DELAYED LINEAR EXPANSION OF TWO ULTRA-LOW EXPANSION DENTAL STONES

A Thesis

by

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MASTER OF SCIENCE

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ABSTRACT

The purpose of this study was to measure the linear setting expansion of two ultra-low expansion dental stones used in definitive cast/ prosthesis fabrication which claim to have very low to no setting expansion. Five specimens of each material, Zero Stone and Whip Mix Experimental, were tested using a custom expansion device as were five control samples of Silky Rock. The setting expansion of each specimen was recorded continuously for 96 hours. Data were analyzed using qualitative statistics. The results showed that there was no statistically significant difference between either stone with regards to amount of setting expansion however the test stones did significantly vary from the control. There was also no statistically significant difference in the setting expansion of the two test materials after the two hour time interval.

DEDICATION

To The 2013 ACP

Educator of the Year

Thank You For Everything You Have Done Dr. Nagy

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank the many people who played a role in forming a truly amazing educational experience at Baylor. It started as chance encounter with Dr. Woody at the ACP in Dallas in 2003, when Dallas and Baylor were not on my intended path. Yet, it was Dr. Woody's encouraging words that brought me back to Dallas for an interview and residency. Our good fortune ushered the arrival of Dr. Nagy to Baylor and to Chad, Champ, Clarisse and me; the unique opportunity to study under the guidance of two superb prosthodontic directors. Dr. Nagy's care, knowledge, persistence, guidance and encouragement have finally taken this endeavor to its conclusion. I must also thank Dr. Seale and Dr. McWhorter of the Pediatric Dentistry Department who allowed me to settle an agonizing decision over which specialty to select and gave me a gift for which I am truly grateful, the chance to pursue a second passion. I especially cherish the opportunity to utilize both disciplines to care for my special needs patients. I will always be profoundly thankful for the amazing network of support that Baylor offered. I wish to also thank Elias Kontogiorgos for his assistance in evaluation of the data for this study.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

TABLE Page

CHAPTER I

INTRODUCTION

Gypsum products are used in many applications in dentistry, both chair-side and within the laboratory, to enable diagnosis, treatment planning, restoration and maintenance/repair. They are used to duplicate hard and soft tissues of the mouth, must be durable, resilient and resist dimensional change over time in order to provide an accurate duplication for fabrication of a successful, well fitting prosthesis (1).

Most gypsum products are obtained from natural gypsum rock which is the dihydrate from of calcium sulfate (2). Plaster and dental stones are made by calcinating calcium sulfate dihydrate. Calcination is the process by which gypsum is exposed to some form of high heat to partially dehydrate the gypsum. Depending on the method of calcination, different forms of the raw gypsum product are derived leading to the variations that we see in designation Types of dental gypsums. Dental plasters are produced when gypsum minerals are heated to about 110° to 120° C in an open kettle. This results in a hemihydrate that is irregular in shape and pourous and is referred to as β-calcium sulfate hemihydrate. This is the basis for Type I and Type II dental gypsums, Impression plaster and Model plaster. When dehydrated in the presence of pressure and water vapor at about 125°C a product which is denser and more uniform in shape results which is referred to as α-calcium sulfate hemihydrate or hydrocal. This is the basis for Type III dental gypsum or dental stone. When gypsum is boiled in 30% CaCl solution, the densest of these gypsums particles is produced, referred to as densite. This material forms the basis for Type IV and Type V dental gypsums. The addition of modifiers affect the final handling characteristics and properties that determine whether a dental gypsum is a Type IV, high-strength/low expansion dental stone, or a Type V high-strength/ high expansion dental stone (2-9).

During the course of setting, gypsum products exhibit dimensional changes. After the mixing of hemihydrate and water, crystals of dihydrate begin to form and grow in size and number. As they impinge on one another these crystals do not deform but rather push each other outward into a larger space volume, thereby causing an expansion (10). Linear setting expansion during the change from hemihydrate to dihydrate is affected by many variables and can greatly influence the accuracy of the cast or die with direct effects on casting fit and occlusion . Therefore the setting environment can impact the amount of expansion and contraction seen in the final product (11). Gypsum products used in dentistry are classified by ADA specification 25 into 5 types (1) Type 1: impression plaster, Type II: model plaster, Type III: stone, Type IV high strength low expansion stone and Type V: high strength high expansion stone.

Implant-supported fixed prostheses should have a passive fit on the abutments when placed into the mouth (12). Failure to achieve this passivity of fit has been indicated as an etiological factor in the development of complications.

While not definitively shown, prosthetic misfit has been implicated in implant complications namely, prosthetic screw loosening, fatigue fracture of implant components, marginal bone loss and failure of osseointegration (13-16). In a 1996 study, Jemt followed one group prospectively for one year and another group retrospectively for 4 years. They measured the amount of bone loss around implants in each group and also evaluated prosthesis misfit in each group. Jemt concluded that no prosthesis evaluated exhibited true passivity of fit. He also concluded that there was no significant correlation between the amount of marginal bone loss around implants and restorations of varying degrees of misfit in either group (17).

However, it has also been shown that implant restorations with radiographically detectable misfit , showed significant marginal bone loss around the implant collar when evaluated at 3 years as compared to implant restorations with no detectable misfit. This study evaluated clinical misfit of single unit cement retained implant crowns with a small sample size (18).

Two other studies attempted to quantify the amount of misfit and correlate this misfit to bony changes. Carr et al in 1996 measured the bone response around implants placed in the mandible of baboons that supported prostheses exhibiting two levels of fit and not loaded occlusally. Screw-retained prostheses that exhibited a mean linear distortion of 38 microns and 345 microns made up two study groups, the fit and misfit groups respectively. However, this study only evaluated the dimension of misfit, and not the stress introduced as a result of the misfit (19).

A second study by Jemt et al in 2000, studied splinted, screw-retained prostheses placed on 3 implants in the tibias of rabbits. The control had what was described as good fit to all three implants. The test group had prostheses connected with a vertical misfit of about 1 mm to the central implant. The intermediate set screws were tightened with a torque ranging from 15 Ncm to 26 Ncm in the different test frameworks, thus introducing different stress levels to the implant/bony complex. Interestingly, the misfit stress levels introduced by both Carr and Jemt did not have a negative effect on osseointegration of the implants; on the contrary the stress induced by the misfit significantly promoted bone remodeling at the thread tip of the implants when compared to the controls. These conclusions suggest that there is a clinical tolerance and perhaps a benefit to misfit (20).

Ultimately it is understood that bone reacts to strain. Depending on the properties of the tissue, a given force may affect different bones or bone tissues differently, but mechanically loaded bones adapt to the load. Isidor in 2006 postulated that if the strain in the bone surrounding an oral implant is in what is considered the mild overload range (1500–3000 microstrain), apposition of bone seems to be the biological response. On the other hand, strain in the bone beyond this range will at some point result in fatigue fracture and bone resorption (21).

There have been attempts made to quantify acceptable and unacceptable misfit. Branemark in 1983 (22) was the first person to define passivity of fit as up to 10um of maximum misfit which could allow bone to respond and remodel as a result of occlusal loads. In other literature, it has been suggested that castings with discrepancies of greater that 30 um or more than 10% of the circumference of the abutment interface would be unacceptable. However, these parameters or lack of adherence to such guidelines have not been clearly and directly linked to marginal bone loss or failure of osseointegration.

In a study by Kallus in 1994, 50 patients of a group of 236 patients that were treated with implant-supported prostheses were evaluated. These patients had not had their prostheses removed in five years and were evaluated based on a number of parameters including framework fit, abutment screw tightness, plaque accumulation and overall gold screw tightness upon prosthesis removal. The conclusions of the study were interesting. No systematic difference in screw tightness was noted based on implant location in the mouth. It was noted however that there was a clinically significant correlation between prosthesis/abutment discrepancy and loose gold screws. The authors do qualify that finding with the assertion that some well fitting prostheses presented with loose gold screws, while other prostheses that were ill-fitting returned with no gold screw loosening. Again, these findings do not make a correlation between prosthesis misfit and marginal bone loss or disintegration of this bone-implant interface. It does suggest however that misfit can play a role in component fatigue and failure. (23)

The literature, while divided, does indicate the prosthesis misfit can have a deleterious on components and supporting bone. Given that the quality of a restoration is greatly affected by the materials used in the fabrication of a die or a definitive cast, stone selection becomes critical. When considering an implant prosthesis, namely a multi-unit prosthesis, a stone that that exhibits little to no expansion, that is stable and high-strength, is ideal. Some authors have sought to examine dental stones to determine whether these characteristics were present and to what degree they demonstrated these ideal properties.

In 2001, Wise compared the fit of implant supported prostheses made between two implant abutments fabricated on master casts made from dental stone, with a max setting expansion of 0.08% and an ultra-low-expansion dental plaster with a maximum setting expansion of 0.02%. The results of this study showed that true passivity of fit was only achieved when master casts were fabricated using the ultra-low expansion plaster with an inter-abutment distance of 35mm. Die stone master casts with a 50mm inter-abutment distance had a mean vertical discrepancy (mvs) of 80 um. Plaster casts of the same dimension had a mean seating discrepancy of 42.8 um. Interestingly, at 35mm die stone had a higher mvs at 84.3 um while plaster casts showed a 0 um mvs. These findings attempt to illustrate the effects that varying material properties in conjunction with potential clinical variations on the accuracy of fit of dental prostheses (12).

Another study by Heshmati et al in 2002 (11) studied the delayed linear expansion of improved dental stone. This study evaluated the linear setting expansion of 6 ADA type IV and V dental stones up to 120 hours. This study found that all dental stones tested exhibited continued expansion while setting under clinical conditions; the expansion of all dental stones tested was completed at 96 hours. The findings offered clinical significance in that the ADA specification 25 indicates that final setting expansion measurements be made at 2 hours yet all dental stone tested continued to expand up to 96 hours. Based on this information and the degree to which this expansion varies, a low expansion die stone would offer the least expansion overall and would likely give the least amount of clinical prosthetic discrepancy.

In 2004, Kenyon et al studied the dimensional accuracy of 7 die materials. Using a master die, replicas were produced using conventional Type IV dental stone, Type V dental stone, epoxy resin, polyurethane resin, copper plating and bis-acryl composite resin. The findings of this study were somewhat logical; Type IV resin impregnated stones and copper plated dies were the most dimensionally accurate, Type IV and Type V dental stones exhibited setting expansions within the range for such materials, Epoxy resins exhibited shrinkage comparable to the rate of dental stone expansions , polyurethane dies displayed a combination of linear expansion and shrinkage, bis-acryl composite resin dies had excessive shrinkage and gypsum based products were more convenient to use. These findings reinforced the recommendation that Type IV dental stones would be ideal for use in dentistry for individual die as well as multiunit implant restorations (24).

Delayed setting and hygroscopic linear expansion were evaluated for three gypsum products in another study in 2009. The authors examined the linear expansion of the materials up to 120 hours, with half of the specimens wet with 25 ml of water for the duration of the data collection. The authors noted that, as in the previous study by Heshmati et al, expansion of all products was completed at 96 hours although Heshmati et al tested Type IV and Type V while this study tested

Type II and Type III dental stones. This study ultimately concluded that linear and hygroscopic expansion are influenced more by the material used and by time than by the addition of water. It is important to note however that this study tested hygroscopic expansion after initial setting reinforcing the notion that hygroscopic expansion only affects setting expansion prior to initial set (1).

In order to minimize prosthesis misfit, a stone with the lowest setting expansion possible would ideally need to be utilized for definitive cast preparation and prosthesis fabrication (25). One must also consider the impression method and material used in the fabrication of a prosthesis and the effect that it could have on restoration fit or misfit. A study by Thongthammachat in 2002 evaluated Vinylpolysilixoane (VPS) noting its ease of use, dimensional stability, good reproduction of detail, accuracy and that it can be poured immediately (26).

Another study by Seelbach et al in 2013 compared the accuracy of full ceramic crowns obtained from intraoral scans with Lava C.O.S. (3M ESPE), CEREC (Sirona), and iTero (Straumann) with conventional impression techniques using both a 2-step and single-step vinyl-polysiloxane impression material. Specimens were evaluated for internal fit and accessible marginal inaccuracy with the conclusions of the study determining that digital impression systems allow the fabrication of fixed prosthetic restorations with similar accuracy as conventional impression methods (27).

Ender et al. conducted an in vitro study to compare the accuracy of full arch scans with the CEREC Bluecam and the Lava C.O.S. The CEREC system showed deviations of 49 ± 14.2 μm and the Lava C.O.S. showed deviations of 40.3 ± 14.1μm. In comparison, deviations of 55 ± 21.8 were measured for a conventional impression technique with a vinyl siloxanether impression material, however, they concluded that the trueness and precision of the digital complete-arch impression are less accurate than of a conventional impression with vinyl siloxanether material and the deviation patterns of conventional and digital impressions are different (28). These studies were mainly concerned with the impression process and its effects on the final fit of the prosthesis whereas we are evaluating the definitive cast and how this pertains to prosthesis fit. They do indicate however the inconsistencies with new modalities and new techniques attempting to replace conventional methods. While these technologies do continue to make advances, we still must continue to dissect and recognize each step of our conventional technique of prosthesis fabrication, in both the impression and the cast processes, as potential sources for dimensional inaccuracy and strive in all aspects of prosthesis fabrication to identify and minimize or eliminate any potential source of error.

ADA Specification 25 indicates that final setting expansion measurements are made 2 hours after mixing. However, it has been reported that delayed linear setting expansion can continue for up to 96 hours when measured up to 120 hours (11). Although numerous investigators have studied the properties of dental stones and improved dental stones, other products have been recently introduced with manufacturer claims of "ultra-low" or no setting expansion. One in- vitro study found that use of an ultra-low setting expansion stone in implant-supported definitive cast fabrication yielded final prostheses with passivity of fit when compared to a conventional die stone (12). However no studies have measured delayed linear setting expansion of ultra-low or zero expansion dental stones.

The purpose of the study was to 1. measure the delayed linear setting expansion of two dental stones used in implant definitive cast/prosthesis fabrication claiming to have very low to no setting expansion, 2. compare their expansion at two hours and 96 hours and 3. characterize the delayed expansion up to 96 hours.

The null hypothesis was that the linear setting expansion seen at 96 hours will not vary significantly from the linear setting expansion seen at 2 hours between the two test stones.

CHAPTER II

DELAYED LINEAR EXPANSION OF TWO ULTRA-LOW EXPANSION DENTAL STONES

Overview

Statement of the Problem. Dental implant prosthesis fabrication requires stable materials that can provide as accurate a duplication as possible of the clinical condition. With the introduction of new dental materials, there have been no studies which have measured the delay linear expansion of ultra-low or zero expansion dental stones.

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Methods and Materials. Five specimens of each material, Zero Stone and Whip Mix Experimental, were tested using a custom expansion device as were five control samples of Silky Rock. The setting expansion of each specimen was recorded continuously for 96 hours. Data were analyzed using qualitative statistics 2 way ANOVA at α=.05.

Results. The delayed linear expansions of Zero Stone and Whip Mix were not statistically different (P=0.778). The delayed linear expansion of Silky Rock was different from both Zero Stone and Whip Mix (P≤0.000). The percentage of setting expansion at 2 hours did vary between the two test stones with 83% of setting expansion occurring at 2 hours for Zero Stone while only 35% of total setting expansion occurred at 2 hours for the Whip mix stone.

Conclusions. There was no statistically significant difference between either stone with regards to amount of delayed linear setting expansion at 2 or 96 hours, however they test stones did vary significantly from the control.

Clinical Implications. Within the limitations of this study, use of either ultra low expansion dental stone could be used during the definitive cast fabrication to decrease the amount of error in prosthesis fabrication.

Introduction

Gypsum products are used in many applications in dentistry, both chair-side and within the laboratory, to enable diagnosis, treatment planning, restoration and maintenance/repair. They are used to duplicate hard and soft tissues of the mouth, must be durable, resilient and resist dimensional change over time in order to provide an accurate duplication for fabrication of a successful, well fitting prosthesis (1).

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The purpose of the study was to 1. measure the delayed linear setting expansion of two dental stones used in implant definitive cast/prosthesis fabrication claiming to have very low to no setting expansion, 2. compare their expansion at two hours and 96 hours and 3. characterize the delayed expansion up to 96 hours.

The null hypothesis was that the linear setting expansion seen at 96 hours will not vary significantly from the linear setting expansion seen at 2 hours between the two test stones.

Materials and Methods

Two improved dental stones used to fabricate implant definitive casts were tested: Zero Stone (Dentona, Dortmund, Germany) and an experimental stone by Whip Mix (Whip Mix, Louisville, KY). These test stones were compared to a control stone, Silky Rock (Whip Mix, Louisville, KY). Five specimens per stone were fabricated to be 100 mm in length and triangular in cross-section (33 x 50 x 33 mm) according to the protocol detailed below as established by Heshmati et al (5). All specimens did conform to ADA Specification 252 and International Standards Organization (ISO) 68737 for measurement of the expansion of dental gypsum products.

A standardized technique that conformed to the manufacturers' instructions and recommendations was used during the fabrication of each specimen. The temperature of the distilled water was held at 78° + or - 2°F, and the room temperature was maintained at 70° + or - 5°F. No other standardized conditions were established during specimen preparation and testing. Every attempt was made to evaluate stone expansion in a realistic clinical and laboratory setting.

Mixing procedures were performed in accordance with each manufacturer's specific recommendations. (Table 1) The stone was obtained in prepackaged form or measured with an electronic scale. Water was placed in a wet vacuum bowl (Whip Mix), and the gypsum powder was added to the water. The mixture was hand-spatulated to incorporate the powder/ water and then mechanically mixed

(Combination Model D; Whip Mix) under vacuum at 25 psi/Hg for the recommended time (Table 2). Each stone was immediately poured with hand vibration into a V-shaped expansion device (EMI 300; SAM Pra¨zisiontechnik GmbH, Munich, Germany) (Figure 1). The expansion tray was lined with rubber dam (Hygenic Dental Dam; Col-tene/Whaledent, Mahwah, N.J.) in accordance with ISO specifications for dental gypsum products. The expansion device was connected to an IBM Notebook computer (ThinkPad T23, White Plains, New York) through a serial interface (MUX 3; SAM Pra¨zision- technik GmbH, Munich, Germany) (Figure 2). The setting expansion of each specimen was measured continuously for 96 hours and automatically recorded on the computer's hard drive. Seven time intervals were selected for analysis. The raw expansion data were expressed in millimeters and converted to a percentage value with the following formula: E/L X 100%, where E is expansion and L is the length of the specimen.

The collected data was subjected to 2-way repeated- measures analysis of variance (ANOVA, P< .05) to determine significant expansion differences among the stones over time. Time was used as a within-subject factor and stone as a between-subject factor (Table 3). Planned comparisons (at a 95% confidence interval for the mean) were made to explore differences between the 2-hour manufacturer expansion values and the 2-hour experimental values. The percent expansion before and after 2 hours was also calculated.

Results

Two-way repeated-measures ANOVA with time as within-subject factor and stone as between-subject factor are listed in Table 3 and shown in Figure3. The expansion data for the 3 materials tested at the 7 time intervals are shown in Table 4.

The two ultra-low expansion stones showed similar expansion properties. The highest setting expansion value at 96 hours was Silky Rock (0.138% ±0.008) and the lowest was seen for Zero Stone (0.024 ±0.015). The setting expansion of Whip Mix E at 96 hours, (0.028 ± 0.008) did not differ significantly from Zero Stone.

The delayed linear expansions between Zero Stone and Whip Mix experimental stone were not statistically different (P=0.778). The two-way repeated-measures ANOVA revealed significant differences between materials and time (P<.0001). The delayed linear expansion of Silky Rock was different from both Zero Stone and Whip Mix (P≤0.000).

The percentages of expansion between the two test stones at 2 hours and after 2 hours are listed in Table 5. For Silky Rock, the majority of total expansion, 75.5% took place at 2 hours. The same was true of Zero stone which had 83.5% of total expansion occur at 2 hours, Whip Mix E however, showed the majority of its expansion, 61% after 2 hours.

Discussion

Modification of dental gypsum products have afforded dentists and dental laboratory technicians the ability to select a product based on certain desirable characteristics. The advent of newer technologies implementing intraoral scans and CAD/CAM definitive cast and prosthesis fabrication have led to the possible premature substitution or elimination of impression making and definitive cast fabrication by conventional methods. As recent research has indicated however, these new modalities are far from superior and in some cases, have been shown to produce less accurate casts and final prostheses. Given this dilemma, this investigation sought to test two relatively new Type IV-like dental stones to determine if the manufacturers' claims of "ultra-low" to "zero expansion" were accurate as well as to determine the percentage of total expansion occurring at and after the ADA standard 2 hour specification.

The results of this study show that the mean total setting expansion at 96 hours of both test materials, Zero stone 0.024 (±0.015) and Whip Mix E Stone 0.028 (±0.008) did not vary significantly from one another. As expected, these stones did vary significantly from the control stone, Silky Rock 0.138 (±0.008) (Table 4).

The linear expansion data obtained in this study for Silky Rock are in agreement with the results described by Heshmati et al (11). They found delayed linear expansion to be greatest (0.14 ±0.01) at 72 hours whereas the greatest linear expansion in this study, (0.138 ±.008) was seen at 96 hours. It is important to note that a review of the raw data after 96 hours for Silky Rock consistently showed that linear expansion ceased at 96 hours. It is also important to note that the percentage of linear expansion at 2 hours for Silky Rock in this investigation (75.5%) was similar to the 71% recorded by Heshmati et al.

Of the stones evaluated in this investigation, Zero Stone showed the least amount of linear expansion (0.024 ±0.01). It is interesting to note that peak linear expansion was achieved at 24 hours and that 83.5% of linear expansion of Zero Stone occurred at 2 hours. While Zero Stone did show the least amount of linear expansion, and while most expansion occurred at 2 hours, these results are not consistent with the manufacturer's claim that Zero stone has no expansion (0.00%) according to its data sheet. Still the values obtained in this investigation indicate that Zero Stone would function well for the clinician or laboratory technician who requires a product with high strength and very low setting expansion where the delayed setting expansion essentially ceases at 24 hours.

While Whip Mix E stone also exhibited a low linear expansion value (0.028 ±0.08) the product exhibited significant delay in achieving peak linear expansion, which occurred at 96 hours. Again, it is important to note that an evaluation of the raw data at and beyond 96 hours did indicate that expansion ceased at 96 hours for Whip Mix. Interestingly, Whip Mix E also varied significantly in terms of percentage of expansion seen at and after 2 hours. Whip Mix E only exhibited 39% of total linear expansion at 2 hours with the bulk of linear expansion occurring thereafter and ceasing at 96 hours. While in the grand scheme, this variance in the linear expansion at and after 2 hours is not clinically significant, when comparing these two ultra-low expansion dental stones, there is a clear benefit to the use of Zero Stone over Whip Mix E from a temporal stability standpoint. With marginally less expansion, Zero Stone also appears to achieve dimensional stability significantly earlier than Whip Mix E.

Accepting the overall minor amount of delayed linear expansion of these specimens, especially when evaluating the changes over 96 hours, one must still appreciate the clinical implications of the extent of delay of linear expansion on the process. There is an obvious impact on the time of fabrication if one must wait 96 hours or even 24 hours to allow for delayed linear setting expansion to cease instead of the 2 hour time frame established by the ADA. In the case of Zero Stone, from 2 hours to 24 hours when the stone expansion ceases, there is an additional increase of expansion of .004% . For Whip Mix E, from 2 hours to 24 hours there is no change but from 24 to 96 hours there is 0.018% increase in expansion. The characteristics of the changes that occur between these specimens over time appear significant however these overall percentages in change over the course of the linear expansion may not be clinically significant given the overall degree of linear expansion that the product exhibits.

In light of these findings but given that the research does not explicitly state that there is a direct and measurable link between the amount of misfit a prosthesis shows and the specific mode of failure that the restoration may display, it is still evident that prosthesis misfit does play a role in short and long term complications with implant supported and retained restorations, and that controlling this misfit is of great importance. As previously stated, the impression process and fabrication of the definitive cast, the steps involved in recreating the clinical scenario, each inherently contribute to an overall dimensional inaccuracy of the final patient replica. The goal of improving dental materials and methods in this arena however has sought to minimize the amount of error introduced in each step to ultimately achieve a restoration that is passive, with no marginal discrepancy or internal fit error.

The results of this study indicate that new dental stones that are described as ultra-low and zero expanding, have greater potential in minimizing the introduction of error into the definitive cast fabrication than other products currently in use. While the percentage of setting expansion before and after two hours did vary between the two experimental stones, the final linear expansion data show that these Type IV-like stones have extremely low linear expansion compared to traditional Type IV dental stones. Table 6 displays the data in order to illustrate this point. At 96 hours, when all specimens ceased expansion, Zero Stone only displayed 17% of the total linear expansion that Silky Rock showed, and Whip Mix exhibited 20% of the total linear expansion that Silky Rock showed.

While every effort was made to standardize the experimental conditions, there were limitations to this study since all aspects of the testing environment could not be controlled for. It is also important to note that in addition to the properties of the dental stone utilized, dimensional change in die materials can be influenced by many other factors that have not be directly tested for in this experiment such as the effect of impression materials on stone, the operator effect, delays in impression pouring and stone setting times, manipulation of the material after setting, and changes in lab conditions.

Another limitation of the study was not following all specimens to 120 hours to determine specimen stability and enable data analysis. The main rationale for this decision was based on the findings from Heshmati et al. However, while the data were not collected and evaluated up to 120 hours for all specimens, a review of the raw data did indicate that expansion ceased at 96 hours.

While the results of this study indicate that these two dental stones may be useful in applications where minimal expansion is necessary, other important characteristics which would affect the applications and usefulness of these stones were not tested. One future study might be to test the compressive strengths of these materials at the ADA time points of 1 hour and 48 hours and again up to 96 hours and compare these findings to Type IV and V dental stones.

Since it has been demonstrated that intra-oral scanning techniques and milling procedures for the production of definitive casts and final prostheses also show inaccuracy, future studies could include a bench study comparison of prostheses made from conventional impression and definitive cast techniques using these two test stones to prostheses made from scanned and milled definitive casts of a patient replica. This study could also be repeated in the live patient model.

CHAPTER III

CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn:

1. Zero Stone and Whip Mix experimental stone did not differ significantly in the amount of liner expansion that they displayed at 96 hours.
2. Zero Stone and Whip Mix experimental stone did differ significantly from the control stone, Silky Rock with regards to linear expansion.
3. While the percent of linear expansion of the two test materials did differ before 2 hours and after two hours, this difference was not significant.

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APPENDIX A

FIGURES

Figure 1: Expansion Device

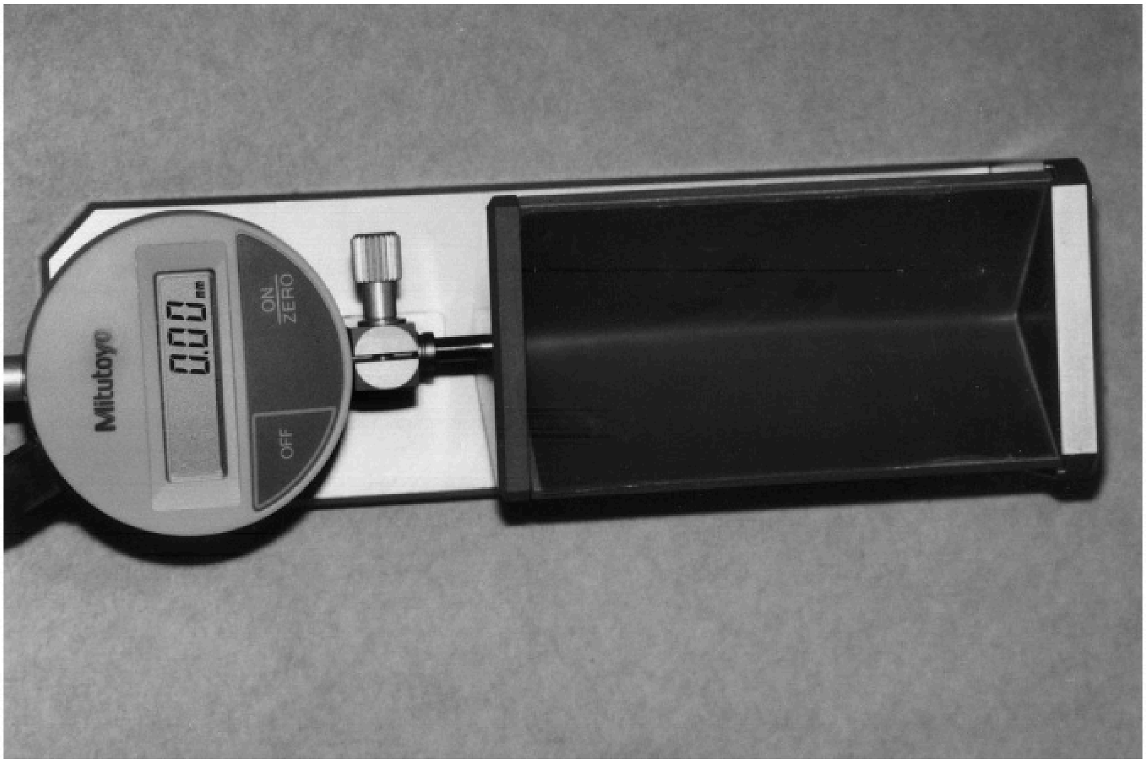
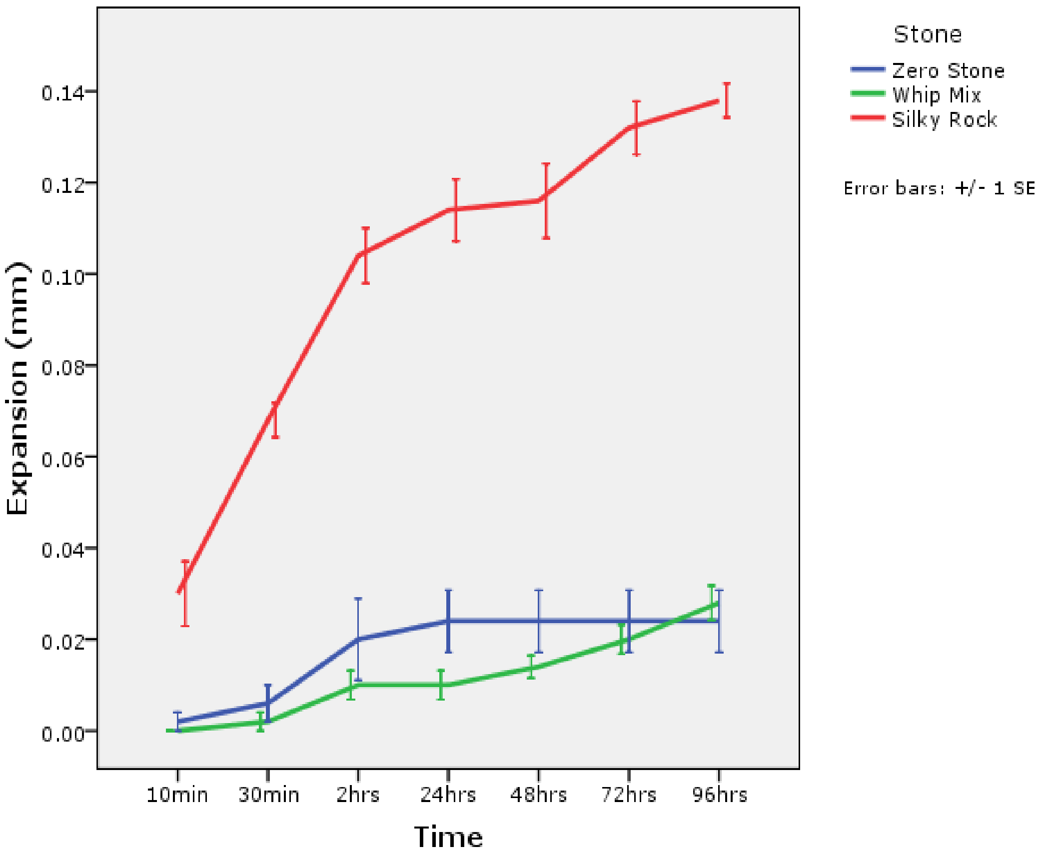


Figure 2: Expansion Device and Serial Interface

Figure 3: Mean Setting Expansion Values (%) at Selected Time Intervals



APPENDIX B

TABLES

Table 1: Types of Dental Gypsum Setting Expansion at 2 hours

Type	**Description**	**Setting time (min)**	**Min %**	**Max %**	**Water/powder Ratio**
I	Plaster,impression	4± 1	0.00	0.15	0.50-0.75
II	Plaster, model	12± 4	0.00	0.30	0.45-0.50
III	Dental Stone	12± 4	0.00	0.20	0.28-0.30
IV	Dental stone HS LE	12± 4	0.00	0.10	0.22-0.24
V	Dental Stone HS HE	12± 4	0.10	0.30	0.18-0.22

Information Taken From ADA Spec 25.

Table 2: Mixing Procedures Mixing Time (Sec)

Stone	**Water(ml)-Powder(g) ratio**	**Method of Mixing**	**Hand**	**Vacuum**
Silky Rock	23-100	Hand and Vacuum	30	60
Zero Stone	23-100	Hand and Vacuum	15	30
Whip Mix E	23-100	Hand and Vacuum	30	60

Table 3: Two-Way Repeated-Measures ANOVA

Two-way repeated-measures MANOVA with time as within-subject factor and stone as between-subject factor (P ≤ .05)

Source	F Value*	Hypothesis df	Error df	Sig.
Time	35.021	6.000	7.000	.000
Time * Stone	7.331	12.000	14.000	.000

*F-values are based on Wilk's Lambda statistics.

Table 4: Mean Setting Expansion Values

Mean setting expansion values (±SD) at selected time intervals (%)			
Time	**Zero Stone**	**Whip Mix**	**Silky Rock**
10 min	0.002 (±0.004)	0.000 (±0.000)	0.030 (±0.016)
30 min	0.006 (±0.009)	0.002 (±0.004)	0.068 (±0.008)
2 hours	0.020 (±0.020)	0.010 (±0.007)	0.104 (±0.013)
24 hours	0.024 (±0.015)	0.010 (±0.007)	0.114 (±0.015)
48 hours	0.024 (±0.015)	0.014 (±0.005)	0.116 (±0.018)
72 hours	0.024 (±0.015)	0.020 (±0.007)	0.132 (±0.013)
96 hours	0.024 (±0.015)	0.028 (±0.008)	0.138 (±0.008)

Table 5: Percentage of Total Mean Expansion at 2 Hours and After 2 Hours

Mean Expansion	**Silky Rock**	**Zero Stone**	**Whip Mix E**
At 2 hours (%)	0.104	0.020	0.010
Percent of total	75.5%	83.5%	39%
After 2 hours (%)	0.034	0.004	0.018
Percent of total	24.5%	16.5%	61%

Table 6: Comparison of Percentage Expansion of Test Specimens to Control

Mean Expansion	**Zero Stone**	**Whip Mix**	**Silky Rock**
At 2 hours (%)	0.02	0.01	0.104
Percent expansion	19% Z:S	9% W:S	
At 96 hours (%)	0.024	0.028	0.138
Percent expansion	17% Z:S	20% W:S	

APPENDIX C

AUTHOR INFORMATION

Delayed Linear Expansion of Two Ultra-Low Expansion Dental Stones

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