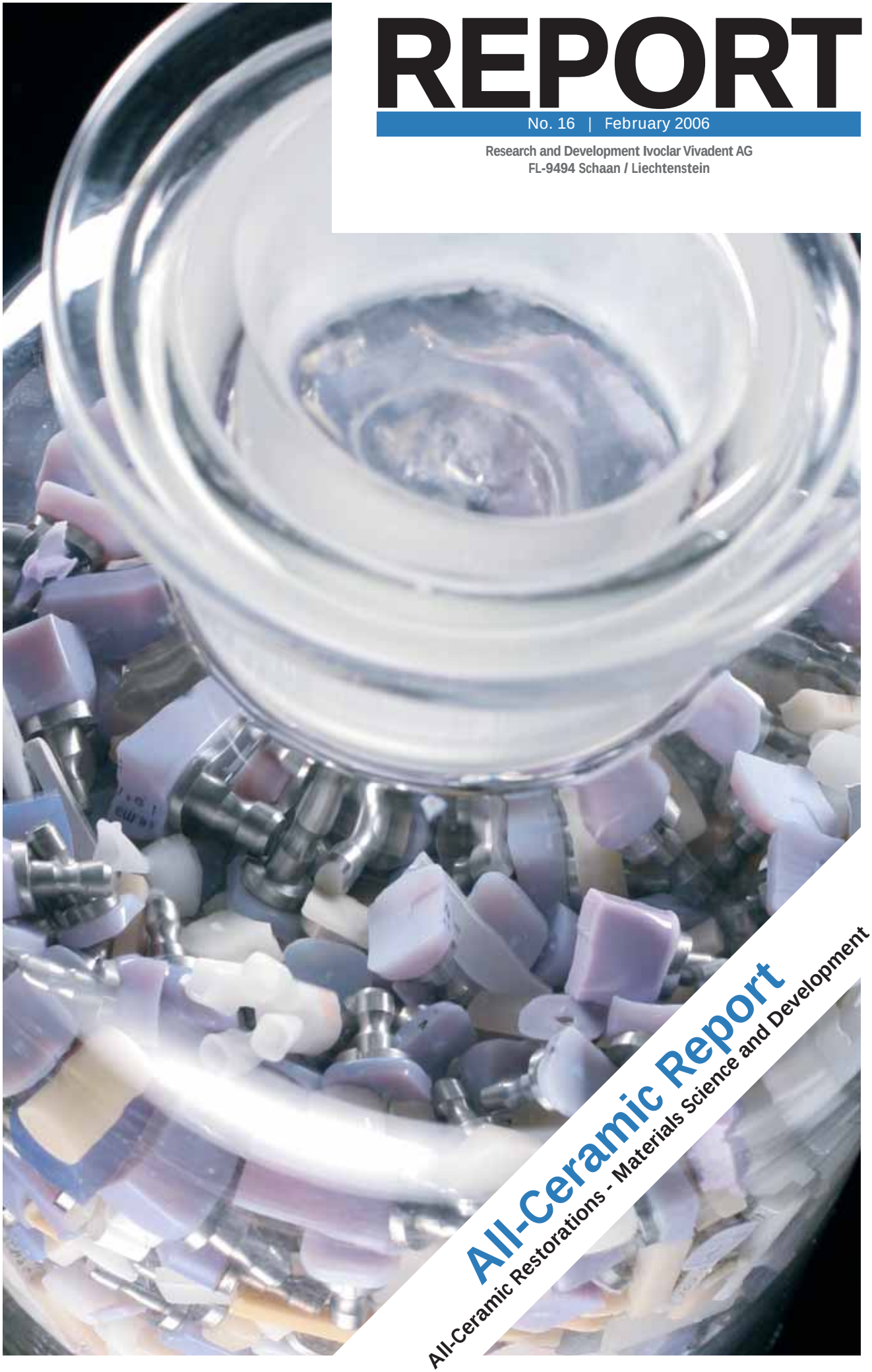
REPORT

No. 16 | February 2006

Research and Development Ivoclar Vivadent AG
FL-9494 Schaan / Liechtenstein



All-Ceramic Report

All-Ceramic Restorations - Materials Science and Development

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Introduction

All-ceramic restorations are increasingly becoming the first choice for highly aesthetic results

The trend towards all-ceramics is becoming more and more popular every year. This development is also reflected by the continuously growing market. The trend not only prevails among experts but particularly among patients, as metal-free restorations ideally meet the increased demands of consumers on aesthetics and comfort. The break-through in metal-free restorations began in 1991 with IPS Empress. For more than 15 years, IPS Empress has been synonymous with highly aesthetic pressed all-ceramic restorations.
For the attractive and strongly expanding CAD/CAM market, Ivoclar Vivadent has been offering the proven leucite-reinforced glass-ceramic blocks IPS ProCAD for years.

Since autumn 2005, the innovative materials system IPS e.max has been ideally supplementing the all-ceramic range from Ivoclar Vivadent with high-strength and highly aesthetic materials for both the PRESS and the CAD/CAM technique.

The independent magazine "Die Zahnarztwoche" (DZW) has compiled an article series covering 12 parts on all-ceramics together with Ivoclar Vivadent. All the important information on all-ceramics for dentists and dental technicians is summarized in these articles. This article series was published in the DZW from September to December 2005. A summary of the articles is presented in this report.

All-ceramics – a real success story…

Dr. Volker Rheinberger

The Director of Research at Ivoclar Vivadent, Dr. Volker Rheinberger, has been instrumental in the development of IPS Empress and IPS e.max. He has gained a wealth of experience in the development of dental all-ceramics over the past 15 years.

Specific requirements for dental all-ceramics

The use of all-ceramics for the fabrication of restorations places specific requirements on the materials system. The strength has to comply with the indication, chemical resistance has to be provided and above all, there are high demands on the optical properties in order to achieve optimum aesthetics.

While sintering ceramics for dental use, particularly oxide ceramics, such as aluminium oxide or zirconium oxide, attain high strength values, compromises have to be made as regards the optical quality. In a completely sintered state, the mentioned materials are very tough – it is physically more appropriate to speak of fracture resistance or fracture toughness. This in turn, requires superior processing techniques. These can be very expensive and therefore uneconomical. However, considerable progress has been made in this respect as a result of the development of CAD/CAM technology and the processing of materials in the presintered, ie still relatively soft state.

Glass-ceramics offer decisive advantages as regards optical quality, ie aesthetics. As the name suggests, glass-ceramics is a bit of both glass and ceramics, that is a combination of the specific properties of glasses and those of ceramics. A glass-ceramic exhibits at least one amorphous glass phase and one crystal phase.

This is achieved by selective and controlled crystallization within a base glass. The chemical composition and correct control of crystallization can be used to endow the glass-ceramic with specific properties, such as those appropriate for dental use. A further advantage of glass-ceramics is that glass can be shaped easily, for example, by casting. Subsequently, the soft glass can be transformed into a tough glass-ceramic without deformation by means of controlled crystallization.

Conventional powder technology

The conventional powder technology, however, is more popular. Here, the glass-ceramic is layered as a powder and subsequently sintered or fired.

An early example of dental glass-ceramics was Dicor (developed by the US company Corning in 1984) – a mica glass-ceramic which utilized both the casting process and mechanical processing for shaping, followed by a crystallization process of several hours.

Aesthetic revolution with IPS Empress

The real break-through in the development of dental all-ceramics was achieved with IPS Empress from Ivoclar Vivadent AG (1991). IPS Empress is a leucite glass-ceramic, ie a glass with reinforcing leucite crystals. It was not only the strength and optical quality of this new glass-ceramic that paved the road to success, but the new press procedure to shape the material represented a considerable contribution to the cost effectiveness of the system. The use of what is known as the viscous flow principle during the press procedure into a mould results in excellent accuracy of fit of the fabricated dental reconstructions.

A leucite-reinforced glass-ceramic that is similar to that of IPS Empress can also be found in the ProCAD blocks (1998), which have been especially developed for use in CAD/CAM systems.

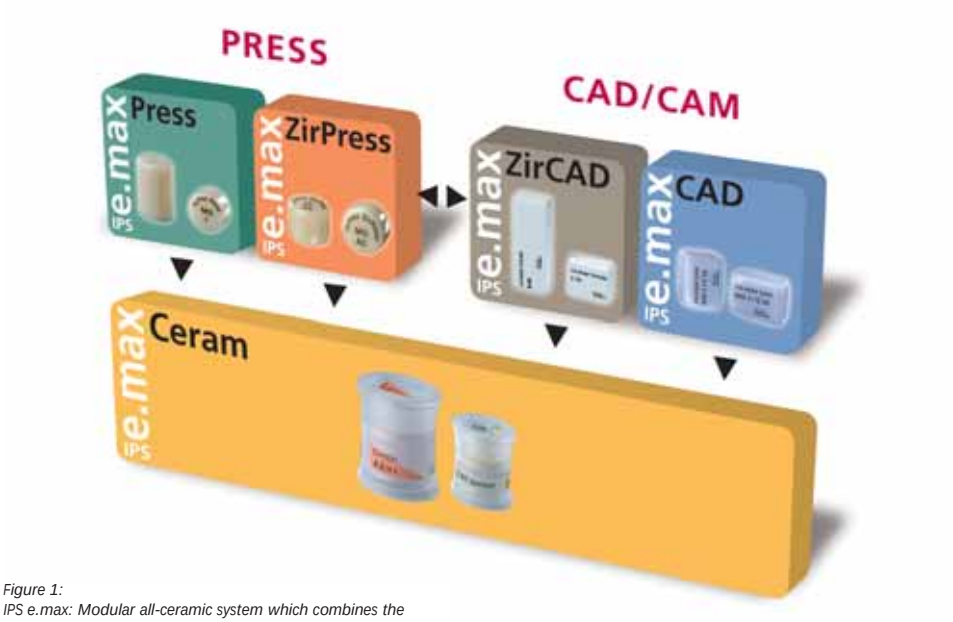


Figure 1:
IPS e.max: Modular all-ceramic system which combines the sintering, press and CAD/CAM technologies.

A further development in dental glass-ceramics was achieved by Ivoclar Vivadent AG with IPS Empress 2 (1998), which is based on a new chemistry. It is a lithium disilicate system. An exceptionally high share of well developed lithium disilicate crystals (65 +/- 5 %) in a glass matrix results in high strength and thus extends the range of indications. For the fabrication of a perfect overall result, the suitable layering ceramic IPS Eris had to be developed. Here, needle-type fluorapatite crystals represent the main phase that is responsible for the tooth-like optical properties.

Market trend 1: press technology

In the meantime, about 25 competitive systems are available. The IPS Empress System is the international market leader. To date, more than 25 million restorations have been fabricated with IPS Empress and the numbers continue to grow. Due to the ongoing market success and the progressive market acceptance, press technology has become a state-of-the-art processing technique.

A slowly emerging trend has been noted, which involves a technique in which another ceramic is pressed onto zirconium oxide. The press-on technique combines both CAD/CAM and press technology.

Market trend 2: CAD/CAM technology

In the CAD/CAM main markets, zirconium oxide has been the main subject of the past few years. The market share compared to conventional all-ceramic systems is still small but characterized by two-digit growth rates. Apart from the main markets Germany and the US, the CAD/CAM market is still a small but tremendously growing segment. Chair-side systems (eg Sirona CEREC) show a remarkable market potential.

Conclusion:

The two technologies can be ideally combined by the press-on technique for zirconium oxide. Consequently, the press technique will also benefit from the success of CAD/CAM technology.

A further emerging trend is the processing of zirconium oxide in a white state, as it is more economical than hard body machining.

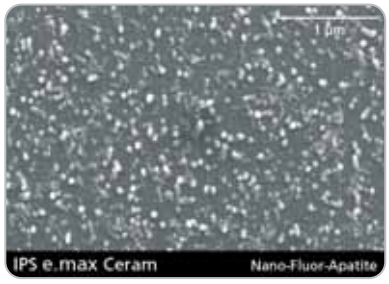


Figure 2:
The SEM image shows fluorapatite crystals in the nanometer range. These crystals are responsible for the tooth-like optical properties of the material.

Figure 3a and b:
The very homogeneous glass is converted into a glass-ceramic with a very high share of lithium disilicate crystals by means of a suitable time/temperature regime (clearly visible on the SEM image).

The evolution continues – IPS e.max

With the launch of IPS e.max (autumn 2005) (Figure 1) Ivoclar Vivadent AG is again setting a new standard in dental ceramics. IPS e.max is a modular all-ceramic system, which combines the conventional powder/sintering technique with CAD/CAM and press technology in such a way that all the modules, ie individual components, are compatible with each other. For this purpose, completely new methods had to be applied in the development, not only as regards the chemical background but also the processing techniques.

The newly developed IPS e.max Ceram (Figure 2) is a glass-ceramic with fluorapatite crystals in the nanometer range, which are responsible for the tooth-like optical properties and thus ensure outstanding aesthetics. IPS e.max Ceram is compatible with zirconium oxide and lithium disilicate. Consequently, the ceramic can be conveniently layered on zirconium oxide and lithium disilicate frameworks.

IPS e.max Press (Figure 3) is an all-ceramic based on lithium disilicate chemistry for use in press technology applications. The previously described high crystal density results in excellent mechanical properties without compromising the optical quality. New processing technologies have been developed for the fabrication process of this new material. The initial glass shows excellent homogeneity and is transformed into glass-ceramics during a further fabrication process by means of a specific time/temperature regime. The outcome is high strength combined with excellent aesthetics.

IPS e.max ZirPress is based on a similar chemistry as that of IPS e.max Ceram. The coefficient of thermal expansion is adjusted in such a way that the material can be directly pressed onto high-strength zirconium oxide frameworks. As IPS e.max ZirPress and IPS e.max Ceram are very similar as fluorapatite glass-ceramics, they are also compatible with each other. Hence, IPS e.max Ceram can be layered on IPS e.max ZirPress to achieve outstanding aesthetic results.

Zirconium oxide is by far the strongest ceramic material for dental use at present. It is not only extremely strong in a densely sintered state but also very tough. Therefore, mechanical processing in this state is problematic from an economic point of view. The processing times are long, the service life of tools is short and the machine costs are relatively high. Consequently, it is better to process zirconium oxide in a white state, ie in a presintered state, and to subsequently sinter it to full density at 1500 °C. The respective software takes the sintering shrinkage in the CAD/CAM technique into account to finally produce an accurately fitting workpiece. IPS e.max ZirCAD is an yttrium-stabilized zirconium oxide in a pre-sintered white state, that can be easily machined using CAD/CAM methods. A zirconium oxide bridge framework is designed to withstand high loading. IPS e.max ZirPress can be pressed onto the frameworks or subsequently the IPS e.max Ceram veneering material can be applied in layers.

An intermediate stage between pure glass and fully developed glass-ceramics is what is known as "blue ceramic", namely IPS e.max CAD (Figure 4). For CAM processing, the material properties and machine parameters have to be coordinated and optimized as regards efficiency. Glass is relatively soft and

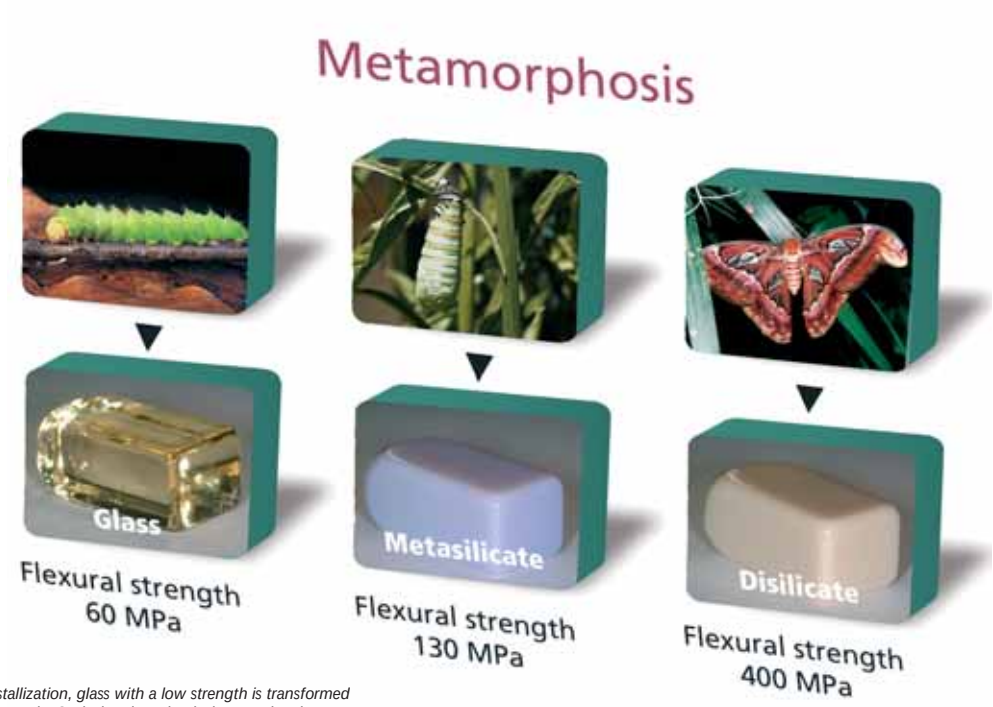


Figure 4:
By means of controlled crystallization, glass with a low strength is transformed into a high-strength glass-ceramic. Optical and mechanical properties change (metamorphosis) while.

exhibits a low resistance during grinding or cutting. In other words: tools and machines are protected from damage. However, glass tends to delaminate and fracture during machining due to the brittleness of the material. On the other hand, the fully crystallized lithium disilicate glass-ceramic is particularly tough. Thus, the material is unlikely to fracture during the CAM process. As a consequence of the desired toughness for dental applications and the high strength of the lithium disilicate glass-ceramic, the service life of the tools is very short and the processing times are long. Thus, something between a pure glass state and a strong glass-ceramic would be ideal for the CAM process. Exactly this goal was pursued in the development of what is known as blue ceramic, IPS e.max CAD. The material is a lithium metasilicate glass-ceramic. The metasilicate crystals reinforce the glass matrix in such a way that the workpiece does not fracture during grinding. At the same time, the material is not that strong as to compromise the efficiency of the process as a result of a long processing time and short service life of the tools. In a downstream thermal treatment in the Programat ceramic furnace, the metasilicate is completely converted into the tough and strong form of the disilicate. In this process, the material obtains its desired tooth shade and translucency. It is an absolutely fascinating material that can appear as one and the same thing in several versions as in a metamorphosis. With exactly the same chemical composition, this material can either be a completely homogeneous and transparent glass or a stronger but not tough blue glass-ceramic, or finally a strong glass-ceramic that exhibits optical properties similar to those of natural teeth. The key to this phenomenon is the accurately controlled crystallization.

The IPS e.max system covers a wide range of indications for dental metal-free restorations by combining various materials and processes.

Typical material properties and materials science aspects of all-ceramic systems

Prof. Heinrich F. Kappert

In this chapter, materials scientist Prof. Dr. Heinrich F. Kappert describes the typical material properties and material science aspects of all-ceramic systems. For almost 25 years, first as a university professor in Freiburg (Germany) and now as Sector Manager in the technical Research & Development Department of Ivoclar Vivadent in Schaan, Prof. Kappert has observed the exciting developments in all-ceramics.

Dental ceramics as an alternative to dental alloys

Dental ceramics are more and more considered to be an alternative to dental alloys. Their attractiveness is mainly based on their aesthetic, tooth-coloured appearance, but also on the largely undisputed compatibility of these materials. More than 40 years of clinical experience are available on metal-ceramic materials to back this fact. For metal-ceramics, however, metal support is indispensable, since this ceramic type does not demonstrate a particularly high strength. Since the development and market launch of In-Ceram, the aluminium oxide-reinforced ceramic (Vita, Bad Säckingen, Germany) [16, 93], and especially the pressed ceramic IPS Empress (Ivoclar Vivadent Schaan, Liechtenstein) at the beginning of the nineties, however, the interest has focused on the use of dental ceramic as a framework material for crowns and bridges. At the end of the nineties, the lithium disilicate ceramic IPS Empress 2 (Ivoclar Vivadent Schaan, Liechtenstein) was introduced to the market [42, 23, 91], which even enabled the fabrication of smaller, metal-free bridges for the anterior region in addition to crowns. With IPS Empress 2, a new glass with the new crystal type 'lithium disilicate' was made usable for dental-lab technology. The oblong, rod-shaped structure of the crystals with a diameter of less than 1 mm and lengths of slightly more than 1 mm (Fig. 1) permits an interlocking of these crystals during the glass phase of crystal growth. The result is a strength of more than 300 MPa, which is unusually high for a glass-ceramic material. The new all-ceramic system from Ivoclar Vivadent (Schaan, Liechtenstein), which is marketed under the brand name IPS e.max for the press and the CAD/CAM technology, represents a milestone in ceramics.

At the moment, the closest attention is paid to zirconium oxide [57, 68, 45, 114] and the hope that all the problems with the weaker ceramic types have been overcome, and that, finally, a material has been found, which permits the fabrication of almost all types of metal-free restorations for the posterior region. In order to assess and appraise this progress in the field of dental ceramics, knowledge of the most important physical properties of ceramic materials is necessary and useful.

Fig. 1:
In IPS e.max Press, the glass matrix is approx. 70 % filled with lithium disilicate crystals. The interlocking of the rod-like crystals produces the high strength. The glass matrix was etched away for the SEM images.

Materials science aspects

Modulus of elasticity and flexural strength

The modulus of elasticity and flexural strength are important parameters of a dental ceramic, if it is intended to be used for the fabrication of metal-free frameworks. Dental ceramics are often accused of not being elastic, but rather brittle. Firstly, this statement is wrong and secondly, illogical

1. Elasticity is quantified by the modulus of elasticity. The modulus of elasticity describes the resistance against elastic deformation under load, which is undone without damage to the material as soon as the load is removed. Basically, all materials have this property. The alloys and ceramics commonly used in dentistry have even a fairly similar modulus of elasticity (Fig. 2). Precious metal alloys show a modulus of elasticity of approximately 80 – 130 GPa, base metal alloys one in the range of 180 – 230 GPa. This fact is utilized for metal-supported dental restorations, if, for example, particularly delicate structures for high-stress areas are required and CoCr alloys are used for the purpose. Dental ceramics feature a modulus of elasticity of 50 GPa for simple glass-ceramics and 300 GPa for aluminium oxide. In case of elastic deformation, therefore, and depending on the ceramic type used, their resistance to stress is similar to that of dental alloys. The statement that ceramics are not elastic is hence wrong.

2. The important aspect is the limit of elastic deformation. For dental alloys, the technical elastic limit is indicated by the 0.2 % proof stress. Any load higher than this limit results in lasting plastic deformation. Lasting deformation constitutes damage to the material. In dentistry, this type of deformation is not acceptable, since it compromises the occlusion, as well as the accuracy of fit. All reconstructions and their cross-sections must be designed in such a way that they never undergo plastic deformation when subject to the usual masticatory forces. Unlike metals, dental ceramics cannot undergo plastic deformation at oral temperatures. Even though they allow elastic deformation similar to metals, once they reach the limit of their elastic deformation they fracture. This fact is called brittleness. All ceramic restorations and their cross-sections and dimensions must be designed in such a way that they never fracture under the usual masticatory forces. The difference between ceramic and metal, therefore, only becomes evident once the elastic limit is reached. Metals suffer plastic deformation under higher loads, while ceramic materials fracture (Fig. 3a-d). The difference between metals and ceramics is, therefore, that one material can undergo plastic deformation (i.e. is ductile or tough), while the ceramic is brittle. Both material groups demonstrate elasticity. The above statement is, therefore, illogical, since brittleness is not the opposite of elasticity, but of plasticity (ductility, toughness).

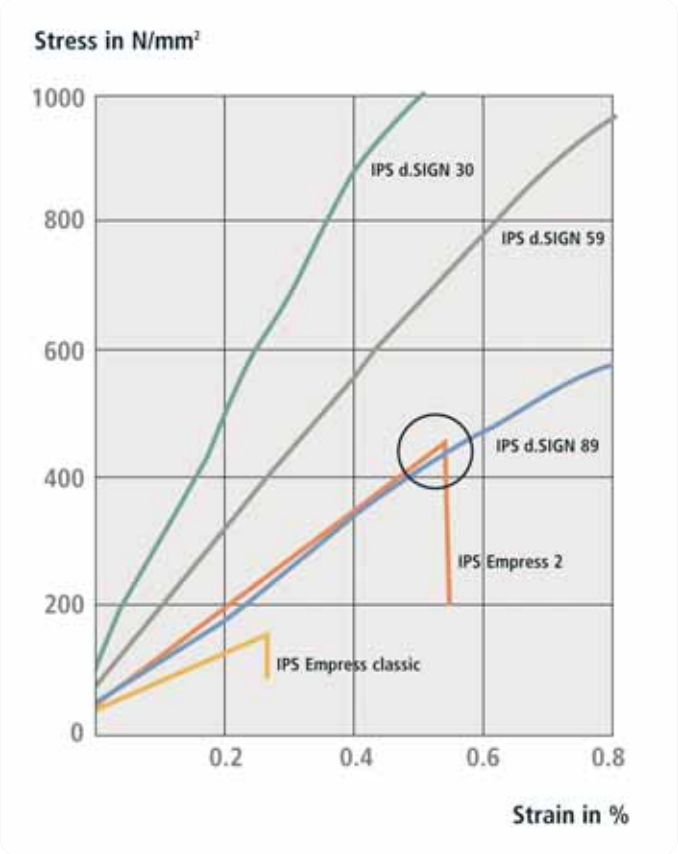


Fig. 2:
Stress-strain diagrams of five dental materials: IPS Empress classic leucite-reinforced glass-ceramic, IPS Empress 2 lithium dislocate-reinforced glass-ceramic, IPS d.SIGN 98 gold alloy, IPS d.SIGN 59 palladium alloy, and IPS d.SIGN 30 CoCr alloys. Especially the comparison of the two measuring curves of IPS Empress 2 and IPS d.SIGN 98 (see blue circle) shows that the linear, elastic part of the stress-strain curve is identical with matching modulus of elasticity until the IPS Empress 2 ceramic fractures at 430 MPa (= flexural strength), which is the same point at which the IPS d.SIGN 98 alloy changes to the plastic range (elastic limit).

The advantage of a higher modulus of elasticity is known in dental-lab technology from comparisons of base metal alloys (e.g. CoCr) with precious metal alloys. One group features a modulus of elasticity of approximately 200 GPa, the other of only 100 GPa. For delicate structures, this advantage is used in dentistry to achieve higher stress resistance and to protect any possibly present ceramic veneer from delamination and crack development with a more rigid framework. In all-ceramic compound systems, the veneering ceramic is also better protected from crack formation and delamination if the resistance against elastic deformation (i.e. a high modulus of elasticity) is higher.

Fracture toughness

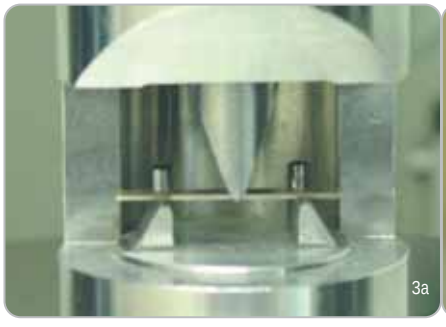
The fracture toughness describes the resistance of a material against crack propagation at the crack opening. This property is particularly pronounced in metals, for which the measured values range between 60 and 100 MPa $m^{1/2}$. In this regard, ceramics are basically inferior to metals. For simple glasses, values of approximately 0.7 – 1 MPa $m^{1/2}$ are measured, while the values for dental ceramics with well-distributed leucite crystals may slightly exceed 1 MPa $m^{1/2}$. The measured values for oxide-reinforced ceramics and the IPS Empress 2 lithium disilicate ceramic range between 3 and 6 MPa $m^{1/2}$, those of oxide ceramics slightly higher. For zirconium oxide, peak values of up to 10 MPa $m^{1/2}$ have been reported.

It goes without saying that the resistance against crack propagation shows its advantage particularly if flaws in the form of pores, entrapped contamination, or actual cracks are present at the surfaces, e.g. as a result of inappropriate grinding. The risk of crack propagation then originates from the most severe flow or even an incipient crack that may be in the mm range and may eventually lead to the premature failure of the ceramic restoration. The higher the resistance against such crack propagation, i.e. the higher the measured value for the fracture toughness, the more reliable is the long-term behaviour of the material under equal conditions of flaw distribution. This is the special appeal of the zirconium oxide ceramic with the highest available fracture toughness value in the field of dental ceramics, which, in combination with possibly flawless, industrially fabricated ingots, provides the highest reliability.

Coefficient of Thermal Expansion (CTE)

In conjunction with the framework material, the veneering ceramic must have two important properties:

1. A sound bond must be formed between the two partners during firing, and
2. the Coefficients of Thermal Expansion (CTE) of the two materials must be coordinated during the cooling phase after firing, as well as upon alternating thermal stress in the oral cavity.


3a


3b


3c

Similar as with all-ceramic systems, some systems pursue the idea that the (stronger) framework ceramics exerts certain compressive stress on the (weaker) veneering ceramic during the cooling phase due to the slightly (up to 10 %) higher CTE and thus creates a certain safety zone for the veneering ceramic. However, this principle must not be overtaxed. Furthermore, the framework ceramic, which is set under tensile stress at the same time, is truly strong enough and is provided with an adequately thick geometry.

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Chemical solubility

The chemical solubility of a material is determined according to the international standard applying for the dental industry in a 16-hour acetic acid test, which is certainly a very one-sided test, since manifold chemical attacks occur in the oral cavity. Nevertheless, the test result provides a rough indication for the oral resistance. The standard only permits ceramic materials with a chemical solubility of less than 100 µg/cm² if they are intended to be directly exposed to the oral environment, such as veneering ceramics. Microscopic investigations have shown that this limit correlates with the formation of surface defects, which result in rougher surfaces and thus to increased plaque retention. These surface defects may also lower the strength of the ceramic. In this way, good chemical resistance directly affects the clinical aspects.

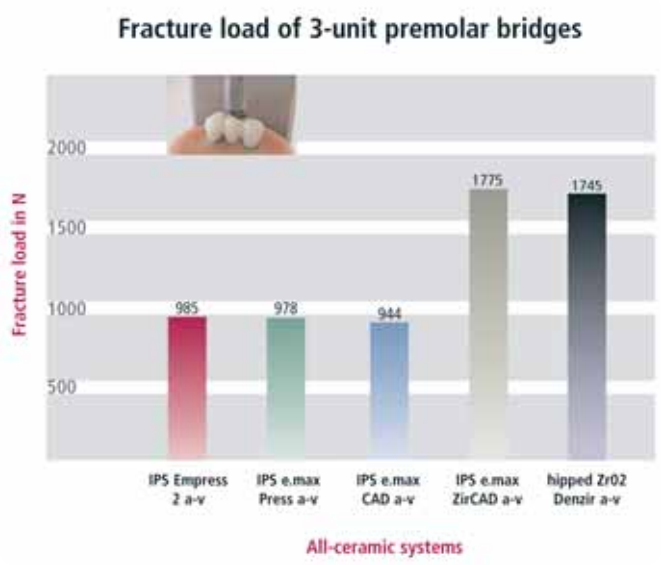


Fig. 4:
Results of the fracture resistance tests of three-unit premolar bridges with connector dimensions of 16 mm2. Since 500 N are sufficient for the physiological masticatory forces, the lithium disilicate bridges feature a double safety margin. The zirconium oxide bridges with these connector dimensions show such a high strength that a reduction of the connector dimensions is permitted.

Component strength and clinical usefulness

New materials might have brilliant properties and new techniques might present fascinating working procedures. Nevertheless, there is no guarantee that the procedure leads to useful results. For the final assessment of the suitability of new processing techniques or materials for the fabrication of dental restorations, the entire dental-lab fabrication procedure must be used with the corresponding materials and the fabricated component, i.e. crowns or bridges, must be able to stand comparative testing. A popular procedure to test the strength of crowns and bridges was described in earlier publications (Fig. 4). The last and absolutely necessary authority for the assessment of a new technology and innovative materials, however, is long-term clinical testing.

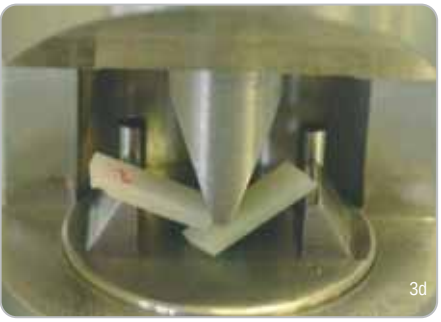


Fig. 3:
Three-point bending test with metal and ceramic test samples:
IPS d.SIGN 98 initial stage,

b) IPS Empress 2 initial stage,
c) IPS d.SIGN 98 at 430 MPa, plastic deformation
b) IPS Empress 2 at 430 MPa, fracture

Chapter 3

Biocompatibility of dental ceramics

Patrik Oehri

How biocompatible are ceramic materials? How much truth is there to the claims regarding the radioactivity of ceramic materials? These issues will be investigated in this part. In his capacity as Sector Manager, Patrik Oehri is responsible for the scientific studies and tests performed on dental materials at the Research and Development Centre of Ivoclar Vivadent in Schaan, Liechtenstein. The Liechtenstein based company carried out extensive investigations on the biocompatibility of dental materials and gathered a great deal of experience and expertise in this field long before it developed and launched IPS Empress – a material which marked the beginning of the triumphal march of all-ceramics through dentistry fifteen years ago.

The ceramic materials used in dentistry are regarded as exceptionally "biocompatible" [2]. In Germany in particular, the debate over the possible harmful effects of metal-containing dental materials has been ongoing for the past two decades. The general gist of this controversy has developed along the lines of moving away from amalgam and saying no to nickel or palladium. In addition to aesthetic reasons, these concerns lie at the heart of the patients' wish to have no metal in the mouth. This requirement has fed the trend towards "biocompatible" all-ceramic systems.

Biocompatibility may generally be regarded as a material's quality of being compatible with the biological environment [67], i.e. the material's ability to interact with living tissues by causing no, or very little, biological reactions. A dental material is considered to be "biocompatible" if its properties and function match the biological environment of the body and do not cause any unwanted reactions [120].

Evaluation of biocompatibility

Biocompatibility describes more than a mere property of a material. More exactly, the term refers to the interaction between a material and the biological environment. The biocompatibility of a medical device such as a dental ceramic is evaluated according to international standards. The most important, relevant standards are EN ISO 10993 – Biological evaluation of medical devices [32] – and EN ISO 7405 [30]. The latter has been specifically formulated for testing the biocompatibility of medical materials used in dentistry. Product standards also apply [29, 31, 54]. These standards define the chemico-physical properties that a material should exhibit. Furthermore, the standards specify strategies and test methods for the expert to evaluate the biological hazard of a material. Essentially, the following criteria come into play: duration of application, degree of invasiveness (application on the tooth surface, in the tooth or bone) and type of contact with the living organism (contact with mucous membrane, bone, blood vessels).

Before actual biocompatibility testing is commenced, the composition and material properties are evaluated. In the process, the evaluator establishes which of the material's substances are well-known and proven to be harmless to the human body. The material's solubility and decomposition profile and its inclination to interact with other substances (e.g. corrosion) are also determined.

Biocompatibility testing proper involves the following two types of tests:

- In-vitro tests with cell cultures and bacteria outside the living organism to assess the cytotoxicity (destructive action on cells) and mutagenicity of the material in question
- Animal testing, mainly on rodents and mini pigs

Clinical studies are often carried out after the biocompatibility tests have been completed. The degree of relevance (including the level of time, work and cost) increases from simple cytotoxity tests to clinical studies. It goes without saying that clinical studies on patients have the highest relevance to the material's fitness for use. Clinical studies with dental materials are hardly ever conducted to test the biocompatibility of a material alone. Such studies are mostly conducted to examine

the function and performance of a material. Side effects that may develop during the study are also observed.

The expert determines how many tests are required to evaluate the biocompatibility of a new material. As many dental materials are composed of ingredients whose effects have been exhaustively investigated, it is often sufficient to conduct simple in-vitro tests only (e.g. cytotoxicity tests).

Generally, in-vitro cytotoxicity and mutagenicity tests are the most commonly conducted investigations in combination with dental materials. On some occasions, animal testing is required to determine the material's irritancy and sensitization or allergic potential. It is important to consider all aspects ranging from material properties and function to the biological environment in evaluating a material's biocompatibility rather than to take into account only a single test or property.

High compatibility of ceramics

Ceramic materials have always enjoyed a good reputation as a biocompatible material [2,3] and this reputation has steadily grown in the past forty years. This trend can certainly be attributed to the distinctive properties of these materials. Naturally occurring feldspar and quartz have been used as raw materials in classic metal ceramic systems for many decades up to the present day. The volatile substances are eliminated in the course of the melting and sintering process involved in the manufacture of the ceramic. The high compatibility of this type of ceramic can be attributed to the following properties:

- Harmless ingredients (mainly oxides of silicon, aluminium, sodium and potassium) [2, 3, 103]
- Very low solubility [103]
- High stability in the oral environment; high resistance to acidic foods and solutions [2, 3]
- Low tendency to plaque formation [2, 3]
- No undesired interaction with other dental materials [2, 3]
- No chemical decomposition involving the release of decomposition products [2,3]

Principally, these ceramics may be described as bioinert [67]. This characteristic does not only apply to classic feldspar ceramic materials. Extensive experience and clinical long-term results have also been gathered for the past ten years [41] on the more recent leucite glass ceramics (IPS Empress, Vita Mark II), which have exhibited excellent compatibility in the oral environment. In the meantime, the most recent types of, in part high-strength, ceramic materials consisting of lithium disilicate glass ceramic (IPS Empress 2), aluminium oxide (Procera) or zirconium oxide (DCS, Lava, Cercon) have also been sufficiently investigated with regard to their behaviour in the oral environment. The relevant results suggest that these materials are also highly biocompatible.

The specialist literature contains data on the implantation and tissue compatibility of sintered TZP zirconium oxide, which is used for artificial hip joints in medical applications. To some extent, these data can be transferred to dental materials, as the initial material is identical in both dental and medical applications.

While extensive investigations have been carried out on composite resins, the dental literature includes only a small number of studies on the biocompatibility of metal and all-ceramic systems [2, 6, 66, 69, 76, 119] due to the excellent reputation of these materials. Most of these studies examine the cytotoxicity of the ceramic materials. The ceramic materials proved to be non-cytotoxic in all publications except one carried out by Messer et al [76]. In Messer's study, freshly prepared IPS Empress 2 showed a cytotoxic effect compared to the other all-ceramic materials investigated. This effect abated as the material aged. It is difficult to find a reason for this result, as it not only contradicts other and in part more relevant toxicological examinations that have been carried out on IPS Empress 2 [80, 117,116] but also stands in stark contrast to the clinical experience gathered on this material over several years [24]. The following chart (Fig. 1) shows the results of a new study carried out on the cytotoxicity of various ceramics by NIOM [80] in Norway. This study did not reveal any statistical difference between individual ceramics but it did show a noticeable difference between the ceramic materials and the resin composites, which were used as a comparison.

It is difficult to find case reports [2, 69] on local or systemic side effects or publications that are critical of dental ceramics. In other words, the experts agree with the generally accepted fact that ceramic materials offer a high level of biocompatibility. Possible antagonist wear of ceramic materials on the opposing dentition continues to be an issue, which, however, is not related to the biocompatibility of a material. Wear mainly depends on the correct choice of material for the appropriate indication as well as on adequate occlusion in the patient.

In view of the existing clinical experience and the data published thus far, we can conclude that, according to the current level of knowledge, the ceramic materials used in dentistry exhibit a high degree of compatibility in the oral cavity. This general statement should not be interpreted to mean that any (new) ceramic is automatically classified as biocompatible. The biocompatibility of each ceramic has to be carefully evaluated in accordance with the relevant standards and regulations and in full knowledge of all the important properties.

Cytotoxicity test

Direct cell contact test, NIOM, 2004

Product	Cellular viability in %
Negative control sample, Teflon	100
Positive control sample, PVC	21.5
Pulp Canal Sealer, Kerr	20
Composite Z100, 3M ESPE	24.5
IPS Empress 2 Framework	84
IPS Empress 2 Layer	105.5
IPS Empress	119.5
IPS e.max Press	109.5
IPS e.max CAD	103.5
IPS Eris	100

Fig. 1:
The cell-toxic effect of various ceramic materials compared to the toxic effect of composite resins or root canal sealers: A cellular viability of more than 80% shows that the material tested is not cytotoxic and a cellular viability below 30% indicates a high level of cytotoxicity.

Radioactivity

Concerns have been raised regarding the possible radioactivity of dental ceramics. The origin of these concerns date back to the seventies, when small amounts of radioactive fluorescent substances [38, 79, 119] were employed in various metal ceramic systems. In this respect, the possible radiation levels were measured in relation to the ceramic materials in the oral cavity [102]. Several alternatives to attain fluorescence in dental materials without using radioactive additives have become available since the eighties. We may therefore assume that all the major manufacturers stopped using radioactive ingredients in their materials from this time onwards. Nonetheless, possible sources of radioactivity cannot be so easily ruled out. Minute impurities of uranium or thorium in raw materials, which are sometimes used in their natural state, or in pigments are difficult to remove [38]. Consequently, the standards on ceramic materials [29, 31, 54] forbid the use of radioactive additives and stipulate the maximum level of radioactivity permissible in ceramic materials. These threshold values are particularly important to zirconium oxide, which is refined and purified from naturally occurring ores.

Biological risk to user and patient

The dental technician is exposed to the highest risk potential (the risk to the dentist is rather negligible) as ceramic materials are frequently ground in the laboratory. The fine mineral dust created in the process should not be breathed in. This potential risk can be eliminated by using suction equipment and a protective mask. The dentist, who handles the completed restoration, is unlikely to face any risk at all. The biological risk posed to the patient is also very low. Ingestion of abraded ceramic particles or swallowing of delaminated ceramic may be considered harmless to the health of the patient. If the ceramic is used for the appropriate indication and adequately fitted to the dentition, local or systemic side effects are unlikely to occur [2, 69].

This synopsis shows that dental ceramics generally involve very low hazard, while they offer a high level of biocompatibility. From this perspective, ceramic materials should be preferred for dental applications.

Chapter 4

Processing technologies for all-ceramic materials (PRESS and CAD/CAM)

Tobias Specht

Two routes to all-ceramic restorations

Tobias Specht, Master Dental Technician and Product Manager for All Ceramics, reports on two major trend developments that he has observed in the past two years: The trend towards aesthetic all-ceramic restorations has accelerated recently, while the cost pressure on dental laboratories has massively intensified. Against such a background, economical CAD/CAM technologies and high-strength zirconium oxide ceramic materials are gaining in importance. However, manufacturing dental reconstructions that are as accurate as they are aesthetic can be a daunting task at times with these technologies.
For the first time ever, a material has now become available that combines the advantages of PRESS and CAD/CAM technologies to achieve truly economical and aesthetic dental restorations. This material is called IPS e.max.

Up into the eighties, gold used to be the material of choice for dentists and dental technicians who sought to circumvent allergic reactions in their patients. However, the trade-off of gold is that it does not allow the request for aesthetic, conservative and metal-free restorations to be fulfilled. Decisive drawbacks of metal-bonded ceramic restorations included corrosion, blockage of light, dark crown margins and discoloured gums. By contrast, all-ceramic restorations offer various benefits: They are compatible with biological tissues, they do not chemically interact with other materials and they transmit light similarly to natural dental enamel. Additionally, they offer a lifelike aesthetic appearance, not least because the margins of all-ceramic restorations are virtually invisible. Modern all-ceramic systems have come a long way from the first all-ceramic materials. In the process, various technologies have been developed. Today, a variety of techniques can be used to achieve all-ceramic restorations.

An early version of a glass ceramic is Dicor (Dentsply International / Corning Glass Works), which was introduced in 1984. This ceramic is processed according to the lost wax technique. A full anatomical wax-up of the restoration is fabricated, embedded in investment material and then the wax is burned out in a purpose-designed furnace. The developers of Dicor took advantage of the fact that glass is comparatively easy to bring into the desired shape. Dicor is poured into the mould by means of a centrifugal casting technique and then subjected to a ceraming process in a ceramic furnace. This process lasts several hours. A major disadvantage of Dicor is its low strength of approx. 160 MPa.

Up until the end of the eighties, the clinical experiences gathered in conjunction with conventionally cemented all-ceramic crown systems proved to be unsatisfactory. In 1989, Vita launched In-Ceram. With this material, the framework is formed from slurries of fine aluminium oxide and water in the slip technique and then sintered. Subsequently, the sintered framework is infused with molten lanthanum glass. This process resulted in single crowns that demonstrated strength values that were in the region of metal-ceramic crowns. Unfortunately, the sintering and infiltration processes required waiting times of up to eight hours. In addition, the resulting restorations demonstrated only low light transmission properties.

Fig.1:
IPS Empress – A state-of-the-art technology since 1991.

PRESS technology – State of the art

In 1991, Ivoclar Vivadent launched IPS Empress. This all-ceramic system allowed the fabrication of all-ceramic restorations in combination with what was then a new technology: the ceramic PRESS technique.

IPS Empress is available in the form of pre-shaded, pre-pressed, vacuum-fired ingots. In the laboratory, a mould is created of a functional, anatomical wax-up according to the lost wax technique. The glass-ceramic ingot is placed in a purpose-designed press furnace, subjected to heat and, having reached the plasticity phase, injected into the mould under pressure. By taking advantage of the material's viscous flow, a high degree of adaptation can be achieved, comparable to the accuracy of fit produced with casting techniques. The desired aesthetic characteristics are attained with stains or layering materials.

IPS Empress restorations are constructed according to the lost wax technique. The mechanical properties of this leucite-reinforced glass-ceramic permit the fabrication of single-tooth restorations, inlays, onlays, veneers, partial crowns and crowns.

The combination of a leucite glass-ceramic and the adhesive bonding technique results in restorations that exhibit outstanding aesthetic and functional properties. Clinical long-term studies, spanning periods of more than ten years, confirm the excellent clinical performance of these restorations.

IPS Empress revolutionized the way in which all-ceramic restorations were fabricated. IPS Empress became the worldwide market leader for the ceramic PRESS technology and all-ceramic systems on account of its highly aesthetic properties and efficacious press technique. In the mid-nineties, a whole host of press ceramic systems were launched on the market; at least twenty such systems are now commercially available.

Given the unmatched aesthetic properties of the TC ingots in particular, the original IPS Empress soon became the yardstick by which all the other all-ceramic systems would be measured. In the past fifteen years, the ceramic PRESS technology has established itself as a state-of-the-art technique, without which most modern dental laboratories would not want to be. Currently, the PRESS technology is gaining in importance due to advent of the press-on technique (e.g. in conjunction with zirconium oxide).

Fig.2:
The EP600 furnace is especially designed for use in combination with the Empress system.

CAD/CAM technology – a trend of the future

Since the seventies, computer-aided manufacturing systems have gradually transformed the working world. Increasing cost pressure and the prospect of being able to manufacture restorations from high-strength ceramic blanks decisively contributed to the fact that CAD technologies (Computer Aided Design) for the CAM production (Computer Aided Manufacturing) of all-ceramic restorations have been developed alongside the ceramic PRESS technology.

Pre-fabricated ceramic ingots offer decisive advantages. For instance, they maintain the physical properties as defined by the manufacturer and they reduce the risk of processing errors. As early as in 1987, Sirona introduced the CEREC system for the chairside construction of ceramic inlays in a single appointment.

CAD/CAM systems digitize the patient's oral situation from a three-dimensional optical image captured in the oral cavity. Consequently, the need for impression-taking is eliminated. The digitized data are transmitted to a computer. Subsequently, the desired restoration is constructed in accordance with the design instructions from the dental database. The design data is then sent to a milling machine, which cuts the restoration out of a prefabricated, homogeneous ceramic block. The whole process takes approx. 20 minutes. The restoration can be customized with ceramic shades and glazes.

The development of such systems has accelerated in recent years. The universal application possibilities of ceramics and the advantages of modern CAD/CAM technologies have encouraged several dental companies to develop digitally controlled manufacturing systems. In as few as three years, the number of dental CAD/CAM systems has steadily risen. These systems can be categorized according to their processing method: Build-up systems reconstruct the crown from the inside by applying ceramic material to a duplicate die. By contrast, cut-back systems read the data of the tooth to be restored and cut the restoration out of a pre-fabricated ceramic blank.

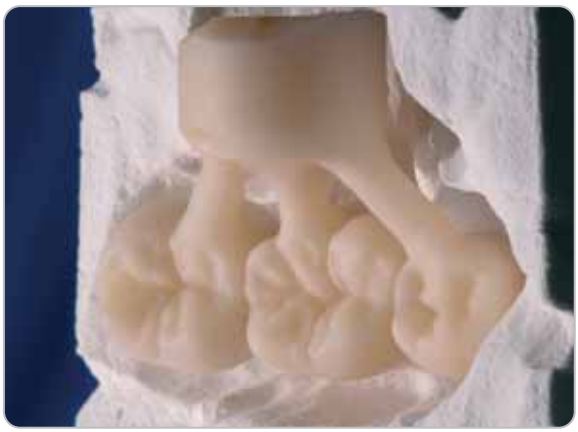


Fig. 3:
The press-on technique opens up new indications.

Economical and reliable

Densely sintered, yttrium-stabilized zirconium oxide is probably the strongest material available for dental applications. Having a strength of 1200 MPa, this material fully covers the load spectrum occurring in the oral cavity. Zirconium oxide is therefore indicated for long-span bridges. Its outstanding qualities enable this material to “heal” defects in the microstructure in what is known as "transformation strengthening". As a result, the material offers excellent long-term stability. However, processing densely sintered zirconium oxide makes high demands on the milling instruments as well as on human patience. Economically speaking, processing the material in a densely sintered form presents a problem.

Fig. 4:
The CEREC unit from Sirona for the chairside fabrication of dental reconstructions

Fig. 5 and 6:
Sirona inLab system and KaVo Everest system

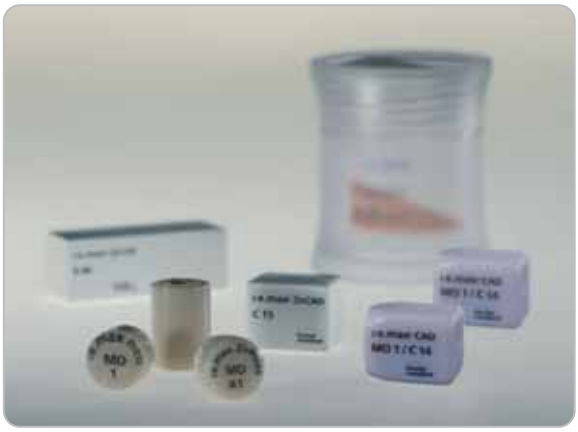


Fig. 7:
With IPS e.max, Ivoclar Vivadent has emphasized its leadership position in the field of all ceramics and closed the gap between PRESS and CAD/CAM technology – and, in doing so, has defined yet another standard.

In order to reduce the time and cost involved in processing this material, most suppliers of CAD/CAM systems predominantly offer zirconium oxide in a partially sintered, "chalky-like" state, which is sometimes also called "white" or "green" phase. If the material is used in this state, the milling times are short and the milling instruments remain in good condition for a prolonged period of time. However, it is important to be aware of the fact that partially sintered zirconium oxide shrinks during the final sintering process. If a cut-back system is used, the CAM unit mills out a framework with a calculated degree of enlargement. As a result, the framework fits on the model only after the final sintering process has been completed. The clinical performance of zirconium oxide restorations has been observed for approx. six years. The results are very promising and confirm that zirconium oxide is capable of fulfilling the clinical requirements of dental restorations.

A stroke of ingenuity

The future of all-ceramic systems, however, does not lie with either the PRESS or CAD/CAM technology alone. In future, laboratories may want to use a combination of both technologies, integrated into a single all-ceramic system, in order to counter the steady increase in cost pressure - a situation that reduces the willingness to invest. As the future in the all-ceramic field rests with both technologies, Ivoclar Vivadent has developed the new IPS e.max all-ceramic system. This system encompasses highly aesthetic, high-strength materials for both the PRESS and CAD/CAM technology. Designing a system that offers simplicity and versatility has been the guiding principle in the development of IPS e.max. As a result, a varied range of materials, from glass ceramic to zirconium oxide, and modern processing technologies have been designed to provide the level of versatility that laboratories require. As all IPS e.max core materials are veneered with the same layering ceramic, a high level of simplicity is ensured - a vital requirement for laboratories that want to work in a profitable, effective manner. Furthermore, IPS e.max offers excellent aesthetic properties, high strength and optimal shade matching, independently of the framework material used. This is particularly advantageous in the fabrication of comprehensive, combined all-ceramic reconstructions.

From inlays to bridges – Indications for the use of all-ceramic materials

Dr. Dr. Andreas Rathke

Inlays are a classic all-ceramic application. With the recent advent of high-strength oxide ceramic materials, it is now even possible to fabricate stress-bearing all-ceramic posterior bridges, which can be cemented in place with a conventional cementation technique. This chapter describes the various indications for the use of all-ceramic materials and the ceramic materials that are best used to cover the individual indications.

The conventional rule that metal-ceramic is indicated for standard treatments and bridges while all-ceramic is best reserved for use in single-tooth restorations has been becoming increasingly obsolete since the introduction of high-strength ceramic materials in fixed dental prosthetics. If the patient prefers to be treated exclusively with all-ceramic restorations, the dentist is now in a position to honour this request. The question arises as to which ceramic material is best suited to cover which indication.

Initial developments of inlay applications

Silicate ceramics, including feldspar and glass ceramics, have proved to be the materials that are best suited for the fabrication of inlays and partial crowns due to their optical properties and reliable long-term clinical performance. Some of these materials feature a particularly homogeneous, dense distribution of leucite crystals and, as a consequence, provide a natural light scattering and balanced chameleon effect. Pressable glass-ceramic materials in particular offer additional, clinically relevant advantages, such as enabling the use of a straightforward anatomical design and providing a high accuracy of fit. All-ceramic inlays are the treatment of choice for high-quality replacements of amalgam fillings (Fig. 1 and 2).

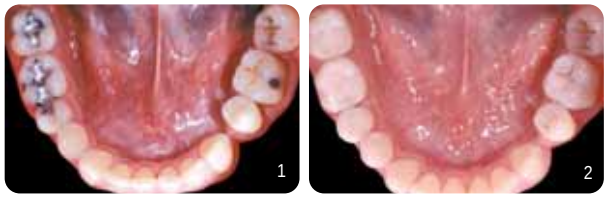


Fig. 1:
The existing amalgam fillings require replacement – a classic all-ceramic indication.

Fig. 2:
The inlays are made of leucite-reinforced glass ceramic (ProCAD, Ivoclar Vivadent) using the CEREC system and cemented in place with an adhesive bonding technique. The resulting restorations naturally blend into the surrounding dentition.

Studies have shown that inlays that have been bonded in place using an adhesive technique achieve a similarly high success rate as cusp-covering partial crowns [70, 71, 97]. Consequently, tooth preparation designs can be restricted to the actual defect and vital teeth can be prepared without cuspal coverage, if possible. The best aesthetic long-term results are accomplished in conjunction with the total bonding technique; as a consequence, the need for the application of a base is eliminated [97].

Veneers and anterior crowns: a subtle interplay of light

Veneers are especially indicated in anterior teeth that allow only minor invasive correction of shade, shape or position. Veneers can be built up in layers with silicate ceramic veneering materials. Usually, feldspar ceramics or glass ceramics, whose optical properties have been enhanced with fluorapatite, are used for this application. Machinable or pressable glass-ceramic materials also present aesthetic options for veneer applications.

Furthermore, glass-ceramic materials are the first choice for anterior crowns and bridges because they offer a high level of translucency and excellent light transmitting properties. It is vital for the light to be able to travel through the remaining tooth structure to the tip of the root in order to endow the restoration with a natural aesthetic appearance. The unnatural looking blockage of light associated with metal ceramic restorations can be avoided if glass ceramic is used. In this respect, crowns fabricated of leucite-reinforced glass ceramic have produced particularly favourable long-term results [40].





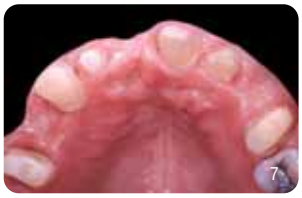
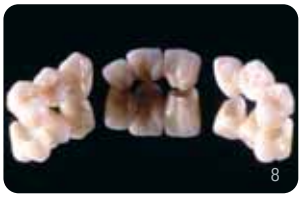




Fig. 3:
The metal ceramic crowns on teeth 11 to 21 caused inflammation and discoloration of the gingiva.

Fig. 4:
After the crowns have been removed, the cast high-gold post-core constructions are exposed. Opaque zirconium oxide frameworks are used to mask the metal structure.

Fig. 5:
Completed zirconium oxide crowns on the model. The crowns are veneered with the IPS e.max Ceram nano-fluorapatite glass-ceramic (Ivoclar Vivadent).

Fig. 6:
The zirconium oxide crowns on teeth 11 and 21 closely match the shade and optical properties of the adjacent teeth.

Fig. 7:
Preparation for three bridges in the anterior maxillary jaw. Tooth 12 is restored with a zirconium oxide post, onto which a core build-up is pressed.

Fig. 8:
Mirror image of the completed bridges made of IPS e.max Press lithium disilicate glass-ceramic (Ivoclar Vivadent). Like the above zirconium oxide crowns, the restorations are veneered with IPS e.max Ceram.

Fig. 9:
The bridges can be cemented in place using a conventional cementation technique due to the high strength of the material.

It may be advisable to use highly opaque ingots or zirconium oxide if metal substructures or severely discoloured prepared teeth are treated (Fig. 3 to 6).

Posterior crowns: robust but beautiful

Both glass and oxide ceramics have proved to be suitable materials for posterior crowns. In clinical studies, lithium disilicate glass ceramic restorations have produced favourable clinical results, including the results for three-unit bridges in the anterior region up to the second premolar, on a par with aluminium oxide ceramic restorations [24]. Recently, a pressable lithium disilicate ceramic demonstrating a flexural strength of 400 MPa has been developed. This high flexural strength, which has not been matched by any other glass ceramic to date, allows the restorations made of this material to be cemented in place using a conventional cementation technique. The manufacturer's directions regarding the field of application, preparation and connector thickness have to be accurately followed to apply this high-strength ceramic correctly (Fig. 7 to 9).

Bridges and abutments: stability matters

For a long time, high stress bearing posterior bridges were regarded as a contraindication of all-ceramic materials. Despite the fact that a relatively limited number of long-term results are available to date, zirconium oxide ceramic is supposed to, at least in part, replace metal ceramic in the future. Given their high strength, zirconium oxide bridges can be cemented in place with a conventional cementation technique. However, if a conventional cementation technique is applied, a retentive tooth preparation design is required. In addition, the restoration should be incorporated in a tension-free manner. If these points are not observed, the material may fail due to its limited fracture toughness. Furthermore, the framework must be adequately dimensioned to prevent the veneering material from delaminating, which, eventually, would require the restoration to be replaced.

The press-on technique presents an alternative to conventionally veneered restorations. In this technique, a glass ceramic material is pressed on a zirconium oxide framework. The resultant glass ceramic layer may be characterized with stains in the staining technique or veneered with a matching veneering material. The press-on technique allows the fabrication of crowns and bridges that feature a similarly high accuracy of fit as pressed glass-ceramic restorations. The staining technique in particular provides a highly economical procedure. Furthermore, zirconium oxide is also suitable for the fabrication of primary crowns, root canal posts and superstructural parts of implant-supported reconstructions.

A veneering material for all indications

Most all-ceramic systems consist of two components: a framework and a veneering ceramic. As the individual systems do not cover the entire range of indications, different framework materials and matching veneering ceramics have to be used for the individual indications. As a result, dental laboratories have been forced to store a large number of ceramic assortments. Now, a newly developed nano-fluorapatite glass-ceramic material provides a solution to this problem. As the firing temperature and coefficient of thermal expansion are coordinated, this ceramic can be used in conjunction with both zirconium oxide and pressed ceramic frameworks (Fig. 5 and 8). Hence, a single all-ceramic system that covers a comprehensive range of indications has become available for the first time ever, eliminating the need for keeping several ceramic systems in store.

Chapter 6

Planning all-ceramic veneers: the art is in creating a natural effect

Dr. Dr. Andreas Rathke

All-ceramic materials are distinguished by their high shade stability and their unique capability of transmitting light into the surrounding tooth structure and gingiva. They are therefore the material of choice for veneer applications. However, the veneering technique requires some finesse, particularly in conjunction with single-tooth veneers. Careful planning is the A and O of creating aesthetically pleasing veneers. The factors affecting the veneer's shade effect have to be considered in the design. Furthermore, a periodontally friendly, conservative preparation method is required. The teamwork between the dentist and dental technician also plays an important role in achieving successful veneer restorations.

Veneers are not only for film stars. They present a non-invasive treatment option for patients with, for instance, discoloured teeth, anterior tooth fractures, multiple composite restorations or occlusal discrepancies (Fig 1 to 6). Additional indications include shape adjustments of single teeth and functional corrections (Fig. 7). The German Society of Dental, Oral and Craniomandibular Sciences (DGZMK) has recognized adhesively bonded all-ceramic veneers which have all margins contained in the enamel as a proven treatment method. With a 15-year survival rate of 93 percent, veneers have provided excellent long-term results [44, 39].

Materials and methods

Very thin layer thicknesses and excellent optical effects can be attained in conjunction with sintered ceramic materials and a refractory die technique. However, the drawback of this technique is that the veneers demonstrate a low strength and therefore are susceptible to breaking during the try-in or cementation procedure [21]. Alternatives to the refractory die technique are available. For instance, excellent aesthetic results can be achieved with pressed glass ceramics, used in conjunction with the staining technique or with a combined press/layering technique. The combination method offers a considerable advantage, as it enables the use of a high- strength ceramic material. In addition, aesthetic adjustments can be applied without difficulty (Fig. 1 to 6). CAD/CAM technologies can also be utilized for manufacturing veneers (Fig. 7).

Fig. 1:
The clinical indication is an extensive restoration. The composite build-up on tooth 21 shows a discoloured incisal edge.

Fig. 2:
Completed veneer made of pressed glass ceramic (IPS Empress Esthetic, Ivoclar Vivadent). In line with the principles of a defect-oriented preparation method, an overlapped incisal edge design has been applied because of the composite restoration.

Fig. 3:
Even single-tooth veneers offering excellent aesthetic results can be attained using a standardized technique that allows a highly effective approach to the fabrication of veneers.

Fig. 4:
Indication: tooth fracture. Tooth 11, which had been fractured in a sports accident, was reconstructed with a metal-bonded ceramic crown, while tooth 21 was restored with a composite build-up.

Fig. 5:
The veneer is sintered with IPS e.max Ceram nano-fluorapatite glass ceramic (Ivoclar Vivadent) and the crown (IPS e.max Press) is veneered with the same ceramic material.

Fig. 6:
As the same veneering ceramic is used for both restorations, a harmonious optical impression is attained.

Fig. 7:
Indication: Shape correction. Due to malocclusion of tooth 12, the canine has been re-shaped into a lateral incisal with the help of a CEREC veneer made of milled glass ceramic (IPS ProCAD, Ivoclar Vivadent), while the first premolar has been changed into a canine using a composite material.

Planning makes all the difference

All-ceramic veneers should be planned carefully. Characteristics that should be assessed before starting the veneer treatment include tooth shape, tooth position, smile line, profile and function. In addition, the tooth shade should be determined. It is often necessary to bleach severely discoloured teeth before the veneer treatment. If bleaching is not possible, it may be necessary to use a ceramic with an increased masking capacity, i.e. a higher degree of opacity. In addition, the ceramic may have to be applied in an increased layer thickness or a crown may be applied instead of a veneer. In this context, it is important to be aware of the fact that coloured luting composites allow only minor shade adjustments [52]. Furthermore, opaque composites and opaquers may annihilate the depth effect of the veneer.

Partial or full-coverage crowns may be required to correct severely misaligned teeth, particularly if orthodontic treatment is not desired. It is advisable to document the procedure with photographs, study models and a diagnostic wax-up to ensure the success of the project.

Defect-oriented preparation

After tooth whitening, it is necessary to wait three weeks before incorporating the veneer to ensure an appropriate adhesive bond. During this period, the shade of the bleached teeth may become slightly darker than the shade immediately after the whitening treatment. Furthermore, professional tooth cleaning should be performed one week before preparing the teeth to make sure that the gums are in a healthy condition. A silicone key is produced from the wax-up and this key serves as a guide during the preparation procedure. The margins of the veneer should be located in the enamel and the proximal contacts and incisal edges should remain intact, if possible. As veneers without incisal edge preparation exhibit similar survival rates as do veneers with an overlapped incisal edge [22], a defect-oriented preparation technique can be applied, i.e. the preparation can be restricted to the actual defect, preserving healthy tooth structure. A chamfer is prepared in the cervical region near the gingiva.

It is often inevitable to extend the preparation into the dentin. A dentin adhesive has to be used in conjunction with exposed dentin. Favourable results can be accomplished if the exposed dentin surfaces are contained within the enamel margins of the preparation. The rate of success significantly decreases if the margins of the veneers are located in the dentin or in composite restoration surfaces [44, 22].

Impression-taking, temporarization and cementation

Impression-taking is performed using a low-viscosity silicone or polyether material. In this context, the advice against using the double-mixing technique should be heeded to prevent the prepared tooth structure from coming into contact with the high-viscosity component of the impression taking material. It is not necessary to place a temporary veneer if only small amounts of tooth structure have been removed and the period between impression-taking and incorporation is short. A desensitizer can be applied in such cases instead. Temporaries can be fabricated either from the silicone key or by using a transparent thermoforming foil. The retraction cords used during adhesive bonding should not contain haemostatic agents in order to avoid marginal discoloration.

It is advisable to use a transparent luting composite, as the shade of the veneer is hardly affected by the luting material anyway. In addition, transparent materials intensify the light transmission and chameleon effect and therefore help to mask the transition between dental enamel and the restoration margin. Luting composites featuring a dentin-like level of fluorescence have proved to be particularly suitable in this respect. Fluorescence is an important light effect that emanates from within the dentin of a natural tooth. This effect can also be achieved by using a ceramic material that demonstrates appropriate fluorescent properties. Finally, truly successful veneers are indistinguishable from the natural dentition.

Conclusions

Ceramic veneers present a conservative treatment option that offers a great deal of aesthetic potential. Careful planning is essential for the success of the treatment. In some cases, tooth whitening may be necessary before the veneer treatment is initiated. Fabricating the veneers requires the practice and laboratory to work particularly carefully and accurately to produce results that match the treatment plan. However, standardized fabrication procedures and streamlined ceramic systems now help to facilitate the working procedures in the laboratory in particular.

Accuracy of fit of all-ceramic restorations

Dr. Thomas Völkel

The clinical success of all-ceramic restorations depends on several factors. The accuracy of fit has a considerable effect on the clinical success along with the preparation method, framework thickness and the design of the final restoration. Dr. Thomas Völkel, chemist at the Research and Development Department of Ivoclar Vivadent in Schaan, Liechtenstein, has been researching this issue for several years.

Minimal marginal gaps and smoothly contoured preparation margins are regarded as essential criteria for the quality of prosthetic reconstructions. Large cement gaps around frameworks in particular may adversely affect the clinical performance of a restoration. The more cement surface area is exposed to the oral conditions, the faster the cement will become abraded and dissolved. Discoloration, leakage and secondary caries may ensue. The resultant deterioration in adhesion may lead to fractures in the framework or even debonding. The clinical performance is less affected by the cement gap if an adhesive bonding technique is used, because bonding composites feature a higher mechanical durability and resistance to oral conditions than do conventional cements. It is known from the literature that marginal gaps of 50 – 100 µm provide optimal adhesion if a composite is used [78]. However, relevant international standards do not exist in this respect.

Furthermore, the accuracy of fit and marginal gap width are also affected by the layer thickness of the adhesive material applied. Crowns bonded in place with a composite exhibit significantly smaller marginal gaps than do crowns incorporated with a zinc phosphate cement [82].

Clinical relevance

Marginal discrepancies may give rise to secondary caries, periodontal lesions, hypersensitivities and premature contacts on teeth. Furthermore, marginal discrepancies have a detrimental effect on the material strength, particularly in conjunction with conventional cementation methods, which may jeopardize the clinical success of the restoration in the long run. In extreme cases, delicate ceramic restorations (e.g. veneers) may break under the tensile stress that develops as a result of volume shrinkage during the curing process if the composite is applied in thick layers.

The precision of the restoration design depends on the operator and the fabrication methods used. Operator-related factors affecting the accuracy of fit are, inter alia, the preparation design, impression-taking technique and manual try-in. On the laboratory side, general factors affecting the fit are the model design and fabrication process. The factors involved in the latter may differ enormously, depending on whether a ceramic press or CAD/CAM technique is used. These factors will be discussed separately.

Operator- and laboratory-related factors mutually affect each other and they may go either towards error propagation or towards a process of consistent improvement and optimization, the latter resulting in a high degree of accuracy of fit.

Accuracy of fit of pressable ceramics

If the ceramic press method is used, a mould is created of a wax-up according to the lost-wax technique. A glass ceramic ingot is then heated up and pressed into the mould of the investment at high temperature. This method reliably results in a high accuracy of fit. For instance, in vitro cement joints of 53 µm were measured in conjunction with the IPS Empress press ceramic [4]. In another study, pressed all-ceramic crowns produced marginal gaps of considerably less than 50 µm, depending on whether a shoulder or chamfer preparation was applied. Furthermore, the pressed ceramic restorations consistently demonstrated a better fit [98] than the milled or sintered ceramic restorations

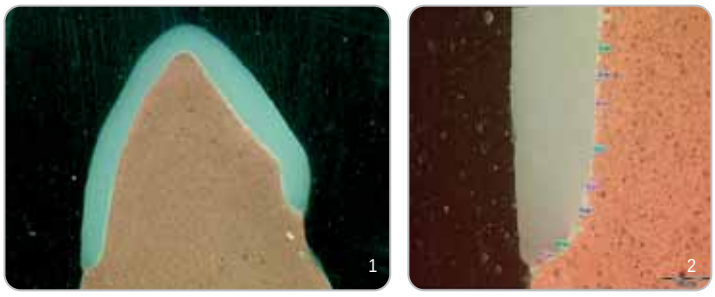


Fig.1
Vertical cross-section of an anterior coping on a plaster die.

Fig.2
Partial labial section after the width of the cement gap has been measured.

in a direct comparison between pressed all-ceramic and CAD/CAM generated restorations. A spacer, which is applied to the model die, is instrumental in pre-establishing the width of the cement joint.

Accuracy of fit of CAD/CAM milled ceramic restorations

CAD/CAM ceramic frameworks and restorations are milled from ceramic blocks. Consequently, the accuracy of fit depends on the optical scan of the model die, data processing program and the milling technique. Furthermore, the size and quality of the milling tools have also a considerable effect on the accuracy of fit.

CAD/CAM systems were introduced to dentistry in the eighties. CEREC 1, a CAD/CAM system for chairside dental applications, was brought to the market by Sirona Dental Systems towards the end of the eighties. At the time, the accuracy of fit achieved with these systems was not always entirely satisfactory due to the inadequate software and the inappropriately large cutting tools. Hardly ever were cement joints of a width below 100 µm measured in such restorations. For instance, a study group compiled a chart presenting the results of clinical studies and laboratory tests performed on inlays fabricated with the CEREC system of the first generation. The marginal gap widths shown on this chart ranged from 80 to 282 µm [112]. The accuracy of CAD/CAM restoration improved from generation to generation as the software, cutting tools and milling technology were consistently further developed.

The marginal fit of modern CAD/CAM ceramics is almost on a par with that of pressed ceramics. Tinschert et al. measured the accuracy of fit in three- to five-unit bridges made of densely sintered zirconium oxide ceramic (DCS). Cement gaps and marginal discrepancies of up to 70 µm were recorded in this study. Values below 50 µm [110] or around 120 µm [74] are clinically acceptable, depending on the author. Discrepancies of such a small magnitude found in restorations of such a wide span do not present a clinical problem; they almost appear to be too perfect for this type of restoration. The inLab (Sirona) and KaVo Everest (KaVo) systems offer the possibility of altering the marginal accuracy by adjusting the spacer parameter of the software accordingly.

Potential for improvement exists with regard to the inside surfaces of delicately structured incisals in crown restorations. Here, the size of the cutting tool has a limiting effect on the accuracy of fit. Consequently, the restorations often have to be reworked manually to improve the fit. In the process, the strength of the ceramic framework may become compromised.

Pre-sintered zirconium oxide ceramic materials (e.g. IPS e.max ZirCAD) can be milled with relative ease, as they are relatively soft. Compared to densely sintered zirconium oxide ceramics, these materials permit shorter milling times and cause less wear on the cutting tools. After the frameworks have been milled from the ceramic, they have to be sintered to their maximum density at a temperature of 1500 °C. In the process, the frameworks may lose up to 30% of their initial volume. It is essential for the user to have a thorough understanding of this shrinking mechanism to ensure that the accuracy of fit does not deteriorate as an effect of volume loss. Insufficient knowledge of the sintering process may result in frameworks that are distorted.

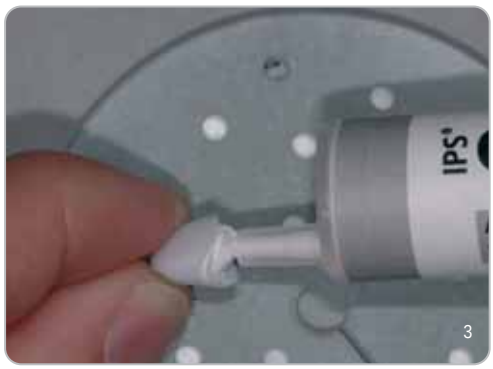
Furthermore, temperature gradients existing in the material may lead to an irregular sintering process and therefore may also be responsible for distortions and marginal discrepancies. In order to prevent such errors from occurring, an aluminium oxide sintering vessel has been especially designed for the IPS e.max ZirCAD zirconium oxide ceramic. This vessel is half filled with small spherical ZrO2 particles. Posterior frameworks are placed on these ZrO2 particles with the occlusal surface facing downwards; anterior frameworks are positioned on the substrate with the labial surface facing downwards. This substrate enables the framework to shrink without friction while the temperature is distributed evenly during the sintering process. Furthermore, the substrate provides even support to the entire framework.

It is also essential that the pre-sintered zirconium oxide blocks feature an evenly distributed density throughout the material to achieve a high accuracy of fit. This requirement is part of the specifications of IPS e.max ZirCAD.

IPS e.max CAD, a newly developed lithium disilicate ceramic for the milling technique, is also processed at a stage prior to full crystallization. This material is supplied in a partially crystallized "blue" phase containing lithium metasilicate crystals. These ceramic blocks are also comparatively soft and are therefore faster and easier to process than conventional lithium disilicate ceramics. After the milling process, the frameworks undergo a crystallization process in a ceramic furnace (Programat P100) at a temperature of 800 °C to obtain the final hardness and shape. In the process, the frameworks shrink by approx. 0.2 % and this volume shrinkage is factored into the parameters in the inLab software program.

Needle-shaped lithium disilicate crystals are formed in the matrix during the crystallization process. In the course, the frameworks are at risk of deforming. The ceramic may distort under its own weight when it is close to its softening temperature. To prevent this, the IPS e.max CAD frameworks are filled with IPS Object Fix (Ivoclar Vivadent) auxiliary firing paste before the firing process is started.

This paste can be easily removed after the firing cycle has been completed. The frameworks must not be sandblasted in order not to compromise the strength of the ceramic. This measure helps to prevent marginal discrepancies.



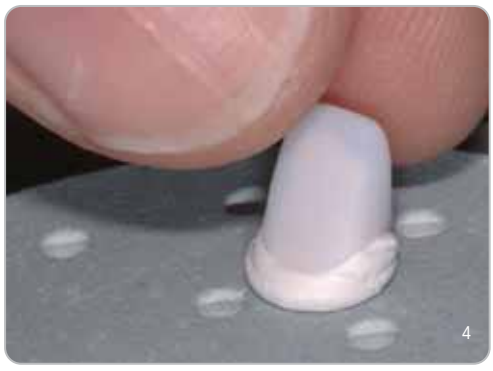


Fig. 3:
The inside of the crown framework is filled with Object Fix auxiliary firing paste.

Fig.4:
The crown framework, which has been made of IPS e.max CAD and filled with Object Fix firing paste, is placed on the firing tray.

Methods to assess the fit of dental restorations

Specially designed silicone materials such as Fit Checker (GC America Inc.) provide the dentist with a quick means of checking the fit of a crown or bridge. Fit Checker is a coloured addition-curing poly(siloxane) material. The components of the material are mixed together and this mixture is applied into the restoration. The material sets to form a mechanically stable film during the try-in and allows the detection of high spots and pressure points.

A high-precision impression technique is often used as a quantitative method to assess the accuracy of fit in dental research. The replicas and model dies are scanned with a 3D laser sensor and the resulting images compared with each other. Positive and negative deviations are assessed against the corresponding measuring points and the findings are recorded on a graph [13]. Other methods use scanning electron microscopy (SEM) to examine, measure and record cement gap widths and inaccuracies at the interface between restoration and preparation margin [8].

Qualtrough and Piddock [96] provide an excellent and critical overview of in vivo and in vitro methods of assessing the accuracy of fit and gap width of dental restorations.

Conclusions

Pressable ceramics such as IPS Empress or IPS e.max Press are associated with a high accuracy of fit. As the CAD/CAM systems have been further developed over the years, milled restorations are now capable of offering a similarly high level of accuracy as pressed ceramic restorations. In spite of these technologies, it is ultimately in the hands of the dental clinician to ensure that a high fit can be achieved by applying an appropriate preparation design and an accurate impression-taking technique. The dental technicians also contribute to the accuracy of fit by using their skills to maximum effect and carefully observing the manufacturer's directions. A high accuracy of fit is essential not only to the aesthetic appearance but also to the longevity of a restoration.

Part 8 of this series of articles on all-ceramic restorations will look into issues related to the wear of ceramic materials.

Fig.5:
Restorations made of IPS e.max ZirCAD and veneered with IPS e.max Ceram (teeth 21, 11 and 12) (University of Munich, Germany)

Chapter 8

Wear of ceramic materials

Dr. Siegward Heintze

Clinical importance and possible prediction

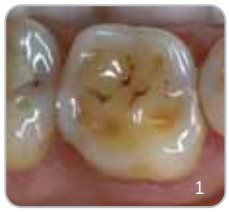
While the previous chapter investigated the accuracy of fit of ceramic restorations, in the present chapter Dr. Siegward Heintze discusses the issues surrounding the wear of dental ceramics. In his function as Head of In Vitro Research, he has been examining suitable methods to predict the wear of dental materials for several years.

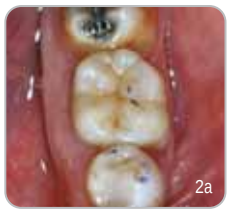
Crowns and bridges whose surfaces consist of ceramic materials are subject to wear just as any other restorative material is. Natural enamel also abrades with time. Several patient-specific factors have an effect on wear, such as dietary habits, parafunctions, and bruxism just to mention a few. Arbitrary grinding and clenching of teeth [5], which mainly occurs during sleep, is associated with an increased risk of high wear of the natural tooth structure [7] as well as of restorative materials [88]. Bruxers may develop biting forces of up to 1000 N and more. These forces are much higher than conventional biting forces [81], which normally range between 20 and 120 N, depending on the type of food eaten. Furthermore, higher biting forces are produced in the posterior than in the anterior region [61, 104]. Neuroreceptors in the periodontal tissue and masticatory muscles are responsible for modulating the masticatory force, which does not build up sharply upon contact with the tooth surface but rather increases gradually. Only in recent years has it been possible to study this mechanism in detail by using small ultra-fine multi-point sensors [61, 62].

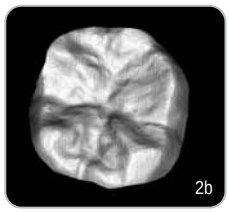
High biting forces, or bruxism, are one of the major reasons for the failure of all-ceramic reconstructions, translating into the delamination of the layered ceramic, i.e. fracture of the crown or bridge. The prevalence of bruxism has dramatically increased in the population in the past few decades. For instance, a study carried out in American college students indicated that bruxism has increased four times over the past three decades (1966: 5.1%, 1999: 22.5%) [50]. However, the higher incidence of bruxism may also, to some extent, be related to the fact that the measuring criteria applied to diagnose bruxism have been refined and, as a result, bruxism is recognized in more patients. All-ceramic restorations should not be placed in patients suffering from bruxism. However, it is rather difficult to diagnose a patient with bruxism in daily practice, if clear signs of wear on the teeth or models are not visible or if the patient's spouse does not report nocturnal tooth grinding. In addition, high wear may also be caused by certain other habits, such as fingernail biting or tobacco chewing [19]. Patients whose staple diet mainly consists of abrasive foodstuffs (e.g. cereals, raw fruit and vegetables) or who spend their working or leisure time in an environment where abrasive agents (e.g. dust, sand) may come into contact with the oral cavity are also likely to show signs of increased wear.

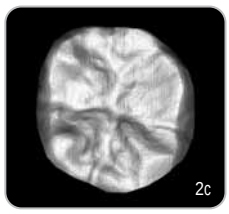
What types of wear patterns occur in the oral cavity?

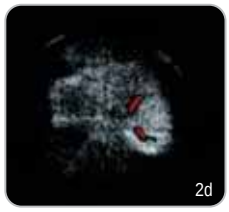
Wear is a general term that applies to the process of losing material from two surfaces that have been rubbed against one another in the oral cavity. Both restorative and natural tooth surfaces are subject to wear. Various laboratory tests and theoretical models are utilized to distinguish between different types of wear mechanisms. In the oral cavity, these mechanisms overlap as they may occur almost simultaneously [65]. When two tooth surfaces, i.e. an enamel antagonist and a ceramic crown surface, come into direct contact with each other during biting or swallowing, two-body wear, or attrition, occurs. By contrast, three-body wear, or abrasion, occurs when an abrasive slurry, i.e. food, is interposed between two surfaces or when toothpaste is moved over the tooth surfaces with a toothbrush. This type of wear also occurs when material becomes displaced from e.g. a composite surface during mastication, as these particles act as "abrasive agents" between the tooth surfaces. In addition, chemical wear, known as erosion, comes also into play (Fig. 1).











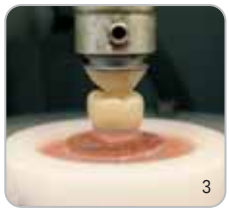


Fig. 1:
The teeth of this fifty-year old patient show severe signs of wear, particularly on the molars, with exposure of dentin. Erosion has possibly been the main wear mechanism at work here.

Fig. 2 a-d:
Quantification of wear with the help of laser technology (Laserscan 3D, Willytec).

Fig 2a:
Occlusal view of an all-ceramic crown on tooth 36, fabricated with the IPS e.max CAD technology (clinical case: F. Perkon/A. Stiefenhofer, Research and Development Department/Ivoclar Vivadent), 12 months after insertion.

Fig. 2b and 2c:
Scanning images of the models: the image on the left shows the situation after 1 week and the image on the right after 12 months.

Fig. 2d:
Differential image after superimposing the individual images. The red areas represent wear zones and correspond with the occlusal stops of the clinical image. In this case, a vertical wear of 45 µm was measured.

Fig. 3:
Ivoclar Vivadent wear testing method: Standardized ceramic crowns are wear-tested against standardized enamel antagonists in a chewing simulator.

Erosion occurs if, for instance, the acid contained in food (e.g. acidic fruit, sweets, soft drinks, etc) or the gastric juice of a patient suffering from anorexia nervosa chemically attacks the enamel or restorative material. In the process, the surfaces become more susceptible to breaking off when exposed to wear forces. Acidic fluoride-containing mouth rinses and fluoride gels (e.g. phosphate fluoride preparations APF, 1.23,%, which are commonly used in North America) or highly concentrated carbamide peroxide tooth whiteners tend to chemically attack and erode ceramic materials in particular. Hence, such preparations should not be used in conjunction with ceramic restorations [14, 20].

Friction also has an effect on the wear of a material. Furthermore, a smooth surface is less susceptible to wear than a rough one. Saliva and its components can reduce wear as they diminish the friction between two surfaces, similar to a lubricant [77].

Fatigue is another type of wear. This type of wear occurs when e.g. large parts of material become detached due to fatigue. Wear by fatigue can also occur in the microstructure of the material. This applies to ceramic in particular, because this material is brittle and more susceptible to breaking when exposed to tensile stress. Composite materials are vulnerable to mechanical and erosive wear in particular, while metal restorations are prone to abrasive wear [27].

What, if at all, is the clinical importance of wear?

Teeth, crowns and bridges that have become abraded look unsightly. This is particularly unfavourable in the visible anterior region, even more so if the patients are unhappy with the appearance of their teeth or if their friends or acquaintances have remarked on this issue. The question arises as to whether wear has an effect on the masticatory apparatus. Even relatively recent dental textbooks state that excessive wear of teeth or restorations may lead to disorders of the temporomandibular joint and the periodontium, to elongation of antagonists and tilting of adjacent teeth. A fairly restricted range of clinical investigations is available on this issue and these investigations do not provide substantive evidence that a connection between wear and these disorders exists. Even in patients who had been observed for twenty or more years and demonstrated high wear or severe vertical loss of tooth substance, a link between wear and temporomandibular disorders or periodontitis could not be established [7, 15, 46, 47, 56, 105]. As far as the elongation and tilting of teeth is concerned, clinical studies in patients with edentulous spaces showed that the adjacent teeth or antagonists shifted into the space by less than 1 mm in most cases (>90%) [49, 107]. Apparently, the stomatognathic system is highly adaptive to change and is generally capable of compensating for wear. Therefore, wear appears to be an aesthetic concern in the first place. It may also compromise the chewing comfort or function, although this has not been scientifically proven.

Is it possible to measure the wear of ceramic materials in the oral cavity?

Dentists only notice wear if severe localized vertical loss of tooth substance is present (> 0.5 mm) or if the loss is distributed over the entire restoration, as can be the case with composite-veneered crowns. Accurate loss quantification, however, involves a lengthy procedure and is no easy business. Wear cannot be measured directly in the oral cavity. Instead, models (replicas), which are produced by means of intraoral impressions, are used for this purpose. Various devices are available for wear measurement. The most advanced equipment, which allows wear to be measured quickly and efficiently, is based on laser technology and is also utilized in CAD/CAM applications [75]. Three-dimensional images of the initial and follow-up models are superimposed one on top of the other and the 3-D device determines the degree of wear (Fig. 2). However, this method is only as good as the quality of the impression. In addition, sample selection and size also play a crucial role: Higher wear rates are measured in samples that consist mainly of patients with high bite forces rather than in patients with low bite forces. The bite force of men is generally higher than that of women. Likewise, the bite force of young people is higher than that of old people [106, 124]. The differences in bite force and dietary habits probably account for the fact that in vivo wear measurements considerably vary from patient to patient. At times, the variance may be 50% from the mean value or even higher [108, 123]. For this reason, it is paramount to include a sufficiently large number of patients (>30) in the investigation to ensure the reliability of the results.

Data on the in vivo wear of ceramic materials are scarce. However, the few data available confirm the practitioners' impression that the wear of ceramic is low and similar to that of enamel. In an investigation, crowns made of different materials were inserted on the same tooth one after the other in patients with a high bite force. Each crown was left in situ for six months before it was removed and weighed. The loss of substance was six times as high in the crowns made of microfilled composite than in the ceramic crowns [28].

The ceramic crowns also demonstrated slightly less loss of substance than the gold crowns9. If we look at the few data that are based on the quantitative measurement of models, we may assume that the mean loss of height in the occlusal contact area is approx. 40-50 µm during the first year of service [18] (see Fig. 2).

Loss of substance is more critical in the opposing dentition (antagonists) than in the restoration. Soon after the introduction of metal-bonded ceramics in the sixties, clinical experience showed that teeth which occlude with ceramic crowns tended to be subject to severe wear. However, the metal-bonded ceramics (e.g. IPS d.SIGN) and leucite-containing all-ceramic systems (e.g. IPS Empress) which were developed in the nineties were gentler to the natural tooth structure than the earlier materials. As a result, excessive wear of opposing tooth surfaces was no longer observed. However, reliable measurements of wear in different materials, performed in a sufficiently large number of patients, are not available. Clinical observations or measurements, which involved only a limited number of patients, seem to suggest that high-strength ceramics (e.g. lithium disilicate ceramics) may cause somewhat more wear in the opposing dentition. Antagonist tooth wear may range from 70 to 120 µm after one year of service, depending on the material used [109]. However, such measurements have not been carried out in substantial numbers of patients to date.

Can wear be simulated in the laboratory?

In the past thirty years, a multitude of devices and methods to verify the wear resistance of dental materials have been developed. Most methods use what are known as chewing simulators, in which the materials to be tested are exposed to antagonists of enamel or synthetic material (e.g. ceramic) at a specific load or force. Some methods use an artificial (e.g. PMMA) or a natural abrasive medium (e.g. millet, poppy seeds) to simulate the effect of food [55]. A few years ago, Ivoclar Vivadent conducted a study in which plane test samples of ten different materials (8 composites, 1 amalgam, 1 ceramic) were sent to five test institutes, each of them using a different method to measure wear [53]. The investigators did not know which materials exactly they were examining. The data returned to Ivoclar Vivadent were statistically assessed. The results obtained in the process showed that the individual methods produced results that hardly correlated with each other. Some methods generated results that were so much at odds with each other that it was virtually impossible to distinguish between the individual materials. This may be explained by the fact that the individual methods utilized different approaches, which resulted in different wear patterns. However, if only the ceramic group was taken into account, the correlation between the individual methods was the highest compared with the correlation among the composite materials. Furthermore, the ceramic materials showed a comparatively low wear rate.

A close look at the individual devices and test methods reveals that there is only one simulator (MTS chewing simulator) that is truly suitable for simulating wear. All the other simulators are not properly equipped for wear simulations, as they do not allow the factors affecting wear to be controlled, i.e. these factors have never been defined. In addition, the methods performed with these devices have not been sufficiently validated to generate reproducible results. Most of these devices and methods would fail to or only partially satisfy the stringent GLP guidelines (GLP = Good Laboratory Practice), which the American Food and Drug Administration (FDA) applies to procedures for testing medical devices [36, 37]. As valid data on wear in the oral cavity is scarce, almost all methods have so far failed to provide evidence that they are capable of producing a prognosis of in vivo wear.

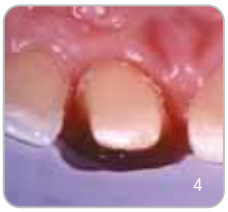
This is not to say that the wear simulation methods that are currently in use are all a waste of time. The accuracy of prognosis regarding in vivo wear can be improved if at least two different wear testing methods are combined with each other. As far as ceramic materials are concerned, the method that Ivoclar Vivadent has developed produces results that, to a certain extent, correlate with the above described clinical observations, particularly with regard to antagonist enamel wear (Fig. 3). We were able to prove that the quality of the surface obtained after the milling process plays a major role in the wear behaviour against dental enamel. For this purpose, we used fully anatomic crowns made with CAD/CAM techniques. Crowns that exhibit rough occlusal surfaces cause twice as much wear on the enamel surface of the opposing tooth. The glazing layer on the crown does not mitigate this effect, as this layer is only about 50 µm thick and quickly wears off.

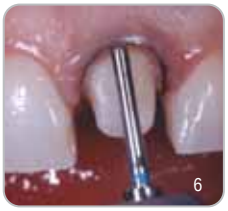
Basic considerations for further research:

- The clinical consequences of wear are mainly of an aesthetic nature. Damage involving health relevant risks have not been observed to date.
- Ceramic materials used for crowns and bridges show clearly lower wear rates than composites. Ceramic wear is hardly noticeable in the oral cavity. However, antagonist enamel wear may be considerably increased, depending on the material used.
- Most in vivo wear simulation methods that are currently in use are not validated and allow only an inaccurate prognosis of in vivo wear.

Tooth preparation for all-ceramic restorations – adhesive versus retentive preparation

Dr. Dr. Andreas Rathke





Undisputedly, all-ceramic restorations require an exacting preparation method. Unlike what is commonly believed, however, adhesive posterior preparations are often easier to carry out than conventional preparations as e.g. required for metal-bonded ceramic restorations. The reason for this is that adhesive all-ceramic restorations do not necessitate retention forms with long abutments and core build-ups.

The resistance and retention form are critical factors in conventional preparation designs. This means that conventional partial crowns require a box-shaped preparation that exhibits accurately defined margins and near-parallel walls, while the abutments of conventional full crowns should be at least 3 to 4 millimetres in height. This height can often only be attained by creating a core build-up or by creating subgingival preparation margins. As a consequence, undercuts occur more frequently in long abutments than in short ones. The angle of convergence should be 6 to 10 degrees in conjunction with restorations cemented in place with a conventional technique [95].

By contrast, the adhesive cementation method reduces the need for a macroretentive preparation form as the effect of microretentive adhesion compensates for these retention forms. Premolars and molars can often be restored without a core build-up; the restorations can be directly bonded to the enamel and dentin [9]. The essential requirements of preparations for all-ceramic restorations, i.e. rounded surface transitions and inner line angels and clearly defined preparation margins, should always be satisfied, regardless of whether an adhesive or a conventional cementation technique is used. With a modicum of practice, the requirements of adhesive preparation can be met with relative ease. However, the opp site is true for the cementation procedure: Here, the adhesive technique tends to involve a higher degree of difficulty than the conventional method (see page 33).

Independently of which cementation method is used, torpedo-shaped abrasive stones, cylindrical burs with rounded edges or with a slight conicity (e.g. ISO 168 or 198) are suitable for tooth preparation (Fig. 1 to 6). Customized instruments, e.g. ultrasonic devices, which enable a particularly conservative preparation procedure, are available for all-ceramic inlays and partial crowns. These instruments may be used as an alternative or in addition to conventional instruments (Fig. 7). The preparation should be completed with finishing diamonds or stones.

All-ceramic systems allow a conservative treatment approach

Fixed all-ceramic restorations are typically associated with an invasive treatment method. However, this premise is no longer fully valid: As adhesive partial crowns and veneers in particular allow for a defect-oriented preparation method, i.e. the preparation can be restricted to the actual defect, they offer a considerably more conservative treatment option than, for instance, metal-bonded ceramic crowns (Fig. 8). It is essential to observe

Fig. 1:
Chamfer preparation for an all-ceramic anterior crown, using a torpedo-shaped diamond.

Fig. 2:
Adequate reduction of the incisal third is essential to the aesthetic appearance of the final veneer.

Fig. 3:
A silicone key was prepared before the preparation procedure was started and is now used to check the dimensions of the crown preparation and the space available for the restoration.

Fig. 4:
The preparation is checked with a silicone key featuring detachable segments. This examination shows that the labial surface has been adequately reduced (the conventional cementation technique used in conjunction with this case is discussed on page 34).

Fig. 5:
Shoulder preparation for an anterior all-ceramic crown, using a cylindrical diamond instrument.

Fig. 6:
A cylindrical instrument coated with diamonds at the front only is best used to create a deep shoulder. This step is carried out with a retraction cord in place (the adhesive cementation of this restoration is described on page 34).

Fig. 7:
Box preparation for all-ceramic inlays and partial crowns can be conveniently performed with ultrasonic instruments that are coated with diamonds on one side.

Fig. 8:
The juxtaposition of these preparations - one for an anterior crown (on the left) and the other for a veneer (on the right) - shows the difference in tooth reduction of these two indications.
All margins of the crown preparation are confined to the dentin, while all preparation margins of the veneer are placed in the enamel.

the material-specific minimum layer and connector thicknesses. Most materials require a cervical thickness of 1 millimetre, an occlusal thickness of 1 to 1.5 millimetres and a thickness of 2 millimetres for the cusps and incisal region. Depending on the tooth position and on the material used, either a chamfer preparation or a shoulder preparation with rounded inner angles may be possible.

Recently, ceramic materials that can be applied in thinner thicknesses than previous materials have been introduced. For instance, zirconium oxide allows the fabrication of crown copings that have a layer thickness of only 0.3 to 0.5 millimetres. Moreover, delicate restorations can also be accomplished with some advanced glass-ceramic materials. For instance, a newly available high-strength pressable ceramic requires a thickness of only 0.6 millimetre for crown copings, as compared to 0.8 millimetre required by the predecessor material. The healthy tooth structure can be preserved accordingly.

Is it necessary for a restoration to contain all margins in the enamel?

The fabrication and placement of adhesive all-ceramic restorations are among the finest disciplines in dentistry. Ideally, the tooth and defect-oriented reconstruction form a mechanical unit; light is optimally transmitted into the tooth structure if the correct technique is applied. Although most cases require the restoration margins to be contained in the enamel, all-ceramic restorations with margins in the dentin have also shown successful survival rates [97, 64]. Furthermore, adhesively cemented all-ceramic restorations enable a far more subtle preparation design than do conventionally cemented restorations. Sharp edges and transitions should be avoided in any case; straightforward preparation forms are therefore preferable in conjunction with the adhesive cementation technique.

All-ceramic crowns and bridges can also be cemented in place with a conventional technique, if they demonstrate a sufficiently high fracture resistance and fracture toughness. Glass ionomer cements are for instance used for this indication. If a conventional technique is used, the above mentioned factors, such as abutment height, convergence angle and retention geometry, have to be taken into consideration. Adhesive cementation may be compulsory if the abutment is too short to attain an adequate retention form; this also applies to zirconium oxide restorations.

Connectors: height is more important than width

If an all-ceramic bridge is designed, it is essential to establish the height of the abutment teeth correctly to achieve a connector that demonstrates an appropriately sized diameter. The height of the connector is more important than the width. For instance, connectors four millimetres long and two millimetres wide are preferable to connectors three millimetres long and three millimetres wide. The strength increases with the increase of the connector length to the power of three [24]. Given its high strength, zirconium oxide is the material of choice for frameworks in stress-bearing regions.

CAD/CAM restorations require a particularly careful preparation design in order to attain successful results. Undercuts, tangential preparations and shoulder preparations with a bevel are not suitable for these restorations, as some scanners may have difficulty in detecting such preparation margins.

Conclusions

All-ceramic systems are not only versatile in terms of indication, but they are also versatile in terms of preparation design. However, a few general characteristics that are common to the entire range of all-ceramic systems have to be borne in mind: all-ceramic preparations require rounded transitions and clearly defined preparation margins. The tooth structure should be preserved to the largest possible extent, which is best achieved in conjunction with an adhesive cementation technique. Unlike the cementation procedure, adhesive preparation designs for all-ceramic restorations can be easier to apply than conventional retentive preparation designs. As long as the material in question provides the required strength, both preparation methods may be used – the choice lies with the clinician.

Dr. Dr. Andreas Rathke

Adhesive versus conventional cementation: Techniques for all-ceramic restorations in a state of flux

For many dentists, the permanent cementation of all-ceramic restorations is quite a daunting task. This is mainly attributable to the complicated adhesive procedure and the effort involved in establishing a dry working field. However, several of the new adhesive luting systems offer simplified working techniques. Moreover, many modern ceramics enable the use of conventional cementation protocols.

Professional cementation of all-ceramic restorations still requires profound knowledge and a meticulous working technique. Nevertheless, this is not preventing an ever-increasing number of dentists from offering all-ceramic restorations as part of their range of services. This trend has been fuelled by the development of dental ceramics that exhibit enhanced fracture strength and fracture toughness, plus a range of indications that is constantly increasing. All-ceramic materials have become indispensable in aesthetic dentistry and are increasingly employed as an alternative to metal-ceramics.

A trend towards conventional cementation

The current trend towards all-ceramic restorations is supported by the fact that many new ceramic materials enable conventional cementation, thanks to their mechanical strength. Apart from aluminium oxide and zirconium oxide, this also applies to several of the glass-ceramic materials used in conjunction with either the press or milling technique, at least in the fabrication of anterior crowns and bridges. According to [60], flexural strength values of above 400 MPa and appropriate methodologies employed by both the dentist and lab-technician are essential pre-requisites. For instance, it is critical that the mechanical properties of the material be supported by retentive cavity preparation and appropriate layer thicknesses.

Clinical studies have shown that e.g. conventionally cemented crowns on pressed glass-ceramic frameworks show survival rates similar to those of adhesively luted ones [24]. The marginal quality of ceramic restorations, which were adhesively luted with composite resin, was shown to be very good in in vitro investigations [99]. Just as with conventional cementation, however, the fracture strength and flexural strength of the material is detrimentally affected by mechanical strain, temperature changes and moisture [33]. Glass ionomer cements, for example, rank among those conventional cementation materials that have proven their worth in clinical use (Figs. 1–3). As retention is only established by enhanced friction between the surfaces involved, it is essential that tooth preparations possess a retentive form.

Fig. 1:
Conventional cementation: Cleaning of the prepared

Fig. 2:
Cementation of the crown with a translucent glass ionomer cement (Vivaglass CEM, Ivoclar Vivadent). Excess removal is easy.

Fig. 3:
The zirconium oxide coping veneered with IPS e.max Ceram (Ivoclar Vivadent) harmoniously blends into the surrounding teeth (preparation of the case see Part 9)

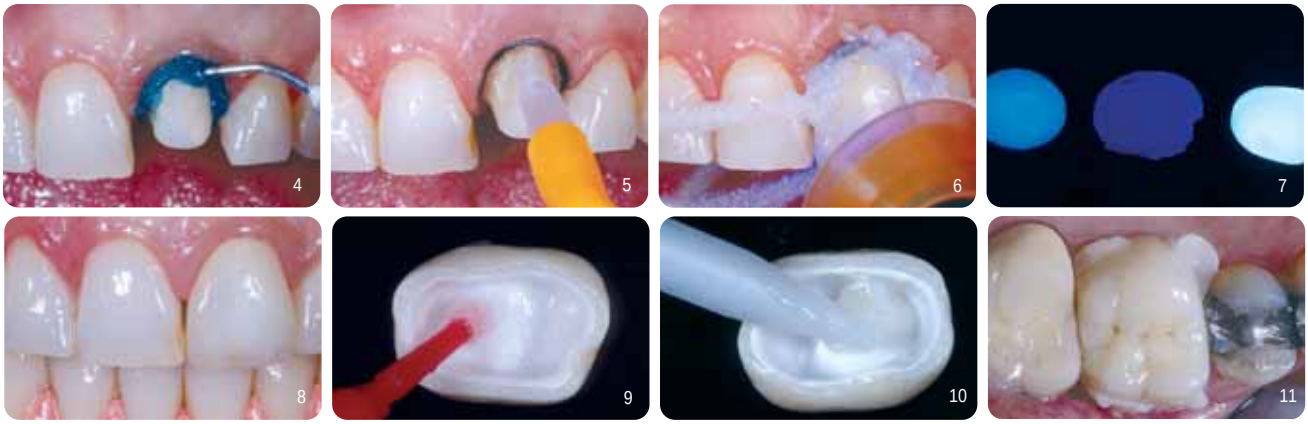


Fig. 4:
Adhesive luting: Etching with phosphoric acid gel

Fig. 5:
Application of Syntac (Ivoclar Vivadent), a classical multi-step adhesive

Fig. 6:
Cementation of the crown with Variolink II. In order to prevent oxygen inhibition, glycerine gel is applied prior to light curing.

Fig. 7:
Fluorescence of different luting composites: A fluorescence similar to that of vital teeth can only be achieved if the ceramic and the composite exhibit the corresponding properties (on the right: Variolink II from Ivoclar Vivadent, the two competitive materials on the left only show low fluorescence, or none at all) (Photo: PD Dr. Daniel Edelhoff, University of Aachen, Germany)

Fig. 8:
Adhesively luted CEREC crown. The milled glass-ceramic framework (IPS e.max CAD, Ivoclar Vivadent) was veneered with IPS e.max Ceram (preparation of the case see Part 9)

Fig. 9:
Simplified adhesive luting procedure: To achieve an adhesive bond, a phosphonate-modified primer (Metal/Zirconia Primer, Ivoclar Vivadent) was applied to the zirconium oxide.

Fig. 10:
Application of the self-curing luting composite Multilink (Ivoclar Vivadent)

Fig. 11:
In the gel phase, excess material can be easily removed. Glass ceramic was pressed onto the zirconium oxide coping (IPS e.max ZirPress, Ivoclar Vivadent) and subsequently, stains were applied.

Adhesive luting – not just for purists

One of the advantages of adhesive luting procedures is that, at least initially, they are capable of establishing a unity between tooth structure and restoration due to the strong bond achieved to both dentin and enamel. The use of a rubber dam is compulsory or at least strongly recommended. For multi-surface inlays and partial crowns, or if restoration margins are not located in enamel, composite resin cements in combination with classical multi-step adhesives and the acid-etch technique are still the material of choice (Figs. 4–8). Contrary to the methodologies promoted in the past, pre-treatment of the dentin with a dentin adhesive has become an established standard. This treatment step ensures reliable adhesion and helps prevent postoperative sensitivity.

Polymerization of the adhesive layer prior to placing the restoration remains a controversial issue. While some believe that it could detrimentally affect the accuracy of fit and lead to an increase in vertical occlusion, many clinicians have gathered positive experiences with pre-polymerized bonding agents. One precondition is that the adhesive is applied in a thin, uniform layer and pooling is avoided. Moreover, removal of excess prior to curing is a must [43]. A precisely fitting restoration is another essential pre-requisite.

Should the restoration be etched, blasted with aluminium oxide or silanized before inserting it? This depends on the material. Glass-ceramics, for example, are etched with hydrofluoric acid and silanized. In the case of zirconium oxide, neither etching nor silanization is useful. If done at all, sandblasting should be performed at a low pressure. In general, zirconium oxide can be adhesively luted with composite resin or conventionally cemented with e.g. glass ionomer cement.

Is there a third possibility?

Apart from composite luting materials requiring complicated working techniques and conventional cements, new composite-based materials systems are available, which offer facilitated working. Instead of three-step adhesive systems, e.g. self-etching bonding agents are applied. If these and the associated composites are also self-curing, valuable time and effort is saved (Figs. 9-11). Based on the literature available, the long-term prognosis of the bond achieved with these materials is less favourable than that achieved with systems which include three-step adhesives [43]. In less complicated cases, or if aesthetic requirements are reduced, a good result may be expected, e.g., in conjunction with zirconium oxide crowns and bridges for the posterior region.

Equally, no long-term clinical results are available for self-adhesive composites, which do not require the use of a separate bonding agent. From initial study results it can be concluded, however, that they have good clinical potential.

Conclusion

The cementation of all-ceramic restorations places high demands upon clinicians. While for inlays, partial crowns and veneers adhesive luting procedures are still a must, crowns and bridges made of high-strength materials also allow conventional cementation in many cases. If sufficient retention cannot be achieved with a retentive cavity design or build-ups, adhesive luting with composite resin remains the only viable option. Apart from the classical multi-step adhesive systems, simplified self-etching systems can be used in these procedures.

Chapter 11

Clinical reliability and experience with all-ceramic restorations

Patrik Oehri

Are all-ceramic materials an adequate alternative to alloys?

In the past fifteen years, all-ceramic materials have mainly been used for single-tooth restorations. Recent developments have seen the introduction of increasingly sophisticated CAD/CAM systems as well as zirconium oxide as a high-strength framework material. In view of these developments, all-ceramic systems are believed to offer great potential for use in extensive bridge restorations in the future.

It is difficult to estimate how long a restoration will stay in the oral cavity, as the service life depends on a multitude of patient-, process- and treatment-related factors. Yet, the question of longevity is the one question to which patients and clinicians would like to have an answer [95]. As in vitro models are not capable of simulating the complexity of oral conditions, clinical trials are required to find out if a restoration method is fit for clinical use and ensures an appropriate level of success. Numerous studies explored the question of how long a restoration survives in the oral cavity and some of these studies focused on all-ceramic restorations. Unfortunately, however, not all of these studies included evidence-based criteria, such as objective quality criteria to determine the failure and survival rates of restorations. Additionally, most of these studies were carried out without including a control group. The following information on the longevity of all-ceramic restorations has been distilled from the latest studies (some of which are only published in abstracts) and study reviews.

Inlays/onlays/veneers

The all-ceramic materials most frequently investigated in publications are IPS Empress and CEREC (Vita Mark I/II), which are leucite-reinforced glass-ceramic materials. Clinical results obtained in periods of up to twelve years have been published to date. Long-term studies on the classic IPS Empress glass-ceramic reported survival rates of 91 to 96 % after seven to twelve years [39, 64]. In a study review, Manhart/Hickel [73] worked out an annual failure rate of 1.9 % for ceramic inlays and a failure rate of 1.7 % for CAD/CAM inlays. By comparison, the failure rate of gold inlays was 1.4 %.

The advent of the adhesive bonding technique has had a beneficial effect on the survival rate of leucite-reinforced glass-ceramic restorations [72]. Adhesive bonding appears to endow these restorations with the required stability.

It can be seen from the results gathered in these studies that adhesively bonded all-ceramic inlays/onlays and veneers (e.g. IPS Empress) provide a high degree of reliability in clinical applications.

Crowns

Several all-ceramic systems are offered for crown restorations. In addition to the classic leucite-reinforced glass-ceramics, high-strength ceramic materials, which are considerably stronger than the glass-ceramics, are also offered for this indication. At present, the range of materials suitable for crown restorations includes:

- Lithium disilicate glass-ceramic: IPS Empress 2, IPS e.max CAD, IPS e.max Press
- Aluminium oxide: Procera, In-Ceram
- Zirconium oxide: Cercon Base, LAVA Frame, DC-Zirkon, YZ-Cube, IPS e.max ZirCAD

An extensive range of clinical data is available on adhesively bonded crowns made of classic glass-ceramic materials such as IPS Empress and Vita Mark II [9, 25, 41, 111]. The 5-year survival rate for Vita Mark II was 97 % for crowns on premolars and 94.6 % for crowns on molars [9]. The 11-year survival rate of IPS Empress crowns was 95 % [41]. Generally, the survival rates of posterior restorations are lower than those of anterior restorations (see Graph 1). In other words, the survival rates in the posterior region were still above 90 % after five years but fell just below 90 % after seven to eleven years [41, 111].

Clinical data extending over periods of four years and considerably more are available for lithium disilicate and aluminium oxide ceramic materials, e.g. IPS Empress 2, IPS e.max Press, In-Ceram and Procera [26, 24, 35, 92 125]. Most data show that these materials are suitable for crown restorations. These materials offer higher strength values than the classic glass-ceramic materials and therefore do not necessitate the application of an adhesive bonding technique (in fact, the adhesive bonding technique is possible in the manner customary in some cases, as the ceramic cannot be etched). Consequently, a conventional cementation method may be used in conjunction with these materials. Furthermore, a small amount of data is also available on veneered zirconium oxide crowns: The results after the first few years have been favourable; virtually no fractures in the zirconium oxide frameworks were reported.

Even if the clinical experiences gathered with all-ceramic crowns do not yet span very long periods of time, particularly not in conjunction with the recently introduced material systems, some all-ceramic systems (e.g. Empress) have been successfully used for the fabrication of dental crowns for periods as long as ten to fifteen years.

Bridges made of lithium disilicate, aluminium oxide and zirconium oxide

On the whole, clinical publications on the clinical performance of all-ceramic bridges are relatively rare. The data on In-Ceram (aluminium oxide) extend over the longest periods of time [83]. The conclusions drawn in the studies on In-Ceram are ambivalent; considerable differences exist between the individual studies as well as between three-unit anterior and posterior bridges. The fracture rates of posterior bridges are so high that the material cannot be recommended for this indication. The data available for lithium disilicate ceramics, e.g. IPS Empress 2, IPS e.max Press, cover periods of up to four years [10, 26, 24, 34, 125]. Here, too, the application of 3-unit bridges is restricted to the anterior region. The manufacturer's directions have to be meticulously followed, particularly with regard to the dimensions of the connectors.

Zirconium oxide materials appear to have the highest potential for fulfilling the requirements of bridge constructions. In view of its exceptionally high strength, zirconium oxide is believed to be suitable even for 4- to 5-unit bridges in the posterior region [83]. Unfortunately, the data published on zirconium oxide bridges to date extend over periods of three to four years only [12, 92, 101, 115, 122] – see Table. It is known from publications and conferences that several studies on zirconium oxide restorations have been initiated at universities in Germany and Switzerland in particular. In the near future, the 5-year results of some of these studies will be published. They will hopefully provide an indication of the true potential of this material.

The weak point of high-strength ceramic restorations is often not the framework but the veneering ceramic. The flexural strength of veneering ceramic materials ranges between 70 and 120 MPa, while the flexural strength of framework ceramics ranges from 300 to 1000 MPa. Delamination of the 'weak' veneering ceramic occurs far more frequently in clinical studies than do fractures of the 'strong' framework (see Table 1). In some cases, delamination is so severe that the entire restoration has to be replaced. This risk can be almost entirely eliminated by creating a cusp-supporting framework using a high-strength ceramic. If the IPS Empress system (IPS e.max Press) is used, the dental technician is responsible for the design of the framework. By contrast, not all CAD/CAM systems are yet capable of designing frameworks that offer appropriate cusp support.

On the whole, the clinical data on all-ceramic bridges are scarce, particularly with regard to long-term clinical experiences of five years and more. The range of indications of lithium disilicate and aluminium oxide ceramic materials has to be limited to 3-unit anterior bridges as a result of the clinical data and strength values of these materials. As a framework material, high-strength zirconium oxide has the potential to cover 4- to 5-unit posterior bridges. However, this statement is made against a background of only four years of clinical experience. It will be necessary to first obtain clinical data that extend over longer periods of time to be able to come forward with a final recommendation.

All-ceramic versus metal ceramic

Metal ceramic materials continue to be the standard against which all other materials are measured when it comes to crown and bridge restorations.

Several decades of clinical experiences are available for metal ceramic materials; the survival rates after five to ten years range between 85 and 95 % [11, 24, 34, 113]. In other words, metal ceramic materials offer a very high degree of clinical reliability. Nonetheless,

the trend towards all-ceramic materials has been growing. The main arguments speaking in favour of all-ceramic systems are:

- Highly aesthetic properties
- No metal in the oral cavity, i.e. high biocompatibility

From an objective point of view, these arguments are not particularly compelling: today's metal ceramic systems (e.g. IPS d.SIGN) provide highly aesthetic restorations and sensitivities to dental alloys tend to occur very rarely. Nonetheless, the trend towards all-ceramic restorations is expected to grow. Against such a background, the question arises as to whether all-ceramic systems offer an adequate alternative to metal-ceramic restorations.

Studies that directly compare all-ceramic and metal-ceramic restorations are difficult to find and those that are available tend to be restricted to crowns [11, 35]. A review study [48] showed that fewer complications occurred with all-ceramic (8%) than with metal ceramic crowns (11%). A long-term survival analysis, which was carried out in Michigan [1] between 1990 and 2002 on 1.9 million crowns placed in insured adults, reported a 95 % survival rate for metal-ceramic crowns and a 90 % survival rate for the all-ceramic ones. In view of the above-mentioned latest clinical data, we may assume that certain all-ceramic systems (e.g. IPS Empress) have, in the meantime, caught up with metal-ceramic systems and now provide similarly high survival rates. Hence, all-ceramic restorations present a true alternative to metal ceramic materials.

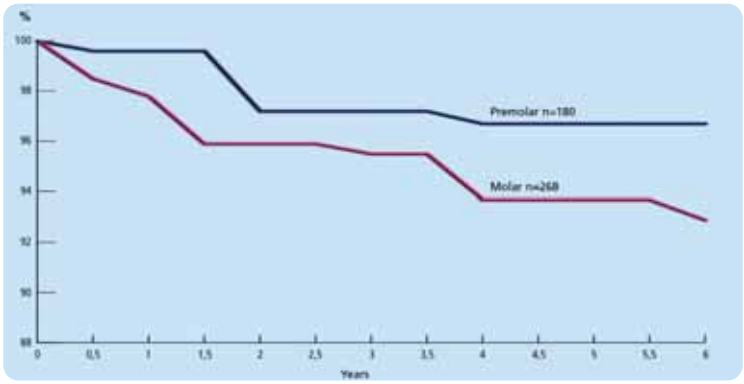
The same cannot be said of bridge restorations, as not enough long-term clinical experience has been gained with this indication to date. Yet, zirconium oxide appears to have the potential to become a true alternative to metal for the fabrication of frameworks (for 4- to 5-unit bridges) in the medium term.

Recommendations for dentists and dental technicians

Dentists and dental technicians can now opt for all-ceramic systems that are also geared towards the fabrication of multiple-unit bridges, i.e. a comprehensive alternative to cast alloys is available. The following points should be taken into consideration, particularly when fabricating all-ceramic restorations for the posterior region:

- Patient-specific factors, such as risk of caries and periodontitis and bruxism
- Process- and treatment-related factors, such as preparation design (e.g. adequate retention), conventional versus adhesive cementation, balanced occlusion, accurate impression
- Utilization of clinically proven all-ceramic systems for which high survival rates (>90-95 %) have been published in clinical studies

The risks have to be assessed properly. An appropriate match between the patient, treatment and processing method (dentist/technician) has to be found. Materials that are capable of matching the requirements of the individual situation should be selected to carry out the treatment. Only if these requirements are satisfied may an all-ceramic system be used to fabricate a large posterior restoration that offers a long service life. It is advisable to opt for a standard treatment method if high risks that may compromise the survival of the all-ceramic restoration are present.



Graph 1: IPS Empress I crowns: Survival rates gathered from several studies

University	Material	Number of units	Mean observation period	Fracture (framework)	Delamination (veneer)
Tinschert, Achen, (25)	DCS	65 bridges	37-38 months	None	4, Vita D
Sailer, Zurich (22)	Cercon	58 bridges	42 months	None	5, experimental ceramic
Bornemann, Göttingen (5)	Cercon	46 bridges 27 bridges	26 months 20 months	None	2, experimental ceramic 0, Cercon Ceram S
Weigl, Frankfurt (27)	Various	38 bridges 71 crowns	26 months	1 bridge framework	3, IPS e.max Ceram
Pospiech, Homburg (20)	LAVA	35 bridges	36 months	None	1 LAVA Ceram

Table 1: Clinical studies with zirconium oxide frameworks

Chapter 12

Refurbishment and revision of all-ceramic restorations (repair and fabrication of new restorations) particularly of zirconium oxide reinforced restorations in the dental practice

Prof. Dr. Jean-François Roulet

Hans-Peter Foser

As has already been extensively described in the chapters presented up to now, modern ceramic systems feature excellent physical and mechanical properties, which render the material clearly suitable for its use in the oral cavity. In this part, the authors describe the possibilities for repairing defective all-ceramic restorations.

A negative property of the ceramic material, which continues to cause problems for the clinician, is its brittleness. As a consequence, fractures may develop during clinical use, in particular if insufficient care was taken when fabricating the crowns and bridges. In general, two types of fractures have to be distinguished:

1. Fractures that lead to the breaking of the restoration, i.e. in crowns, these are fractures where the stump is uncovered and, in bridges, these are normally fractures in the area of the connectors which cause the continuity of the restoration to be interrupted.
2. Fractures in the form of delaminated parts which do not impair the primary function of the restoration in general.

Whereas the first type of fractures requires the restoration to be replaced, the latter provides at least the option of repairing the original restoration. If the restoration has not been placed adhesively (conventionally cemented), and only then, does the option exist of removing the complete work with the objective of repairing the restoration in the dental laboratory. This option is accompanied by many risks. When removing the restoration by force, it is realistic to assume that more damage will be done. In addition, the dental professional often does not know how the restoration was placed. A safer option is to repair the restoration in situ with composite materials and the adhesive technique. This article basically deals with the possibilities and the limits of this kind of repairs as well as the options a dental technician has to additionally modify crowns and bridges before they are definitively placed.

Patients consider fractured restorations as failures and they are highly inconvenient for the clinician. It is thus advisable to consult the literature in order to gather information on the dimensions of the problem. As larger all-ceramic restorations have only recently started to be used, corresponding data is scarcely available. However, some information about metal-ceramic restorations and veneers can be found.

After having been in place in the oral cavity for 10 years, the percentage of fractured (delaminated) ceramics amounts to 2.4 % for metal-ceramic restorations [17]. Reasons are mainly bruxism and/or wrong design of the metal framework (41 out of 52). These data were confirmed in a meta-analysis [113]. On the basis of thousand restorations, a fracture rate of 3.2 % was determined. [89] reported on the long-term behaviour of veneers after 10 years. The examined cases consisted of feldspar ceramics that had been sintered on models made of investment material (Cosmotech, GC). Whereas only 4% of the fractured restorations were observed at the 5-year recall, the number increased to 34% after 10 years. However, it is important to note that only 11% of the cases were rated as being clinically unacceptable. Only 2 of these 9 incidents required the veneer to be replaced, the other 7 cases could be repaired.

Visible fracture lines (21%) without further consequences most commonly occurred. In a retrospective study of [39], 182 veneers (mainly IPS Empress, Ivoclar Vivadent) were re-examined during a period of 6 to12 years. Five fractures were detected; 2 cases required the veneer to be replaced and 3 veneers were repaired or luted anew. A clinical long-term study by [41] reports on 170 IPS Empress crowns, of which 125 were still available for evaluation purposes after a maximum of 11 years. A total of 6 failures could be observed which corresponds to a survival rate of 95.2% according to Kaplan-Meier. Four of these six failures were caused by fractures of the crown. Partial fractures did not occur.

The reasons for fractures are manifold [86]:

1. Subcritical crack growth due to wear. In this case it is important to know that defects in the ceramic can initiate cracks. Traumatic finishing of the ceramic (including grinding-in) in particular can cause initial cracks. If the adhesive technique used is defective when cementing glass-based ceramics, this may also initiate fractures.
2. Mechanical reasons e.g. mechanical overload (occlusal trauma due to a deficient occlusion design) or a material thickness that is too low.
3. Defective design of the substructure made of high-strength ceramic material.
4. Traumas caused by accidents.

Prevention is the best remedy. Thus, dental technicians and dentists should spare no efforts to achieve high quality in their work.

"Repairs" in the dental laboratory before placing the restoration and extra-oral repair possibilities

Apart from the aesthetic, anatomical and functional adaptation to the oral surroundings, time has to be provided for final corrections of the restoration after the try-in. This includes the grinding-in of the occlusal relief in particular and the adjustment of the contact points to the neighbouring tooth as well as the antagonist. In the case of bridge reconstructions, the area of the pontic and its gingival tissue side in particular has to be especially considered for aesthetic and also hygienic reasons. If marginal corrections are absolutely required, this is considered to be a "young repair" in metal-ceramic work. Here, the margin is virtually extended with metal by soldering or applying laser. By contrast, this is standard in all-ceramics and the procedure is easily carried out with a "ceramic relining" using margin material or applying the "add-on" ceramic materials, which are offered by most of the renowned ceramic manufacturers.

If problems of fit arise in the indication range of the bridge, this normally requires the restoration to be fabricated anew. Recent tests with "glass soldering" after having separated and fixed the restoration in situ, have been successful. However, clinical long-term results are as yet unavailable.

There are many reasons why cracks or fissures develop in a ceramic. In the majority of cases, these incidences can be traced back to proportional deficiencies in the framework design. The frameworks have been built featuring too little support for the veneering or layering ceramic. Thus, undesired warping takes place in the restoration which may result in initial fractures or fractures in the long-term. Chipping in the oral cavity later on is a logical consequence, which then leads to the actual repair. For safety reasons, it is recommended to have a new framework planned and fabricated.

Fig. 1:
Ceramic Repair Set. This set assists the dental technician in the laboratory when carrying out long-lasting repairs of fractures in the ceramic restoration (chipping).

Thermal incompatibility is another reason why cracks can develop. Modern furnaces counteract this problem with the options of long-term, normal or short-term cooling. A thermal healing process takes place during a post-sintering procedure in a final firing of the ceramic restoration. Thus, the restoration is transferred through the stress phase from a soft to a solid state in a targeted fashion.

Fractures are especially difficult to repair if the restoration has already been worn. This can be the case after a temporary time of wearing it or if a conditional removal of the restoration from the oral surroundings is required. This also includes decementation. This type of restoration is extremely warped in most cases, be it because of functional or chemical aspects in the mouth. First of all, thorough cleaning is a prerequisite – all organic contaminations (plaque, pellicles and if necessary food residues) are to be removed. In addition, thorough removal of the cementation material is required by carefully sandblasting it, to avoid gas formation (formation of air bubbles) during the subsequent thermal treatment. Then, it is absolutely necessary for the restoration to undergo thermal tension release before the repair is carried out by adding a ceramic layer and subsequently firing it. It is important that the number of firing cycles remain low, so as not to vitrify the already fired ceramic restoration and to avoid "sagging" of the shape.

Optionally, resins can be used to add on adjustments to damaged ceramic restorations. For this purpose, conventional C&B materials like SR Ivocron or light-curing resin materials, e.g. SR Adoro, can be used. Another possibility is the Ceramic Repair Set of Ivoclar Vivadent, which is based on Tetric and includes all the necessary components from the bonding agents, silane and opaquer materials to dentin/incisal materials (Fig. 1).

If larger delaminations of ceramic restorations occur in bridge constructions, the following procedure offers a suitable option: The dentist prepares the site of fracture for a partial crown or laminate veneer. Thus, he/she can avoid a risky oral removal. The fabrication of laminate veneers or build-up of edges is profitably carried out in the dental laboratory similarly to the classic all-ceramic systems. In this connection, press ceramics like e.g. IPS Empress provides for excellent aesthetic results with regard to fit and minimal preparation guidelines.

The dentist then adhesively cements this ceramic veneer to the fractured restoration. If this procedure is appropriately performed, a "substandard" restoration can be completely covered and forgotten.

Repairs by the dentist after clinical use

In order to achieve a successful restoration, it is absolutely requisite to use a perfected adhesive technique and a highly aesthetic composite material (e.g. fine-particle hybrid composite materials or Tetric EvoCeram, Ivoclar Vivadent). The adhesive technique to be used has to be compatible with the substrate, i.e. with the type of ceramic material that is to be repaired. It is fundamental to strive for an enlargement of the surface with the objective of achieving micromechanical retention which is then obtained by optimally wetting the surface with the material used for the repair.

Glass-based ceramics: the following ceramic materials belong to this category [58]:

- All veneering ceramics (feldspar and fluor-apatite ceramic materials)
- Feldspar ceramics for CAD/CAM applications (e.g. Vita Mk. II, Vita)
- IPS Empress (Ivoclar Vivadent) and similar products
- Leucite ceramics (e.g. IPS ProCAD, Ivoclar Vivadent)
- Lithium disilicate ceramics (e.g. IPS e.max CAD, Ivoclar Vivadent)

The most efficient method for obtaining good and permanent retention is to etch the material with HF (Figs. 2 a-d). Hydrofluoric acid is very toxic; thus, it is absolutely necessary to use a rubberdam. In addition, the eyes of patients and the dentist have to be protected with glasses. It is recommended to use buffered HF gels containing concentrations between 5% and 9.6% which are supplied in syringes from which the gel can be applied where it is needed (e.g. Ceramic Etching Gel, Ultradent). Due to the toxicity of the material, the patient has to be informed about the risks. Replacing the restoration is also risky. Therefore, the risks have to be evaluated together with the patient. Depending on the ceramic material and the etching gel, application times between 30 and 120 seconds are recommended. Subsequently, the restoration has to be cleaned very thoroughly with water to remove not only the residues of the etching gel, but also to eliminate as many of the precipitates formed as possible. First, the restoration is thoroughly air-dried. As ceramics are hydrophylic, the surface is very quickly wetted by moisture from the surrounding air, which counteracts the wetting with the hydrophobic resins of composite systems. Thus, silane has to be applied to the ceramic surface (e.g. Monobond-S, Ivoclar Vivadent) (Fig. 3) which then renders the ceramic hydrophobic, thus increasing the wettability for composite systems. Silane forms a Si-O-Si compound with the glass phase of the ceramic restoration. In order to become reactive, silanes have to be hydrolized. If single-bottle silanes are used, the water needed stems from the surrounding air. When the solution is applied, water from the surrounding air can enter the bottle and lead to the formation of silane di-, tri- and oligomers which results in the solution becoming ineffective. If the silane becomes visibly cloudy, it is a clear indication for such a process. In a case like this, it is advisable to discard the silane. If a dual-bottle silane is used (e.g. Rosilan, Hoffmann & Richter), the material is hydrolized when it is mixed. Thus, a freshly mixed solution is guaranteed, which is to be discarded immediately after its use.

Basically, it would be possible to roughen the ceramic by means of blasting it with an aluminium oxide abrasive (Al2O3) instead of etching it, but this results in a significantly lower adhesion of the material used for the repair [100]. This can be explained by the fact that blasting the ceramic with an aluminium oxide abrasive - Al_2O_3 – always leaves Al_2O_3 particles on the surface. Silane can also react with Al; however, the Si-O-Al compound is weaker than is the Si-O-Si one. In addition, the Si-O-Al compound provides significantly less hydrolytical stability [85]. For repairs accomplished with the COE-Jet (3M ESPE), a survival rate of 89% after nearly 3 years was reported [84]. The majority of failures occurred between 1 week and 3 months after repair. Traumas, occlusal trauma and the non-use of rubber dam were stated as reasons for the repair failures.

Aluminium oxide ceramics (Inceram, Procera) contain only small amounts of glass or they do not contain any at all. Thus, retention cannot be obtained by etching the material with HF gels. In this case, the surface has to be roughened by blasting it with an aluminium oxide abrasive. To couple such a surface optimally with silane, it has to be treated with silicates. This is best achieved with a tribochemical treatment, which is used to process the surface with a silicate-layered blasting abrasive. In this way not only the surface is roughened, but it is also coated with SiO_2, which has to be available as a reactive partner for the silane. The first system of this kind was designed for use in the laboratory (ROCATEC, 3M ESPE) [51]. In the meantime, also miniaturized versions for clinical use are available. Here, the blasting agent is applied with a "microetcher" (COJet, 3M ESPE).

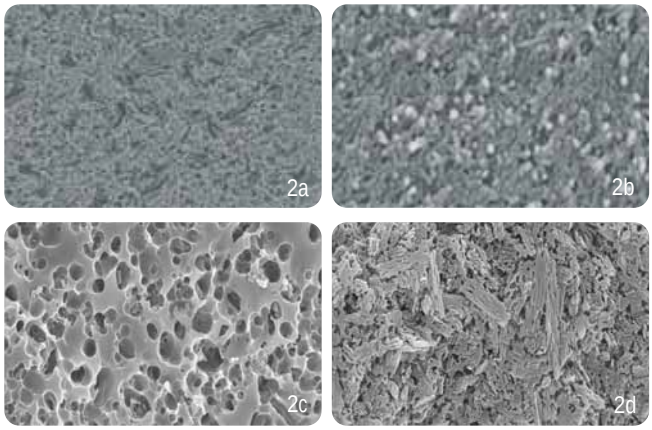


Fig. 2a:
If the glass-based ceramic is etched with HF, excellent etching patterns for micromechanical retention can be achieved.

Fig. 2a:
Veneering ceramic (IPS InLine)

Fig. 2b:
Veneering ceramic (fluoro-apatite glass ceramic, e.g. IPS e.max Ceram or IPS e.max ZirPress)

Fig. 2c:
Leucite ceramic (IPS Empress)

Fig. 2d:
Lithium disilicate ceramic (e.g. IPS Empress 2 or IPS e.max CAD)

Zirconium oxide (e.g. IPS e.max ZirCAD, Ivoclar Vivadent; LAVA, 3M ESPE; Cercon, Degndent): Due to its microstructure, zirconium oxide is extremely dense and inert. It cannot be etched and blasting with an aluminium oxide abrasive is ineffective. It therefore makes sense to chemically couple zirconium oxide with another material. Phosphonic acid acrylate is a suitable agent which is dissolved in organic solvents in low concentrations (e.g. Metal-Zirconia Primer, Ivoclar Vivadent). With this product, bond strength values of approx. 30 MPa (shear bond strength, 24h value) can be achieved on zirconium oxide, which, in addition, are hydrolytically stable to a large extent (internal data, Ivoclar Vivadent).

Besides good bonding properties with the ceramic material, the surface quality of the composite used is of utmost importance for long-term success. A material is to be used which can be polished to a high gloss. This is feasible with the fine-particle hybrid composite materials featuring a mean filler size of 0.5 µm (e.g. Artemis, Ivoclar Vivadent, Point 4 Kerr Hawe) or with Tetric EvoCeram, which has been optimized in particular with regard to its good surface properties. A composite material exhibiting a significant chameleon effect (Tetric EvoCeram), makes the work of a dentist definitely easier and enables him/her to obtain successful results to a great extent. In order to achieve good integration of the repaired surface, a smooth surface is created by using rubber polishers (e.g. Astropol, Ivoclar Vivadent) and polishing discs that are coated with aluminium oxide (e.g. Soflex, 3M ESPE). Afterwards, diamonds are used to realize surface structures which correspond to those of the surroundings. Final polishing is then carried out with abrasive polishing tips (Astrobrush, Ivoclar Vivadent) (Fig. 4).

Fig. 3
Silane for achieving a hydrophobic surface of glass-based ceramics (Monobond-S)

Fig. 4
Abrasive brush for polishing the repaired restoration to a high gloss (Astrobrush).

Conclusion

Fractures of all-ceramic restorations can be avoided to a great extent if the indication is correct and the work has been carried out very carefully in the laboratory and the clinic. If access is possible and the function of the restoration can be preserved, it is possible nowadays to repair fractures and defects by using an adequate adhesive technique and composite materials.

Chapter 13

Refurbishment of all-ceramic restorations

Prof. Dr. Jean-François Roulet

Dr. Alexander Stiefenhofer

Clinical procedure for repairing a fractured ceramic veneer

The authors Jean-François Roulet and Alexander Stiefenhofer examined the possibility of repairing defective all-ceramic restorations. They describe the individual working steps for refurbishing a fractured ceramic facet.

The clinical case involves a three-unit bridge extending from tooth 11 to 22. The bridge consists of a zirconium dioxide framework, which is veneered with layered ceramics (fluoroapatite glass ceramic). In the area of the pontic, delaminations on the mesial side occurred, which extended to the crown of tooth 11 and partially uncovered the zirconium dioxide framework of the pontic (Fig. 1).

Surface conditioning is carried out by etching the ceramic veneer with a gel-like hydrofluoric acid (HF). As contact between the HF acid and mucuous membrane has to be avoided, it is absolutely necessary to use a rubberdam. For restorations involving a bridge, a u-shaped flap is cut between the perforations of the rubberdam where the crowned teeth are situated. This flap can be slid under the pontic and sewed together with the surrounding rubber material. Thus, sealed and isolated conditions in the oral cavity are provided (Fig. 2).

The HF gel (IPS Ceramic Etching Gel 5%, Ivoclar Vivadent) is applied to the fractured areas and the marginal areas with a brush in the direction of the intact ceramic (Fig. 3) and allowed to react for 60 seconds. After this reaction time, the HF gel is thoroughly washed off using water spray and the surface is dried. Extreme care should be taken when carrying out the procedure to avoid splashing of the HF gel. After the surface of the etched glass-based ceramic has dried, it should have a mat appearance. (Fig. 4).

The ceramic is conditioned in two steps in the case at hand. The partially uncovered zirconium oxide framework is conditioned with phosphonic acid acrylate (Metal/Zirconia Primer, Ivoclar Vivadent) and left to react for 180 seconds (Fig. 5).

The veneering ceramic is silanized (Monobond-S, Ivoclar Vivadent AG) (Fig. 6). After a reaction time of 60 seconds, the solvent has evaporated and the surface of the ceramic can be veneered with a composite material.

Before the composite material is applied, a monomer (Heliobond, Ivoclar Vivadent) with low viscosity should be used (Fig. 7) to optimally wet the surface of the ceramic with the composite. The applied bonding material is dispersed to a thin layer and then cured (Fig. 8). The curing time is 20 seconds in the Low Power mode (650 W), if a high-performance LED light is used (bluephase, Ivoclar Vivadent).

The build-up of the fractured incisal edge is carried out with the composite material Tetric EvoCeram in the shades Transparent and A2 in the case at hand. The dentin core is built up with the material A2 (Fig. 9) and light cured (Fig. 10). The curing time for polymerizing the material up to a layer thickness of 2 mm is 20 seconds in the High Power mode (1100 W), if the LED curing light bluephase (Ivoclar Vivadent) is used. Subsequently, the transparent material is layered to complete the shape of the fractured crown (Fig. 11). Curing is carried out similarly to that of the dentin core.

For finishing the restoration, fine diamonds in various shapes up to a grit-size of 30 µm have proven to be favourable (Fig. 12). Polishing discs are suitable for further polishing along the lines of finishing a composite restoration (e.g. Sof-Lex discs, 3M ESPE) (Figs. 13a and 13b) and rubber polishing systems like Astropol (Ivoclar Vivadent) for polishing the surface of composite restorations (Fig. 14).

A structured tooth surface can be achieved by targeted roughening with a diamond featuring a grit-size of 80 µm, after the restoration has been finished and polished. For achieving a final high-gloss on the surface, the brushes containing silicon carbide (e.g. Astrobrush, Ivoclar Vivadent) have proven themselves to be suitable for polishing composite materials to a high lustre (Fig. 15).

The final clinical picture (Fig. 16) shows the repaired fracture.

Conclusions

Fractures of all-ceramic restorations can be avoided to a great extent if the indication is correct and the work has been carried out very carefully in the laboratory and the clinic. If access is possible and the function of the restoration can be preserved, it is possible nowadays to repair fractures and defects by using an adequate adhesive technique and composite materials.

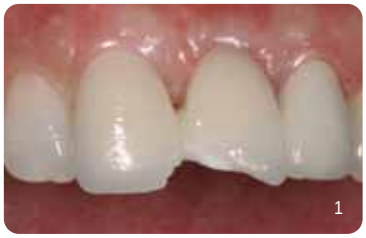


Fig. 1 : Initial clinical situation: Delaminations of the ceramic veneer in the area of pontic 21 extending to crown 11. The zirconium dioxide framework is partially uncovered.
Fig. 2 : Placed rubberdam for absolute dry conditions and protection when using the HF gel.
Fig. 3: Application of the HF gel with a brush
Fig. 4: After the restoration has been thoroughly cleaned and dried, the etched ceramic surface appears whitish/mat.
Fig. 5: Application of the Metal/Zirconia Primer on the zirconium dioxide framework where it is needed
Fig. 6: Monobond-S is applied on the etched surface of the veneering ceramic.
Fig. 7: Pre-application of a monomer using Heliobond
Fig. 8: Light-curing of the pre-applied monomer for 20 seconds
Fig. 9: A dentin core is built up with Tetric EvoCeram (A2).
Fig. 10: The restoration is cured with the bluephase curing light for 20 seconds in the High Power mode.
Fig. 11: The 'enamel coat' is modelled with Tetric EvoCeram Transparent. It has to be taken into consideration that the tooth shape is almost perfect due to the excellent modelling properties of the composite material.
Fig. 12: Finishing with very fine diamonds (Composhape, Intensiv)
Fig. 13a: The edge characteristics are finished with the aluminium oxide-coated coarse disc (Soflex).
Fig. 13b: Coarse pre-polishing of the facial surface
Fig. 14: The restoration is polished with polishing tips (Astropol)
Fig. 15: High-gloss polishing with Astrobrush
Fig. 16: Final picture

List of authors

Dr. Volker Rheinberger
- Born 1948 in Vaduz/FL
- Elementary school in Vaduz and subsequently grammar school Kollegium Marianum with school leaving examination in 1968.
- Study of chemistry at the University in Basel and doctorate in chemistry.
- Postgraduate studies at the University of St Gallen with licentiate in economics. Various practical courses in the industry during his studies.
- After a short working period at a company in St Gallen, he started as a developmental chemist at Ivoclar
- Today, he is a Member of the Corporate Management and responsible for the entire Research and Development Department.

Prof. Heinrich F. Kappert
- Training as a machine fitter
- Study of physics, mathematics, philosophy, and education at the Universities of Münster and Freiburg (Germany)
- Promotion in physics
- 1 years as a consultant for semi-conductor and computer technology at IBM US
- 1980 habilitation in physics at the University of Dortmund (Germany)
- April 1982-2002: Prof. for dental materials science at the Dental School of the University of Freiburg (Germany)
- Since April 1, 2002: Head of Research & Development technical, Ivoclar Vivadent AG, Schaan/FL

Patrik Oehri
- Born in 1963
- Degree in chemical engineering form the Federal Institute of Technology, Zurich, Switzerland
- As of 1990: Member of scientific staff at Research & Development, Ivoclar Vivadent AG/FL
- 1994–2001: Head of Scientific Service, Research & Development, Ivoclar Vivadent AG/FL
- As of 2001: Sector Manager of Research & Development Services, Ivoclar Vivadent AG/FL

Tobias Specht
- 1992–1996: Apprenticeship as dental technician
- 1996–1999: Dental technician and deputy laboratory manager
- 1999–2000: School of Master Dental Technicians, Freiburg, Germany Diploma: Master Dental Technician
- since 2000: Product Manager All Ceramics/Composite Ivoclar Vivadent AG, Schaan/ Liechtenstein

Dr. Dr. Andreas Rathke
- Born 1969 in Düsseldorf/Germany
- 1989–1994: School of Dentistry, University of Bonn, Germany
- 1996: Doctoratedegree, University of Bonn, Germany
- 1998: Doctorate degree, University of Zurich, Switzerland
- 1995: Assistant in general dental practice, Bielefeld, Germany
- 1995–1998: Scientific staff member and instructor in the department of tooth coloured and computer assisted restorations, Clinic for Preventive Dentistry, Periodontics and Cariology, University of Zurich, Switzerland
- 1998–2001: Dentist in the department of Clinical Research, Research & Development, Ivoclar Vivadent, Schaan, Liechtenstein
- 2001–2004: Product Manager, Dentistry and New Technologies, Marketing and Product Management, Ivoclar Vivadent, Schaan, Liechtenstein
- Since 2003: Dentist in private practice, Liechtenstein

Thomas Völkel
- Degree in chemistry from the University of Bayreuth, Germany
- Doctorate degree in macromolecular chemistry
- 1989–1993: Research visits: Université Bordeaux, France; Rijksuniversiteit Gent, Belgium; Ciba Research Centre in Marly, Switzerland
- 1994–1994: Head of Department, Synthesis, Research & Development, Ivoclar Vivadent AG/FL
- Since 2002: Scientific Services, Research & Development, Ivoclar Vivadent AG/FL

Dr. Siegward Heintze
Born in 1959
- Born in 1959
- 1978–1984: Studies in dentistry at Freie Universität Berlin, Germany
- 1984–1989: Member of Scientific Staff, Conservative Dentistry
- 1989–1993: Member of Scientific Staff, Paediatric Dentistry
- 1989–1992: Dentist in private practice
- 1992: Doctorate
- 1993: Hufeland Prize
- 1994–1996: Research grant of the German Research Foundation for a research project in Brazil (fluoridation of drinking water)
- 1997–2001: Head of Clinical Research, Ivoclar Vivadent
- since 2001: Head of In Vitro Research, Ivoclar Vivadent, FL

Prof. Dr. Jean-François Roulet
- born 1947 in Aarau, Switzerland
- 1974: D.D.S.
- 1976: Assistant medical doctor, Department for restorative dentistry, University of Bern
- 1977: Doctorate of dentistry (University of Bern)
- 1978: Visiting Scientist, University of Connecticut, Health Center, Farmington, Conn. USA
- 1980–1981: Visiting Scholar, Dept. of Dental Materials, University of Michigan, Ann Arbor USA
- 1981: Assistant medical doctor, head of the working group of acrylics research, department of cariology, periodontology and preventive medicine at the University of Zurich
- 1984–1994: Department head of the department for restorative dentistry north, Freie Universität Berlin (FU)
- 1985–1991: Vice-dean of the clinic for dental medicine, FU Berlin
- 1986: Habilitation thesis (University of Zurich)
- 1989–1990: Visiting Professor, Dept. of Biomaterials, University of Florida, Gainesville Fla. USA
- 1991–1994: Dean of the clinic for dental medicine, FU Berlin
- 1994: Dentist of the public health service
- 1994: Department head of the department for preventive dentistry, Charité – Universitätsmedizin Berlin, Humboldt-Universität in Berlin
- 2002: Visiting Professor Universita degli Studi di Siena, Facoltà di Medicina e Chirurgia
- Since 2003: Sector Manager of the department of research and development clinical, Ivoclar Vivadent, Schaan, FL

Hans-Peter Foser
- Born 1953 in Balzers/FL
- 1969–1973: Vocational training as dental technician in Trübbach/SG (Switzerland)
- 1973–1975: Dental technician employed at practice laboratory Dr. Harder, Geneva
- 1975–1978: Dental technician employed at dental laboratory Huser AG, Olten/Wangen (CH)
  Specializing in: milling technique, telescopics, hybrid and implant denture prosthetics, C & B / ceramics
- 1978–1988: Chief technician in the practice laboratory Dr. Hartmann, Vaduz, FL, general techniques, ceramics
- 1987–1989: School for master craftspeople in dental technology in Zurich
  Certified Master Dental Technician
  Diploma: Master Dental Technician
- 1988: Instructor at Ivoclar Vivadent, Schaan, FL
- since 1991 Head of the R & D dental laboratory
- Since 1991: Lecturer at the schools for master craftspeople in Geneva and Zurich
- 1991: Diplomé Ingenieur Dentaire (certified dental engineer), Accademie d'Art Dentaire, Geneva
- Since 1991: Chief expert for prosthetics at the school for craftspeople in Zurich

Dr. Alexander Stiefenhofer
- Born 1963 in Munich
- 1990–2001: Assistant dentist at the Clinic for Prosthetic Dentistry at the University Julius-Maximilian in Würzburg; Bavaria
- 1991: Doctorate of dentistry
- 1999: Appointment as assistant medical doctor
- Since 2001: dental and scientific work at Ivoclar Vivadent AG, Schaan, FL, specializing in prosthetic dentistry

Bibliography

[1] Alswueilem A, Eklund S. Long-Term Survival Analysis of Single Indirect Restorations Among Insured Adults. Abstract 3045, 2005 IADR 83rd General Session, Baltimore

[2] Anusavice KJ. Degradability of Dental Ceramics. Adv Dent Res, Sept 1992;6:82-89

[3] Anusavice KJ. Dental Ceramics. Phillips' Science of Dental Materials 2003;11:655-720

[4] Audenino G, Bassi F, Carossa S, Bresciano M. In vitro evaluation of the precision of fit of three ceramic inlay systems. Int J Prosthodont 1998;11:90

[5] Baba K, Clark GT, Watanabe T, Ohyama T. Bruxism force detection by a piezoelectric film-based recording device in sleeping humans. J Orofac Pain 2003;17:58-64

[6] Baumann M, Heidemann D. Biocompatibility of Dental Inlay Ceramics. Int. Symposium on Computer Restaurations, May 1991, Zürich

[7] Bernhardt O, Gesch D, Splieth C, Schwahn C, Mack F, Kocher T, Meyer G, John U, Kordass B. Risk factors for high occlusal wear scores in a population-based sample: results of the Study of Health in Pomerania (SHIP). Int J Prosthodont 2004;17:333-9

[8] Bindl A, Mörmann WH. Clinical and SEM evaluation of all-ceramic chair-side CAD/CAM-generated partial crowns. Eur J Oral Sci 2003;111:163-9

[9] Bindl A, Richter B, Mörmann WH. Survival of ceramic computer-aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry. Int J Prosthodont 2005;18:219-224

[10] Bohlsen F, Wegner S, Wolfart S, Kern M. Clinical Outcome of a New All-Ceramic-System for Fixed Partial Dentures. Abstract 4076, 2004 IADR 82nd General Session, Hawaii

[11] Borchard R, Erpenstein H, Kerschbaum Th. Langzeitergebnisse von galvanokeramischen und glaskeramischen (Dicor) Einzelkronen unter klinischen Bedingungen. Dtsch Zahnärztl Z 1998;53:616-9

[12] Bornemann G, Rinke S, Wehle S, Hüls A. Prospektive klinische Langzeitstudie zur Bewährung drei- und viergliedriger CERCON-Seitenzahnbrücken – Zwei Jahres Ergebnisse. 53. DGZPW Tagung in Kiel, 2004, Abstract P 4

[13] Bornemann G, Lemelson S, Luthardt R. Innovative method for the analysis of the internal 3D fitting accuracy of CEREC-3 crowns. Int J Comput Dent 2002;5:177-82

[14] Butler CJ, Masri R, Driscoll CF, Thompson GA, Runyan DA, Anthony von Fraunhofer J. Effect of fluoride and 10% carbamide peroxide on the surface roughness of low-fusing and ultra low-fusing porcelain. J Prosthet Dent 2004;92:179-83

[15] Carlsson GE, Egermark I, Magnusson T. Predictors of signs and symptoms of temporomandibular disorders: a 20-year follow-up study from childhood to adulthood. Acta Odontol Scand 2002;60:180-5

[16] Claus, H. Vita In - Ceram, ein neues Verfahren zur Herstellung oxidkeramischer Gerüste für Kronen und Brücken. Quintessenz Zahntechnik 1990;16:35-46

[17] Coornaert J, Adrians P, De Boever J. Long-term clinical study of porcelain-fused-to-gold restorations. J Prosthet Dent 1984;51:338-42

[18] CRA. Posterior full crowns 2001, Part 3: 2-year clinical peformance of CAD-CAM copings & full crowns. CRA Newsletter 2001;25:1-3

[19] Dahl BL, Carlsson GE, Ekfeldt A. Occlusal wear of teeth and restorative materials. A review of classification, etiology, mechanisms of wear, and some aspects of restorative procedures. Acta Odontol Scand 1993;51:299-311

[20] Demirel F, Yuksel G, Muhtarogullari M, Cekic C. Effect of topical fluorides and citric acid on heat-pressed all-ceramic material. Int J Periodontics Restorative Dent 2005;25:277-81

[21] Dumfahrt H. Porcelain Laminate veneers. A retrospective evaluation after 1 to 10 years of service: Part I – Clinical procedure. Int J Prosthodont 1999;12:505-13

[22] Dumfahrt H, Schäffer H. Porcelain laminate veneers. A retrospective evaluation after 1 to 10 years of service: Part II – Clinical results. Int J Prosthodont 2000;13:9-18

[23] Edelhoff D, Spiekermann H, Rübben A, Yildirim M. Kronen - und Brückengerüste aus hochfester Presskeramik. Quintessenz 1999;50:177-89

[24] Edelhoff D , Spiekermann H, Brauner J, Yildirim M. IPS IPS Empress 2 – adhäsiv und konventionell befestigt. dental-praxis 2005;22:21-33

[25] Edelhoff D, Horstkemper Th, Richter EJ, Spiekermann H, Yildirim M. Adhäsive und konventionell befestigte IPS Empress 1 Kronen: Klinische Befunde nach vierjähriger Tragedauer. Dtsch Zahnärztl Z 2000;55:326-30

[26] Edelhoff D, Spiekermann H, Kinnen B, Yildirim M. Adhäsive und konventionell befestigte Kronen und Brücken aus IPS Empress 2 – Klinische Ergebnisse nach vierjähriger Tragedauer. 53. DGZPW Tagung in Kiel, 2004, Abstract KV 9

[27] Ekfeldt A, Fransson B, Soderlund B, Oilo G. Wear resistance of some prosthodontic materials in vivo. Acta Odontol Scand 1993;51:99-107

[28] Ekfeldt A, Oilo G. Wear of prosthodontic materials - an in vivo study. J Oral Rehabil 1990;17:117-29

[29] EN ISO 6872 (1998) Dental Ceramic

[30] EN ISO 7405 (1997). Dentistry – Preclinical evaluation of biocompatibility of medical devices used in dentistry – Test methods for dental materials

[31] EN ISO 9693 (2000) Metal-Ceramic dental restorative systems

[32] EN ISO 10993-1(2003) Biological evaluation of medical devices

[33] Ernst CP, Cohnen U, Stender E, Willershausen B. In vitro retentive strength of zirconium oxide ceramic crowns using different luting agents. J Prosthet Dent 2005;93:551-8

[34] Esquivel-Upshaw JF, Anusavice KJ, Young H, Jones J, Gibbs C. Clinical performance of a lithia disilicate-based core ceramic for three-unit posterior FPDs. Int J Prosthodont 2004;17:469-75

[35] Etman MK, Woolford MJ, Dunne SM, Wilson N. 54 months clinical performance and crack propagation in all-ceramic restorations. Abstract 423, 2005 IADR 83rd General Session, Baltimore

[36] FDA, Health CfDaR. Good Laboratory Practice (GLP). (PART 58 52 FR 33780, 1978, last revision 2004) 1978

[37] FDA, Health CfDaR. Guideline on general principles of process validation. No. 820 1987

[38] Fischer-Brandies E, Pratzel H, Wendt T. Zur radioaktiven Belastung durch Implantate aus Zirkoniumoxid. Dtsch Zahnärztl Z 1991;46:688-90

[39] Fradeani M, Redemagni M, Corrado M. Porcelain laminate veneers: 6- to 12-year clinical evaluation – a retrospective study. Int J Periodontics Restorative Dent 2005;25:9-17

[40] Fradeani M, Redemagni M. Clinical evaluation of leucite-reinforced glass-ceramic crowns over 11 years. Quintessenz 2003;54:379-86

[41] Fradeani M, Redemagni M. An 11-year clinical evaluation of leucite-reinforced glass-ceramic crowns: A retrospective study. Quintessence Int 2002;33:503-10

[42] Frank M, Schweiger M, Höland W, Rheinberger V. High-strength translucent sintered glass-ceramic for dental restorations. Glass Sci Technol Glastech Ber 1998;71C:345-8

[43] Frankenberger R. Was hinter dem richtigen Kleben steckt. Die Zahnarzt Woche 2004;12:14-6

[44] Friedman MJ. A 15-year review of porcelain veneer failure – a clinician's observations. Compend Contin Educ Dent 1998;19:625-38

[45] Geis-Gerstorfer J, Fäßler P. Untersuchungen zum Ermüdungsverhalten der Dentalkeramiken Zirkondioxid-TZP und In-Ceram. Dtsch Zahnarztl Z 1999;54:692-4

[46] Genco RJ. Current view of risk factors for periodontal diseases. J Periodontol 1996;67:1041-9

[47] Gesch D, Bernhardt O, Kirbschus A. Association of malocclusion and functional occlusion with temporomandibular disorders (TMD) in adults: a systematic review of population-based studies. Quintessence Int 2004;35:211-21

[48] Goodacre CJ, Bernal G, Rungcharassaeng K, Kan JY. Clinical complications in fixed prosthodontics. J Prosthet Dent 2003;90:31-41

[49] Gragg KL, Shugars DA, Bader JD, Elter JR, White BA. Movement of teeth adjacent to posterior bounded edentulous spaces. J Dent Res 2001;80:2021-4

[50] Granada S, Hicks RA. Changes in self-reported incidence

of nocturnal bruxism in college students: 1966-2002. Percept Mot Skills 2003;97:777-8
[51] Guggenberger R. Das Rocatec System – Haftung durch tribochemische Beschichtung. Dtsch Zahnärztl Z 1989;44:874-6
[52] Hajtó J. Veneers – Materialien und Methoden im Vergleich. Teamwork 2000;3:195-202
[53] Heintze SD, Zappini G, Rousson V. Wear of ten dental restorative materials in five wear simulators-Results of a round robin test. Dent Mater 2005;21:304-17
[54] ISO 13356 (1997). Implants for surgery – Ceramic materials based on ytria-stabilized tetragonal zirconia (Y-TZP)
[55] ISO 14569-2 (2001). Dental materials - Guidance on testing of wear. Part2: Wear by two-and/or three body contact. Technical Specification
[56] John MT, Frank H, Lobbezoo F, Drangsholt M, Dette KE. No association between incisal tooth wear and temporomandibular disorders. J Prosthet Dent 2002; 87:197-203
[57] Kappert HF. Dental Material: New ceramic systems. Academy of dental Materials. Transactions 1996;9:180-99
[58] Kappert HF. Keramische Verblendmassen. In Meiners H, Lehmann KM (Hersg.). Klinische Materialkunde Hanser, München 1998:313-24
[59] Kappert HF. Vollkeramischer Zahnersatz. In Meiners H, Lehmann KM (Hersg.). Klinische Materialkunde Hanser, München 1998:349-63
[60] Kappert HF. Bedeutung verschiedener Material-parameter für den klinischen Erfolg. Referat auf dem Keramik-Symposium der AG Keramik, München 2003
[61] Kohyama K, Hatakeyama E, Sasaki T, Azuma T, Karita K. Effect of sample thickness on bite force studied with a multiple-point sheet sensor. J Oral Rehabil 2004;31:327-34
[62] Kohyama K, Hatakeyama E, Sasaki T, Dan H, Azuma T, Karita K. Effects of sample hardness on human chewing force: a model study using silicone rubber. Arch Oral Biol 2004;49:805-16
[63] Komine F, Tomic M, Gerds T, Strub JR. Influence of different adhesive resin cements on the fracture strength of aluminum oxide ceramic posterior crowns. J Prosthet Dent 2004;92:359-64
[64] Krämer N, Frankenberger R. Clinical Performance of bonded leucite-reinforced glass ceramic inlays and onlays after eight years. Dent Mater 2005;21:262-71
[65] Kunzelmann KH. Verschleissanalyse und -quantifizierung von Füllungsmaterialien in vivo und in vitro. Aachen: Shaker Verlag, 1998.
[66] Lorenz S. Verhalten primärer humaner Epithelzellen und Gingivafibroblasten unter dem Einlfuss verschiedener Dentalkeramiken – eine in vitro Untersuchung. Dissertation, Zentrum für ZMK, J.W Goethe Universität Frankfurt, 1994
[67] Ludwig K. Lexikon der zahnmedizinischen Werkstoffkunde 2005, Quintesssenz Verlag
[68] Luthardt R, Herold V, Sandkuhl O, Reitz B, Knaak JP, Lenz E. Kronen aus Hochleistungskeramik. Dtsch Zahnarztl Z 1998;53:280-5
[69] Mackert JR. Side-Effects of Dental Ceramics. Adv Dent Res, Sept 1992;6:90-3
[70] Malament KA, Socransky SS. Survival of Dicor glass-ceramic dental restorations over 14 years: Part I. Survival of Dicor complete coverage restorations and effect of internal surface acid etching, tooth position, gender, and age. J Prosthet Dent 1999;81:23-32
[71] Malament KA, Socransky SS. Survival of Dicor glass-ceramic dental restorations over 14 years: Part II. Effect of thickness of Dicor material and design of tooth preparation. J Prosthet Dent 1999;81:662-7
[72] Malament KA, Socransky SS. Survival of Dicor glass ceramic dental restorations over 16 years Part III. Effect of luting agent and tooth substitute core structure. J Prosthet Dent 2001;86:511-9
[73] Manhart J, Chen H, Hamm G, Hickel R. Review of the clinical survival of direct and indirect restorations in posterior teeth of the permanent dentition. Operative Dentistry 2004;29:481-508
[74] McLean JA, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J 1971;131:107-11
[75] Mehl A, Gloger W, Kunzelmann KH, Hickel R. A new optical 3-D device for the detection of wear. J Dent Res 1997;76:1799-807
[76] Messer RL, Lockwood PE, Wataha JC, Lewis JB, Norris S, Bouillaguet S. In vitro cytotoxicity of traditional versus contemporary dental ceramics. J Prosthet Dent 2003;90:452-8
[77] Milosevic A, Dawson LJ. Salivary factors in vomiting bulimics with and without pathological tooth wear. Caries Res 1996;30:361-6
[78] Molin MK, Karlsson SL, Kristiansen MS. Influence of film thickness on joint bend strength of a ceramic/resin composite joint. Dent Mater 1996;12:245-9
[79] Moore JE, MacCulloch WT. The inclusion of radioactive compounds in dental porcelains. Br Dent J 1974;136:101-6
[80] NIOM. Test report 012/04 (März 2004)
[81] Nishigawa K, Bando E, Nakano M. Quantitative study of bite force during sleep associated bruxism. J Oral Rehabil 2001;28:485-91
[82] Oilo G, Evje D. Film thickness of dental luting cements. Dent Mater 1986;2:85-9
[83] Olsson KG, Furst B, Andersson B, Carlsson GE. A long-term retrospective and clinical follow-up study of In-Ceram Aluminia FPDs. Int J Prosthodont 2003;16:150-6
[84] Özcan M, Niedermeier W. Clinical study on the reasons for and location of failures of metal-ceramic restorations and survival of repairs. Int J Prosthodont 2002;15:299-302
[85] Özcan M, Alander P, Vallittu PK, Huysmans MC, Kalk W. Effect of three surface conditioning methods to improve bond strength of particulate filler resin composites. J Mater Sci Mater Med 2005;16: 21-7
[86] Özcan M. Evaluation of alternative intraoral repair techniques for fractured ceramic-fused-to-metal restorations. J Oral Rehabil 2003;30:194-203
[87] Özcan M. Fracture reasons in ceramic-fused-to-metal restorations. J Oral Rehabil 2003;30:265-9
[88] Pallesen U, Qvist V. Composite resin fillings and inlays. An 11-year evaluation. Clin Oral Investig 2003;7:71-9. Epub 2003 May 10
[89] Peumans M, De Munck J, Fieuws S, Lambrechts P, Vanherle G, Van Meerbeek B. A prospective ten-year clinical trial of porcelain veneers. J Adhes Dent 2004;6:65-76
[90] Piwowarczyk A, Ottl P, Lauer HC, Kuretzky T. A Clinical Report and Overview of Scientific Studies and Clinical Procedures Conducted on the 3M ESPE Lava All-Ceramic System. J Prosthodont 2005;14:39-45
[91] Pospiech P, Kiestler St, Frasch C, Rammelsberg P. Clinical evaluation of posterior crowns and bridges of IPS Empress II: Preliminary results after one year. Abstract 1610, 1999 IADR Vancouver, Kanada. Submitted, J Dent Res 78: 307
[92] Pospiech P, Nothdurft FP. Long-term behaviour of Zirconia-based bridges: Three years results. Abstract 230, IADR-CED 2004, Istanbul
[93] Pröbster, L. Survival rate of In-Ceram restorations. Int J Prosthodont 1993;6:259- 263
[94] Pröbster L. Klinische Langzeiterfahrung mit voll-keramischen Kronen aus In-Ceram. Quintessenz 1997;48:1639-46
[95] Pröbster L. Stellungnahme von DGZMK/DGZPW: Sind vollkeramische Kronen und Brücken wissenschaftlich anerkannt? Dtsch Zahnarztl Z 2001;56:575-6
[96] Qualtrough AJE, Piddock V. Fitting accuracy of indirect restorations: a review of methods of assessment. Eur J Prosthodont Rest Dent 1992;1:57-61
[97] Reiss B, Walther W. Clinical long-term results and 10-year Kaplan-Meier analysis of CEREC restorations. Int J Comp Dent 2000;3:9-23
[98] Rinke S, Behi F, Hüls A. Fitting accuracy of all-ceramic posterior crowns produced with three different systems. J Dent Res 2001;80:651 (#997)
[99] Rosentritt M, Behr M, Lang R, Handel G. Influence of cement type on the marginal adaptation of all-ceramic MOD inlays. Dent Mater 2004;20:463-9
[100] Roulet JF, Söderholm KJM, Longmate J. Effects of Treatment and Storage Conditions on Ceramic/Composite Bond Strength. J Dent Res 1995;74:381-7

[101] Sailer I, Lüthy H, Feher A, Schumacher M, Schärer P, Hammerle CHF. 3- year results of zirconia posterior fixed partial dentures, made by Direct Ceramic Machining (DCM). J Dent Res 2003;82 (Spec Iss B): B-21 (#74)
[102] Sairenji E, Moriwaki K, Shimizu M, Noguchi K. Estimation of radiation dose from porcelain teeth containing uranium compound. J Dent Res 1980;59:1136-40
[103] Schäfer R, Kappert HF. Die chemische Löslichkeit von Dentalkeramiken. Dtsch Zahnärztl Z 1993;48:625-8
[104] Schindler HJ, Stengel E, Spiess WE. Feedback control during mastication of solid food textures - a clinical-experimental study. J Prosthet Dent 1998;80:330-6
[105] Seligman DA, Pullinger AG, Solberg WK. The prevalence of dental attrition and its association with factors of age, gender, occlusion, and TMJ symptomatology. J Dent Res 1988;67:1323-33
[106] Shinogaya T, Bakke M, Thomsen CE, Vilmann A, Sodeyama A, Matsumoto M. Effects of ethnicity, gender and age on clenching force and load distribution. Clin Oral Investig 2001;5:63-8
[107] Shugars DA, Bader JD, Phillips SW Jr., White BA, Brantley CF. The consequences of not replacing a missing posterior tooth. J Am Dent Assoc 2000;131:1317-23
[108] Soderholm KJ, Lambrechts P, Sarrett D, Abe Y, Yang MC, Labella R, Yildiz E, Willems G. Clinical wear performance of eight experimental dental composites over three years determined by two measuring methods. Eur J Oral Sci 2001;109:273-81
[109] Sorenson JA, Cruz MA, Berge HX. In vivo measurement of antagonist tooth wear opposing ceramic bridges. J Dent Res 2000;79:172 (#232)
[110] Spiekermann H. The marginal fit of crowns and bridges. Dtsch Zahnärztl Z 1986;41:1015-9
[111] Studer S, Lehner C, Schärer P. Seven year results of leucite reinforced glass ceramic crowns. J Dent Res 1998;77:803 (#1375)
[112] Sturdevant JR, Bayne SC, Heymann HO. Margin gap size of ceramic inlays using second-generation CAD/CAM equipment. J Esthet Dent 1999;11:206-14
[113] Tan K, Pjetrusson BE, Lang NP, Chan ES. A systematic review of the survival and complication rates of fixed partial dentures (FDPs) after an observation period of at least 5 years. Clin Oral Implants Res 2004;15:654-66
[114] Tinschert J, Schimmang A, Fischer H, Marx R. Belastbarkeit von zirkoniumoxidverstärkter In-Ceram Alumina-Keramik. Dtsch Zahnärztl Z 1999;54:695-9
[115] Tinschert J, Natt G, Latzke P, Schulze K, Heussen N, Spiekermann H. Vollkeramische Brücken aus DC-Zirkon – ein klinischen Konzept mit Erfolg? Dtsch Zahnärztl Z 2005;60:435-45
[116] Toxikon Report 03-5930-G1 Short term intramuscular implantation test, 2004
[117] Toxikon Report 03-5936-G1 14 day repeat dose intravenous toxicity study, 2004
[118] Uo M, Sjoren G, Sundh A, Watari F, Bergman M, Lerner U. Cytotoxicity and bonding property of dental ceramics. Dent Mater 2003;19:487-92
[119] Viohl J. Radioaktivität keramischer Zähne und Brennmassen. Dtsch Zahnärztl Z 1976;31:860
[120] Wataha JC. Principles of biocompatibility for dental practitioners. J Prosthet Dent 2001;86:203-9
[121] Weigl P, Edelhoff D. Ästhetik und Verweildauerwahrscheinlichkeit einer neuen Verblendkeramik für Gerüste aus Zirkoniumoxid – Erste klinische Ergebnisse. 53. DGZPW Tagung in Kiel, 2004, Abstract IF 2
[122] Weigl P. Zirkonium Oxide based crown and bridges: first results of a prospective clinical trial. Interner Bericht für Ivoclar Vivadent, März 2005
[123] Willems G, Lambrechts P, Braem M, Vanherle G. Three-year follow-up of five posterior composites: in vivo wear. J Dent 1993;21:74-8
[124] Yeh CK, Johnson DA, Dodds MW, Sakai S, Rugh JD, Hatch JP. Association of salivary flow rates with maximal bite force. J Dent Res 2000;79:1560-5
[125] Zimmer D, Gerds T, Strub JR. Überlebensraten von IPS Empress 2 Vollkeramikkronen und -brücken: Drei-Jahres-Ergebnisse. SSO 2004;114(2):115-9

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Ivoclar Vivadent Report
Published by Ivoclar Vivadent AG, Schaan, Liechtenstein

600716/0206/e/W

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