IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)
e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 15, Issue 3 Ver. IX (Mar. 2016), PP 32-39
www.iosrjournals.org

Dental Ceramics- Past, Present and Future – Literature Review

Dr Karishma Shah[1] , Dr Abhilasha Bal[2]
[1]*(B.D.S (Mumbai), M.Sc Restorative Dentistry (U.K, LEEDS),*
[2] *(B.D.S(Mumbai) M.D.S (Prosthodontics)*

Fixed prosthodontics in dentistry (Historical Considerations)

The word Ceramic originated from the Greek term keramos meaning "potter or pottery".

Restorative dentistry can be traced back to early Egyptian times. Dentistry existed in Etruria but remained relatively undeveloped until the 18th century. At that time dental prosthesis were made from human teeth, animal teeth carved to human size and shape and porcelain (Kelly, Nishimura et al. 1996). Human teeth were difficult to procure and when found were expensive. Animal teeth on the other hand corroded easily due to the nature salivary agents. John Greenwood used hippopotamus teeth for George Washington's denture (Johnson 1959; Kelly, Nishimura et al. 1996).

The desire for an aesthetic and durable material led to the use of porcelain in dentistry. Porcelain has had a wide variety of applications through the centuries; the Chinese manufactured porcelain as early as the 9th century and the French and English in the 18th century used porcelain for dinner ware (Anusavice 2003).

The introduction of porcelain in dentistry by Alexis Duchateau in 1774 is one of the most significant historic developments in dentistry. There have been some reports that in 1728 Fuchard, a French dentist, used baked enamel (Capon, 1927)(Anusavice 2003). Duchateau, a French apothecary was dissatisfied with his dentures as they were stained. He noticed that on the other hand his glazed ceramic utensils seemed resistant to chemicals and grinding. This was probably the source of his novel idea to make himself a set of mineral dentures. The main problem Duchateau had to overcome was the large firing contraction of porcelain. He tried resolving it by the use of oversized models however was largely unsuccessful. He was only successful after his collaboration with a dentist called Nicolas Dubois de Chemant, after which the method of fabrication greatly improved.

In 1808 an Italian dentist invented a " terrometallic" porcelain tooth which was held into place by a platinum pin which was subsequently improved by Ash in 1837.The first porcelain crown was developed by Land in 1903(Lynch, O'Sullivan et al. 2006).

The increased demand for aesthetics led to the development of all ceramic restorations.

McLean added aluminium oxide to feldspathic porcelain in order to develop a superior dental material. The addition of aluminium oxide improved physical and mechanical properties however the material appeared to be still be extremely brittle. The material also lacked tensile strength, wear resistance, needed a veneering porcelain and had poor marginal adaptation; it did though lead to the development of an all ceramic restoration that could withstand deformation without fracturing (Anusavice 2003).

Porcelain fused to metal crowns and bridges

Metal- ceramic restorations have been used since 1950's when Brecker described a method of baking porcelain onto gold. The original metal-ceramic crowns have undergone several refinements to develop crowns with adequate strength and reasonable aesthetics. The extent of tooth preparation and considerations of aesthetic and of allergy to nickel has led to the emergence of a variety of metal-free restorations (Barnfather and Brunton 2007).

According to Hickel and Manhart (2001) ceramic materials such as spinel, alumina, and glass- ceramic reinforced with lithium disilicate have been used for the construction of metal-free restorations. The introduction of new restorative treatment patterns, materials and techniques has improved the longevity and aesthetics of fixed dental prostheses. Metal- ceramic restorations in many studies exhibited good longevity however Sailer, Pjetursson et al. (2007) argued that there was some difficulty in the imitation of natural aesthetics especially in areas where there was limited space for veneering material. Manicone, Rossi Iommetti et al. (2007) added that the metal-free crowns allowed preservation of soft tissue color similar to the natural gingiva compared to porcelain fused to metal. The advantage of all- ceramic restorations is the ability of the material to achieve optimal aesthetics however the lack of mechanical stability historically deemed them suitable only for single crowns (Hickel and Manhart 2001; Olsson, Fürst et al. 2003). All-ceramic restorations combining aesthetic veneering porcelains and strong ceramic cores were able to resist fracture during function as well as parafuction in both anterior as well as posterior areas (Conrad, Seong et al. 2007). Veneering porcelains typically consist of glass or crystalline phase of aluminum oxide; fluoroapatite or leucite and materials used for cores consist of lithium-disilicate, aluminum oxide or zirconium oxide. The use of these materials customizes the restoration in terms of form and aesthetics. Zirconium oxide (zirconia) is one of the most stable ceramics and has flexural strength and fracture toughness values of approximately 900 MPa and 9 MPa $m^{1/2}$, (Seghi, Denry et al. 1995); these values are almost two times higher than those produced by glass-ceramics and glass-infiltrated alumina (In Ceram Alumina) (Olsson, Fürst et al. 2003; Sailer, Pjetursson et al. 2007). Some comparisons are given in Table 1. In a systematic review conducted by Sailer et.al (2011) all- ceramic restorations had a significantly lower survival rate when compared with metal-ceramic FPD's. They found failure rates of 11.4% in 5 years for all ceramic crowns and 5.6% for metal ceramic crowns. The most common reason for failure was fracture between the framework and veneering ceramic, however with zirconium oxide copings the failures were primarily due to biological and technical reasons rather than fracture of the framework. The most common biological complication, the systematic review reported, was loss of vitality of the teeth when observed over a period of 5 years (Sailer, Pjetursson et al. 2007).

The uses of ceramics in dentistry

Dental ceramics is one of the fastest developing areas of dental material research and development. During the past two decades numerous types of ceramics have been developed with various processing methods have been introduced. These material are used to form inlays, onlays, veneers, crowns and more complex FPD's. The increased demand for the development of tooth colored materials has led to increased demand for ceramic and polymer based restorations and reduced demand for amalgam and cast metals (Anusavice 2003).

Classification of ceramic based materials

Dental ceramics can be classified based upon either: (Anusavice 2003)

1) Uses or indications (e.g. anterior, posterior crown, veneer, post and core, fixed prosthesis, ceramic stain, glaze)
2) Composition
3) Principal crystal matrix phase (silica glass , leucite-based feldspathic porcelain, leucite-based glass ceramic,lithia disilicate-based glass-ceramic,leucite disilicate-based glass-ceramic, aluminous porcelain, alumina, glass-infused alumina, glass-infused-spinel,glass-infused alumina/zirconia)
4) Processing method (casting, sintering, partial sintering and glass infiltration, slip casting and sintering, hot isostatic pressing, CAD-CAM milling and copy milling)
5) Firing tempreture (ultralow fusing, low fusing, medium fusing and high fusing)
6) Microstructure (amorphous glass, crystalline, cystalline particles in matrix)
7) Transluency (opaque, translucent, transparent)
8) Fracture resistance (low, medium, hard)
9) abrasiveness (comparison relative to enamel, against tooth enamel)

Zirconia based ceramic restorations

Zirconia finds a wide range of applications outside of dentistry:

- Zirconia is commonly used as a thermal insulator and in fuel cells due to its extraordinary mechanical and physical properties (Al-Amleh, Lyons et al. 2010).
- Zirconia occurs in 3 temperature dependant polymorphic forms i.e. monoclinic (room temperature to 1170 ^{o}C), tetragonal (1170-2370 ^{o}C) and cubic (2370 ^{o}C until the melting point) (Al-Amleh, Lyons et al. 2010) (figure 1).
- The transition from tetragonal to monoclinic phase results in increased volume by 3-5% producing cracks in the zirconia samples.
- The addition of Mg, Ca, Sc, Y and Nd to the high temperature tetragonal phase can result in its stabilization at room temperature (Anusavice 2003).
- Zirconia has similar mechanical properties to those of stainless steel. Cales and Stefani found that 50 million cycles were necessary to break the samples with a force of 90 kN. Failure of the samples occurred after 15 cycles thus depicting zirconia high fracture resistance.(Cales and Stefani 1994).

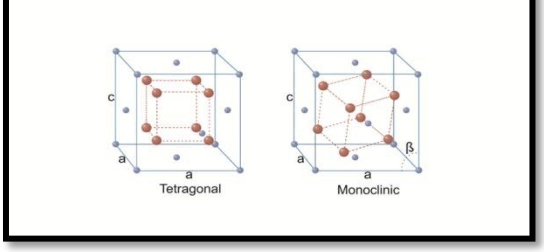

Figure 1 Crystalline structure of zirconia adapted from *(Anusavice 2003)*

Property	Leucite	Lithium Disilicate	Zirconia (Y-TZP)	Ceramic with HAP Nanocrystals for Veneering Y-TZP
Crystallalinity (vol%)	35	70	≥ 97.5 (may also include crystalline HfO_2, Al_2O_3,Na_2O, SiO_2, and Fe_2O_3, etc)	N/A
Flexural Strength (Mpa)	85 - 112	215 – 400	900	85 – 110
Fracture Toughness (MPa-m$^{1/2}$)	1.3 - 1.7	2.2 – 3.3	8 - 10.3	0.75 – 1.0
Vickers Hardness (GPa)	5.9	6.3	8.8 – 11.8	4.8 – 5.4
Expansion Coefficient ($10^{-6/k}$)	15.0 – 15.4	9.7 – 10.6	10.0 – 11.0	9.8
Elastic Modulus (GPa)	65 – 86	95 – 103	210	65
Chemical Durability (mUg/cm^2)	100 - 200	30 – 50	30	10 - 20

Table 1 Properties of veneering and core ceramic restoration adapted from *(Anusavice 2003)*

Hot isostatically pressed (HIP) versus Non hot isostatically pressed

Advances in CAD-CAM technology allow complex shapes to be milled from blanks. The prepared abutment is scanned using software and the block is then milled to form a zirconia framework.

The framework can be hard milled or soft milled. Soft milling involves machining zirconia from large presintered blanks of zirconia in the green state following which the framework is sintered to its maximum strength resulting in shrinkage of 25%. Common examples of soft milling are LAVA, IPS, EMAX and Procera (Raigrodski 2004).

HIP processing involves a closed system in which high temperatures and pressures are applied to densify zirconia, gaining approximately 20% more strength (Anusavice 2003).

Densely sintered zirconium that is hot isotatically pressed (HIP) is hard milled. This form of milling tends to cumbersome since it involves a longer milling cycle; consequently most manufacturers prefer soft milling to hard milling since its less time consuming. There are advantages and disadvantages both; soft milling may result in marginal discrepancy owing to shrinkage of 25% whilst hard milling on the other hand may induce micro cracks in the framework (Al-Amleh, Lyons et al. 2010).

When Reich and his colleagues examined the marginal gaps of 4 unit FPDs they found an average discrepancy of 77µm in 24 FPD non HIPed samples which was a the clinically acceptable level (100-200mm)(Reich, Kappe et al. 2008).

In vitro studies support the use of both HIP and non-HIP; however there are no clinical trials proving these claims either way. It was noted though that the highest number of clinical fractures occurred in Non HIP (Al-Amleh, Lyons et al. 2010).

In order to study the difference between HIP and Non HIP longer studies with larger samples need to be carried out (Raigrodski 2004).

Transformation toughening

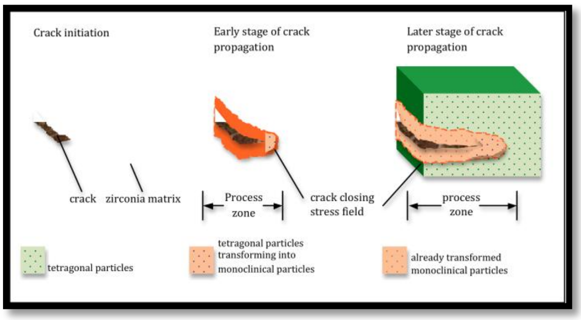

Figure 2 Transformation toughening

The process of transformation on tetragonal particles to monoclinic zirconia particles (adapted from *(Brown Feb, 2010))*

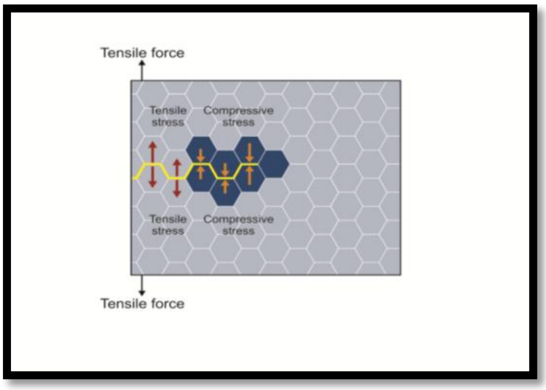

Figure 3 Schematic illustration of transformation toughening

Adapted from (Anusavice 2003)

Zirconia has an extremely low thermal conductivity (20% of that of alumina). It is also chemically inert and corrosion resistant. Zirconia undergoes a large volume expansion when is undergoes transformation from cubic to tetragonal to monoclinic phases leading to structural expansion and tensile stresses that cause zirconia to crack during cooling (Anusavice 2003). Magnesium oxide, yttrium oxide, calcium oxide and cerium oxide are added to zirconia to stabilize the tetragonal phase at low temperature. The most common stabilizer used in dentistry is yttria which induce vacancies in the crystal lattice (Manicone, Rossi Iommetti et al. 2007).

The addition of 3-5-mol % of yttrium results in the formation of yttrium –stabilized zirconia or yttria-stabilized tetragonal zirconia polycrystals (Y-TZP). The structural stabilization of zirconia by yttria results in significant proportion of metastable tetragonal phase. The metastable tetragonal phase strengthens and toughens the structure by a localized transformation into monoclinic phase when tensile stresses develop at crack tips (Anusavice 2003). The volume expansion adjacent to crack tips produces increased localized fracture toughness and inhibits the potential for crack propagation (Manicone, Rossi Iommetti et al. 2007) (figures 2 and 3). Accordingly, transformation toughening is a method of crack shielding which results in an increase in the tensile strength and flexural fracture resistance.

Low temperature degradation

The long-term stability of zirconia may be hampered by its susceptibility to hydrothermal degradation. Even though in most reports hydrothermal degradation of zirconia occurs between 200-300°C, exposure in the oral environment may also cause zirconia degradation causing an increase in surface roughness, fragmented grains and micro cracks. The degradation process initiates the transformation of the surface to the monoclinic phase that in turn transfers stresses into adjacent grains(Kobayashi, Kuwajima et al. 1981). Hydroxyl ions are responsible for this transformation that results in the breakdown of the atomic bonds on the surface producing residual stresses (Anusavice 2003). Low temperature degradation differs in severity amongst different manufacturers; in fact, it differs by different processing methods by the same manufacturer(Chevalier, Deville et al. 2004)

Colouring process of zirconia

Zirconia frameworks are aesthetic compared to metallic frameworks however they still lack translucency and appear to be white. The coloured zirconia frameworks aims to enhance the esthetics and overall colour of the restoration. The colouring process varies depending upon the manufacturer .Different techniques include adding metallic pigments to the initial zirconia powder or dipping the milled framework in pigments. The advantage of colouring the milled frameworks is the reduction in veneer thickness to mask the underlying colour (Aboushelib, Kleverlaan et al. 2008). 3M – ESPE literature claims that the colouring process itself enhances the strength of the restoration. 3M™ ESPE™ Lava™ zirconia is not coloured by pigments but instead by colouring ions. The pre-sintered zirconia is immersed in the shading dye. The porous nature of zirconia allows it to soak up the colouring ions. These soaked up ions are incorporated in the structure during the final sintering step (Piwowarczyk, Ottl et al. 2005).In a study comparing zirconias from different manufacturers, structural similarities and chemical similarities were seen even though they had different milling techniques and colouring method(Aboushelib, Kleverlaan et al. 2008).

These dyes correspond to shades of the veneering porcelain (Table 2)

Colouring Dye	Shade
FS1	A1and B1
FS2	B2 and C1
FS3	A2 and A3
FS4	A3.5and A4
FS5	B3
FS6	C2, C3 and C4
FS7	D2, D3and D4

Table 2 Colouring dye and corresponding shade produced for LAVA zirconia

Failure of zirconium oxide based material

The porcelain veneer tends to be weaker compared to the zirconia core material thus tending to fail under low loads. The cracks most often occur from the surface of the veneer and the inner surface of the core (Von Steyern, Carlson et al. 2005) . Heat pressing tends to improve the mechanical property of the veneer material (Tsalouchou, Cattell et al. 2008). The dimensions of the core and veneer material, the processing errors and the preparation design are amongst the factors which may affect the fracture and fatigue behaviour of the material used (Tsalouchou, Cattell et al. 2008).

Although the increase in thickness of ceramic copings tends to aesthetically pleasing it is important not to compromise the aesthetics of the crown by overcontouring or overreduction (Proos, Swain et al. 2003).

Uses of zirconia based materials in dentistry

The clinical applications of dental zirconium oxide include endodontic posts, implants and implant abutments, orthodontic brackets and fixed partial frameworks(Conrad, Seong et al. 2007)

Zirconium oxide implants and abutments

The replacement of missing teeth requires functional and aesthetic evaluation. The intrasulcular zirconium oxide abutment design obtains a natural looking emergence profile and eliminates the risk of metallic shimmer through the soft thin tissue (Zembic, Sailer et al. 2009). The use of ceramic abutments for implants ensures optimal adaptation between margins of the restoration and soft tissue. Titanium implants are considered a gold standard however one of the major drawbacks is that they cause grayish discoloration of the peri-implant mucosa (Zembic, Sailer et al. 2009). In a study conducted on 54 zirconia implant abutments over a period of 4 years, it was found that there were no fractures of the abutment noted in the anterior or premolar region (Glauser, Sailer et al. 2004) compared to alumina abutments which had a 7% failure rate in 1 year(Andersson, Taylor et al. 2001). A 3-5 year follow-up for posterior zirconia implant abutments depicted survival rates of 97.8% -100%(Raigrodski, Chiche et al. 2006; Sailer, Zembic et al. 2009). Zirconia ceramic abutments have proved to withstand high functional occlusal loading while maintaining adequate esthetics. Zirconia and titanium abutments have exhibited the same degree of plaque accumulation in-fact no differences were found regarding the amount of plaque accumulation between natural teeth and abutments. Another study supporting this evidence was conducted by Scarano et al who reported that the bacterial coverage on zirconium was 12.1%, compared to titanium that was 19.3%(Scarano, Piattelli et al. 2004). Zirconia abutments provide an adequate marginal and periodontal seal without any bacterial infiltrations(Manicone, Rossi Iommetti et al. 2007).

The purpose of an all -ceramic implant system is to develop a system which is biocompatible, fabricated out of tooth-coloured material to improve aesthetics and which is able withstand masticatory forces.(Kohal and Klaus 2004)

In an experimental study conducted on rabbits, Sennerby compared osseointergration and removal torque between zirconia implants and titanium implants. The study compared modified oxidized titanium implants; surface modified zirconia implants and machined ziconia implant surfaces. It was found the torque removal of the surface modified zirconia implants was similar to that of titanium oxide implants and 4 fold more than machined implants thus concluding modifications on zirconium oxide implant surface could enhance its stability.(Sennerby, Dasmah et al. 2006).

An *in-vitro* study testing zirconia implants concluded that they were able to with stand high chewing stresses. The mean fracture load after cyclic stress on a titanium implant with a porcelain fused to metal restoration was 668.6 N whereas the zirconium implant with an all-ceramic restoration fractured at 555.5 N. A similar load bearing capacity concludes that zirconia implants can be used for anterior teeth(Kohal, Klaus et al. 2006).

Tooth coloured posts system for non-vital teeth were introduced in order to develop esthetic restorations for non-vital teeth(Ahmad 1998). Metallic posts on the other hand cause corrosion and may induce an inflammatory reaction with the periodontium. Zirconia posts are considered to be chemically stable with optimal physical properties ideal for the construction of esthetic restorations(Ahmad 1998). There have been some reports of zirconia posts being weaker than metal posts thus requiring additional removal of radicular tooth structure to accommodate a thicker post(Schwartz and Robbins 2004). The other problem commonly encountered with zirconium posts is that they cannot be etched thus making bonding with composite core material difficult(Butz, Lennon et al. 2001). Retrieval of zirconia posts tends to be cumbersome in case of endodontic retreatment or fracture of the post. Some ceramic material can be removed by grinding away the material however it is impossible to grind away the entire zirconia post.(Schwartz and Robbins 2004). A four-year retrospective study conducted on zirconia posts with indirect glass-ceramic cores depicted a higher failure rate using the same posts with direct composite build –ups. The current evidence suggests the use of zirconium posts should be avoided and a post and core material with properties similar to dentine should be used(Peroz, Blankenstein et al. 2005).

References

[1]. ABOUSH, Y. E. 1998. Removing saliva contamination from porcelain veneers before bonding. The Journal of Prosthetic Dentistry, 80**,** 649-653.

[2]. ABOUSHELIB, M. N., FEILZER, A. J. & KLEVERLAAN, C. J. 2010. Bonding to zirconia using a new surface treatment. Journal of Prosthodontics, 19**,** 340-346.

[3]. ABOUSHELIB, M. N., MIRMOHAMADI, H., MATINLINNA, J. P., KUKK, E., OUNSI, H. F. & SALAMEH, Z. 2009. Innovations in bonding to zirconia-based materials. Part II: focusing on chemical interactions. Dental Materials, 25**,** 989-993.

[4]. AHMAD, I. 1998. Yttrium-partially stabilized zirconium dioxide posts: an approach to restoring coronally compromised nonvital teeth. The International journal of periodontics & restorative dentistry, 18**,** 454.

[5]. AL-AMLEH, B., LYONS, K. & SWAIN, M. 2010. Clinical trials in zirconia: a systematic review. Journal of oral rehabilitation, 37**,** 641-652.

[6]. ALBERS, H. F. 2002. Tooth-colored restoratives: principles and techniques, BC Decker.

[7]. ANDERSSON, B., TAYLOR, A., LANG, B., SCHELLER, H., SCHÄRER, P., SORENSEN, J. & TARNOW, D. 2001. Alumina ceramic implant abutments used for single-tooth replacement: a prospective 1-to 3-year multicenter study. The International journal of prosthodontics, 14**,** 432.

[8]. ANUSAVICE, K. J. 2003. Phillips' science of dental materials, Saunders.

[9]. ATSU, S. S., KILICARSLAN, M. A., KUCUKESMEN, H. C. & AKA, P. S. 2006. Effect of zirconium-oxide ceramic surface treatments on the bond strength to adhesive resin. Journal of Prosthetic Dentistry, 95**,** 430-436.

[10]. BARNFATHER, K. & BRUNTON, P. 2007. Restoration of the upper dental arch using Lava™ all-ceramic crown and bridgework. British Dental Journal, 202**,** 731-735.

[11]. BLATZ, M. B., SADAN, A. & KERN, M. 2003. Resin-ceramic bonding: a review of the literature. Journal of Prosthetic Dentistry, 89**,** 268-274.

[12]. BOTTINO, M. A., VALANDRO, L. F., SCOTTI, R. & BUSO, L. 2005. Effect of surface treatments on the resin bond to zirconium-based ceramic. The Journal of Prosthetic Dentistry, 94**,** 369.

[13]. BURKE, F. 2005. Trends in indirect dentistry: 3. Luting materials. Dental update, 32**,** 251.

[14]. BUTZ, F., LENNON, A. M., HEYDECKE, G. & STRUB, J. R. 2001. Survival rate and fracture strength of endodontically treated maxillary incisors with moderate defects restored with different post-and-core systems: An in vitro study. The International journal of prosthodontics, 14**,** 58.

[15]. CALES, B. & STEFANI, Y. 1994. Mechanical properties and surface analysis of retrieved zirconia hip joint heads after an implantation time of two to three years. Journal of Materials Science: Materials in Medicine, 5**,** 376-380.

[16]. CASUCCI, A., MONTICELLI, F., GORACCI, C., MAZZITELLI, C., CANTORO, A., PAPACCHINI, F. & FERRARI, M. 2011. Effect of surface pre-treatments on the zirconia ceramic–resin cement microtensile bond strength. Dental Materials, 27**,** 1024-1030.

[17]. CHEVALIER, J., DEVILLE, S., MÜNCH, E., JULLIAN, R. & LAIR, F. 2004. Critical effect of cubic phase on aging in 3mol% yttria-stabilized zirconia ceramics for hip replacement prosthesis. Biomaterials, 25**,** 5539-5545.

[18]. CHRISTENSEN, G. J. 2006. Has the'total-etch'concept disappeared? The Journal of the American Dental Association, 137**,** 817.

[19]. CONRAD, H. J., SEONG, W. J. & PESUN, I. J. 2007. Current ceramic materials and systems with clinical recommendations: a systematic review. J Prosthet Dent, 98**,** 389-404.

[20]. DE MUNCK, J., VARGAS, M., VAN LANDUYT, K., HIKITA, K., LAMBRECHTS, P. & VAN MEERBEEK, B. 2004. Bonding of an auto-adhesive luting material to enamel and dentin. Dental Materials, 20**,** 963-971.

[21]. DE OYAGÜE, R. C., MONTICELLI, F., TOLEDANO, M., OSORIO, E., FERRARI, M. & OSORIO, R. 2009. Influence of surface treatments and resin cement selection on bonding to densely-sintered zirconium-oxide ceramic. Dental Materials, 25**,** 172-179.

[22]. DENRY, I. & KELLY, J. R. 2008. State of the art of zirconia for dental applications. Dental Materials, 24**,** 299-307.

[23]. EICHLER, A. 2001. Tetragonal Y-doped zirconia: Structure and ion conductivity. Physical Review B, 64**,** 174103.

[24]. EIRIKSSON, S. O., PEREIRA, P. N. R., SWIFT, E. J., HEYMANN, H. O. & SIGURDSSON, A. 2004. Effects of saliva contamination on resin–resin bond strength. Dental Materials, 20**,** 37-44.

[25]. ERNST, C. P., COHNEN, U., STENDER, E. & WILLERSHAUSEN, B. 2005. In vitro retentive strength of zirconium oxide ceramic crowns using different luting agents. Journal of Prosthetic Dentistry, 93**,** 551-558.

[26]. GLAUSER, R., SAILER, I., WOHLWEND, A., STUDER, S., SCHIBLI, M. & SCHÄRER, P. 2004. Experimental zirconia abutments for implant-supported single-tooth restorations in esthetically demanding regions: 4-year results of a prospective clinical study. The International journal of prosthodontics, 17**,** 285.

[27]. GOTTI, V. B., SHIMANO, M. M., BORGES, G. A., BORGES, L. H. & DE SOUZA GONÇALVES, L. 2011. Influence of ceramic primers on microshearbond strength between resin cements andzirconia-based ceramic. Brazilian Journal of Oral Sciences, 10**,** 124-129.

[28]. HEUER, A., CLAUSSEN, N., KRIVEN, W. & RUHLE, M. 1982. Stability of tetragonal ZrO2 particles in ceramic matrices. Journal of the American Ceramic Society, 65**,** 642-650.

[29]. HICKEL, R. & MANHART, J. 2001. Longevity of restorations in posterior teeth and reasons for failure. The journal of adhesive dentistry, 3**,** 45.

[30]. HILL, E. & LOTT, J. 2011. A clinically focused discussion of luting materials. Australian dental journal, 56**,** 67-76.

[31]. JOHNSON, W. W. 1959. The history of prosthetic dentistry. The Journal of Prosthetic Dentistry, 9**,** 841-846.

[32]. KELLY, J. R. 1997. CERAMICS IN RESTORATIVE AND PROSTHETIC DENTISTRY1. Annu. Rev. Mater. Sci, 27**,** 443-68.

[33]. KELLY, J. R., NISHIMURA, I. & CAMPBELL, S. D. 1996. Ceramics in dentistry: historical roots and current perspectives. The Journal of Prosthetic Dentistry, 75, 18-32.
[34]. KERN, M. & WEGNER, S. M. 1998. Bonding to zirconia ceramic: adhesion methods and their durability. Dental Materials, 14, 64-71.
[35]. KITAYAMA, S., NIKAIDO, T., TAKAHASHI, R., ZHU, L., IKEDA, M., FOXTON, R. M., SADR, A. & TAGAMI, J. 2010. Effect of primer treatment on bonding of resin cements to zirconia ceramic. Dental Materials, 26, 426-432.
[36]. KLOSA, K., WOLFART, S., LEHMANN, F., WENZ, H. J. & KERN, M. 2009. The effect of storage conditions, contamination modes and cleaning procedures on the resin bond strength to lithium disilicate ceramic. The journal of adhesive dentistry, 11, 127.
[37]. KOBAYASHI, K., KUWAJIMA, H. & MASAKI, T. 1981. Phase change and mechanical properties of ZrO< sub> 2</sub>-Y< sub> 2</sub> O< sub> 3</sub> solid electrolyte after ageing. Solid State Ionics, 3, 489-493.
[38]. KOHAL, R. J. & KLAUS, G. 2004. A zirconia implant-crown system: a case report. The International journal of periodontics & restorative dentistry, 24, 147.
[39]. KOHAL, R. J., KLAUS, G. & STRUB, J. R. 2006. Zirconia-implant-supported all-ceramic crowns withstand long-term load: a pilot investigation. Clinical oral implants research, 17, 565-571.
[40]. LÜHRS, A. K., GUHR, S., GÜNAY, H. & GEURTSEN, W. 2010. Shear bond strength of self-adhesive resins compared to resin cements with etch and rinse adhesives to enamel and dentin in vitro. Clinical oral investigations, 14, 193-199.
[41]. LYNCH, C., O'SULLIVAN, V. & MCGILLYCUDDY, C. 2006. Pierre fauchard: the'father of modern dentistry'. British Dental Journal, 201, 779-781.
[42]. MANICONE, P. F., ROSSI IOMMETTI, P. & RAFFAELLI, L. 2007. An overview of zirconia ceramics: basic properties and clinical applications. Journal of dentistry, 35, 819-826.
[43]. NICHOLLS, J. 1988. Tensile bond of resin cements to porcelain veneers. The Journal of Prosthetic Dentistry, 60, 443.
[44]. O'BRIEN, W. J. 1997. Dental materials and their selection, Quintessence publishing Chicago.
[45]. OLSSON, K. G., FÜRST, B., ANDERSSON, B. & CARLSSON, G. E. 2003. A long-term retrospective and clinical follow-up study of In-Ceram Alumina FPDs. The International journal of prosthodontics, 16, 150.
[46]. ÖZCAN, M. & VALLITTU, P. K. 2003. Effect of surface conditioning methods on the bond strength of luting cement to ceramics. Dental Materials, 19, 725-731.
[47]. PEUMANS, M., VAN MEERBEEK, B., LAMBRECHTS, P. & VANHERLE, G. 2000. Porcelain veneers: a review of the literature. Journal of Dentistry, 28, 163-178.
[48]. PHARK, J. H., DUARTE, S., KAHN, H., BLATZ, M. B. & SADAN, A. 2009. Influence of contamination and cleaning on bond strength to modified zirconia. Dental Materials, 25, 1541-1550.
[49]. PROOS, K. A., SWAIN, M. V., IRONSIDE, J. & STEVEN, G. P. 2003. Influence of core thickness on a restored crown of a first premolar using finite element analysis. The International journal of prosthodontics, 16, 474.
[50]. RAIGRODSKI, A. J. 2004. Contemporary materials and technologies for all-ceramic fixed partial dentures: a review of the literature. The Journal of Prosthetic Dentistry, 92, 557-562.
[51]. RAIGRODSKI, A. J., CHICHE, G. J., POTIKET, N., HOCHSTEDLER, J., MOHAMED, S. E., BILLIOT, S. & MERCANTE, D. E. 2006. The efficacy of posterior three-unit zirconium-oxide–based ceramic fixed partial dental prostheses: A prospective clinical pilot study. The Journal of prosthetic dentistry, 96, 237-244.
[52]. REICH, S., KAPPE, K., TESCHNER, H. & SCHMITT, J. 2008. Clinical fit of four-unit zirconia posterior fixed dental prostheses. European journal of oral sciences, 116, 579-584.
[53]. RELYX, U. 2012. RelyX Ultimate Technical Data Sheet: 3M ESPE AG ,Seefeld Germany;.
[54]. SAILER, I., PJETURSSON, B. E., ZWAHLEN, M. & HÄMMERLE, C. H. F. 2007. A systematic review of the survival and complication rates of all-ceramic and metal–ceramic reconstructions after an observation period of at least 3 years. Part II: fixed dental prostheses. Clinical oral implants research, 18, 86-96.
[55]. SAILER, I., ZEMBIC, A., JUNG, R. E., SIEGENTHALER, D., HOLDEREGGER, C. & HÄMMERLE, C. H. F. 2009. Randomized controlled clinical trial of customized zirconia and titanium implant abutments for canine and posterior single-tooth implant reconstructions: preliminary results at 1 year of function. Clinical oral implants research, 20, 219-225.
[56]. SANO, H., SHONO, T., TAKATSU, T. & HOSODA, H. 1994. Microporous dentin zone beneath resin-impregnated layer. Operative Dentistry, 19, 59.
[57]. SCARANO, A., PIATTELLI, M., CAPUTI, S., FAVERO, G. A. & PIATTELLI, A. 2004. Bacterial adhesion on commercially pure titanium and zirconium oxide disks: an in vivo human study. Journal of Periodontology, 75, 292-296.
[58]. SCHWARTZ, R. S. & ROBBINS, J. W. 2004. Post placement and restoration of endodontically treated teeth: a literature review. Journal of Endodontics, 30, 289-301.
[59]. SEGHI, R., DENRY, I. & ROSENSTIEL, S. 1995. Relative fracture toughness and hardness of new dental ceramics. The Journal of prosthetic dentistry, 74, 145-150.
[60]. SENNERBY, L., DASMAH, A., LARSSON, B. & IVERHED, M. 2006. Bone Tissue Responses to Surface-Modified Zirconia Implants: A Histomorphometric and Removal Torque Study in the Rabbit. Clinical Implant Dentistry and Related Research, 7, s13-s20.
[61]. SHOPPER, D. P. & SHOPPER, H. P. 2012. A Clinical Update on Temporization and Definitive Restoration Placement.
[62]. SORENSEN, J., KANG, S. & AVERA, S. 1991. Porcelain-composite interface microleakage with various porcelain surface treatments. Dental Materials, 7, 118-123.
[63]. SUH, B. 2010. Bonding to Zirconia: Innovation in Adhesion.]. [Online]. Available: Available at: http://www.dentalaegis.com/special-issues/BISCO/2010/03/bonding-to-zirconia-innovation-in-adhesion [Accessed 22 December 2012 2012].
[64]. SUNDH, A., MOLIN, M. & SJÖGREN, G. 2005. Fracture resistance of yttrium oxide partially-stabilized zirconia all-ceramic bridges after veneering and mechanical fatigue testing. Dental Materials, 21, 476-482.
[65]. SWIFT, B., WALLS, A. & MCCABE, J. 1995. Porcelain veneers: the effects of contaminants and cleaning regimens on the bond strength of porcelain to composite. British Dental Journal, 179, 203-208.
[66]. TSALOUCHOU, E., CATTELL, M. J., KNOWLES, J. C., PITTAYACHAWAN, P. & MCDONALD, A. 2008. Fatigue and fracture properties of yttria partially stabilized zirconia crown systems. Dental Materials, 24, 308-318.
[67]. TSUO, Y., YOSHIDA, K. & ATSUTA, M. 2006. Effects of alumina-blasting and adhesive primers on bonding between resin luting agent and zirconia ceramics. Dental materials journal, 25, 669-674.
[68]. VAN MEERBEEK, B., DE MUNCK, J., YOSHIDA, Y., INOUE, S., VARGAS, M., VIJAY, P., VAN LANDUYT, K., LAMBRECHTS, P. & VANHERLE, G. 2003. Adhesion to enamel and dentin: current status and future challenges. OPERATIVE
[69]. DENTISTRY-UNIVERSITY OF WASHINGTON-, 28, 215-235.

[70]. VÖLKEL, D. T. 2011. Scientific Documentation Ivoclean. Ivoclar Vivadent AG.

[71]. VON STEYERN, P., CARLSON, P. & NILNER, K. 2005. All-ceramic fixed partial dentures designed according to the DC-Zirkon® technique. A 2-year clinical study. Journal of oral rehabilitation, 32**,** 180-187.

[72]. YANG, B., BARLOI, A. & KERN, M. 2010. Influence of air-abrasion on zirconia ceramic bonding using an adhesive composite resin. Dental Materials, 26**,** 44-50.

[73]. YANG, B., LANGE-JANSEN, H., SCHARNBERG, M., WOLFART, S., LUDWIG, K., ADELUNG, R. & KERN, M. 2008. Influence of saliva contamination on zirconia ceramic bonding. Dental Materials, 24**,** 508-513.

[74]. ZEMBIC, A., SAILER, I., JUNG, R. E. & HÄMMERLE, C. H. F. 2009. Randomized-controlled clinical trial of customized zirconia and titanium implant abutments for single-tooth implants in canine and posterior regions: 3-year results. Clinical oral implants research, 20**,** 802-808.