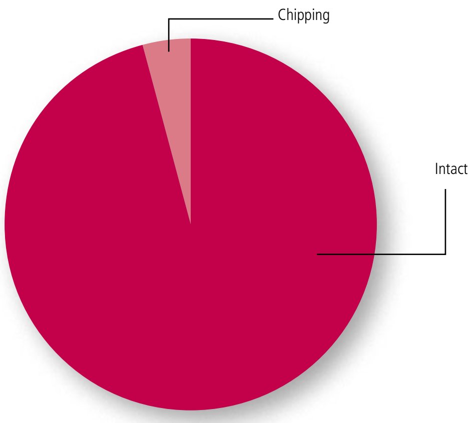

Fig. 34: Clinical efficiency of bridges made of IPS e.max ZirCAD veneered with IPS e.max Ceram.

Summary:
No absolute failures were reported in an observation period of 46.7 ± 5 months. The survival rate is at 100%. Two small (cohesive) chippings within the veneering ceramic were reported.

Conclusion:
With a survival rate of 100%, the clinical efficiency of IPS e.max ZirCAD ZrO_2 bridges is excellent.

Reference:
(Sorensen et al., 2009a)

Title of the study: **Clinical evaluation of CAD/CAM zirconium ceramic crowns and fixed partial dentures**

Place of the study: University of Michigan, Ann Arbor, USA

Time : 2005–2009

Author(s): D. J. Fasbinder

Method:

Incorporation of 31 crowns and 10 bridges made of IPS e.max ZirCAD (ZrO_2), pressed-over with IPS e.max ZirPress.

Results:

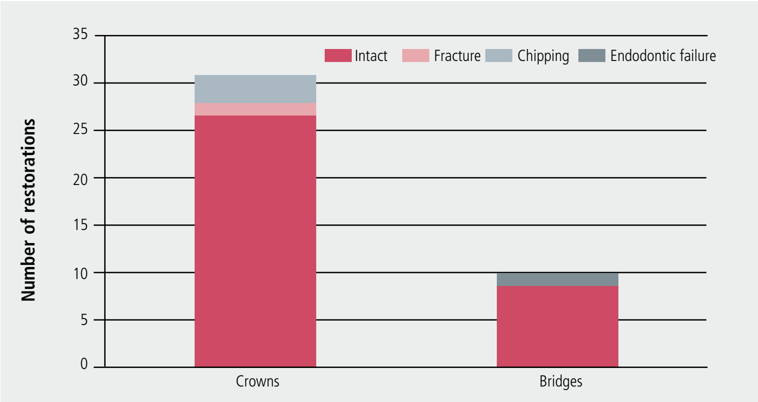

Fig. 35: Clinical efficiency of crowns and bridges made of IPS e.max ZirCAD, pressed over with IPS e.max ZirPress.

Summary:

Three fractures of the veneering material of the crowns were reported after an observation period of up to 3 years. The framework of one crown failed and required replacement. In the group of bridges, only one failure caused by endodontic treatment occurred.

Conclusion:

Restorations made of IPS e.max ZirCAD, pressed over with ZirPress showed excellent clinical behaviour.

Reference:

(Fasbinder and Dennison, 2009)

Title of the study: **Clinical study on all-ceramic restorations made of zirconium oxide ceramic veneered with a new veneering ceramic**

Place of the study: Ludwig Maximilian University Munich, Munich, Germany
Time: 2005–2009
Author(s): F. Beuer, W. Gernet

Method:

Incorporation of 50 crowns and 18 bridges (3 to 4 units) made of IPS e.max ZirCAD (ZrO_2), veneered with IPS e.max Ceram.

Results:

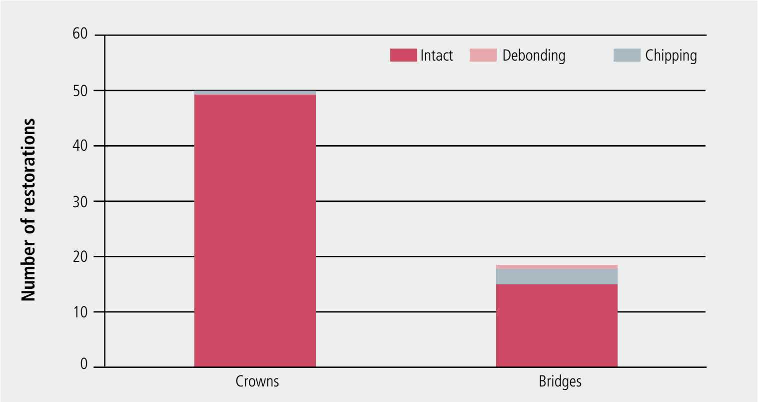

Fig. 36: Clinical efficiency of crowns and bridges made of IPS e.max ZirCAD and veneered with IPS e.max Ceram after 5 years.

Summary:

After an observation period of up to five years, no crown failures occurred, only one case of chipping of the veneering ceramic. For the bridges, five cases of chipping were reported. Furthermore, there was one case of repeated decementation, which resulted in the bridge being newly fabricated thus counting as failure. 98.5% of the restorations are still in clinical use.

Conclusion:

Crowns and bridges made of IPS e.max ZirCAD showed an excellent clinical performance; none of the restorations fractured during the study period of 5 years.

Reference:

(Beuer et al., 2010; Beuer, 2011)

Title of the study: **Clinical performance of PFM, zirconia and alumina three-unit posterior prostheses**

Place of the study: CR Foundation, Provo, USA

Time: 2006–2008

Author(s): R. Christensen

Method:

Two hundred and ninety-three 3-unit bridges with metal or ceramic frameworks were veneered, among others with IPS e.max ZirPress (n=33), and incorporated by 116 dentists. The restorations were examined with regard to esthetic and functional parameters during regular recalls.

Results:

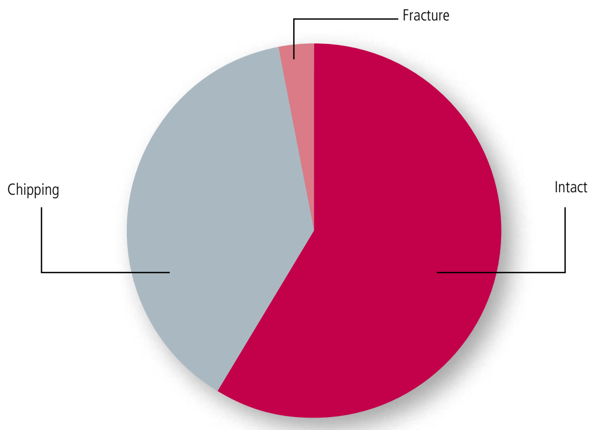

Fig. 37: Clinical efficiency of bridges made of IPS e.max ZirCAD veneered with IPS e.max ZirPress after 2 years.

Summary:

Of the 33 bridges made of IPS e.max ZirCAD and veneered with IPS e.max ZirPress, one bridge had to be replaced due to a fracture of the veneer after an observation period of two years. A number of minor chipping cases occurred, but they were replaced in-situ without any problems and did not require replacement of the restoration. (Remark: Numerous cases of chipping also occurred in zirconium oxide restorations of other manufacturers).

Conclusion:

The survival rate of IPS e.max ZirCAD veneered with IPS e.max ZirPress was 97% after 2 years.

Reference:

(Christensen RJ, 2008)

Title of the study: **Clinical evaluation of a self-adhesive resin cement on all-ceramic crowns**

Place of the study: The State University of New York, Buffalo, USA

Time: 2006–2009

Author(s): C. A. Muñoz

Method:

Forty-two IPS e.max ZirCAD crowns (ZrO_2), veneered with IPS e.max Ceram or IPS e.max ZirPress, were cemented with a self-adhesive luting composite.

Results:

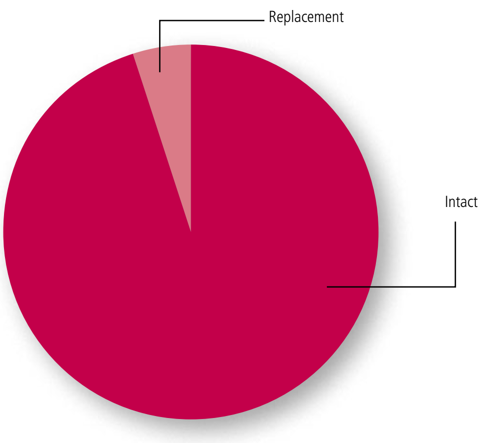

Fig. 38: Clinical efficiency of crowns made of IPS e.max ZirCAD.

Summary:

After 2 years, only 2 crowns had to be replaced due to veneer fractures.

Conclusion:

The study confirms the clinical suitability of veneered IPS e.max ZirCAD as crown material.

Reference:

(Munoz, 2009)

Title of the study: **Comparison of bridges made of IPS e.max® ZirCAD veneered with IPS e.max® Ceram or IPS e.max® ZirPress**

Place of the study: University of Zurich, Zurich, Switzerland

Time: 2005–2008

Author(s): I. Sailer and A. Bindl

Method:

Incorporation of 40 restorations made with IPS e.max ZirCAD (ZrO_2) frameworks. Twenty of the frameworks were veneered with IPS e.max Ceram, and 10 each with IPS e.max ZirPress and/or IPS e.max ZirPress and IPS e.max Ceram.

Results:

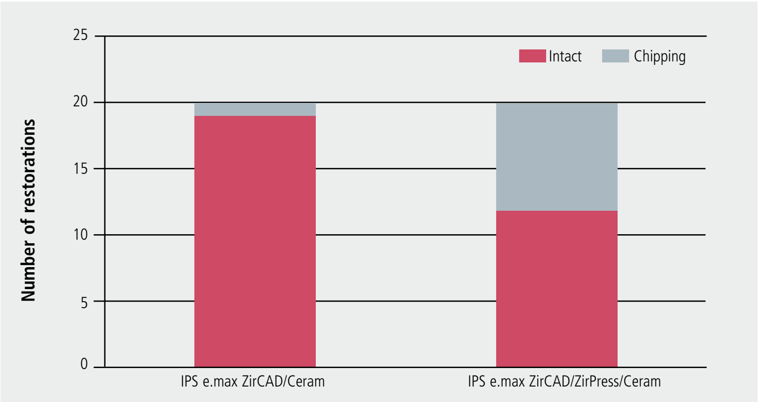

Fig. 39: Clinical efficiency of bridges made of IPS e.max ZirCAD veneered with different materials (IPS e.max Ceram or IPS e.max ZirPress) after 19.4 months.

Summary:

No framework fractures occurred after a mean observation period of 19.4 months. Several local cases of chipping were reported, but they could be repaired by means of grinding.

Conclusion:

Bridges made of IPS e.max ZirCAD proved their clinical efficiency over a period of 19.4 months; no fractures occurred. The survival rate of IPS e.max ZirCAD veneered with IPS e.max ZirPress was 97% after 2 years.

Reference:

(Hicklin et al., 2008)

Title of the study: **Twelve months' clinical performance of IPS e.max® CAD-on-restorations (lithium disilicate fused to zirconium oxide frameworks)**

Place of the study: R&D, Ivoclar Vivadent AG, Schaan, Liechtenstein
Time: 2009–2011
Author(s): R. Watzke, A. Peschke, J.F. Roulet

Method:

Twenty-five restorations (20 crowns, 5 3-unit bridges) were fabricated with a new type of CAD/CAM technique. The frameworks were fabricated of IPS e.max ZirCAD (ZrO_2), the veneers of IPS e.max CAD (LS_2). The framework and veneer were fused by means of Ivomix and IPS e.max CAD Crystall./Connect. The restorations were conventionally cemented.

Results:

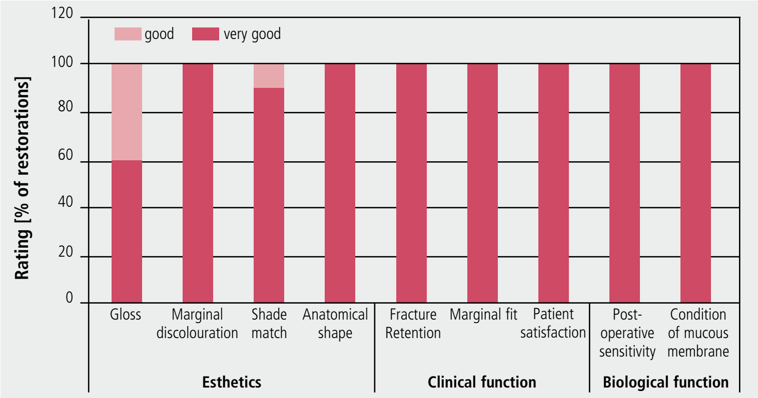

Fig. 40: Clinical efficiency of crowns and bridges made of IPS e.max ZirCAD and veneered with IPS e.max CAD ("CAD-on") after 12 months.

Summary:

The IPS e.max CAD-on restorations were rated very good to good for all clinical parameters (esthetics, function, biological parameters) after 12 months.

Conclusion:

The IPS e.max CAD-on technique permits the fabrication of reliable restorations with high esthetics, which prove their clinical efficiency after an observation period of 12 months. IPS e.max CAD-on restorations are very well suitable for implant-retained crowns and 3-unit bridges.

Reference:

(Watzke et al., 2011)

Title of the study: **Crystal with IPS e.max® Ceram 1-year clinical performance**

Place of the study: USA
Time : 2009–2010
Author(s): The Dental Advisor, USA

Method:

A total of 393 restorations (Crystal Zirconia veneered with IPS e.max Ceram) were placed in roughly 300 patients. 22% were anterior crowns, 67% posterior crowns, 9% bridges, 2% implants.
90% of the restorations were cemented with a self-adhesive cement, while 10% were conventionally cemented.

Results:

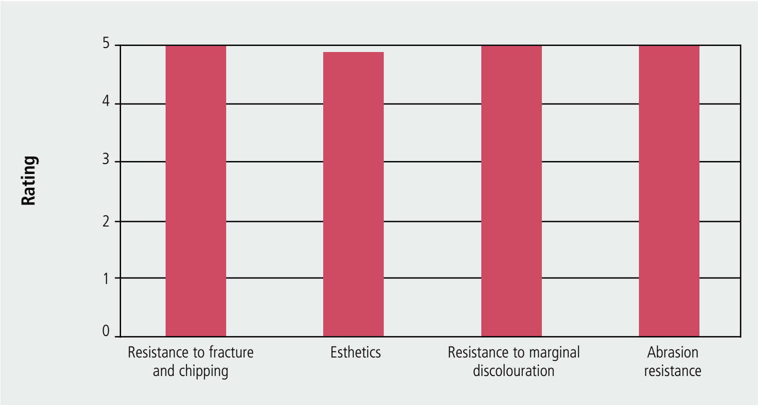

Fig. 41: Assessment of restorations made of Crystal Zirconia, veneered with IPS e.max Ceram after 1 year.
(5=excellent; 4=very good; 3=good; 2=sufficient, 1=poor).

Summary:

Ninety restorations (23% of the total number) were examined after a wear period of 3–15 months. One crown fractured 24 h after cementation. No fractures or cases of chipping occurred in the restorations examined during the recall. No marginal discontinuation whatsoever and no abrasion of the antagonist tooth occurred. The esthetic appearance was rated very good to excellent.

Conclusion :

IPS e.max Ceram is very well suited for the veneering of zirconium oxide. It is convincing with regard to esthetics and function.

Reference:

(Farah and Powers, 2010)

Biocompatibility
Definition of Terms
Literature

Biocompatibility is defined as the absence of any undesired effect of a substance or a material (e.g. of a dental material) on human beings. The test indicates the reactivity or tolerance of individual cells (most frequently mouse fibroblasts) on soluble compounds of a (dental) material. If the test results show positive effects, further, more complex tests must be conducted to enable the assessment of the biocompatibility in the human organism. Cytotoxicity is the biological property easiest to measure, but it has only limited significance as an independent test to evaluate the biocompatibility of a dental material. Only clinical experiences provide a final and significant evaluation of the biocompatibility.
The biocompatibility of lithium disilicate glass-ceramics was intensively assessed on the basis of toxicity data as well as data found in the literature. The studies included cytotoxicity tests conducted by various institutes (see list below). In these tests, lithium disilicate showed no cytotoxicity, mutagenicity or in vivo toxicity.

Cytotoxicity:

- 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.

Mutagenicity:

- 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.

In vivo toxicity:

- Toxicon Report 03-5936-G1 14 day repeat dose intravenous toxicity study, November 2004
- Toxicon Report 03-5930-G1 Short term intramuscular implantation test, December 2004

Solubility:

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. The analysis of ions dissolved of IPS e.max Press and IPS e.max CAD specimens in artificial saliva and acetic acid demonstrate a rather low content of detectable ions. The concentrations were in the same range as those of other dental ceramics. Therefore, it can be considered extremely unlikely that the soluble components of the ceramic cause negative effects, such as cytotoxicity.

Conclusion:

IPS e.max lithium disilicate ceramic was examined for its toxicological potential with regard to its use as a medical product. Even though dental ceramics are generally known to demonstrate high biocompatibility, various studies were conducted by independent laboratories. Furthermore, ten years of clinical experience are testament to the safety of the material.
Many researchers publish toxicological data. The experimental conditions may be selected in such a way that an immense variability of the results ensues. This explains why certain tests detected cytotoxicity, while others did not. The clinical efficiency over more than ten years, as well as the results of several certified testing institutions with regard to cytotoxicity and in vivo tests are more significant than individual publications on in vitro toxicity.

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). The flexural strength strongly depends on the measuring method used and the surface texture (polished, ground). In order to compare data, the method always has to be indicated in diagrams. The comparison of flexural strength values achieved with different measuring methods is not admissible. The strength is indicated in MPa (megapascal).

Fracture load / Fracture resistance

The fracture load/fracture resistance indicates the value that causes a component to fracture. These values are mostly indicated in N (Newton), which is actually a load.

Fracture toughness

The fracture toughness K_{IC} is a unit of measure for the resistance of a material to crack propagation. K_{IC} 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. Same as for the flexural strength values, the results of individual measurements can only be compared if the same methods are used to measure the fracture toughness K_{IC}. It is not the purpose of this documentation to discuss each individual method in detail. Instead, the two methods utilized to determine the fracture toughness of IPS e.max Press are briefly described below.

IF (Indentation Fracture Technique):
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):
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 created by means of a diamond bur, razor blade, and polishing paste. The test specimens are then subjected to a strength test. The K_{IC} value is calculated in accordance with ISO 6872:2008.

Modulus of elasticity

The modulus of elasticity describes the stiffness of the material, i..e the resistance against elastic deformation.

Fatigue behaviour

Fatigue is the damage of a component caused by cyclic stress. Cyclic tests are used to determine the fatigue behaviour of a component / material. Thermocycling tests, for example, are fatigue tests.

Hardness

The hardness of a material is the resistance of a material to the penetration by another body. There are various methods to determine the hardness, e.g. Vickers, Knoop, Brinell, 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 the hardness, the corresponding method and sometimes also the load and duration of the load application has to be indicated. A comparison of values is only admissible if the values were obtained with the same method.

Kaplan-Meier survival

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 a restoration. A special characteristic of these survival curves is that they also take the subjects (patients and/or restorations) which drop out of the study at a certain time, e.g. because a patient does not appear for the recalls, into account.
With the help of the Kaplan-Meier curves, forecasts can be made, for example about how many restorations are still intact after a certain number of years.

Chewing simulation

During the development of new materials, it is important to determine the fracture proneness of said materials under the expected stress conditions in the oral cavity. In addition to clinical studies in the oral cavity of patients, and most frequently before those, chewing simulations can be conducted. The advantage of a chewing simulator is that the results are available in a comparatively short time and that materials can be tested and compared under heavily standardized conditions.

The test specimens are adhesively cemented to standardized PMMA dies and then subjected to cyclic, eccentric load with a pointed steel antagonist in a water bath. The load is continuously increased, e.g. 100,000 cycles with approximately 80 N, 100,000 cycles with approximately 150 N, 100,000 cycles with approximately 220 N (0.8 Hz). At the same time, the test specimens are subjected to thermocycling of 105 s each at 5 °C and 105 s at 55 °C. The number of cycles until the occurrence of fracture or chipping 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 subjected to 2 million cycles (2 Hz, water at 37 °C/99 °F).

Cohesive /adhesive chipping:

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 framework material and veneer.

Mechanical properties

In materials science, there are numerous test methods to determine the mechanical properties of materials. The objective of mechanical testing of dental materials is to make estimates about the clinical efficiency of a material. However, the standard test methods most frequently test only isolated stress conditions; the effects on a material are much more complex in clinical reality. Nevertheless, materials science examinations in a laboratory permit the comparison of different materials and their relative suitability.

Studies

Studies are conducted to forecast or examine the behaviour of materials when used for the intended application. Most frequently, the aspects of functionality, reliability and safety, compatibility, or user friendliness are of interest.

***In vitro* studies:**

In vitro means "in glass", i.e. these are examinations conducted in a laboratory. Many materials science or toxicological tests are carried out "in vitro", since they cannot be conducted on human beings for practical (test assembly cannot be used in patients) or ethical reasons. Moreover, in vitro studies present the advantage that researches can work under standardized conditions, while the results of studies involving human beings always exhibit a certain natural scattering due to the differences among individuals. Additionally, laboratory examinations are quicker and less expensive than in vivo studies.

In vivo studies:

In vivo means "on the living object", i.e. clinical studies on human beings. The advantage of in vivo studies is that they are conducted under "real" conditions, while laboratory examinations are always artificial to a certain degree and thus have only limited significance. In vivo studies, however, are very complex due to the wealth of possible influencing factors and require exact planning, systematic methods and statistically correct evaluation. Randomized and controlled studies are the most valuable ones. This means that there are two study groups, which should be similar with regard to age, gender, social and medical background to as large an extent as possible (randomization). Controlled is defined as follows: One group obtains the test material, while the other is treated with a (known, clinically tested) comparable material.

Prospective study:

A study planned to be conducted in the future in order to test a certain hypothesis (e.g. 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 subsequently evaluated.

Retrospective study:

Analysis of data collected in the past. 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.

Survival rate:

The share of restorations that are entirely intact or show only repairable deficiencies (e.g. chipping that can be repaired by polishing or with composite; crowns that can be recemented after decementation) so that the restorations may remain in the oral cavity.

Toxicity/cytotoxicity

The **toxicity** is the property of a substance to have a poisonous effect on an organism. There are different toxic effects on various parts of the body depending on whether individual organs or cells are affected or the entire organism shuts down. The various mechanisms leading to toxicity are also distinguished (e.g. inhibition of cellular functions, causing cancer).

A substance is **cytotoxic** if it causes the death of cells. Causes may include, for example, the interruption of the energy supply of the cell or the dissolution of the cell membrane. In case of low cytotoxicity, only few cells are affected, which often does not have any lasting consequences for the organism since most cells can be regenerated. High cytotoxicity, however, may cause lasting damage, for example, if too many liver cells or blood cells die off so that the body cannot properly function any longer.

Weibull theory, Weibull statistics

Compared to other materials, ceramics show a special strength behaviour. Ceramic fractures originate from imperfections in the component. Hence the number of imperfections greatly influences the strength values, which causes a relatively wide scattering of the measured data. Furthermore, the values also depend on the size of the component, i.e. the smaller the component, the less imperfections are present and, consequently, the higher is the strength. Weibull statistics takes these aspects into consideration.

The Weibull modulus m makes a statement about the reliability of a material; the higher m is, the more reliable are 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, what is known as the Weibull strength $\sigma_{63.21\%}$ is often mentioned, which indicates the load at which 63.21% of all samples measured in a single series of measurements fail. Other terms used for Weibull strength are "characteristic strength" or "mean strength".

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