Clinical and laboratory evaluation of CAD/CAM All-ceramic crowns
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Citation for published version (APA):
Begazo, C. M. C. (2004). Clinical and laboratory evaluation of CAD/CAM All-ceramic crowns
CHAPTER 1

General Introduction
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As a restorative material, ceramic is one of the oldest materials used for dental prosthetic treatments. In the 18th century, porcelain teeth were already used in complete dentures whereas in 1886 Land introduced the first fused feldspathic porcelain inlay and crown\(^1\). As no dental investment materials were available at that time, these restorations were sintered on a platinum foil that was burnished directly in or on the tooth in the shape of the inlay or crown preparation. After the sintering process had taken place, the foil was removed leaving a space for the luting cement. Later on, techniques were developed to leave the metal foil in place and to bond the ceramic material to the metal foil. This development enhances not only an improved seat of the restoration but also some kind of metal reinforcement of the brittle ceramic restoration.

The transparency and light scattering of dental ceramic restorations are similar to the natural tooth, resulting in restorations with a more or less natural appearance. Moreover, ceramics show excellent biocompatibility characteristics when compared to metal-based restorations. Despite these advantages they failed to gain widespread popularity until the introduction of alumina as reinforcing phase in dental porcelain\(^2\). Everyone knows the fragility of nice full porcelain objects, used in a household. When used in the mouth, they usually fail due to internal crack formation and crack growth, which is caused by repeated stress absorption. Dental ceramics show a comparable behavior resulting frequently in porcelain fracture due to their brittleness, while metals are ductile, it means that they are able to flex and deform under applied stresses that exceed their elastic limit without breaking.

The introduction of the lost wax technique in 1907 by W.H. Taggart made the production of metal crowns possible. With this improvement, cast crowns became very popular resulting in a limited and/or decreasing use of all-ceramic restorations in the dental office. In the late 1950's, porcelain fused to metal crowns (PFM) were developed, before the ceramic restoration, now as PFM-restoration, gained again popularity. Nevertheless, the metal substructure of porcelain fused to metal restorations influences the aesthetic properties of the restoration negatively, which encourages the search for stronger all-ceramic systems. Fracture toughness of brittle materials like porcelain can be improved by dispersing an inert filler phase into the matrix phase\(^3\). Fillers like alumina reduce micro-crack formation and bulk fractures.
However, the addition of such fillers may influence the aesthetic as well\(^4\). Therefore most of the newer all-ceramic systems that came on the market make use of a strong ceramic coping and a veneer of conventional porcelain to produce a good looking restoration with enough strength. Other systems are based on new production methods which enable the use of stronger materials or exclude the creation of voids originated by the manual production procedure\(^5\).\(^6\).\(^7\).

Besides many different technical factors, the final preparation shape created by the dentist may influence the longevity of all-ceramic restorations as well\(^8\). With respect to all-ceramic jacket crowns, it was required that the dentist makes a preparation with a taper of approximately 7 degrees and a straight shoulder which is at least 1.0 mm wide. This type of preparation appears to prevent mostly the occurrence of the undesirable tensile forces, while the straight shoulder supports the all-ceramic jacket crown in such a way that most forces occur in compression. This concept is still applied, however the straight shoulder is replaced frequently by a deep chamfer preparation. Nevertheless, the dentist cannot always meet such preparation requirements, as he is also responsible for maintaining tooth’s vitality. Anatomical properties as, for example the, “fossa canina” of the first upper premolar may interfere with the creation of a shoulder and maintaining the tooth vitality at the same time. Therefore a study to reveal the ‘created’ preparation shape compared to the one that the manufacturer requires, is of interest.

Not only ceramic brittleness and/or fracture toughness are important material parameters, which determine the longevity of all-ceramic restorations; also the accuracy of the fit between the ceramic unit and the tooth is extremely important. The tooth will support a well-adapted crown whereas an unsupported crown including one, which is supported by an overthick layer of cement, will be more likely to flex and then fail prematurely\(^9\).\(^10\). Therefore, a good bond between the porcelain and the tooth could reduce crack formation and affect the longevity positively. That means that the choice of cement and a proper cementation procedure is also critical for their success.

Following an appropriate preparation, a ‘strong’ supporting coping, an accurate fit to the tooth and highly adhesive cementation system as well as a strong veneering ceramic, are essential for the success of all-ceramic dental restorations.

In the early fifties\(^3\) developed alumina are used to reinforce feldspatic porcelain for the creation of a stronger base for the all-ceramic jacket crown. The idea behind filler reinforcing is that the growth of small cracks will stop when they come into
contact with the strong filler particle\textsuperscript{11,12}. As the matrix is still relatively weak, only the resistance to fatigue loading is increased while the tensile strength is hardly influenced, as that is mainly dependent on the relatively weak matrix. Due to the manual production method, often the glass matrix contains many voids and air bubbles, which will have a weakening effect too. Consequently, the reinforcement by adding fillers is limited.

The search into the development of really strong cores continued. Two main directions can be recognized, one based on the exclusion of a glass matrix and another on the homogenization of the glass matrix by excluding the voids and air bubbles. Both developments require new production methods. CAD/CAM-based processing techniques castable or pressable glass-ceramics are examples of this development.

To exclude or minimize the glass matrix, manufacturers aim for possibilities to increase the amount of the strong alumina or zirconia fillers to near 100%. Both materials can only sinter to each other at extremely high temperatures (\(>> 1000\, ^\circ\text{C}\)) with relatively long sintering times. Moreover, like all dental ceramics, during the sintering process high sintering shrinkage occurs. However, as it is aimed to minimize or exclude the "flowable" glass matrix phase, flow of the ceramic material during cooling of these materials is not possible. Therefore, the shape of the ceramic restorations mainly composed from alumina or zirconia, has to be made larger before sintering to compensate the shrinkage.

\textit{In-Ceram}

VITA In-Ceram is an example of an infiltration ceramic production procedure, which has been introduced for a wide range of indications and as an adequate alternative to metal-ceramic restorations\textsuperscript{13}. The slip casted substructure is processed in a porously sintered state, while the final hardness of the substructure is achieved by glass infiltration. As a result no sintering shrinkage occurs, i.e. the dimensions of the substructure remain unchanged during the two processing steps. The cap is finally veneered with Vitadur Alpha veneering porcelain.

\textit{Empress}

The IPS Empress system (Ivoclar) was introduced in the early 1990's as a new standard of excellence in aesthetic fixed prosthodontic materials. The IPS Empress
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system makes use of a highly aesthetic hot pressed glass ceramic material for fabrication of single crowns. Adhesive cementation of the system is recommended as it not only contributes to the aesthetic but it is also necessary for increased strength of the crown. The fabrication methodology involves a lost-wax investment technology for the hot pressed ceramic system that dental technicians are familiar with. After de-investing, the aesthetic of the crown can be improved by staining or veneering

**CAD/CAM**

The fabrication of the strong ceramic coping with an accurate fit is not easy. Solutions are found in using CAD/CAM (Computer Aided Design/Computer Aided Machining). In the last decade many CAD/CAM based systems for the automated production of dental restorations have appeared on the market. Some are designed for use in the dental laboratories, like Procera, others for use in the dental office (chair side) like Cerec. A way to look at the CAD/CAM system development is by classifying the systems based on a division of the CAD/CAM process in modules; scanning, design and production, and on the place of activity; dental technicians office, dentist office, or centralized production plant. As a result three ways of processing a CAD/CAM restoration are possible of which only some will be commercially feasible.

In dentistry no interchangeable modules are available on the market. For most contemporary systems each manufacturer has developed its own software and hardware for all system modules. As a consequence, the interfaces between the modules are not standardized and, as a result, the modules of different manufacturers are not interchangeable. The knowledge needed for building a perfect CAD/CAM-based dental restorative system varies amongst others from dentistry to micro-mechanical science, to information technology and to materials science. It is hard to believe that one manufacturer can build a perfect system without cooperating with many others. For that reason, from the systems available on the market, it happens that good properties are combined with less good ones in one system.

Another way to look at the different systems is to classify them according to the goal the manufacturer wants to reach with it: the replacement of highly skilled labor by automated production or the creation of the possibility to use materials that cannot be processed by manual production methods in a reliable way. For instance the CAD/CAM procedure may be able to handle sintering shrinkage and may offer
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materials with more homogeneity and strength than could be obtained manually. However, the real advantage of automated production will be the independence from extensive and expensive laboratory procedures making costly restorative procedures feasible for more people. Nevertheless, most available systems do not offer this advantage but are mainly developed to enable the use of new stronger materials that cannot be handled manually.

Scheme 1. Overview of possible locations of the different CAD/CAM modules, with some inter-relationships. The dashed arrow represents the CEREC process, the line arrow the CICERO process, the dotted line both Procera AllCeram process options, the dash-dot arrow many CAD/CAM systems, which are aiming for being used only by the dental technician. Remarkably, no system offers the connection between a dentist scan and the technician design and production.
At the time this thesis started many different CAD/CAM products were available in the market, like Procera AllCeram, CICERO, Cerec, DCS, etc. This research was aimed to study the added value of high strength CAD/CAM produced ceramic substructures for crowns. Only the first two systems could be used to reach this goal; therefore they will be explained more extensively in this chapter.

- Procera AllCeram System consists of a mechanical sapphire ball contact scanner and a computer controlled design system. The stone model of an impression of a crown preparation is scanned in a dental laboratory. A coping is designed with the design software system by the dental technician. The design is then sent by email to the Procera Sandvik AB in Stockholm, Sweden, that fabricates a coping. The coping is manufactured from pure sintered aluminum oxide and is made by compacting high-purity alumina powder with a dry pressing technique against enlarged models of the prepared teeth. These enlarged models are milled by the Procera copy milling machine. The enlargement compensates for the expected sintering shrinkage (12-20 vol.%) of the compacted alumina powder. Hereafter the compacted un-sintered coping is removed from the enlarged die and is sintered at 1550 °C for one hour. The sintered coping is sent back to the dental laboratory where it can be veneered with conventional veneering porcelain (AllCeram Porcelain, Ducera) with a matching thermal expansion coefficient $^{19-27}$.

- The basic aim of CICERO is to mass-produce ceramic restorations at one integrated production site. The activity is directed toward rapid custom fabrication of high-strength alumina copings and semi-finished crowns to be delivered to dental laboratories for porcelain layering or finishing. The first step in the automated fabrication of an all-ceramic coping is an optical impression obtained by laser scanning of the cast. The computer automatically identifies the margin. The CICERO CAD/CAM system makes use of a fast laser-stripe scanning method to measure the 3-dimensional geometry of the preparation and its immediate surroundings. In the CAD module of the system, an aluminum oxide coping is designed with a thickness of approximately 0.6 to 0.7 mm throughout to provide a substructure with optimal support for the veneering porcelain. The production starts by milling a negative of the interior of the restoration in a refractory support. To allow the subsequent sintering and milling step, the refractory support is supplied with a double prismatic bottom part of the refractory block to create the ability to be reproducibly repositioned in the milling machine with high precision. A
new high-strength core material based on aluminum oxide with a zirconia-glass phase is sintered against the refractory core without cracking or detaching. After firing and cooling down, the refractory material is removed by sandblasting. Checking the fit on the laboratory model and measuring the thickness is part of a final check of the copings. The dental technician retrieves the coping by mail to execute the veneering procedure using special porcelain (Sintagon, Elephant Dental B.V., The Netherlands) according to the color selection made by the general practitioner.28-31.

Both CAD/CAM systems offer the production of stronger ceramic copings but, due to new innovative ways of production and the use of new materials, may introduce new production related errors too. As a consequence many new research questions related to the use of CAD/CAM all-ceramic procedures arise:

- Do the dentists prepare the tooth suitable for all-ceramic restorations?
- Are CAD/CAM produced all-ceramic restorations strong enough for clinical use?
- What kinds of luting cementation procedures are most effective?
- How accurate are CAD/CAM procedures; what is the precise internal fit; what is the accuracy of the fit?
- How is the clinical aesthetic of CAD/CAM restorations?

The aim of this PhD-study was to evaluate CAD/CAM based all-ceramic restorations in vitro as well as in vivo in order to get more information regarding the possibilities and shortcomings of this new technology. The study involved:

- A field-test evaluation of preparation guidelines prescribed by the manufacturer (Chapter 2). All-ceramic restorations should have a minimum thickness and an appropriate shape to facilitate a favorable stress distribution and a stress-transfer to the supporting teeth. For that reason manufacturers of all-ceramic systems have developed preparation guidelines according to their necessities. Each system includes specific tooth preparation guidelines for the dentist who decides to make use of it. However, it is questionable whether the dentist can follow preparation guidelines in all cases. It was hypothesized that, under clinical circumstances, the final preparation frequently does not match in shape and size with the preparation requested by the manufacturer as the dentist has to give priority to other parameters of influence. An analysis of the feasibility of the preparation guidelines required by the manufacturer in relation to the biological
requirements as perceived by the dentist was executed on more than 3000 preparations for all-ceramic restorations.

- A one-year clinical evaluation of a product already on the market (Chapter 3).
- An evaluation of different luting cement procedures; shear bond strength of different types of luting cements to an aluminum oxide reinforced glass ceramic core material (Chapter 4).
- A laboratory assessment of CAD/CAM systems’ precision to realize predefined shape-related requirements (Chapter 5).
- A short-term clinical comparison of two different CAD/CAM systems (Chapter 6).

References


