MECHANICAL PROPERTIES OF CERAMIC BASED FUNCTIONALLY GRADED DENTAL CROWNS PRODUCED BY ADDITIVE MANUFACTURING

A Thesis

by

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ABSTRACT

All-ceramic dental crowns present a higher incidence of fracture and chipping when supported by dental implants as opposed to natural teeth. This study attempted to replicate the graded structural design of a natural tooth in an implant-supported all-ceramic crown to improve its fracture resistance by using additive manufacturing (AM). The purpose of this in vitro study was to compare the fracture resistance and ultimate compressive strength of implant-supported milled zirconia (MZr), milled lithium disilicate (MLD), AM zirconia (AMZr) and AM graded structural (AMGS) crowns.

A maxillary cast with a dental implant replacing the right second bicuspid was obtained. Custom abutments and full-contour crowns were digitally designed. The STL files were used to mill 40 zirconia abutments and fabricate 10 crowns for each of the aforementioned 4 groups: MZr, MLD, AMZr and AMGS. The crowns were cemented to implant supported zirconia abutments in accordance with the manufacturer's guidelines and mounted onto polyurethane foam blocks. The fracture resistance and ultimate compressive strength were determined for all the groups by vertical force application using a computer controlled universal testing machine at a crosshead speed of 2mm/min. Kruskal-Wallis test (α=0.05) was used to analyze the data and the mode of failure was determined for all the groups.

Based on the experimental design, MZr revealed the highest mean value for fracture resistance (1330±111 N) and ultimate compressive strength, followed by MLD (1257±169 N), AMZr (1179±247 N) and AMGS (1169±163 N). However statistical analysis showed no significant differences in fracture resistance and ultimate compressive strength between the groups ($p>0.05$). All the samples fractured at the implant-abutment interface.

Within the limitations of this in vitro study, it can be concluded that AM crowns demonstrated similar strengths to milled crowns, when cemented to implant supported zirconia abutments.

DEDICATION

I would like to dedicate this thesis to my parents, Haleema and Dr. Iqbal Methani, for their unconditional love and unwavering support throughout my studies and my life. I hope that one day I will be able to partly pay them back for all they have done for me. Thank you for everything.

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CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a thesis committee consisting of Dr. Amirali Zandinejad (chair) and Dr. Marta Revilla Leon (Co-chair) of the Department of General Dentistry, and Dr. Xiaohua Liu (member) of the Department of Biomedical Sciences.

This work was a part of a continuous research project led by my mentor, Dr. Amirali Zandinejad.

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NOMENCLATURE

PFM	Porcelain Fused to Metal
DEJ	Dentinoenamel Junction
FDP	Fixed Dental Prosthesis
CAD/CAM	Computer Aided Design/Computer Aided Manufacturing
AM	Additive Manufacturing
ATZ	Alumina Toughened Zirconia
STL	Standard Tessellation Language
MZr	Milled Zirconia
MLD	Milled Lithium Disilicate
AMZr	Additively Manufactured Zirconia
AMGS	Additively Manufactured Graded Structure
Co-Cr	Cobalt-Chromium
PMMA	Poly Methyl Methacrylate

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CHAPTER I

INTRODUCTION

The four major classes of biomaterials used in restorative dentistry include ceramics, metals, polymers and composites.(1) As reported by the American College of Prosthodontists, 55% of the US population is missing at least 1 tooth. Given for the aging population, this number is expected to rise over the upcoming years.(2) Loss of dentition has serious implications towards the social and systemic wellbeing of an individual, and the ultimate goal of restorative treatment is comprehensive functional and esthetic rehabilitation.

Owing to their inertness, strength and most importantly, their optical properties and natural tendency to mimic tooth color, ceramics relish widespread approbation as restorative materials in dentistry.(3) Their wide spread clinical applications include crowns, bridges, inlays, onlays and veneers.(4) The initial dental porcelains had a high feldspathic content, which rendered them extremely weak and brittle for dental applications.(5) However, the resolution of dilemma pertaining to the mismatch of coefficient of thermal expansion (CTE) between porcelain and metal led to the development of porcelain fused to metal (PFM) restorations.(6)

Rising demands for esthetic restorations have led to several advances with regards to the mechanical properties and fabrication of dental ceramics.(7, 8) The development of high strength ceramics with significant crystalline content (>50%) led them to be used as core materials, which were layered with feldspathic porcelain for the production of all ceramic restorations.(9) The advent of high strength ceramics has led to a significant diminution in the popularity of PFM restorations over the past decade. As of 2007, 65.3% of all the fixed dental prosthesis (FDP) were PFM, in contrast to 23.9% all-ceramic restorations. Currently, however, 80.2% of all the fixed dental prosthesis produced in the US are all ceramic as opposed to 16.9% PFM.(10) Given for the soaring metal prices and exigence for metal free restorations, the aforementioned number is likely to increase for all ceramic restorations in the future.(2)

Recent advances have led to the introduction of stronger and tougher polycrystalline zirconia ceramics in dentistry.(2) Pure zirconia is monoclinic at room temperature and tetragonal above 1170°C.(11) Upon cooling, pure zirconia undergoes reversible tetragonal to monoclinic (t-m) phase transformation, which is accompanied by a volumetric expansion of approximately-4.5%.(12) The given magnitude of volumetric change is sufficient to produce catastrophic failure in zirconia, which necessitates its stabilization with the oxides of either Calcium, Magnesium or Yttrium. Alloying zirconia with one of the aforementioned oxides controls the stress induced t-m transformation.(13) Zirconia ceramics used for dental applications are most commonly stabilized with 3 mol% Yttria.(11) Retention of the tetragonal structure at room temperature with oxide stabilization efficiently arrests crack propagation in zirconia, leading to high toughness, strength and wear resistance.(14, 15) Amongst the dental ceramics currently available, zirconia demonstrates the highest flexural strength and fracture toughness, and has been referred to as ceramic steel.(16, 17)

Natural-tooth appearance, high mechanical properties, insolubility in water, biocompatibility, reduced bacterial adhesion, low corrosion potential and radiopacity of zirconia make it highly suitable for the fabrication of crowns and bridges.(14, 18, 19) Zirconia can be used as a substrate for producing full contour monolithic or porcelain veneered restorations.(20) Monolithic restorations are mechanically superior and do not encounter complications associated with veneering porcelain, including chipping.(18) However, monolithic zirconia is dull white and extremely opaque. Even after the application of structural dyes, monolithic zirconia restorations deliver esthetically inferior results when compared to porcelain veneered frameworks, which makes them less popular.(21) Furthermore, yttria stabilized zirconia is vulnerable to low temperature aging degradation in the oral environment, which leads to the formation of cubic grains and disruption of the structural integrity of zirconia restorations.(22) Besides exploiting the optimum esthetic potential of all ceramic prosthesis, feldspathic porcelain in veneered restorations acts as a protective covering for the underlying zirconia coping from the oral environment.(18, 23) However, chipping of the veneering porcelain remains to be the most common technical complication associated with zirconia-ceramic restorations.(24)

Esthetic superiority of ceramics has led them to mitigate the frequent utilization of titanium abutments in implant dentistry. Replacing missing teeth in the aesthetic zone seems to be a challenging, but predictable procedure.(25, 26) Zirconia abutments offer an esthetic alternative to metal abutments, particularly for patients presenting with a high smile line and thin gingival margins. In combination with all ceramic crowns, zirconia abutments deliver esthetically optimal results.(27) However, fracture of the veneering material, including porcelain chipping is the most common technical complication associated with implant supported prostheses. Contrarily, tooth-supported fixed restorations have a significantly lower risk of ceramic fracture or chipping (2.9% compared with 8.8% for the implant supported metal ceramic restorations).(28) A possible explanation for this observation might relate to the fact that unlike natural teeth, implants are Osseo-integrated in the bone and lack periodontal ligaments.

Interestingly, contrasting the layered tooth structure, i.e., enamel and dentin, with other multilayer systems, such as porcelain fused to metal restorations or all ceramic restorations, reveals that a natural tooth is invulnerable to chipping or cracking problems.(29) The concept of biomimetics was introduced in dentistry in the nineties, which is based on development of dental biomaterials to serve as substitutes for intraoral tissues.(30) The integration of biomimetic concept in restorative dentistry requires solicitation of materials simulating the properties of natural tissues forming the teeth. Porcelain, for example has been used to replace enamel while composites have been used to replace dentine.(31) Recently, however, it has been demonstrated that enamel and dentin are not confined to a homogeneous structure, but rather exhibit a graded structural design. This unique structural combination of human enamel and dentin is the reason behind the long-term survival of this system.(32, 33) Therefore, contrary to the rationale behind the biomimetic concept, a truly bioinspired restorative design should follow a graded structural design.

In a very recent study by He et al., enamel shows a decreasing elastic modulus and hardness from cusp tips to DEJ. The graded enamel is better adapted to stress distribution in the enamel and along the DEJ.(33) Zhang and co-workers fabricated graded structures by infiltrating glass into zirconia plates, thereby reducing its modulus of elasticity. The results showed a significant increase in the fracture loads of the infiltrated material.(34) Huang and coworkers employed a functionally graded layer between the dental ceramic and cement in a tri-layered model, which resulted in a significant reduction in stress.(35) All these studies reflect on the improvements in the mechanical properties of the models emulating a graded structural design.

The incorporation of digital workflow in dentistry has led to the widespread application of zirconia-based ceramics for the fabrication of FDP.(23) The concept of digital workflow is based on 3 principal components: 1) Data acquisition and digitization of the intraoral hard and soft tissues; 2) Data processing, computer aided design (CAD) and creation of the standard tessellation language (STL) file for prosthesis; 3) Computer aided manufacturing (CAM) of the designed dental prosthesis.(36) CAD/CAM milling or subtractive manufacturing is currently regarded as state-of-the-art technology for fabricating zirconia restorations.(37) Zirconia structures can be fabricated by utilizing pre-sintered or fully sintered blocks as substrates for milling. Given for their ease of machining, most of the commercial systems utilize pre-sintered zirconia blanks for milling restorations.(14) Oversized blanks are used to compensate for shrinkage associated with subsequent sintering.(38) Even though computer numerically controlled (CNC) milling is the most widely used manufacturing technique for machining zirconia in dentistry, there are some inherent drawbacks associate with the technique. Firstly, it involves an extensive amount of raw material wastage, which has been reported to be as much as 90%.(39) Secondly, subjection of the zirconia blocks to cutting instruments results in the introduction of surface microcracks during milling of the restoration.(15) Thirdly, the complexity of a shape that can be milled is a functional limitation of the size of the milling tool.(40)

Additive manufacturing (AM) is developing as an alternate to milling and has been successfully used in manufacturing resin and metal prosthesis(41, 42) with only limited progress in fabrication of zirconia and ceramic restorations.(39, 43, 44) Additive Manufacturing has been defined by the American society of Testing and Materials (ASTM) as “the process of joining materials to make objects from 3-dimensional (3D) model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.”(45) In addition to being able to form complex geometries with nominal wastage, additive manufacturing has the potential to print structures in multiple materials having different mechanical and optical properties.(9) The ASTM has defined the following 7 categories of AM: stereolithography, direct energy deposition, binder jetting, material jetting, material extrusion, powder bed fusion and sheet lamination.(46) Following techniques specifically relate to the AM of ceramics: powder-based fusion, stereolithography, binder jetting, material jetting and material extrusion.(44, 47)

AM technologies can be employed to create dental restorations with complex macro geometries and controlled gradient porosities, which cannot be fabricated using conventional machining techniques.(48-55) This study attempted to replicate the graded structural design of the natural tooth in an all ceramic crown by utilizing AM. The AM graded structural crowns were printed in 2 layers. The outer layer harboring the occlusal surface and emulating enamel was printed in Alumina Toughened Zirconia (ATZ). The inner layer emulating dentine and containing the intaglio surface was printed in zirconia.

The purpose of this study was to two-fold. Firstly, it was aimed at comparing the mechanical properties of printed and milled crowns. Secondly, and more specifically, the study was designed to contrast the mechanical properties of AM graded structural crowns with milled zirconia, lithium disilicate and full contour AM Zirconia crowns. The mechanical properties analyzed in the study were fracture resistance and ultimate compressive strength.

CHAPTER II

MATERIALS AND METHODS

Maxillary and mandibular Kavo study models (Kavo Dental) were selected and scanned for a digital impression and bite registration using the iTero scanner (iTero element, Cadent). Upper right first premolar was removed from the maxillary study model, which was re-scanned using same scanner. STL file was transferred to the milling center for fabrication of milled maxillary and mandibular Cadent models, which were subsequently used for implant placement. Pre and Post scan STL files were exported to the implant placement planning software (coDiagnostix, dental wings, Montreal, QC, Canada). Implant placement was planned on the coDiagnostix software using original scan (Pre-scan) as a reference for the ideal tooth position. Formlabs SLA 3D printer (Form 2, Form labs, Boston USA) was used to fabricate the surgical guide using Dental SG resin (Form labs, Boston, USA) and Straumann H4 RC BL sleeve (Straumann, Basel, Switzerland). Thereafter, the tooth was replaced with Straumann Bone level, regular connection implant using Straumann guided surgery kit and protocol (Straumann, Basel, Switzerland). The created maxillary master model with implant was used for the study (Figure 1).

Figure 1 Maxillary master model with implant replacing right maxillary first premolar.

Articulated maxillary and mandibular cadent models, along with the pre-scan maxillary arch STL file were sent to the Straumann milling center (Arlington, TX) to be used as a reference for designing zirconia abutments and full contour all ceramic crowns. A dental laboratory scanner (DWOS 7 Series scanner; Straumann) was used to digitize the master cast. A dental CAD software (CARES Software; Straumann) was used to design a custom abutment and the STL1 file was obtained which was used to manufacture a zirconia implant abutment (CARES zirconium-dioxide abutment; Straumann) with a chamfer finishing line. The preparation of the abutment had a total convergence angle of 10 to 12 degrees and a circumferential chamfer margins of 1 mm (Figure 2). A total of 40 zirconia abutments were milled.

Figure 2 Milled Zirconia abutment for cemented crown restoration.

The same dental laboratory scanner and CAD software were used to digitize the zirconia custom abutment and design a cemented crown. The thickness of the restorative material ranged from 1.0 mm to 2.0 mm. The designed STL2 file (Figure 3) was used to mill 10 lithium disilicate (IPS e.max CAD crown HT A1; Ivoclar Vivadent, Amherst, USA) and 10 zirconia (3M™ ESPE™, Lava TM, Plus Zirconia W1, 3M, USA) implant supported crowns replacing tooth#4 (Figure 4 A, B).

Fig 3 STL2 File

Figure 4 A: Milled full contour lithium disilicate crown. B: Milled full contour monolithic zirconia crown

A

B

The STL2 file was used for additive manufacturing (CeraMaker 900; 3DCeram Co) of 10 full-contour zirconia (3DMix ZrO2 paste; 3DCeram Co) crowns. Thereafter, the STL2 file was split in thickness into 2 layers (Figure 5). The bottom layer facing the intaglio surface was printed in zirconia and the top layer harboring the occlusal surface was printed in Alumina Toughened

Zirconia (ATZ) (Table 1). A count of 10 was printed for each component layer. Each bottom layer was cemented (Speed Speedcem plus; Ivoclar Vivadent, Amherst, USA) to its corresponding top layer to attain 10 samples of full contour premolar crowns printed in a graded structure. All the AM samples were produced by the manufacturer (3DCeram Co) (Figure 6).

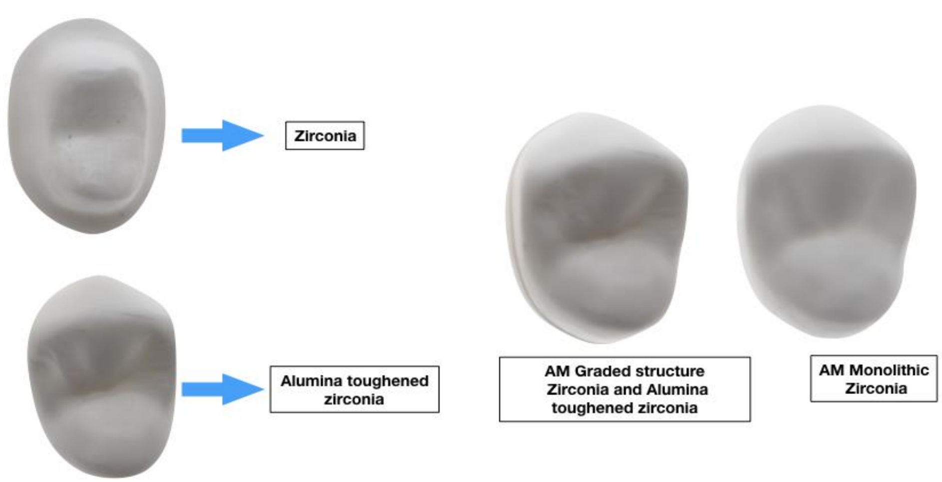
Figure 5 The STL2 file split in top and bottom layers

Table 1 Physical and mechanical properties of additive manufactured zirconia and alumina toughened zirconia material. Information provided by the manufacturer.

Physical and MECHANICAL PROPERTY	**3DMix ZrO_2 3D CERAM**	**3DMix ATZ**
Grade	700	NP*
Particle size (µm)	0.1-0.8	>5,2
Density (g/cm^3)	5.97	>5,2
Vickers Hardness (GPa)	12.6	NP*
Young´s modulus (GPa)	209.4	220
Weibull modulus	NP*	5,8
Shear modulus (GPa)	79.8	NP*
Flexural strength (MPa)	1088	1094
Compressive strength (MPa)	2070	NP*
Coefficient thermal expansion (K^{-1})	12.4	7,50 to 8,33

*NP: Not provided.

Figure 6: AM Zirconia and Graded structural design with Zirconia and alumina toughened zirconia



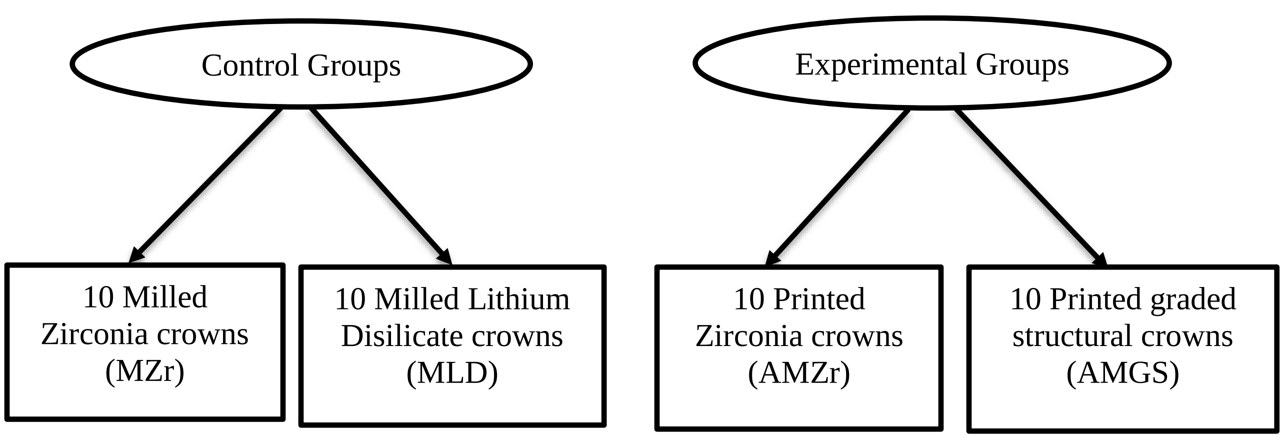
All the zirconia abutments were positioned and torqued to 35 N/cm on an implant analog (Straumann RC; Straumann)(Figure 7) (56) and divided into 4 groups: milled zirconia crowns (MZr); milled lithium disilicate crowns (MLD), additively manufactured full-contour zirconia crowns (AMZr), and additively manufactured crowns reflecting a graded ceramic structure (AMGS)(Table 2)(Figure 8).

Figure 7 All abutments torqued to 35 N/cm as recommended by the manufacturer.

Table 2 Characteristics of milled and stereolithography (SLA) additive manufactured (AM) zirconia specimens.

Group	Material	Fabrication technique	Composition
MZr	Cares Zirconia (Straumann)	Milling 5-axis	NP*
MLD	Lithium disilicate	Milling 5-axis	NP*
AMZr	3DMix ZrO2 (3D Ceram)	Laser Stereolithography (SLA)	Zirconia stabilized with 3% yttria
AMGS	3DMix ATZ (3DCeram)	Laser Stereolithography (SLA)	The ceramic ATZ combines both Alumina (20%) and Zirconia (80%) ceramics in one

Figure 8 Control and Experimental groups



The screw access on the abutment was sealed with Teflon tape, and the abutments in all the groups were treated with Ivoclean as per the manufacturer's instructions (Figure 9). The intaglio surfaces of the crowns in MZr, AMZr and AMGS groups were cleaned similarly (Ivoclean; Ivoclar Vivadent) (Figure 10), while the MLD crowns were treated with hydrofluoric acid (IPS ceramic etching gel, Ivoclar vivadent, Amherst, USA), followed by the application of silane coupling agent (Monobond, Ivoclar vivadent, Amherst, USA). Subsequently, the intaglio surfaces of the crowns were filled with a self-adhesive resin (Speedcem plus;Ivoclar Vivadent, Amherst, USA) (Figure 11) followed by the placement of crowns on the abutments (Figure 12). The crowns were seated using thumb pressure and the excess cement was wiped off using a 2x2 gauze, followed by the application of LED curing light (3M ESPE Elipar S10) for 20 seconds on all the 5 external surfaces of the crown (buccal, lingual, mesial, distal, occlusal) to ensure adequate polymerization.

Figure 9 All zirconia abutments cleaned by Ivoclean

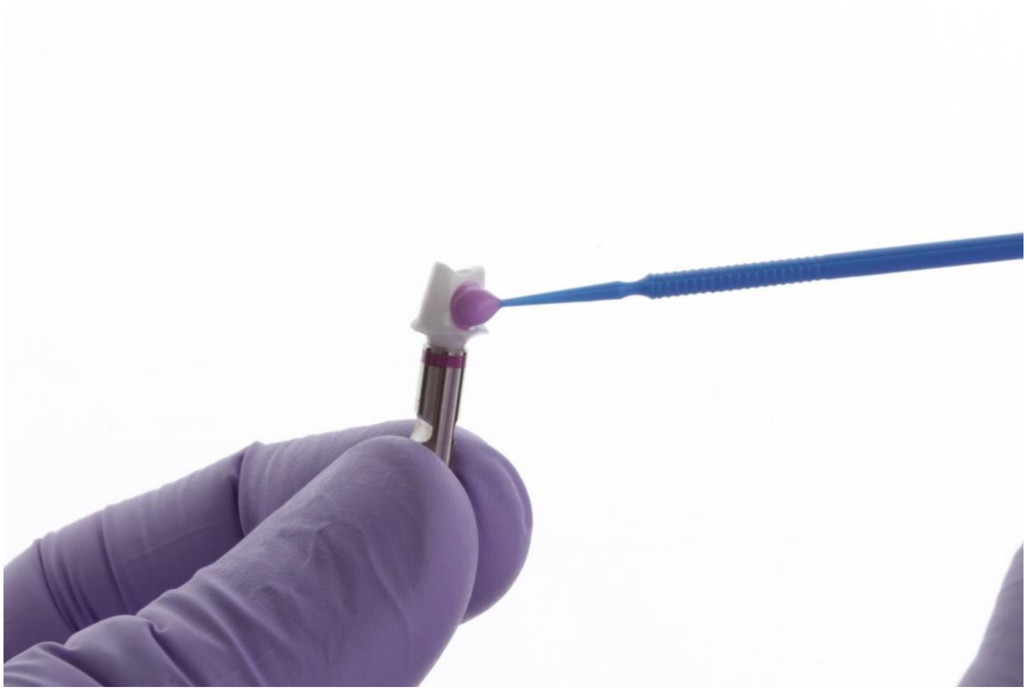


Figure 10 Milled and AM zirconia crowns cleaned with Ivoclean prior to cementation.

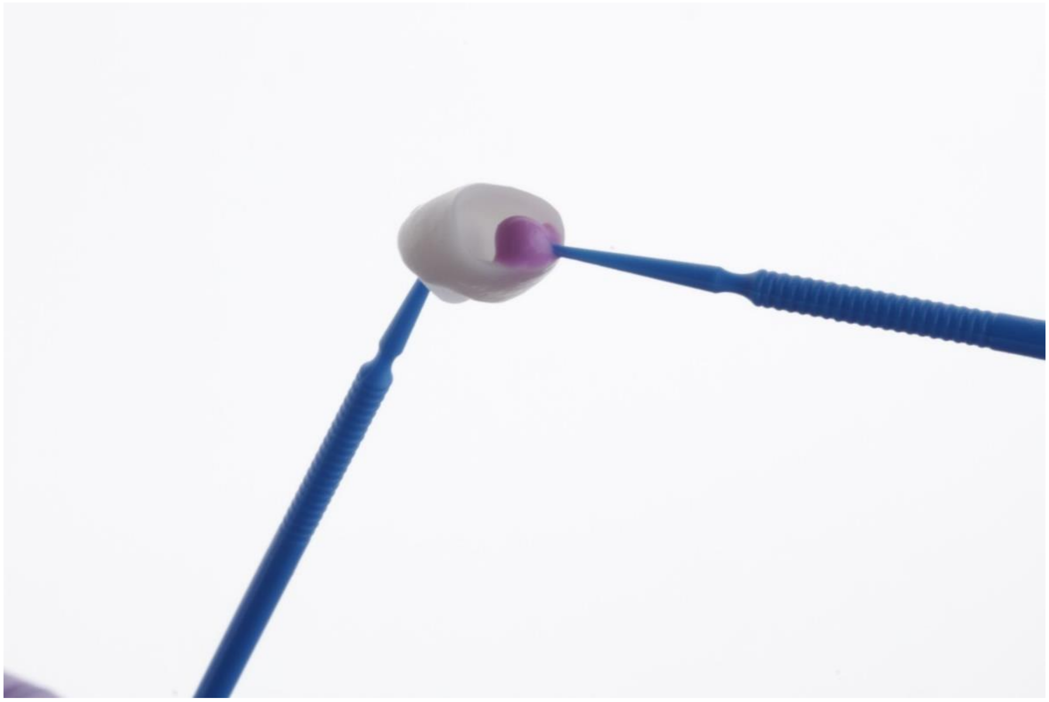


Figure 11 All milled and AM crowns cemented with resin cement following manufacturer's instruction for the material

Figure 12 AM full contour monolithic zirconia cemented on zirconia abutment before mechanical testing.

The implant analog, abutment and crown assemblies were subsequently mounted into solid rigid polyurethane foam blocks (Saw Bones, Vashon WA, USA). A 12 mm deep hole was drilled into the center of cuboid polyurethane blocks for mounting the implant analogs harboring the abutment and cemented crown. Poly methyl methacrylate (PMMA) (Monomer-Polymer & Dajac Laboratories INC., Trevose PA, USA) was used for cementing the analogs within the polyurethane blocks. The cement was allowed to set for 24 hours before subjecting the samples to mechanical loading.

Lower right second Bicuspid (Tooth#29) was prepared on a mandibular Kavo study model (Kavo Dental model, Kavo, NC, USA) to receive a cast Co-Cr stainless steel crown (Argen, San Diego, CA, USA)(Figure 13). The Co-Cr crown was used as an antagonist to load the experimental crowns. It was cemented using PMMA (Monomer-Polymer & Dajac Laboratories INC., Trevose PA, USA) on a Titanium rod, which in turn was cemented into a cylindrical wooden block.

Together this assembly contributed to the loading arm which was mounted onto the loading frame of the Universal Testing Machine (MTS Bionix 370, MTS Systems Corp. Eden Prairie, MN, USA) (Figure 14 A, B).

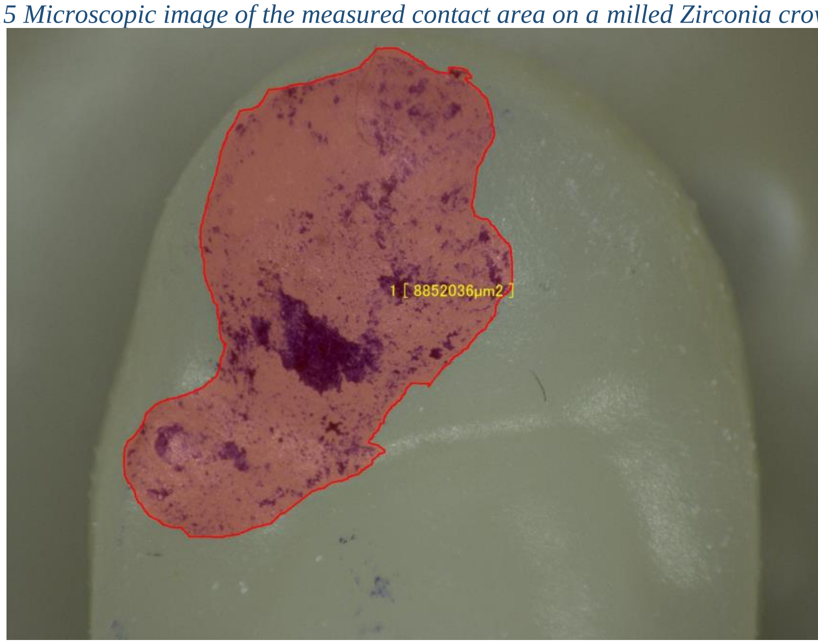
Figure 13 Antagonist Co-Cr stainless steel crown replacing tooth # 29.

Figure 14 A: The milled Co-Cr stainless steel crown for mandibular lower second premolar with proper design and in occlusion with AM zirconia crown. B: The assembly of loading arm which was mounted onto the loading frame of the Universal Testing Machine before final repositioning of the sample.

A  B 

Polyurethane blocks harboring the cemented crown on zirconia abutment were mechanically affixed between two metal arms on the horizontal platform of the Universal Testing Machine (MTS Bionix 370, MTS Systems Corp. Eden Prairie, MN, USA) (Fig. 14B). Prior to mechanical loading, the experimental and the antagonist metal crowns were locked into maximum intercuspation. Thereafter, each specimen was subjected to static vertical loading using the Universal Testing Machine (MTS Bionix 370, MTS Systems Corp. Eden Prairie, MN, USA) at a crosshead speed of 2mm/min and 25kN load cell failure.(56) The machine was stopped on the observation of a reduction in force on the force displacement curve, which marked the mechanical failure of the system. Force-displacement curves were recorded for all the specimens. Before un-mounting, an articulating paper was placed between the Co-Cr antagonist crown and the experimental samples followed by a brief reloading to mark the area of contact (Figure 15). The contact area was calculated on several samples using an epi-illumination stereomicroscope (VHX-2000 series digital microscope; Keyence America) and an average was determined. The contact area was used to convert force-displacement curves into stress-strain curves.

Figure 15 Microscopic image of the measured contact area on a milled Zirconia crown.



Following mechanical loading, all the specimens were analyzed to determine the mode of failure. The stress-strain curves were recorded for individual samples in all the 4 groups. These curves were used to determine the Ultimate Compressive Strength and Fracture resistance of the specimens.

Statistical software (SPPS v22; IBM Corp) was used to calculate the means and standard deviations of the fracture resistance and ultimate compressive strength in all the 4 groups. Data analysis, histograms and box plots revealed that fracture resistances and ultimate compressive strengths were not normally distributed. Therefore, the Kruskal-Wallis test was used to determine the existence of a significant difference, if any, in fracture resistance and ultimate compressive strength between the 4 groups.

CHAPTER III

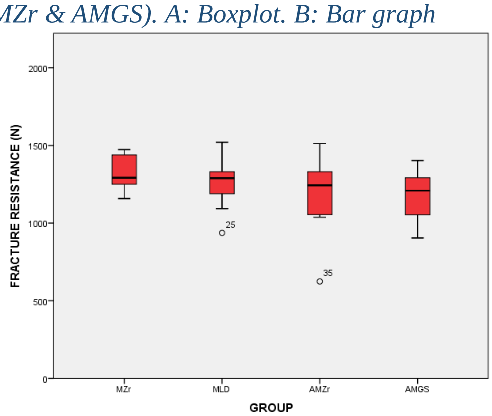
RESULTS

Based on the experimental design, MZr revealed the highest mean value for fracture resistance (1330±111 N), followed by MLD (1257±169 N), AMZr (1179±247 N) and AMGS (1169±163 N) (Table 3) (Fig. 16 A, B).

Table 3 Fracture resistance values, mean and standard deviation for each group.

FRACTURE RESISTANCE (N)				
Sample	MZr	MLD	AMZr	AMGS
1	1250	1093	1355	1143
2	1439	1387	1331	904
3	1400	1331	1038	1193
4	NOT RECORDED	1520	1205	1244
5	1473	1256	1308	1300
6	1292	937	1512	1053
7	1158	1189	624	1225
8	1261	1289	1054	929
9	1444	1308	1077	1292
10	1249	NOT RECORDED	1282	1403
Mean	1330	1257	1179	1169
Standard Deviation	111	169	247	163

Figure 16 Graphical representation of the fracture resistance of control (MZr & MLD) and experimental groups (AMZr & AMGS). A: Boxplot. B: Bar graph



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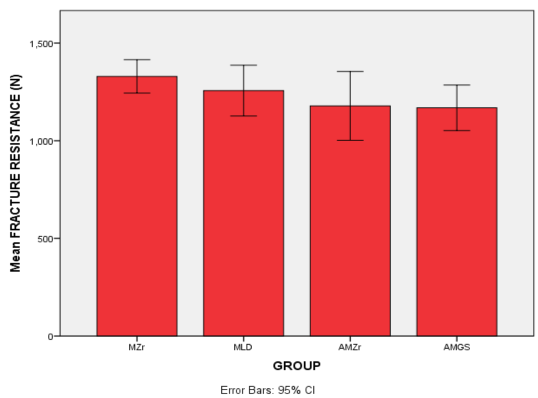


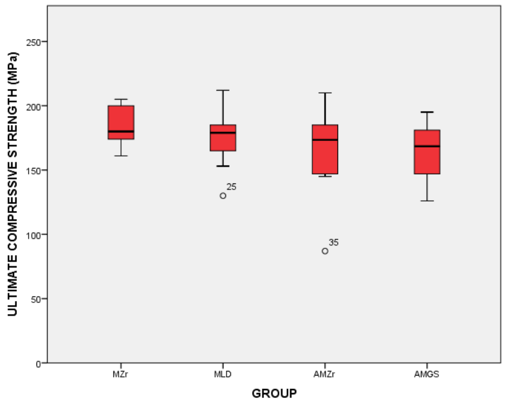
B

Similarly, MZr revealed the highest mean value for ultimate compressive strength (185±15 MPa), followed by MLD (175±24 MPa), AMZr (164±34 MPa) and AMGS (163±23 MPa) (Table 4) (Fig. 17AB).

Table 4 Ultimate compressive strength values, mean and standard deviation for each group.

ULTIMATE COMPRESSIVE STRENGTH (MPa)				
Sample	MZr	MLD	AMZr	AMGS
1	174	153	189	159
2	200	193	185	126
3	195	185	145	166
4	NOT RECORDED	212	168	173
5	205	175	182	181
6	180	130	210	147
7	161	165	87	171
8	176	179	147	129
9	201	182	150	181
10	174	NOT RECORDED	179	195
Mean	185	175	164	163
Standard Deviation	15	24	34	23

Figure 17 Graphical representation of the ultimate compressive strength of control (MZr & MLD) and experimental groups (AMZr & AMGS). A: Boxplot. B: Bar graph



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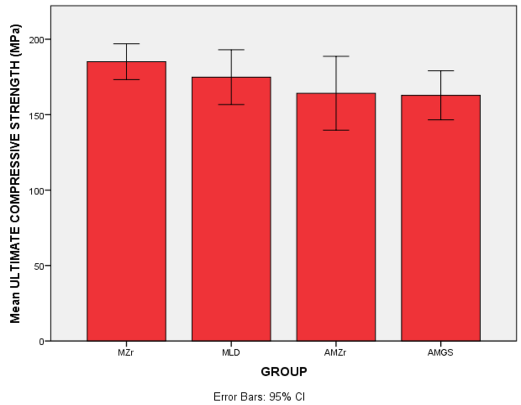
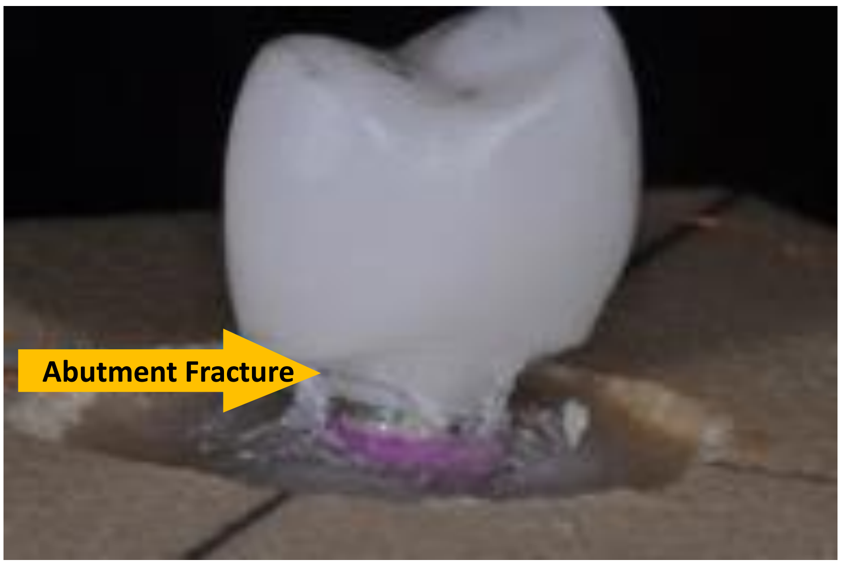


B

The Kruskal-Wallis test indicated that there was no significant difference in fracture resistance ($p>0.05$) and ultimate compressive strength ($p>0.05$) between any of the 4 groups.

Upon their visual examination subsequent to mechanical loading, samples in all the 4 groups revealed fractures at the neck of zirconia abutment with the crowns intact. No significant differences were found in the mode of failure between any of the 4 groups (Figure 18).

Figure 18 The fracture of zirconia abutment which was recorded for all samples in all groups.



CHAPTER IV

DISCUSSION

The graded structural ceramic restorations were expected to demonstrate higher values for fracture resistance and ultimate compressive strengths, owing to their tendency to absorb and dissipate the applied forces. In this study, however, the results revealed no significant differences between the groups.

Zirconia abutments were used in this study as they offer an esthetic alternative to metal abutments, particularly for patients presenting with a high smile line and thin gingival margins. In combination with all ceramic crowns, zirconia abutments deliver esthetically optimal results.(18, 27, 57) However, Van Thompson and coworkers demonstrated that titanium abutments withstood significantly higher loads before fracture than zirconia abutments in an in vitro study that tested fatigue using cyclic loading.(58) Other studies have reported similar concerns regarding zirconia implant abutments.(57) However, clinical performance of these abutments was clinically satisfactory while providing the most desirable esthetic outcomes in some clinical cases.(59-61) In this study, full-contour zirconia abutments were used, which turned out to be a common mode of failure for all the samples consequent to mechanical loading. Using titanium abutments or a combination of titanium base and zirconia could have potentially changed the outcome of this study by switching the weakest point, which was the zirconia abutment.

Fracture of the veneering material, including porcelain chipping is the most common technical complication associated with implant supported prostheses. Contrarily, tooth-supported fixed restorations have a significantly lower risk of ceramic fracture or chipping (2.9% compared with 8.8% for the implant supported metal ceramic restorations). This percentage is even higher for all-ceramic restorations.(28) Collectively, the advantages of all ceramic restorations deem it essential to mitigate the complications associated with their clinical applications, particularly in implant dentistry.

Additive manufacturing enjoys several advantages over subtractive manufacturing, including fabrication of complex geometries and the ability to form structures in multiple materials. All the rapid prototyping techniques are based on a similar premise. It has been demonstrated that by using different fabrication parameters, rapid prototyping can produce both fully sintered (solid), and partially sintered (more porous) structures. It is possible to utilize this process to create dental restorations with complex macro geometries and controlled gradient porosities, which cannot be fabricated using conventional machining technique. AM potentially allows for the fabrication of functionally graded dental restorations emulating the mechanical properties of human enamel and dentin. The goal of this study was to replicate a graded structural design in order to reduce the abrupt mismatches of elasticity and achieve desirable longevity for dental restorations.(51, 53-55). In this study, no significant differences were found in fracture resistance between graded structural crowns and other groups. However, the concept of a truly graded structure relies upon replacing enamel and dentin in a way that it mimics the natural tooth architecture. That means the reduction in hardness and modulus of elasticity should reflect a continuous gradient from outer enamel to dentino-enamel junction and thereafter.(33, 55) Although the concept has been described,(55) the AM technology hasn’t matured enough to be able to imitate such a bio inspired structure. Also, the limitation of materials available for 3D printing of ceramics constrained the selection of appropriate materials for the duplication of mechanical properties of enamel and dentin in this study.(33) However, these problems are expected to resolve in the near future, following advances in the AM technology.

There have been very limited studies on 3D printing of all ceramic, particularly zirconia dental restorations and this study seems to be the first one to investigate the fracture resistance of fully printed ceramic crowns supported by implants.(62, 63) Therefore, it was not possible to compare and validate the experimental findings.

CHAPTER V

CONCLUSION

Based on the experimental design and the limitations of the present study, no significant differences were encountered in fracture resistance and ultimate compressive strength between the experimental and control groups. However, it can be concluded that AM all ceramic crowns cemented on to Zirconia abutments had a comparable fracture resistance to milled restorations in this invitro study. Based on the results obtained, AM appears to be a promising technology for all ceramic restorations with great potential for improvement in the near future.

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