ALL CERAMIC SYSTEMS - AN OVERVIEW

Authors: Dr. Sunitha Naveen Shamnur
Reader, Department of Prosthodontic
Bapuji Dental College & Hospital,
Davangere.
Email: sunithans77@yahoo.com

Dr. Santosh Doddamani
Reader, Dept. of Prosthodontics
College of Dental Sciences, Davangere.

Dr. Naveen Shamnur
Professor, Dept. of Orthodontics
College of Dental Sciences,
Davangere.

ABSTRACT:

In the search for alternative and esthetic restorative materials, many all-ceramic systems have been introduced for the general practitioner. They are used as veneers, inlays/onlays, crowns, and as enamel/dentin bonded partial or total coverage without macroretention. This article describes a classification of the different commercial all-ceramic systems and gives a review of their clinical durability. The primary changes in the field were the proliferation of zirconia-based frameworks and computer-aided fabrication of prostheses, as well as, a trend toward more clinically relevant in vitro test methods. Newer reinforced ceramics showed better durability then the earlier fired ceramic reconstructions. This report includes an overview of ceramic fabrication methods, suggestions for critical assessment of material property data.

KEY WORD

All Ceramic restoration, CAD/CAM, Zirconia, Lithium Disilicate.

INTRODUCTION:

All ceramic is the most esthetic choice for full coverage restorations, If given a choice , a patient will always select the natural looking restoration over an artificial one. Although the quest for the ideal all ceramic material continues, some materials used today approach the esthetics and strength of the enamel- dentin complex in natural dentition.

Metal ceramic restorations have been available for more than three decades.[1] This type of restoration has gained popularity from its predictable performance and reasonable esthetics.[2] Despite its success, the demand for improved esthetics and the concerns regarding the biocompatibility of the metal has lead to the introduction of all-ceramic restorations.[3]

DISCUSSION:

Historical perspectives of ceramics: For nearly 1,000 years after its discovery, porcelain was used primarily to produce fine dishware and utensils.It was also used to create objects of art and jewelry for those who could afford it. In 1723, Fauchard first used porcelain to enamel the metal bases of dentures. He is also credited with recognizing the potential of porcelain enamels and initiating experiments that would lead to further advances in the use of porcelainin dentistry. In 1774, Duchateau experimented with dentures fabricated with hard porcelain; 20 years later,de Chament improved Duchateau's process and secured a patent for "mineral teeth," which became the first denture teeth.[4] In 1885, Logan introduced the Richmond Crown, in which porcelain was fused to a platinum post ; a year later, Land made the first fused porcelain inlay and crown backed by platinum foil.[4] The use of porcelain as a viable restorative option in dentistry gained little further momentum until 1949, when the Dentist's Supply Company of New York invented the vacuum firing of dense and translucent porcelain teeth. In 1958,the first dental porcelain for veneering was introduced, which led to the widespread use of metal-ceramic restorations in the 1960s and beyond, followed by the invention of the porcelain jacket crown that was popularized
in the 1960s by McLean 4 1970s saw the advent of early experiments in CAD/CAM crown fabrication, followed by an influx of ceramic-based restorative systems from the 1980s through to the present day.

Indications for all ceramic restorations: Esthetics: ceramics are considered the best in mimicking the natural tooth appearance.[5] The optical behavior of ceramic materials differ from system to system and this should be taken into consideration during the selection of which system to be used.[6]

Contraindications of all ceramic restorations:

Limited interocclusal distance: in cases of short clinical crowns, deep overbite, or
with a super erupted opposing tooth.[7]

Heavy occlusal forces:Due to the brittle nature of the material and its abrasive potential, ceramic restorations should be avoided in patients with parafunctional habits such as bruxism.[8]

Inability to maintain a dry field: ceramic restorations require good moisture control at the time of their cementation to ensure positive outcomes.[8]

Deep subgingival preparations:this is not considered an absolute contraindication, although supragingival preparations are desirable to produce a more accurate recording during impression taking.[8]

Advantages: Esthetics: is considered the primary advantage.[9]

Wear resistance: ceramics are more wear resistant than direct restorative materials. Precise contour and contacts: indirect fabrication of all ceramic restorations provides more precise contour and contacts than directly placed restorations.

Biocompatibility:The allergic reaction by some to metal alloys is a weak point against metal ceramic restorations which increased the demand on the more biocompatible all ceramic restorations. However, the degree of cytotoxicity of the metal alloys largely depends on the type of the dental alloy used in the fabrication of the metal ceramic restoration.[10]

Disadvantages: Cost and time: all ceramic restorations are fabricated indirectly and require at least two appointments to be delivered. The additional laboratory fees make this type of restoration more expensive than other direct restorations.[5]

Brittleness of the ceramics:adequate thickness of ceramic should be provided to avoid the fracture of the restoration.[8]

Wear of apposing dentition and restorations: ceramics can cause wear of opposing restorations and/or dentition. This problem has been considered during the improvement of ceramic restorations.[11]

Low repair potential : If fracture occurs, repair is not considered a definitive treatment.[8]

Difficult intraoral polishing : ceramic restorations are difficult to polish once they are cemented because of access problems and lack of proper instruments to perform this task.[8]

Simplifying concepts in understanding dental ceramics:[12]

Two concepts help in simplifying the understanding of dental ceramics.

First, ceramics fall into three main composition categories

- Predominantly glass
- Particle–filled glass
- Polycrystalline

Second ,ceramics can be considered as a composite material ,in which the matrix is a glass that is lightly or heavily filled with crystalline or glass particles.

Predominantly glass: have a high content of glass making this type of dental ceramic highly esthetic .This type is the best in mimicking the optical properties of enamel and dentin.Optical effects are controlled by manufactures by adding small amount of filler particles.

Particle-filled glass: Filler particles are added to the glass matrix to improve the mechanical properties. Fillers can be crystalline particles of high-melting glasses.

Polycrystalline: This type of ceramic contains no glass. Atoms are packed into regular crystalline arrangement making it tougher and less susceptible to crack propagation.

Similar composition of ceramics could be fabricated in different ways.[5]

Classification according to method of fabrication:

1. Powder condensation:

This is considered the traditional way for fabrication of an all-ceramic restoration.This technique involves applying moist porcelain using a specialbrush, then compactingthe porcelain by removing the excess moist. The porcelain is then fired under vacuum allowing further compaction.[5]

Ceramics fabricated by this technique have a great amount of translucency and are highly esthetic13,and are used mainly as veneering layers.[5]

Examples of systems utilizingthis technique:[5]

- Duceram LFC(Dentsply)
- Finesse low fusing(Dentsply)
- IPSe .maxCeram (Ivoclar-Vivadent)
- IPSEris (Ivoclar-Vivadent)
- Lava Ceram (3MESPE)
- VitaD (VitaZahnfabrik)
- Vitadur Alpha (VitaZahnfabrik)
- VitaN (VitaZahnfabrik)

Powder condensation utilizes feldspathic porcelain.

Feldspathic porcelain:

Potassium and sodium feldspars are naturally occurring elements composed mainly of potash (K2O) and soda (Na2O),they also contain alumina (Al2O) and soda(Na2O).Leucite and a glass phase are formed when potassium feldspar is fired to high temperatures. This glass phases oftens during firing allowing coalescence of the porcelain powder particles.This process is called liquid phase sintering.This process occurs at a relatively high temperature allowing the formation of a dense solid. Since leucite has a large coefficient of thermal expansion, it is added to some glasses to control their thermal expansion.

2. Slipcasting:

This technique involves forming a mold of the desired framework geometry and pouring a slip into the formed mold. Gypsum is usually utilized to form the mold due to its ability of extracting some of the water from the slip. The slip then becomes compacted against the mold forming a framework. The framework is then removed from the mold by partial sintering. The resulting ceramic is very weak and porous and must be infiltered with glass or fully sintered before application of the veneering porcelain.[5]

Materials processed byt his technique tend to have fewer defects from processing ,and exhibit higher toughness than the conventional feldspathic porcelain.[14]

The use of this technique in dentistry has been limited to one of three products.5This limitation might be due the complicated steps,which makes achieving an accurate fit difficult.[13,15,16]

In-CeramAlumina® (Vita Zahnfabrik)

This material was first introduced in 1989, and was the first all-ceramic system available for single unit restorations and 3-unit anterior FPDs.[17]

A slurryof Al2O is applied on a refractory die and sintered for 10 hours at1120°C.[18, 19] This produces a porous framework of alumina particles which is infiltrated with lanthum glass during a second firing for 4 hours at 1100°C.This procedure is done to remove porosities, increase strength ,and limit crack propagation sites.[19]

Then feldspathic porcelain is used to veneer the produced coping.[20]

In-Ceram Alumina is considered to be a strong material having a mean biaxial flexure strength of 600 MPa.21The material should not be used in esthetic zones because it does not fully allow light transmission.2In-Ceram Alumina is recommended for anterior and posterior crowns and anterior FPDs.[4]

In-CeramSpinell ®(Vita Zahnfabrik)

In-Ceram Spinell was introduced in 1994 to overcome the opacity of In-Ceram Alumina. The framework contains a mixture of magnesia and alumina (MgAl2O4)to improve the translucency of the material.[2,22] The basic principles of fabrication are the same as those for In-Ceram Alumina.It has a flexural strength of 250 Mpa which is lower than that for In-Ceram Alumina.4In Ceram Spinell is indicated for anterior crowns because of its low flexural strength.[23]

In-Ceram Zirconia®(VitaZahnfabrik)

In Ceram Zirconia is considered a modification of In-Ceram Alumina system with the addition of 35%of partially stabilized zirconia oxide to the slip to increase the strength of the ceramic.24 The ceramic is fabricated using the traditional slip-casting technique.[7] In-Ceram Zirconia is considered the strongest of three cores of the slip-casting technique having a flexural strength of 700 MPa.[4] The material is considered opaque and has poor translucency limiting its use for posterior crowns and posterior FPDs.[24,25]

3. Hotpressing: Molds for pressable dental ceramics are formed utilizing the lost wax technique.

Pressable ceramics are available as glass-ceramic ingots which are supplied from manufacturers. The ingots have a similar composition of powder porcelains, however; they have less porosity and more crystalline content. The ingots are heated to a high temperature where they become a highly viscous liquid, and then pressed slowly into the formed mold. The advantage of this techniqueis that it utilizes the experience that the lab technician already has in lost wax method with metal alloys.[15,16]

IPS Empress® andIPS Empress 2® (IvoclarVivadent) are representatives of materials utilizing hot pressing technique for fabrication.

IPS Empress® (IvoclarVivadent)

IPS Empress is a leucite-reinforcedglassceramic(SiO_2-Al_2O_3).26IPSE mpress has a low flexural strength of112±10 MPa limiting its use to single unit complete-coverage restorations in the anterior region.[4,26]

IPSEmpress 2®(IvoclarVivadent)

IPS Empress 2 is a lithium-disilicate glass ceramic(SiO_2-Li_2O).7IPS Empress 2 has a flexural strength of400±40 MPa which is much highert han that of IPS Empress.4,26Its increased flexural strength makes it suitable for the usage for fabrication of 3-unit FPDs in the anterior region, and can extend to the second premolar.27, 28 Both IPS Empress and IPSEmpress 2 are recommended in situations where average to high translucency is needed.2They are considered as monochromatic restorations which can be surface characterized to the desired shade and produce comparable esthetics to the layering techniques.[29]

Another example is the IPSe.maxPress®(IvoclarVivadent), which was introduced in 2005.It is considered as an enhanced press-ceramic material when compared to IPSEmpress 2.It has better physical properties and improved esthetics.[30]

4 Computer aided design/computer aided manufacturing:

Machinable ceramics are available as prefabricated glass-ceramic ingots.They are cut by tools that are controlled by the computer. After the tooth is prepared, an optical impression is taken for the preparation by a special scanner. Thei mage is then transferred to the system's software. Then the software designs the restoration and sends the data to the computer-

Controlled milling machine that grinds the ceramic block according to the desired shape.[31]

Examples of materials available for the CAD/CAM technology:32

(a) Silica based ceramics

(b) Infiltration ceramics

(c) Oxide high performance ceramics.

Several CAD/CAM systems offer silica based ceramic blocks for the fabrication of inlays, onlays,veneers, partial crowns and full crowns. Blanks with multicolored layers[VitablocsTriLuxe (Vita), IPSEmpress CAD Multi (IvoclarVivadent)] are available in addition to the monochromatic blocks for the fabrication of posterior crowns.

(b) Infiltration ceramics:

Blocks of infiltrated ceramics for CAD/CAM systems originate from theVitaIn-Ceram system. They have the same composition and clinical indications of the three previously mentioned VitaIn-Ceram products.[32]

(c) Oxidehigh performance ceramics

Blocks of aluminum oxideand zirconium oxide are currently available for the CAD/CAD technology.[32]

Alumina Oxide(Al_2O_3)

It is considered as a high performance ceramic.It is ground then sintered at a temperature of 1520°C.It is clinically indicated in cases of crown copings in the anterior and posterior area,and 3-unit FPDs in the anterior region. In-CeramAL Block(Vita) and inCoris Al (Sirona) are examples of aluminum oxide Blocks that are available in the market.[32]

Yittrium stabilized zirconium oxide(ZrO_2Y-TZP)

Zirconium dioxide ceramics have excellent mechanical properties. They have high flexural strength (750->1000 MPa)when compared to other dental ceramics.32, 37Yttrium-oxide is added to zirconiain order to stabilizethetetragonal phase at room temperature, which asa result can prevent crack propagationin the ceramic (Transformation strengthening).[7,40,41]

Zirconium oxide ceramics are indicated for the fabrication of crowns, FPDs and individual implant abutments. 32The cores have high radiopacity which is very useful in evaluation of marginal integrity .Zirconia has a color similar to teeth but if translucency is needed then other ceramic materials should be considered.

Examples of Zirconium oxide blocks:[32]

- LavaFrame®(3M ESPE)
- CerconSmart Ceramics® (DeduDent)
- EverestZSundZH® (KaVo)
- inCorisZR® (Sirona)
- In-Ceram YZ® (Vita)

Systems availablefor themachining ofthe ceramicblocks:32

- DCS Precident®(1989)
- Procera®(1993)
- CEREC inLAB® (2001)
- Cercon® (2001)
- Everest® (2002)
- Lava ®(2002)
- CEREC 3D® (2003)
- TurboDent® (2005)
- E4D Dentist® (2008)

Marginal integrity ofCAD/CAM restorations

Software limitations as well as accuracy of milling devices may affect the fit of CAD/CAM restorations.7Most clinicians agreed that marginal gap should not be greater than 100 μm.

It has been reported in the literature that restorations produced by CAD/CAM systems can have marginal gaps of 10-50μm which is considered to be within the acceptable range.[15,]

Cementation of all-ceramic restorations:

The protocol used for cementation of all-ceramic restorations can be essential for success.9Clinicians can effectively etch silica-based all-ceramics for adhesive bonding.The clinical lifespan ofsuch all-ceramic restorations significantly increased when this protocol is used. Zirconia and alumina-based all ceramicmaterials cannot be etched and bonded.

Survival of all-ceramic restorations:

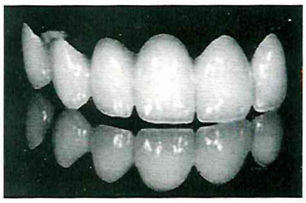
It is very important to consider the available survival data for all-ceramic materials when selecting a treatment strategy. This could be very challenging due to the numerous all- ceramic systems available and the definition of failure that varies in the literature.It has been reported that survival rates of all-ceramic restorations range from 88to 100% after service for 2-5years, and up to 97% after 5-15years.[7,20,]

Long-term survival was related to the fabrication method of all-ceramic restorations. Restorations fabricated using the hot pressing technique had the highest long-term survival. CAD/CAM ceramics had the next highest long-term survival. The lowest long-term survival was for restorations fabricated by powder condensation.[5]

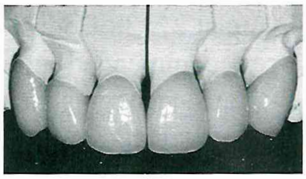
CONCLUSION:

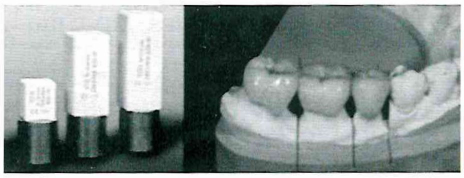
Advances in ceramic science are focusing on the development of materials that exhibit eathetics and translucency with good strength and physical properties. All-ceramic materials and systems will continue to improve.The dental practitioner should be aware of this development. The quest for the "Holy grail" , the perfect all ceramic crown material continues.

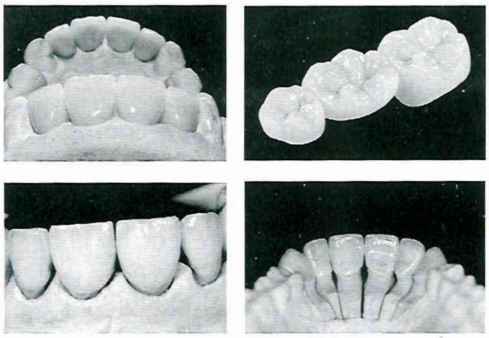
Vita Inceram



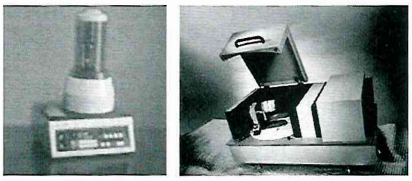
Inceram Zirconia



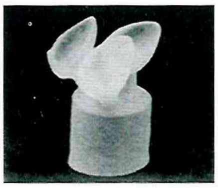




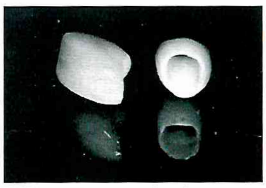
Inceram Zirconia



Machinable Ceramic



Dicor



Inceram alumina

REFERENCES:

1. Philips' Science of Dental Materials, ed11. Saunders, 2003
2. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA. Relative translucency of six allceramic systems. PartII: core and veneer materials. J Prosthet Dent 2002;88(1):10-5.
3. FischerH, MarxR. Fracture toughness ofdental ceramics: comparison of bending and indentation method. DentMater 2002;18(1):12-9.
4. Kalanta K. A crash course in ceramics. Available : http://www.bethesdamed.navy.mil/careers/postgraduate_denal_school/comprehensive_dentistry/Pearls/Pearlsa2.htm.Accessed on March 19, 2005
5. Griggs JA. Recentadvances in materialsfor all-ceramic restorations. DentClin North Am 2007;51(3):713-27,viii.
6. RaptisNV, MichalakisKX, HirayamaH. Opticalbehavior ofcurrentceramicsystems. Int JPeriodontics Restorative Dent 2006;26(1):31-41.
7. Conrad HJ, SeongWJ, PesunIJ. Current ceramicmaterials and systems with clinical recommendations: a systematic review. JProsthetDent 2007;98(5):389-404.
8. Sturdevant'sArt &Scienceof Operative Dentistry, ed4. Mosby2002
9. Donovan TE. Factorsessentialfor successful all-ceramic restorations. JAm Dent Assoc 2008;139 Suppl:14S-18S.
10. Kansu G, Aydin AK. Evaluation of thebiocompatibilityof various dentalalloys: PartI-- Toxic potentials. EurJProsthodontRestor Dent 1996;4(3):129-36.
11. Al-Hiyasat AS, Saunders WP, Smith GM. Three-bodywearassociatedwiththree ceramicsand enamel. JProsthet Dent 1999;82(4):476-81.
12. KellyJR. Dental ceramics: what is this stuff anyway?JAm Dent Assoc2008;139 Suppl:4S-7S.
13. Craig's Restorative Dental Materials, ed12.Mosby,2006
14. Antonson SA, AnusaviceKJ. Contrast ratio ofveneeringandcoreceramicsas a function of thickness.Int JProsthodont 2001;14(4):316-20.
15. SulaimanF, Chai J,JamesonLM, Wozniak WT.A comparison of themarginal fit ofIn- Ceram,IPS Empress, and Proceracrowns.Int JProsthodont 1997;10(5):478-84.
16. YeoIS, YangJH,Lee JB.In vitro marginal fit ofthree all-ceramic crownsystems.J Prosthet Dent 2003;90(5):459-64.
17. HaseltonDR,Diaz-Arnold AM, Hillis SL. Clinical assessment ofhigh-strength all- ceramiccrowns. JProsthet Dent 2000;83(4):396-401.
18. Chai J, Takahashi Y, SulaimanF, ChongK,LautenschlagerEP. Probabilityof fractureof all-ceramic crowns.IntJProsthodont 2000;13(5):420-4.
19. Xiao-ping L, Jie-mo T, Yun-long Z,LingW. Strength and fracture toughness of MgO- modified glass infiltratedaluminaforCAD/CAM.Dent Mater 2002;18(3):216-20.
20. Bindl A, Mormann WH.An up to 5-yearclinical evaluation ofposteriorin-ceram CAD/CAM core crowns.Int JProsthodont 2002;15(5):451-6.
21. Guazzato M, AlbakryM,Swain MV,IronsideJ. Mechanical properties ofIn-Ceram Alumina andIn-CeramZirconia.Int JProsthodont2002;15(4):339-46.
22. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA. Relative translucencyofsixall-ceramicsystems.PartI:corematerials. JProsthet Dent 2002;88(1):4-9.
23. Magne P, Belser U. Esthetic improvements and invitro testingofIn-CeramAlumina andSpinell ceramic.Int JProsthodont 1997;10(5):459-66.
24. Sundh A, Sjogren G. Acomparison of fracture strength ofyttrium-oxide-partially- stabilized zirconia ceramic crownswith varying corethickness,shapes andveneer ceramics. JOral Rehabil2004;31(7):682-8.
25. Raigrodski AJ. Contemporarymaterials and technologies for all-ceramicfixed partial dentures: a review of theliterature. JProsthet Dent 2004;92(6):557-62.
26. Fradeani M, RedemagniM. An 11-yearclinical evaluation ofleucite-reinforcedglass-ceramiccrowns:aretrospectivestudy.QuintessenceInt2002; 33(7):503-10.
27. Oh SC, DongJK,LuthyH, Scharer P. Strengthand microstructure ofIPS Empress 2 glass-ceramic after different treatments.Int JProsthodont 2000;13(6):468-72.
28. Esquivel-Upshaw JF, Chai J, Sansano S, ShonbergD. Resistance tostaining, flexural strength,and chemical solubilityofcore porcelainsfor all-ceramiccrowns.IntJ Prosthodont 2001;14(3):284-8.
29. Herrguth M, WichmannM, Reich S. The aesthetics of all-ceramicveneered and monolithic CAD/CAM crowns. JOral Rehabil 2005;32(10):747-52.
30. StappertCF, AttW, GerdsT, StrubJR. Fracture resistance of differentpartial-coverage ceramic molar restorations:An in vitro investigation. JAm Dent Assoc 2006;137(4):514-22
31. Luthardt RG, Sandkuhl O, Herold V, Walter MH. Accuracyof mechanicaldigitizingwith a CAD/CAM system forfixed restorations.Int JProsthodont 2001;14(2):146-51.
32. Edward A. McLaren, DDS, MDC, and Lu Hyo, MDC .Inside Dentistry November/December 2006, Volume 2, Issue 9

Systems availablefor themachining ofthe ceramicblocks:32

- DCS Precident®(1989)
- Procera®(1993)
- CEREC inLAB® (2001)
- Cercon® (2001)
- Everest® (2002)
- Lava ®(2002)
- CEREC 3D® (2003)
- TurboDent® (2005)
- E4D Dentist® (2008)

Marginal integrity ofCAD/CAM restorations

Software limitations as well as accuracy of milling devices may affect the fit of CAD/CAM restorations.7Most clinicians agreed that marginal gap should not be greater than 100 µm.

It has been reported in the literature that restorations produced by CAD/CAM systems can have marginal gaps of 10-50µm which is considered to be within the acceptable range.[15,]

Cementation of all-ceramic restorations:

The protocol used for cementation of all-ceramic restorations can be essential for success.9Clinicians can effectively etch silica-based all-ceramics for adhesive bonding.The clinical lifespan ofsuch all-ceramic restorations significantly increased when this protocol is used. Zirconia and alumina-based all ceramicmaterials cannot be etched and bonded.

Survival of all-ceramic restorations:

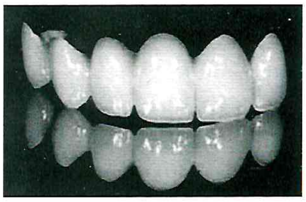
It is very important to consider the available survival data for all-ceramic materials when selecting a treatment strategy. This could be very challenging due to the numerous all- ceramic systems available and the definition of failure that varies in the literature.It has been reported that survival rates of all-ceramic restorations range from 88to 100% after service for 2-5years, and up to 97% after 5-15years.[7,20,]

Long-term survival was related to the fabrication method of all-ceramic restorations. Restorations fabricated using the hot pressing technique had the highest long-term survival. CAD/CAM ceramics had the next highest long-term survival. The lowest long-term survival was for restorations fabricated by powder condensation.[5]

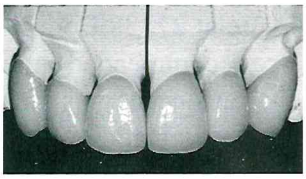
CONCLUSION:

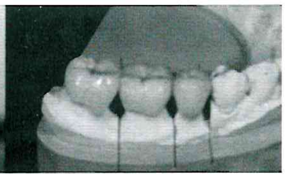
Advances in ceramic science are focusing on the development of materials that exhibit eathetics and translucency with good strength and physical properties. All-ceramic materials and systems will continue to improve.The dental practitioner should be aware of this development. The quest for the "Holy grail" , the perfect all ceramic crown material continues.

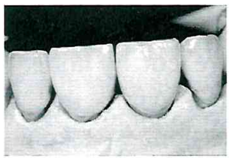
Vita Inceram



Inceram Zirconia

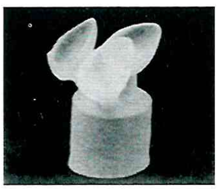




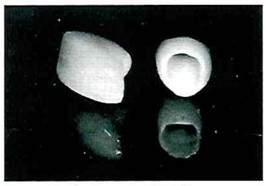


Inceram Zirconia

Machinable Ceramic



Dicor



Inceram alumina

REFERENCES:

1. Philips' Science of Dental Materials, ed11. Saunders, 2003
2. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA. Relative translucency of six allceramic systems. PartII: core and veneer materials. J Prosthet Dent 2002;88(1):10-5.
3. FischerH, MarxR. Fracture toughness ofdental ceramics: comparison of bending and indentation method. DentMater 2002;18(1):12-9.
4. Kalanta K. A crash course in ceramics. Available : http://www.bethesdamed.navy.mil/careers/postgraduate_denal_school/comprehensive_dentistry/Pearls/Pearlsa2.htm.Accessed on March 19, 2005
5. Griggs JA. Recentadvances in materialsfor all-ceramic restorations. DentClin North Am 2007;51(3):713-27,viii.
6. RaptisNV, MichalakisKX, HirayamaH. Opticalbehavior ofcurrentceramicsystems. Int JPeriodontics Restorative Dent 2006;26(1):31-41.
7. Conrad HJ, SeongWJ, PesunIJ. Current ceramicmaterials and systems with clinical recommendations: a systematic review. JProsthetDent 2007;98(5):389-404.
8. Sturdevant'sArt &Scienceof Operative Dentistry, ed4. Mosby2002
9. Donovan TE. Factorsessentialfor successful all-ceramic restorations. JAm Dent Assoc 2008;139 Suppl:14S-18S.
10. Kansu G, Aydin AK. Evaluation of thebiocompatibilityof various dentalalloys: PartI-- Toxic potentials. EurJProsthodontRestor Dent 1996;4(3):129-36.
11. Al-Hiyasat AS, Saunders WP, Smith GM. Three-bodywearassociatedwiththree ceramicsand enamel. JProsthet Dent 1999;82(4):476-81.
12. KellyJR. Dental ceramics: what is this stuff anyway?JAm Dent Assoc2008;139 Suppl:4S-7S.
13. Craig's Restorative Dental Materials, ed12.Mosby,2006
14. Antonson SA, AnusaviceKJ. Contrast ratio ofveneeringandcoreceramicsas a function of thickness.Int JProsthodont 2001;14(4):316-20.
15. SulaimanF, Chai J,JamesonLM, Wozniak WT.A comparison of themarginal fit ofIn- Ceram,IPS Empress, and Proceracrowns.Int JProsthodont 1997;10(5):478-84.
16. YeoIS, YangJH,Lee JB.In vitro marginal fit ofthree all-ceramic crownsystems.J Prosthet Dent 2003;90(5):459-64.
17. HaseltonDR,Diaz-Arnold AM, Hillis SL. Clinical assessment ofhigh-strength all- ceramiccrowns. JProsthet Dent 2000;83(4):396-401.
18. Chai J, Takahashi Y, SulaimanF, ChongK,LautenschlagerEP. Probabilityof fractureof all-ceramic crowns.IntJProsthodont 2000;13(5):420-4.
19. Xiao-ping L, Jie-mo T, Yun-long Z,LingW. Strength and fracture toughness of MgO- modified glass infiltratedaluminaforCAD/CAM.Dent Mater 2002;18(3):216-20.
20. Bindl A, Mormann WH.An up to 5-yearclinical evaluation ofposteriorin-ceram CAD/CAM core crowns.Int JProsthodont 2002;15(5):451-6.
21. Guazzato M, AlbakryM,Swain MV,IronsideJ. Mechanical properties ofIn-Ceram Alumina andIn-CeramZirconia.Int JProsthodont2002;15(4):339-46.
22. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA. Relative translucencyofsixall-ceramicsystems.PartI:corematerials. JProsthet Dent 2002;88(1):4-9.
23. Magne P, Belser U. Esthetic improvements and invitro testingofIn-CeramAlumina andSpinell ceramic.Int JProsthodont 1997;10(5):459-66.
24. Sundh A, Sjogren G. Acomparison of fracture strength ofyttrium-oxide-partially- stabilized zirconia ceramic crownswith varying corethickness,shapes andveneer ceramics. JOral Rehabil2004;31(7):682-8.
25. Raigrodski AJ. Contemporarymaterials and technologies for all-ceramicfixed partial dentures: a review of theliterature. JProsthet Dent 2004;92(6):557-62.
26. Fradeani M, RedemagniM. An 11-yearclinical evaluation ofleucite-reinforcedglass-ceramiccrowns:aretrospectivestudy.QuintessenceInt2002; 33(7):503-10.
27. Oh SC, DongJK,LuthyH, Scharer P. Strengthand microstructure ofIPS Empress 2 glass-ceramic after different treatments.Int JProsthodont 2000;13(6):468-72.
28. Esquivel-Upshaw JF, Chai J, Sansano S, ShonbergD. Resistance tostaining, flexural strength,and chemical solubilityofcore porcelainsfor all-ceramiccrowns.IntJ Prosthodont 2001;14(3):284-8.
29. Herrguth M, WichmannM, Reich S. The aesthetics of all-ceramicveneered and monolithic CAD/CAM crowns. JOral Rehabil 2005;32(10):747-52.
30. StappertCF, AttW, GerdsT, StrubJR. Fracture resistance of differentpartial-coverage ceramic molar restorations:An in vitro investigation. JAm Dent Assoc 2006;137(4):514-22
31. Luthardt RG, Sandkuhl O, Herold V, Walter MH. Accuracyof mechanicaldigitizingwith a CAD/CAM system forfixed restorations.Int JProsthodont 2001;14(2):146-51.
32. Edward A. McLaren, DDS, MDC, and Lu Hyo, MDC .Inside Dentistry November/December 2006, Volume 2, Issue 9