



# Effect of Digital Flow Veneering Techniques on Bond Strength between Zirconia Core and Veneering Ceramics

Lubica Hallmann<sup>1\*</sup> and Mark Danieł<sup>2</sup>

<sup>1</sup>Department of Prosthodontics, Kiel University, Germany

<sup>2</sup>Institute of Material Science, Kiel University, Germany

## Abstract

**Objectives:** The aim of this study is to evaluate the effect of digital flow veneering technique on bond strength between zirconia framework and veneer.

**Materials and Methods:** An electronic Medline search complemented by manual searching was conducted to identify the effect of digital flow veneering technique on the stability of the dental restorations.

**Results:** The long-term stability of a dental restoration depends on many factors: the veneering technique, the geometry of the framework design, the thermal mismatch (CTE) between the framework and the veneer, the veneering materials, the pigments, the veneer/core thickness ratio etc. The CAD/CAM engineering technique seems to improve the stability of restorations due to the simplicity and therefore high reproducibility of the fabrication process.

**Conclusion:** CAD/CAM veneering technique seems to be a promise method to improve the stability of dental restorations.

## Introduction

The development of high strength ceramics in dental materials has opened up the new opportunity to avoid the long-term and high costs of conventional dental laboratory technology required for the preparation of dental restorative and prosthetic device such as inlays, onlays, crowns, fixed partial dentures, and removable dentures. The conventional methods such as lost-wax precision casting, dough modeling and curing of acrylic resins, and layered powder sintering of veneers are well established, but the results depend on the time and the experience of the dental technician [1].

The difficulties encountered in producing dental devices using the high strength ceramics as well as the difficulties with conventional methods has initiated the development of new methods to overcome these problems. One of these solutions was the introduction of Computer Aided Design and Computer Aided Machined (CAD/CAM). Duret et al. pioneered with such a dental CAD/CAM system in 1971 [1-6]. The development and establishment of CAD/CAM technology in dentistry has changed the production of restorative materials. Most of them are recently produced using industrially modern processes, ensuring quality standards which are only difficultly achieved under practical laboratory conditions. In contrast to the traditional additive technique, their processing uses the subtractive route by machining the blocks and blanks into their final shape. This procedure allows the application of high strength ceramics as Yttria-Stabilized Tetragonal Zirconia Polycrystal (Y-TZP), alumina and their composites [7-21]. Recently, glass-ceramics such as lithium silicate, zirconia reinforced lithium silicate, feldspar, polymer containing materials, ceramic-network materials and recently, lithium-disilicate-strengthened lithium aluminosilicate are developed for CAD/CAM technology [22-29].

Dental Zirconia is opaque and must be covered with a veneering ceramic to achieve an optimum esthetic appearance in color and translucency. Different techniques, such as layering, pressing, CAD-on and rapid layer can be applied to veneer the core materials [10]. In the layering technique, the veneering ceramics are mixed with a modeling liquid, and the mixture is brush-applied on the zirconia core. Its layer thickness is larger than the final dimensions to compensate for the shrinkage of veneers. Multiple applications and four firing processes are required for the final veneer. The pressing technique is based on the injection of porcelain onto a zirconia framework and has the

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### \*Correspondence:

Lubica Hallmann, Department of Prosthodontics, Propaedeutics and Dental Materials, School of Dentistry, Kiel University, Arnold-Heller-Str. 16, Kiel, D-24105, Germany, Tel: +49-43150026415; Fax: +49-43150026402; E-mail: lhallmann@proth.uni-kiel.de

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advantage of eliminating the porosity within the veneer thereby improving the mechanical properties of the dental device. The CAD-on technique is based on coating the zirconia framework with a CAD/CAM lithium disilicate glass-ceramic layer using a fused glass solder. On the other hand, the rapid layer technique uses the cementation of CAD/CAM milled veneer onto the zirconia framework with a dual-cure resin-based luting agents [10].

The exact identical replica of natural teeth is one of the great challenges for dental technicians. In addition to knowledge of the shape and surface of natural teeth, they need to also master the handling of ceramics perfectly. The layered technique requires a highly skilled dental technician. In the pressing technique, a final contour anatomical waxing is prepared on the core. After elimination of the wax in a furnace, ceramics are heat-pressed to the core. This method has some advantages on the layering technique such as the reduction of processing time, increasing accuracy, offering a higher stability, and eliminating the shrinkage [30].

The initial enthusiasm attitude towards dental zirconia was decreased by the increase of restoration failures compared to metal-ceramic restorations. For zirconia cores, delamination (chipping) of the veneering ceramics from the core is a major failure mode [8,31-43]. The chipping of veneers depends on many factors, such as the excessive tensile stress due to the thermal mismatch (CTE) between the veneer and zirconia framework, the geometry of the framework design, core/veneer thickness ratio, the interfacial bonding strength, the veneer itself, the pigments, and also the veneering technique. In the layering technique, the number of firings, the heating and cooling rate, the firing time and temperature, can affect the quality of the final restoration.

A large mismatch in the CTE between veneer and framework can lead to delamination, micro-cracking, or chipping in the veneer. Therefore, manufactures have developed veneering materials with a slightly lower of even identical CTE to that of the framework [43].

Chipping of veneers is currently the subject of intensive investigations [8,9,30,32-36,44-50]. For this reason, recently, new veneering materials and/or new methods are introduced to use CAD/CAM technology in final restoration to increase the efficiency of laboratory processing and the quality of restorations.

Since the factors, which are responsible for the veneer chipping, are still under debate, avoiding the use of veneers is another possibility to prevent chipping. At the beginning, the veneers were used to improve the aesthetic properties of zirconia because of its poor translucency. The advances in dental material sciences improve the aesthetics of zirconia. For example, full-contour zirconia restorations employing internal and external stain techniques can be used, but these are limited to the posterior regions with little aesthetic demands [51]. So, for the anterior regions the use of veneers is unavoidable.

The aim of this study was to investigate the influence of the veneering techniques on the bonding strength between zirconia core and veneers, since there are hardly any studies about the stability in long term of zirconia restoration using the CAD/CAM veneering technique.

## Shear Bond Strength (SBS)

Hafez et al. [51] have studied the shear bond strength between zirconia and veneers. They have applied two techniques: manual layering respectively press-on (press-on). According to these authors,

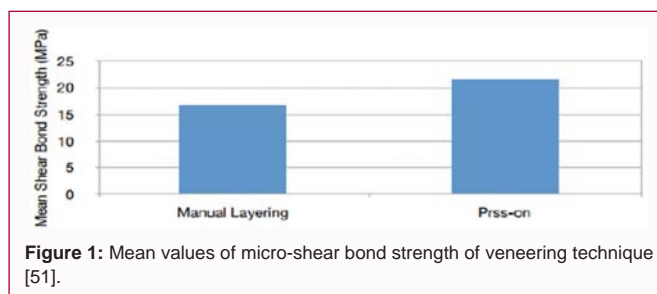


Figure 1: Mean values of micro-shear bond strength of veneering technique [51].

irrespective of the surface technique, press-on veneering showed statistically a significantly higher mean micro-shear bond strength value ( $21.5 \pm 4$  MPa) compared to layering veneering with mean values of ( $16.8 \pm 5.9$  MPa) (Figure 1).

All specimens, which were prepared by manual veneering, showed adhesive failure. This might originate from the multitude of air bubbles observed in the veneering.

Specimens veneered by press-on technique showed cohesive failures, with a dense, bubble-free, and homogeneous surface. Hafez et al. [51] attribute this failure behavior and the high shear bond strength for the press-on veneers to mainly the controlled fabrication conditions. These result in less structural defects, improved wetting of the zirconia surface by the molten pressed ceramic, and reduced incorporation of air bubbles. Especially the reduced incorporation of air bubble is of high importance in terms of reliability, since air-bubbles have a highly negative effect on the mechanical strength of veneering ceramic itself and its bond strength to the underlying framework materials. Based on these advantages Hafez et al. [51] concluded that press-on veneering is a more reliable compared to manual layering.

Sim et al. [52] studied the shear bond strength between the veneering ceramic and zirconia. Layering, pressing and digital techniques to veneer the zirconia frameworks were employed in their investigations. A fusion powder was used to bond the CAD/CAM prepared veneers to zirconia framework. The highest shear bond strength was obtained for CAD/CAM veneered zirconia frameworks (28.29 MPa). Lower shear bond strengths were obtained for the layering (18.65 MPa) and press-on (18.89 MPa) technique showing no significant difference between the press-on and layering technique. The CAD/CAM veneered specimens appeared to be more homogeneous had lower porosity and the best interface bond strength. Therefore, CAD/CAM veneered specimens should provide better long-term stability in the intra-oral environment compared to those prepared by layering and heat press-on technique. Based on these results Sim et al. [52] consider the CAD/CAM veneering method to be more effective in clinical uses because the SBS is significantly higher than the ones obtained by the heat-press-on or layering.

Kim et al. [53] have investigated the influence of the layering technique and CAD/CAM technique on the Micro-Tensile Bond Strength (MTBS) at the zirconia core/veneer interface. The milled glass ceramic veneer was joined to the zirconia core using fusion porcelain. The best results were achieved for the digital veneering technique with a MTBS of 37.8 MPa. The failure mode was 94% cohesive and 6% mixed (cohesive and adhesive). The layering technique provided a significantly lower MTBS, of 28.1 MPa. The failure mode changed to 78% cohesive, 22% mixed. The high MTBS obtained by the CAD/CAM veneering technique explained with having fewer defects. Using this technique, the specimens also had a reduced firing-shrinkage.

**Table 1:** Mean shear bond strength and standard deviation (MPa) [55].

Veneering procedure	Mean shear bond strength
Vita, layering	24.23 ± 9.8
Cerec Bloc, resin cement, no surface treatment	15.29 ± 2.2
Cerec Bloc, resin cement, acid etched	18.47 ± 3.7
Cerec Bloc, resin cement, glaze layer	10.76 ± 2.5
Cerec Bloc, fusion porcelain	25.35 ± 5
IPS e.max CAD, resin cement, no surface treatment	9.82 ± 2.8
IPS e.max CAD, resin cement, acid etched	19.83 ± 6.6
IPS e.max CAD, resin cement, glaze layer	10.97 ± 5.9
IPS e.max CAD, fusion porcelain	27.11 ± 7.7

According to Kim et al. [53], the CAD/CAM veneering technique appears to be better in terms of bond strength compared to the other investigated techniques.

Zaher et al. [54] applied the heat press-on and the CAD/CAM technique to study the influence of the veneering technique on the shear bond strength. The joint between CAD/CAM veneer and zirconia core was performed by a low fused ceramic (Ivoclar). A high SBS was found for the CAD/CAM veneered specimens ( $41.2 \pm 6.3$  MPa) whereas for the heat-pressed ones, the SBS was only  $21.3 \pm 4.3$  MPa). The failure mode was mostly adhesive at the ceramic interface for the both specimen groups. Nevertheless, larger parts of the veneer were still attached to the zirconia core for the specimens prepared by the CAD/CAM technique, whereas for the heat-press-on ones either none or only minor traces of veneer remained attached on the zirconia core. Based on these finding, Zaher et al. [54] concluded that the CAD/CAM veneering technique is advantageous when using low-fusing glass-ceramics as connector compared to the heat press-on technique.

Cakirbay et al. [55] investigated the shear bond strength between different CAD/CAM veneer materials and the zirconia framework proving a possible explanation for the reason chipping of zirconia restorations. They stated that many factors affect the stability of veneered zirconia frameworks. One of them is the weakness of the bond strength between the veneering material and framework. For their study, they have applied two veneering techniques: layering and CAD/CAM. IPS e.max CAD and Cerec Bloc were used for the CAD/CAM technique using resin cement or low fusing porcelain as connector. Also, the effect of the surface treatment was studied. Three surface treatments were applied for the resin cemented groups: no surface treatment, acid (4% HF) etching of the bonding interface of the veneer for 20s, and HF acid etching of the bonding interface of the veneer in combination with the application of a glaze to the zirconia surface. The low fused ceramic was used as connector for CAD/CAM veneered group (Table 1).

Based on this study, the veneering technique and the surface treatments affected the bond strength between zirconia and resin cement, while the veneering materials had no effect. The CAD/CAM fused low ceramic veneering technique provided similar results compared to those with conventional layering (Table 1). Based on these results, the authors concluded that the fused CAD/CAM veneering technique can be an alternative to the conventional layering. They state there are certain advantages of the fused CAD/CAM veneering technique over the conventional. The first one is that handling-steps, such as modeling, impression and finishing

**Table 2:** Mean Shear Bond Strengths (SBS) [57].

Group	SBS
	(MPa)
Control (C)	32.52 ± 10.15
Sandblasting with 50 µm Al <sub>2</sub> O <sub>3</sub> particles (S)	33.03 ± 5.05
Er:YAG laser irradiation (E)	31.02 ± 4.96
Femtosecond laser irradiation (F)	36 ± 3.31

are completed by computer-controlled design and fabrication resulting in the desired shade, translucency, high homogeneity and a fast fabrication process. The second is that the fabrication of dental restorations does not need an experienced technician to minimize defects during the preparation of the dental device. Kim et al. [53] and Kanat et al. [56] reported a higher bond strength for the CAD/CAM veneering technique compared to the layering one. According to Cakirbay et al. [55] this difference can be explained by the different brand of zirconia, the veneering materials, and the fusing ceramic and different testing parameters. From this study, it can be concluded that the application of the glaze layer onto the zirconia surface does not improve the bond strength at the veneer/framework interface. The properties of resin cement and its ability to be chemically or physically bound at the interface play an important role in the stability of the dental restoration. This means that the bond strength at the resin/glaze interface affects the results.

Savas et al. [57] have investigated the effect of different surface treatments on the shear bond strength of lithium disilicate ceramics to the zirconia core. In their study, they have treated the zirconia surfaces as follows: no treatment (group C, control), sandblasted at a pressure of 3 bar for 10s (group S), irradiated with Er-YAG laser (group E) and irradiated with a femtosecond laser pulses (group F). A low fused ceramic was used as a connector between the veneer and the framework (CAD-on, Ivoclar).

As can be seen from Table 2, the surface treatment of the zirconia core (sandblasting, Er.YAG laser, and femtosecond laser) does not affect the shear bond strength at the veneer/zirconia interface. Cohesive and adhesive failures have been observed for all testing groups. The occurrence of cohesive failures in all groups are a clear indication for a high SBS at the veneer/core interface. The authors explain the high shear bond strength in group F by the creation of regular pits which were filled with fused ceramic and act as micromechanical retention. In case of group E, the eroded zirconia surface can be responsible for the slightly lower SBS compared to group C. From this study, it can be concluded that the CAD-on technique does not need a surface treatment of the zirconia core for a good SBS.

## Fracture Strength

Turk et al. [30] have investigated the effect of veneering technique on the fracture strength of the zirconia framework. They applied the layering and press-on technique to veneer the zirconia framework. The load at fracture was determined by the first discontinuity in the load, whether it was an early cracking or a catastrophic failure.

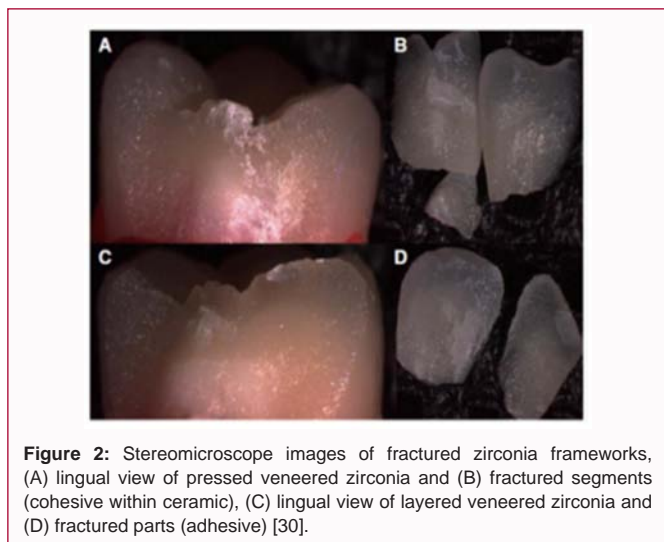
Table 3 presents the results of the mean fracture loads for the layered veneering and the press-on veneering of the zirconia framework. The layered veneering shows slightly higher mean fracture loads ( $1884 \text{ N} \pm 190 \text{ N}$ ) compared to the press-on veneering samples  $1722 \text{ N} \pm 239 \text{ N}$  (Table 3). Looking at the fractures, both adhesive as well as cohesive failure within the veneering ceramics was

**Table 3:** Mean fracture loads (N) [30].

Specimens	Fracture loads (N)
Layered veneered zirconia core	1884 ± 190
Heat-pressed veneered zirconia core	1722 ± 239

**Table 4:** Fracture types of zirconia frameworks [30].

Specimens	Adhesive	Cohesive within framework	Cohesive within ceramic (chipping)
Layered veneered zirconia core	7	-	3
Heat-pressed veneered zirconia core	8	-	2

**Figure 2:** Stereomicroscope images of fractured zirconia frameworks, (A) lingual view of pressed veneered zirconia and (B) fractured segments (cohesive within ceramic), (C) lingual view of layered veneered zirconia and (D) fractured parts (adhesive) [30].

observed as depicted in Figure 2 and Table 4.

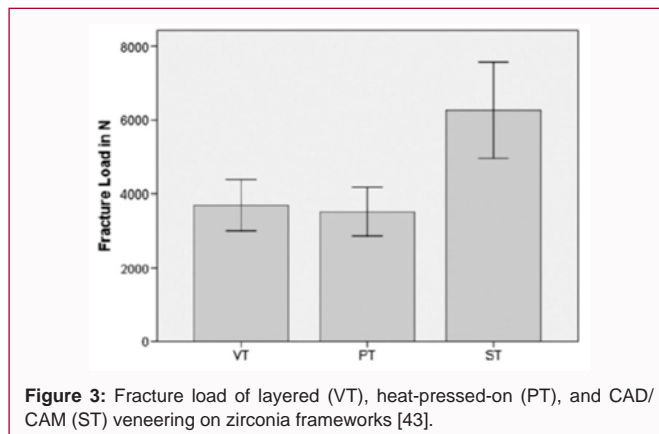
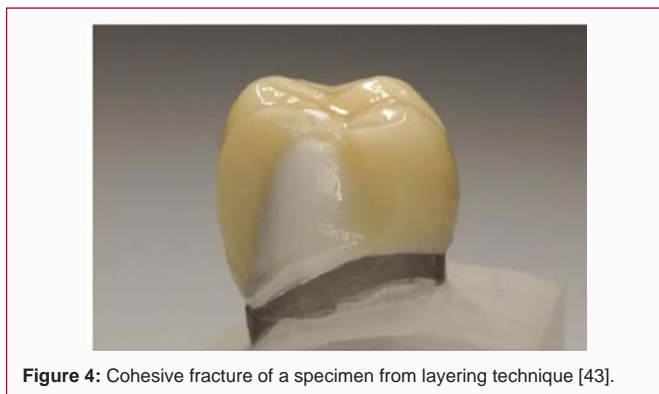
The layered veneered specimens exhibited a small tendency to fail more often adhesively compared to the pressed-on ones (Table 4).

A fracture within the zirconia framework was never observed indicating that the veneering method does not negatively affect the mechanical properties of the zirconia core.

Turk et al. [30] attribute the fracture behavior with the veneering process itself. They state that during the heating and cooling cycles, the phase stabilization of zirconia can be affected. This may influence both the strength and the long-term behavior of this material. The low fracture forces observed for pressed-on specimens in comparison to layered ones explained by a higher pressing temperature of 910°C for the pressed-on ones compared to the processing temperature of the layering veneers (750°C). Due to the misfit in the coefficient of thermal expansion a higher mechanical stress can be build up at the interface at higher processing temperatures. The chipping of the veneer for zirconia restorations are explained with the defects in the veneering materials, incorrect cooling rates during the veneering processes, a weak bonding between the zirconia core and the veneer, and traumatic occlusion. The authors conclude in their study that the fracture loads of veneered zirconia cores are not affected by the used veneering technique if the same framework material is used.

Beuer et al. [43] used layering (VT), heat-pressing (PT), and CAD/CAM (ST) veneering technique for zirconia frameworks. CAD/CAM framework and CAD/CAM veneer were connected by means of a low-fusing ceramic material (Ivoclar).

High fracture strength was obtained for the CAD/CAM veneered specimens compared to the layered and heat-pressed-on veneered

**Figure 3:** Fracture load of layered (VT), heat-pressed-on (PT), and CAD/CAM (ST) veneering on zirconia frameworks [43].**Figure 4:** Cohesive fracture of a specimen from layering technique [43].

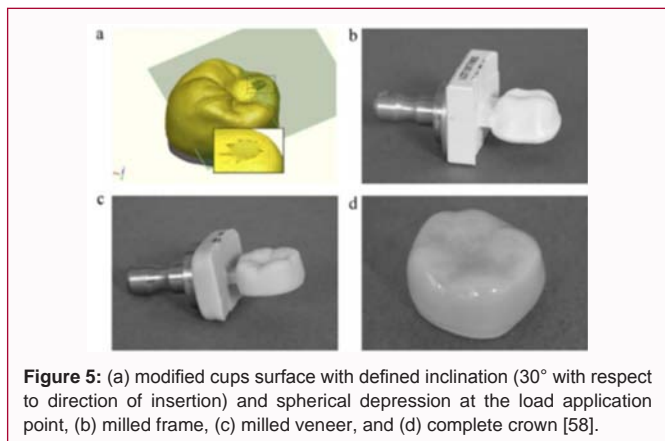
specimens (Figure 3).

Two failure types were observed: Total fracture, through both core and veneer and partial fracture through veneer only (chipping). In all instances of partial fracture, the fracture was cohesive within the veneer (Figure 4).

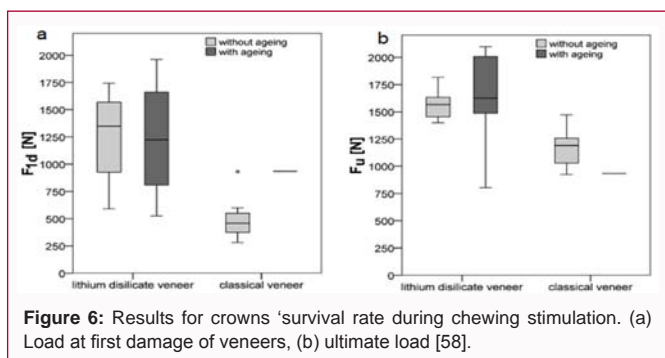
One of the factors responsible for the failure of dental ceramic restorations is the surface tension, which results in slow propagation of cracks and flaws. In all-ceramic systems the flaw population (size, number, and distribution) depends on the material itself and on its fabrication process. It is predicted that the heat-pressing process introduces fewer flaws than the layering process, resulting in higher strength properties, because the fabrication process is a more controlled procedure. The layering technique is more sensitive and subject to the skill of the dental technician and the firing procedures. However, the results of Beuer et al. [43] do not confirm this hypothesis. They found no statistical difference between layered and heat-pressed-on veneered specimens. The authors explain their results with the homogeneity and the distribution of flaws which seem to be similar for both specimen groups. The failure modes are inconclusive and exhibit both, cohesive and adhesive. The cohesive failure mode observed for the layering technique explained by the good interfacial bond between the framework and veneering material which is critical for the success of the dental devices.

These authors state that the CAD/CAM veneering technique leads to an extremely cost-effective fabrication of all-ceramic veneered crowns merely using established CAD/CAM facilities for the production of the two parts, which have to be joined by only one firing procedure [43].

Schmitter et al. [44] investigated the ultimate load to failure of



**Figure 5:** (a) modified cups surface with defined inclination (30° with respect to direction of insertion) and spherical depression at the load application point, (b) milled frame, (c) milled veneer, and (d) complete crown [58].



**Figure 6:** Results for crowns 'survival rate during chewing stimulation. (a) Load at first damage of veneers, (b) ultimate load [58].

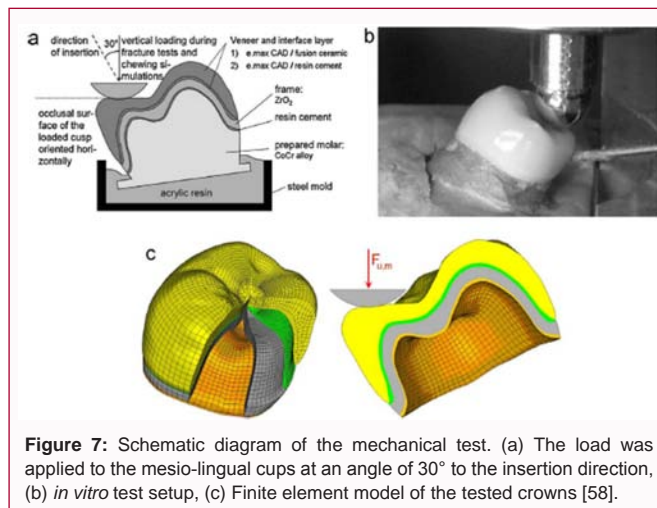
zirconia-based crowns veneered with CAD/CAM manufactured ceramic. This study aims to find the origin of the chipping phenomena of zirconia restorations. Dental zirconia has excellent properties in comparison to metal restorations due to its high fractural and toughness strength, biocompatibility, and its aesthetic appearance. In comparison to metal-ceramic restorations, zirconia restorations suffer from adhesive (delamination) and cohesive (chipping) failures. When the failure of veneer affects the functional or aesthetic area, a repeated restoration is mandatory which is time-consuming for dental labor and the worse-case for both dentist and patient [44]. CAD/CAM-veneering and layered-veneering as control group were used.

The joint between the CAD/CAM manufactured veneer and the framework was made using the low fusing ceramic (Figure 5).

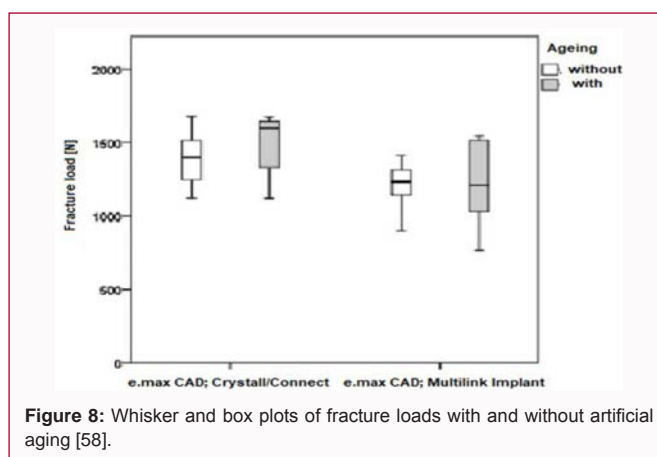
These authors also investigated the influence of artificial ageing on the critical load responsible for the adhesive failure at the framework/ veneer interface and/or the cohesive failure within the veneer ceramics. The ageing process consisting of 10,000 thermocycles.

They demonstrated that the crowns made of zirconia frameworks veneered with CAD/CAM manufactured lithium disilicate ceramics display a higher fracture strength resistance compared to manually veneered crowns (Figure 6A). CAD/CAM veneered crown seem not to be affected by the artificial ageing, whereas almost all manually layered crowns failed during chewing test (Figure 6B). To reduce the rate of adhesive and cohesive failures for zirconia frameworks a lot of works has been done. This includes optimizing of firing protocol, the framework design, the fabrication process, the use of pressed ceramics etc.

Another possibility is the application of CAD/CAM technology for the production of framework and veneer. These authors concluded that the CAD/CAM production of veneers restorations with zirconia



**Figure 7:** Schematic diagram of the mechanical test. (a) The load was applied to the mesio-lingual cups at an angle of 30° to the insertion direction, (b) *in vitro* test setup, (c) Finite element model of the tested crowns [58].



**Figure 8:** Whisker and box plots of fracture loads with and without artificial ageing [58].

**Table 5:** Mean fractural loads of zirconia frameworks veneered by two different veneering techniques [44].

Group	Without Aging	After Aging
CAD-on	1388 ± 190 N	1492 ± 206 N
Resin cemented veneer	1211 ± 158 N	1226 ± 290 N

framework is a promising way to reduce the failures. Schmitter et al. [58] suggest that optimizing of firing protocol can improve the fatigue behavior and fracture strength of hand-layered veneered zirconia framework. According to these authors, the veneering material also plays an important role on the quality of zirconia restoration.

In the other work Schmitter et al. [58] have investigated the effect of the attachment technique on the fracture strength of the zirconia framework. Zirconia frameworks and veneers were milled by CAD/CAM technique. The attachment of the veneers onto the zirconia was carried out by two methods:

- Multilink implant: First, the veneering layer was etched with 5% hydrofluoric acid for 20s, after that Monobond Plus was applied to the sandblasted zirconia framework to attach the veneer.
- The CAD-on technique was used for the second group.

The effect of aging on the fracture strength of zirconia frameworks was investigated for both groups.

The fracture strength was measured according to the Figure 7. As can be seen from Figure 8 and Table 5 better results were obtained for CAD-on groups.

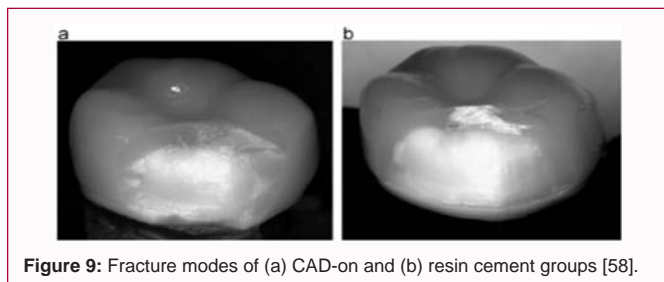


Figure 9: Fracture modes of (a) CAD-on and (b) resin cement groups [58].

Table 5 shows that the aging process significantly affects the fracture strength of the CAD-on group, while it has hardly an impact on the resin cemented veneer.

All crowns survived the chewing stimulation which means the bonding at CAD/CAM milled veneer/zirconia interface is insensitive to the aging processes.

Adhesive failures of the veneer were predominant in both groups with a smaller delamination area for CAD-on group. It can be concluded that the bond strength at luting resin/framework and luting resin/veneer interfaces control the failure modes of the luting group, because the veneer has no direct contact to the framework. For the CAD-on group, other factors, such as the homogeneity of the contact layer, the CTE, the bond strength at veneer/framework interface etc., have an impact on the failure modes.

For high fracture loads, a damage of the margin of zirconia framework was observed for the CAD-on group, while the luting group was not affected (Figure 9).

This behavior can be explained by the tensile stresses within the veneer and at the interfaces, which are created by the firing process of the CAD-on group. During the firing process, two hard interfaces, veneer/fused ceramic and fused ceramic/frame, generate tensile stresses within the veneer and the interface layer that lead to a fracture of the veneer under high fracture loads. In the case of the luting group, the hard interface is missing and the soft resin at the interface reduces tensile stresses. The chemical and physical properties of luting cements are important factors for the clinical success of dental restorations [27]. The ability to promote a stable and strong joint between the restorative materials, a high resistance to delamination, a suitable Young's modulus, biocompatibility, etc., are the properties which must be considered for the luting technique. This technique requires a surface treatment of framework, which can influence the fracture resistance of the framework. Although omitting this factor in their discussion, the authors concluded that both techniques can be used in a clinical setting. They recommend luting of veneer for two reasons. The first is, it is much easier and could be performed chair-side in the dental practice. The second is, the framework and the veneer can be sintered at the same time, which saves time, in contrast to fused crowns, for which the frame must be sintered first. This procedure of fused crowns is impossible to be used because veneer and framework have a different sintering temperature and thus, cannot be sintered at the same time. Secondly, veneers being prepared by CAD/CAM method using blanks require no sintering step. The authors recommend the CAD-on technique because of its higher fracture resistance.

Kanat et al. [56] have investigated the effect of different veneering procedures (layering, over-pressing, and CAD-on) on the Fracture Resistance (FR) of single molar crown restorations with zirconia framework. They have investigated also the effect of the Flexural

Table 6: Fracture loads, flexural strength and shear bond strength of differently veneered specimens [56].

Veneered Specimens	Fracture Resistance (FR) (N)	Flexural Strength (FS) (MPa)	Shear Bond Strength (SBS) (MPa)
Over-pressed	2507 ± 594	566 ± 54	30 ± 8
layered	4323 ± 462	428 ± 41	28 ± 5
CAD-on	4408 ± 608	583 ± 63	49 ± 6

Strength (FS) of the veneering ceramic on the FR of the restoration, the effect of interfacial bonding on the FR by a Shear Bond Strength test (SBS).

A lower fracture resistance was obtained for over-pressed veneered specimens (Table 6), whereas the layered and CAD-on veneered specimens do not show large FR differences.

The authors explained the high FR of the layered veneered groups by the anatomical framework design. Layered veneered specimens exhibit a low flexural strength, whereas the other two veneering groups showed almost the same FS. A high SBS was obtained for CAD-on veneered specimens, the SBS of the other two veneering groups are drastically lower than the CAD-on ones, but very similar compared to each other (Table 6). No signs of imperfections within the ceramic or along the interfacial area are detected for the CAD-on veneered specimens, whereas many lateral cracks and porosities are observed for the other specimen groups. Porosity and partial detachment of veneers along the zirconia/veneer interface is observed for the layered and over-pressed specimens.

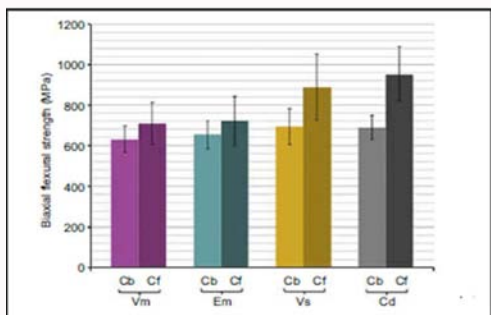
One of the factors for the lack of porosity or other imperfection in CAD-on veneered specimens is the homogeneity of the ceramic block. Lateral cracks and porosities observed for layered and over-pressed veneered specimens can be explained by the sensitivity of these veneering techniques. According to Kanat et al. [56], the veneering technique, the properties of the veneering materials, the interfacial bonding, and the anatomical framework design play a crucial role for the stability of the dental restoration. They concluded that the CAD-on technique could decrease ceramic chipping due to a higher strength of the ceramic and interfacial bonding. The anatomical framework design can further improve the fracture resistance if the layering technique is applied.

Tangsathatham et al. [59] have investigated the effect of CAD/CAM veneering ceramics and different bonding techniques on the flexural strength of zirconia cores.

As CAD/CAM veneering ceramics they have used feldspathic Vita blocks (Vm), IPS e.max CAD (Em), Vita Suprinity (VS) and Celtra Duo (CD). Two methods were employed to apply the veneer to the zirconia cores: CAD-bonding (Cb) and CAD-fusing (Cf).

This study indicates that the flexural strength of zirconia core strongly depends on the veneering ceramic and techniques. A high flexural strength was obtained for Celtra Duo (CD) 953.12 ± 134.30 MPa, (Figure 10 and Table 7).

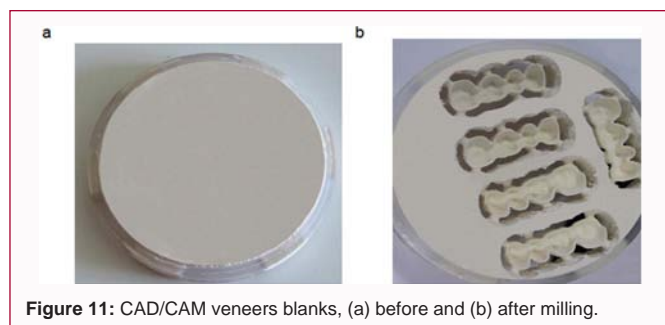
The authors explain the high flexural strength obtained for Cd and Vs veneers only by the high flexural strength of these veneers (~420 MPa). Em and Vm have a flexural strength of 360 MPa to 400 MPa and 154 MPa, respectively. There are different factors which affect the flexural strength of the zirconia core: the CTE mismatch between veneer and core, the bond strength at the veneer/core interface, the tetragonal to monoclinic phase transformation of the zirconia core



**Figure 10:** The effect of veneering ceramic types on the fracture strength [59].

**Table 7:** The mean flexural strength of veneered zirconia cores [59].

Group	Flexural strength (MPa)
Vm (Cb)	630 ± 65.08
Vm (Cf)	709 ± 102.88
Em (Cb)	651 ± 69.48
Em (Cf)	721 ± 121.28
Vs (Cb)	692.83 ± 89.10
Vs (Cf)	888.61 ± 164.26
Cd (Cb)	687.17 ± 59.39
Cd (Cf)	953.12 ± 134.30



**Figure 11:** CAD/CAM veneers blanks, (a) before and (b) after milling.

as a result of sandblasting or firing [60-64], the cracks created during sandblasting/firing processes etc. In the case of the Cb technique, the CTE mismatch between veneer and zirconia does not affect the flexural strength of the core because resin cement separates the two materials. In the case of the Cf technique, additional factors affect the flexural strength of the core: the wettability of the fused ceramic on the zirconia core, the homogeneity of the interfacial layer, the bonding strength at the veneer/core interface, and the firing process etc. From the results of this study, it can be concluded that the CAD-fused technique, could achieve a better clinical outcome, because it provides a higher flexural strength than the Cb-bonded technique.

## Futures

A new method is developed to produce CAD/CAM blanks which can be applied for all veneer's kinds. The blanks are multilayers and can be used to veneer zirconia or metal frameworks (Figure 11).

CAD/CAM banks are typically produced by using the slurry method: water as solvent, and polymers (dispersant, bonder, plasticizer and anti-foamier) [61]. After milling the joint between zirconia or metal core and the CAD/CAM veneer is performed using the same ceramic powder of the blanks or a low fused ceramic powder. The connector is not supplied in the form of a separate paste.

The dental technicians must mix the ceramic powder with the same liquid as in the production of CAD/CAM blanks. The paste is applied to the surface of the framework by a brush. The properties of these blanks are currently under investigation by Hallmann et al [61]. The multilayered CAD/CAM veneering blanks simplify the work of dental technicians, since many work steps are reduced, the efficiency of the dental laboratory is increased and the veneering of frameworks does not require technicians who master the handling of ceramics perfectly.

## Conclusion

The stability of a ceramic restoration depends on many factors such as: the type of bonds (chemical or physical), flaws, cracks and their propagation. The choice of the veneering fabrication technique has a great influence on the mechanical stability of the ceramic restoration. The CAD/CAM engineering technique seems to improve the stability of restorations due to the simplicity and therefore high reproducibility of the fabrication process. Many steps required to prepare dental restorations are avoided, and firing/cooling cycles are shortened (one firing cycle), which in turn increase the efficiency of the application in clinical practice. The CAD-veneering technique avoids the negative influences of human error offering higher precision and reduced cost.

CAD/CAM technology for the preparation of dental restorations have increased the productivity of dental laboratories tremendously and changing them to modern digital production centers. In the future, the CAD/CAM technology will replace more and more the currently widely-used convectional techniques in restorative dentistry.

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