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FRACTURE RESISTANCE OF OCCLUSAL RESTS IN CAD/CAM ALL-CERAMIC SURVEY CROWNS

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ABSTRACT

FRACTURE RESISTANCE OF OCCLUSAL RESTS IN CAD/CAM ALL-CERAMIC SURVEY CROWNS

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Metal-ceramic survey crowns have been the gold standard for integrating fixed and removable prosthodontics due to their advantageous mechanical properties and esthetics. Improvements in CAD/CAM technology and the enhanced physical properties of monolithic ceramics make all-ceramic restoratives a viable alternative to metal-ceramic survey crowns in supporting clasp-type removable partial dentures (RPD). The objective of this study was to compare failure loads at the occlusal rests of zirconia and lithium disilicate survey crowns before and after one year simulated aging. Virtual premolar survey crowns were designed with CAD software (Exocad) incorporating the manufacturer’s recommended minimum thickness requirements for zirconia (IPS e.max ZirCAD LT) and lithium disilicate (IPS e.max CAD). The survey crown preparation designs had adequate reduction for an occlusal RPD rest. Monolithic zirconia (n=16) and lithium disilicate (n=16) survey crowns were milled using a 5-axis milling machine. Individual dies were directly fabricated by injecting composite resin (3M Filtek Universal Restorative) into the lubricated crown intaglio. The crowns were then cemented to the dies using a resin cement (Ivoclar Multilink Automix) following the manufacturer’s instructions. Peak failure loads at the rest seat were recorded for eight samples in each group using a static load testing machine (crosshead speed 1.5mm/min). One year of wear was simulated for remaining crowns ($n = 8$) using a chewing simulator. A two-way ANOVA indicated that there is a statistically significant difference between the means of two materials ($p < 0.001$), however no significant relationships were found in aging processes ($p = 0.055$) nor interaction between material and aging ($p = 0.055$). Occlusal rests of both zirconia and lithium disilicate crowns demonstrated higher mean peak failure loads (771.65 ± 158.57 N and 1040.07 ± 280.45 N, respectively) than documented average bite forces (708.8 ± 313.9 N) for human populations. Therefore, both materials should be considered as viable options to be sued as survey crowns supporting clasp-type RPDs.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATONS

CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
RPD	Removable Partial Denture
TZP	Tetragonal Zirconia Polycrystal

CHAPTER 1: Introduction

Survey crowns have long been the key for integrating fixed and removable prosthodontics. They can be defined as a single crown used to support clasp-type removable partial dentures (RPDs). Survey crowns provide pre-planned guide surfaces, rest seats, retentive areas, and axial contours to support and retain clasp-type RPDs [1]. Traditionally, metal-ceramic restorations were considered the gold-standard for survey crowns due to their mechanical properties and acceptable esthetics.

When preparing a tooth for a survey crown, the normal demands of fixed prosthodontics as well as those of the planned removable prosthesis must be met [1]. The preparations must accommodate rest seats of at least 1mm thickness as well as adequate thickness of selected survey crown material [2]. In general, when fabricating a metal-ceramic survey crown, the occlusal rest seats are fabricated without veneering porcelain. This allows for more conservative tooth preparation as the metal alone requires less thickness than the metal and ceramic together.

With the advancement of CAD/CAM technology, all-ceramic restorative systems have gained popularity. These systems offer improved esthetics and ease of fabrication over their metal-ceramic forbearers. Lithium disilicate and zirconia crowns have been reported as alternatives to metal-ceramic survey crowns. Some earlier studies used polylithic ceramic restorations as survey crowns, veneering aluminum oxide or zirconia substructures with esthetic porcelains. Kancyper *et al*. used a dual analog-digital workflow, waxing up a survey crown with porcelain cutback on a model poured from a physical impression, scanning the model and the wax-up [3]. They sent the digital information to the Procera company to fabricate an aluminum oxide coping. Once returned, veneering porcelain was added in the traditional manner. Kancyper *et al.* simply elucidated a method for fabricating an all-ceramic survey crown using CAD/CAM technology available at the time, without describing the delivery of the milled crown. More scientific publications have followed as CAD/CAM technology has improved. Carracho and Razzoog produced a similar article outlining a method of fabricating an all-ceramic survey crown with zirconia copings [4]. They also used a dual analog-digital approach, scanning a physical wax-up of the survey crown with porcelain cutback. This study does, however incorporate images of the surveyed restorations delivered intraorally and with the RPD seated, unlike the article by Kancyper, et al.

More recent studies have used the power of CAD/CAM technology to fabricate all-ceramic survey crowns to fit existing RPDs. A study by Yoon and Chang published a case study demonstrating the use of CAD/CAM to replicate a patient's existing crown in fabricating a new survey crown in lithium disilicate [5]. Paek *et al.* also used CAD/CAM technology to fabricate a ceramic survey crown to fit an existing RPD [6]. The authors used zirconia instead of lithium disilicate. They fabricated a direct resin pattern in the study subject's mouth registering the guide planes and cingulum rest of the existing RPD. This resin pattern was duplicated digitally and a zirconia survey crown was milled. A common theme from these case studies was a minimal sample size (n = 1) with no follow up after the survey crown was delivered. Therefore, there is little to no evidence of survival rates of these restorations once in function with the RPD.

When testing the "strength" of dental materials, the types of stress the materials will undergo and the system as a whole should be carefully considered. Traditionally, *in-vitro* studies of ceramic crowns test the materials in stress states and failure modes do not simulate what is seen clinically. Fracture mechanisms of ceramic crowns are determined by the combined effect of the tooth structure, crown restoration, and the luting agent [7]. Kelly *et al.* developed test methods to evaluate ceramic crowns and validly simulated many aspects of clinical failure [8]. Finite element analysis of clinically failed crowns revealed that failure began at the intaglio of ceramic crowns. The tension that led to this mode of failure was caused by the bending of the fully supported ceramic against the less stiff substrate. This tensile stress was affected by three factors: 1) the ratio of elastic modulus of the ceramic to the substrate; 2) the thickness of the ceramic; and 3) the diameter of the loaded contact area. Kelly *et al.* emphasized the importance of cyclic load tests versus monotonic load to failure tests. Dental ceramics accumulated damage during low-load cyclic blunt indentation that was not seen during single-load failure testing [9].

Fracture strength of monolithic ceramic restorations has been related to the thickness of the material, and some materials require more thickness than others to achieve the same strength. Cyclic loading of zirconia prostheses revealed that a thickness of just 0.7mm or greater had the highest fracture resistance and lowest stress values under vertical and oblique loading [10]. In fact, Kelly *et al*. found that bonded ceramic was not sensitive to thickness variations from 0.5mm to 2.5mm and may sustain less stress at 0.5mm than at 1.5mm or 2.5mm [9]. This was in part due to the compressive stresses directly below the indenter in a laboratory test of ceramic crowns, countering tensile stresses at the ceramic-cement interface, which may or may not be true clinically.

The main purpose of this study was to determine if zirconia and lithium disilicate all-ceramic dental materials are suitable for use as survey crowns supporting clasp-type RPDs. Our hypothesis was (1) the zirconia rest seats would demonstrate higher peak failure loads than lithium disilicate, and (2) a simulated aging process will lead to lower peak failure loads

CHAPTER 2: Materials and methods

STUDY DESIGN

A total of sixteen survey crowns were split into two groups, eight zirconia and eight lithium disilicate. Those groups were further divided with four from each group underwent single load failure testing and the other four from each group underwent peak failure load testing after application of a cyclic load simulating one year of chewing.

SAMPLE PREPARATION

Two typodont mandibular premolars were prepared for survey crowns incorporating manufacturer's recommended minimum thickness requirements for zirconia (IPS e.max ZirCAD LT) and lithium disilicate (IPS e.max CAD) with traditional recommended requirements for RPD rest thickness. For lithium disilicate, this was overall 1.5mm occlusal reduction with a total 3.0mm reduction in the area of the rest seat. For zirconia, this was overall 0.6mm occlusal reduction with a total 2.1mm reduction in the area of the rest seat. Once prepared, the typodont teeth were scanned using a lab scanner (DOF Freedom HD), and crowns were designed in CAD software (exocad DentalCAD). Crowns were milled in wax (Imill Wax Beige 98x16mm, Imagine Milling; imes-icore COREiTEC 150i). Occlusal rests were manually prepared in wax crowns, ensuring minimum material thickness for lithium disilicate and zirconia respectively. The wax crowns were then copy-milled in lithium disilicate (IPS emax CAD; Dentsply Sirona inLab MCXL) and zirconia (IPS ZirCAD LT; imes-icore COREiTEC 150i). Sixteen lithium disilicate crowns and sixteen zirconia crowns were milled.

Once all crowns were fabricated, composite resin dies were fabricated. The intaglio of each crown was lubricated with a thin layer of petroleum jelly, and composite resin was injected to fill crown and light cured for 40 seconds (3M Filtek Universal; Acteon Mini LED 2 Autofocus). A clear, resin template was used to ensure all dies were fabricated with the same dimensions to predictably fit specimen holders for fatigue simulation and failure load testing (**Figure 1**).

Crowns were bonded to dies according to manufacturer's instructions. The intaglio surfaces of lithium disilicate crowns were pre-treated by etching with 5%HF acid for 20 seconds (Ivoclar Ceramic Etching Gel). The resin dies were pre-treated with MultiLink primer A&B and the crowns were bonded with MultiLink Automix resin cement (Ivoclar Vivadent). The cement was light cured for 40 seconds (Acteon Mini LED 2 Autofocus), and residual cement was removed. The intaglio surfaces of zirconia crowns were pre-treated with air particle abrasion with aluminum oxide (100µm, 1 bar). The zirconia crowns were then bonded to the resin dies in the same manner as lithium disilicate using MultiLink Automix resin cement.

Sample Testing

The peak failure load of eight lithium disilicate and eight zirconia crowns was tested using the MTS universal testing machine. The crowns were loaded specifically at the location of the occlusal rest seat. A 5000N load cell was applied to each specimen at a crosshead speed of 1.5mm/min. Peak failure load was recorded upon visual identification of a crack.

One year of fatigue was simulated on eight lithium disilicate and eight zirconia crowns (SD Mechatronik Chewing Simulator). The load was applied specifically to the occlusal rest seat of each crown with a custom milled titanium load applicator. The specimens were vertically loaded with 70N for 1,200,000 cycles.

After fatiguing, peak failure load of specimens was tested using MTS with the same loading parameters as the non-fatigued crowns. Again, peak failure load was recorded upon visual identification of a crack.

A two-way ANOVA test was completed to determine if there are any interactions between the material and aging, ultimately testing for the differences in means with the independent factor effects.

CHAPTER 3: Results

The mean ±standard deviation of peak failure loads measured at time zero was 771.65 ± 158.57 N for the zirconia group and 1040.07 ± 280.45 N for the lithium disilicate group. The mean ±standard deviation of peak failure loads measured after a year of simulated fatigue was 771.73N ± 165.16N for the zirconia group and 1353.06 ± 256.27 N for the lithium disilicate group (**Figure 2**).

A two-way ANOVA test (**Table 1**) indicated there is a statistically significant difference between the zirconia and lithium disilicate ($p = 0.0000088$), however a minimal interaction exists between the variables of material and aging ($p = 0.05583$). One year simulated aging processes led to a minimal (not statistically significant) difference ($p = 0.0557$).

CHAPTER 4: Discussion

Although the lithium disilicate occlusal rests were able to withstand greater forces before failure, both survey crown materials demonstrated average peak failure loads before and after fatiguing that were higher than the maximum bite forces of patients with distal extension RPDs according to Aras [11]. In that study, patients with Kennedy Class 1 RPDs exhibited an average maximum occlusal force of 708.8 ± 313.9 N. Although the average peak failure load for the zirconia rest seats in our study was higher than the average maximum occlusal force recorded in Aras' study, some zirconia samples fractured at lower failure loads during our testing. Therefore, there may be some scenarios where the zirconia may not be able to withstand a maximum occlusal force *in-vivo*.

Interestingly, the fatigued lithium disilicate survey crowns fractured at a higher average peak load than those that didn't undergo chewing simulation. All lithium disilicate samples that were tested without aging experienced a crack along the marginal ridge. The fatigued samples of lithium disilicate with the highest peak failures loads demonstrated catastrophic failure. The crowns as well as the resin dies fractured beyond repair. These crowns with the highest peak failure loads were also the last of the crowns to be tested. Throughout testing it was observed that the titanium load applicator began to wear, creating a slightly larger diameter that engaged the rests. It is possible that the load applicator's larger diameter more broadly distributed the load, allowing the crowns to withstand a greater force.

In order to simulate a clinically relevant scenario, each survey crown material was prepped to the minimum recommended thickness according to the manufacturer. The zirconia occlusal rests were 40% the thickness of the lithium disilicate. Ivoclar Vivadent now recommends their emax lithium disilicate can be as thin as 1.0mm. The peak failure loads of the lithium disilicate occlusal rests may have been different than those recorded if tested at 1.0mm thick instead of 1.5mm.

In this study, 3Y-TZP zirconia was used. This is generally considered to be the strongest and least esthetic zirconia available. When increasing the yttria concentration, the zirconia becomes more translucent, making it more esthetic and less strong. Patients and clinicians are demanding more natural esthetic outcomes with all-ceramic crowns leading to the increased use of zirconia with higher concentrations of yttria. This study should be repeated using both 4Y-TZP and 5Y-TZP to compare the effect on the peak failure load of increasing yttria concentrations.

The peak failure loads of the occlusal rests tested in this study were lower than most recorded failure loads for zirconia and lithium disilicate[12]. This could, in part, be due to the off-axis load applied directly to the occlusal rest seat instead of directly over the center of the occlusal table. Lan evaluated the stresses in zirconia implant crowns loaded vertically and obliquely. The crowns loaded obliquely exhibited greater von Mises stress values, indicating greater stress on the material when experiencing off-axis loading[10]. Presumably in a clinical scenario, with a properly contoured RPD rest, the patient's occlusal forces would be directed toward the long axis of the tooth. This would somewhat relieve the greater forces exhibited with off-axis loading, perhaps allowing the all ceramic survey crowns to withstand even greater loads.

During chewing simulation, it was observed that the titanium load applicators experienced wear against both lithium disilicate and zirconia survey crowns. It is known that titanium wears against zirconia[13]. Most RPD frameworks are made with cobalt-chromium dental alloys. Compared to other dental alloys, cobalt-chromium exhibits the least amount of wear against polished zirconia surfaces *in-vitro*. It does however cause changes to the zirconia when observed with scanning electron microscope[13]. Cha's work found that, after wear testing against cobalt-chromium, the zirconia exhibited a rough surface[14]. It is unclear how these changes may affect the strength of the zirconia. Although the zirconia survey crowns in this study were fatigued using conventional techniques, this study may be benefited from a verification experiment using a cobalt-chromium load applicator to evaluate the effect of the surface changes on the strength of the zirconia.

CHAPTER 5: Conclusions

Within the limitations of this study, the lithium disilicate crowns performed better than zirconia crowns under our laboratory parameters. However, occlusal rests of both zirconia and lithium disilicate crowns demonstrated higher mean peak failure loads than documented average bite forces for human populations. Therefore, zirconia and lithium disilicate should both be considered viable options as survey crowns supporting clasp-type RPDs.

Table 1. Two-way ANOVA results for materials and aging.

Source	DF	Sum of squares	Mean square	F	P
Material	1	1444143.327	1444143.327	29.3608	**0.000008843**
Aging	1	196028.4674	196028.4674	3.9854	**0.0557**
Interaction	1	195803.1202	195803.1202	3.9809	**0.05583**
Error	28	1377209.895	49186.0677		
Total	31	3213184.81	103651.1229		

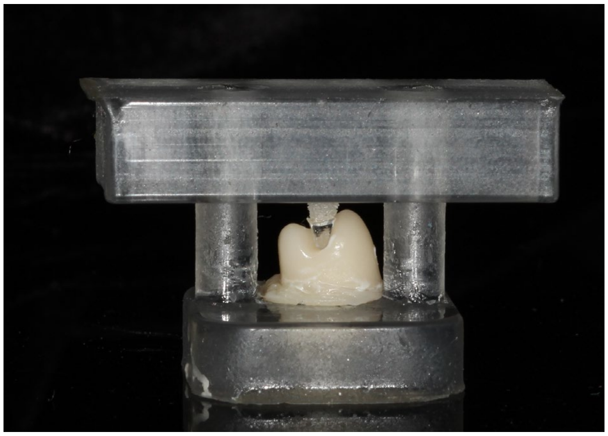

Figure 1. Clear matrix for die fabrication. A clear plastic matrix was used to fabricate dies with uniform size and shape. This allowed each sample to be predictably placed in the universal testing machine and the chewing simulator.

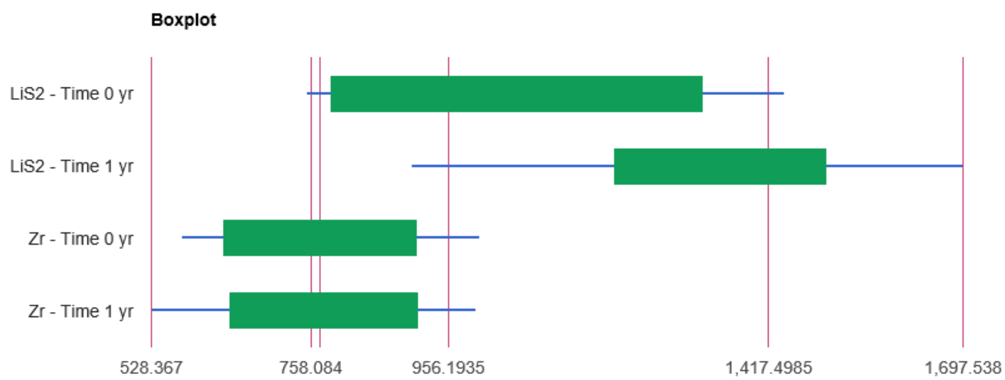

Figure 2. Results of static compressive load to crown fracture in Newtons (N). Boxplot comparing peak failure loads of zirconia (Zr) and lithium disilicate (LiS2) rests without fatiguing (Time 0 yr) and after one year simulated wear (Time 1 yr).

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