Delayed linear dimensional changes of five high strength gypsum products used for the fabrication of definitive casts

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Statement of problem. Prolonged storage of definitive casts made from Type IV and Type V gypsum products, especially in an environment of increased temperature and low humidity, may result in contraction.

Purpose. The purpose of this study was to evaluate the linear dimensional changes of 5 different high strength stones after exposing them to 2 different storage conditions over a period of 3 weeks.

Material and methods. Three Type IV dental stones (Fujirock, Vel-Mix, Suprastone) and 2 Type V dental stones (Hard Rock, Jade Stone) were tested in this study. A circular conical stainless steel die with a diameter of 66 mm and a height of 10 mm was made. Two V-shaped grooves, 38 mm apart, were scribed on the surface of the die for the purposes of measurement. A conical stainless steel ring with a bottom inner diameter of 68 mm and a top inner diameter of 65 mm was also fabricated to fit precisely around the stainless steel die. The dental stone was mixed with water under vacuum and poured under vibration onto the stainless steel die, which was surrounded by the ring. The specimens (n=20) were separated from the stainless steel die 1 hour after pouring. Half of these specimens (control) were stored in a room at 22 ±1°C with relative humidity of 50 ±5%, while the rest of the specimens were placed in a temperature regulating incubator at 40 ±1°C and relative humidity of <20%. The linear dimensional changes were recorded at designated time intervals with a traveling microscope over a 3 week period. Collected data were subjected to a 2-way repeated-measures analysis of variance (ANOVA) (α=.05).

Results. The highest expansion values for the specimens in the control group were recorded between 72 and 96 hours. A contraction was noticed thereafter for all specimens, in both groups. No difference in the measurements was registered between the second and third week. ANOVA revealed significant differences (P<.001) among different Type IV and V dental stone products, time, and storage conditions.

Conclusions. The highest expansion values for all specimens in the control group were recorded between 72 and 96 hours. The highest expansion values for all specimens in the experimental group were recorded at 24 hours. For all specimens, contraction was noticed up to the 2-week measurements. All factors examined (dental stone, time, storage condition) significantly affected the linear dimensional changes. (J Prosthet Dent 2012;108:189-195)

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CLINICAL IMPLICATIONS

If environmental conditions are likely to be hot and dry, waxing and finishing of the definitive restorations should be completed as soon as possible to prevent dimensional changes of the definitive casts.

Traditional fabrication of definitive restorations requires the use of gypsum products. Plaster and stone products used in dentistry are made by calcining calcium sulfate dihydrate. The principal constituent of gypsum based products is calcium sulfate hemihydrate, $(CaSO_4)_2 \cdot H_2O$. Depending on the method of calcination, 2 different forms of calcium sulfate hemihydrate can be produced. These can be classified as α- and β-calcium sulfate hemihydrate.[1-3]

According to the American National Standards Institute/American Dental Association (ANSI/ADA) Specification No. 25, dental gypsum products are classified into 5 types, depending on their physical properties and use[4]: Type I: impression plaster; Type II: model plaster; Type III: stone; Type IV: high strength, low expansion stone; and Type V: high strength, high expansion stone. Plasters contain particles of the β-hemihydrateform and have irregular and spongy crystals. Conversely, stones contain α-hemihydrate particles with crystals that are prismatic and more regular in shape.[1-3] This cuboidal shape of the particles provides properties such as hardness,[5,6] abrasion resistance,[7-9] and strength.[10,11] These properties are necessary since stone dies are used for the fabrication of wax patterns and are subjected to sharp stainless steel instruments. Additionally, the finishing of the metal framework is usually performed on the dies.[12,13] Therefore, the dies should be durable to withstand these technical procedures.[14]

Types IV and V dental stones are routinely used for the fabrication of definitive casts, and they are manufactured with high density raw materials called densite and crystacal. The powders of these stones are produced with a controlled grinding procedure and are dense.[2]

Since Type IV and V dental stones are used for the fabrication of definitive casts, their dimensional stability is important.[14] However, dental stones exhibit dimensional changes during the setting process.[15-17] A volumetric contraction may be observed in early setting stages while the mix is still fluid.[18] With the advancement of the reaction, gypsum crystals start forming and an isotropic expansion is observed.[19-23] The literature reports that this expansion may continue for up to 120 hours.[24] Nevertheless, ANSI/ADA Specification 25 requires linear expansion measurements to be made 2 hours after mixing the dental stone powder with water.[4] Stone and high strength stones have different water/powder ratios.[1-3] This is due to differences in the apparent densities of different products. High strength dental stones require less water than dental stones.[1-3] Their water requirement is 0.18 to 0.25 mL/100 g of powder. At the end of the chemical reaction some unreacted water remains in the final product. This unreacted water, which is less in high strength stones, represents a saturated solution of calcium sulfate, and it weakens the stone product.[1] Research data indicate that the water can be eliminated by low-temperature drying. This procedure results in the presence of microscopic porosity, which likely affects the strength of the cast.[2]

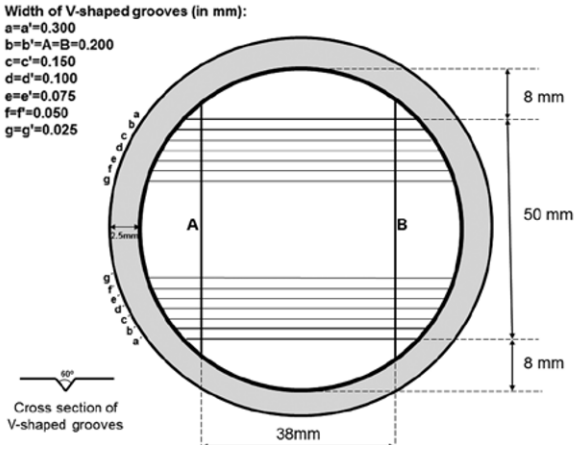
There are insufficient data, however, as to whether this elimination of water has an effect on the dimensional stability of the casts. Additionally, there is a lack of research regarding the dimensional stability of dental stone products over an extended period of time. This information could be useful since in commercial dental laboratories delays between the fabrication of definitive casts and waxing procedures are usual.

The purpose of this study was to evaluate the linear dimensional changes of 5 different high strength stones at 1, 24, 48, 72, 96 hours, and 1, 2, and 3 weeks after subjecting them to 2 different storage conditions. The null hypothesis was that linear dimensional changes of the examined high strength stones would not be affected by time and different storage conditions.

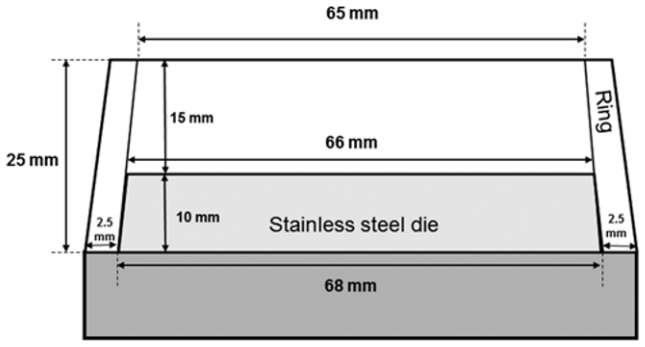
MATERIAL AND METHODS

Five high strength stone materials used routinely for the fabrication of definitive casts were included in this study: Fujirock EP (GC America Inc, Alsip, Ill), Vel-Mix (Kerr Corp, Orange, Calif), Suprastone (Kerr Corp), Hard Rock (Whip Mix Corp, Louisville, Ky), and Jade Stone (Whip Mix Corp). The first 3 gypsum products are classified as Type IV stones and require a powder (g) to water (mL) ratio of 100:20, while the last 2 are classified as Type V dental stones and require powder (g) to water (mL) ratios of 100:21 and 100:22 respectively.

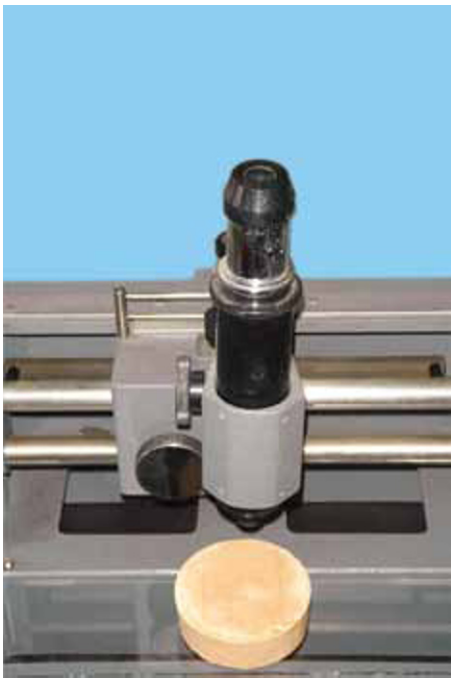
A circular conical stainless steel die, similar to the one described in the ANSI/ADA specification No. 25 was made (Fig. 1).[4] Its base diameter was 68 mm, its top diameter was 66 mm and its height was 10 mm. Two vertical V-shaped grooves (A and B) were scribed on the top surface to be 14 mm from the perimeter of the die. Another 14 V-shaped grooves of varying width were scribed perpendicular to grooves A and B. The widths of the V-shaped grooves ranged from 0.025 mm to 0.3 mm. Seven of these hori-



1 Top view of stainless steel die used for measurement purposes of delayed linear changes of high strength stone products.



2 Side view of stainless steel die and ring assembly.



3 Traveling microscope used for measurement purposes.

zontal V-shaped grooves (a, b, c, d, e, f, g) were close to one edge of the die, while the other seven (a′, b′, c′, d′, e′, fv, g′) were close to the opposite edge of the die. The mid points of the first of these horizontal V-shaped grooves (a and a′) were 8 mm from their respective sides of the periphery of the die. The horizontal V-shaped grooves of each group were 2.5 mm apart from each other. The apices of the 2 vertical V-shaped grooves (A and B) were 38 mm apart, while the apices of the horizontal V-shaped grooves (a and a′) were 50 mm apart. A stainless steel ring with a diameter of 68 mm was also fabricated to fit precisely around the stainless steel die (Fig. 2). The top diameter of this stainless steel ring was 65 mm in order to be slightly conical and therefore facilitate removal of the stone specimens. The height of this stainless steel ring was 15 mm, while the thickness of its walls was 2.5 mm. The stainless steel die was lubricated with a silicone separating medium (Rikospray; Silicone 3M, St Paul, Minn) and a stream of compressed air was used for 10 seconds to dry the surface of the die. Manufacturers' instructions were followed for the mixing procedures. An electronic scale (EC-411; Acculab Sartorius Group, Goettingen, Germany) was used to measure the stone powder. Distilled water was first measured and added in a vacuum bowl (Twister Pro; Renfert GmbH, Hilsingen, Germany). The stone powder was added, and a spatula with a stiff blade (3R; Buffalo Dental Mfg Co, Syosset, NY) was used for a 15-second hand mixing to fully incorporate the powder into the water; this was followed by mechanical mixing under vacuum at 25 mmHg for 45 seconds. The mixture was poured under vibration (No. 200 Vibrator; Buffalo Dental Mfg Co) onto the die, which was surrounded by the ring. The specimens were separated from the die 1 hour after pouring. No power analysis was performed to determine the number of specimens required in each test group. Instead, the same number of specimens as that used

in the previous work of the authors on a similar subject was adopted.[25] Therefore, 20 specimens were made for each one of the dental stones, giving a total of 100 specimens. Half of these specimens (control group) were stored in a room where the temperature was 21 ±1°C and the relative humidity was 50 ±10%, while the rest of the specimens (experimental group) were placed in a temperature regulating incubator where the temperature was 40 ±1°C and the relative humidity was <20%.The temperature and the relative humidity were recorded each day throughout the experiment. Measurements for each specimen were made at 8 time intervals: 1, 2, 24, 48, 72, and 96 hours and 1, 2, and 3 weeks. A traveling micrometer microscope (Griffin Ltd, London, UK) with an accuracy of 0.01 mm was used to measure the linear changes in the specimens (Fig. 3) by measuring the distances between the vertical V-shaped grooves A and B. No measurement was made between the horizontal a, b, c, d, e, f, g and the a′, b′, c′, d′, e′, f′, g′ V-shaped grooves. Measurements were always made by the same operator. The linear dimensional change raw data were converted to a percentage value with the following expression[24,25]:

(Lc/Lo) × 100%,

where Lc represents the specimen's change in length, and Lo represents the original specimen length in millimeters. The temperature of the distilled water used was 23 ±2°C.

Two-way repeated-measures analysis of variance (ANOVA) (α=.05) was used to determine statistically significant differences among different stone products and different treatment conditions over time.

RESULTS

The descriptive statistics for mean linear dimensional changes and standard deviation values at different time intervals for specimens stored in normal temperature/humidity and elevated temperature/low humidity conditions are summarized in Table I. The highest expansion values for the specimens in the control group were recorded between 72 and 96 hours. Mean expansion values for Type IV stone specimens in the control group ranged from 0.01% ±0.008% at 1 hour to 0.19% ±0.017% at 96 hours, while the mean expansion values for Type V stone specimens in the control group ranged between 0.13% ±0.018% at 1 hour and 0.36% ±0.02% between 48 and 96 hours. The mean expansion values for Type IV stone specimens in the experimental group ranged between 0.01% ±0.008% at 1 hour to 0.13% ±0.017% at 24 hours, while the mean expansion values for Type V stone specimens in the experimental group ranged between 0.12% ±0.02% at 1 hour and 0.30% ±0.015% at 24 hours. Type IV dental stones in the control group presented a contraction at the 1-week and 2-week measurements. However, no difference was registered between 2 weeks and 3

TABLE I. Mean linear dimensional change values (standard deviations) at different time intervals for specimens in control (Ctrl) and experimental (Exp) groups (%)

Time	FR (Ctrl)	FR (Exp)	VM (Ctrl)	VM (Exp)	SS (Ctrl)	SS (Exp)	HR (Ctrl)	HR (Exp)	JS (Ctrl)	JS (Exp)
1 h	0.01	0.01	0.06	0.05	0.04	0.04	0.21	0.2	0.13	0.12
	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
2 h	0.08	0.08	0.09	0.09	0.07	0.05	0.29	0.27	0.16	0.15
	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)
24 h	0.16	0.13	0.13	0.13	0.12	0.10	0.34	0.30	0.20	0.20
	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
48 h	0.18	0.08	0.15	0.09	0.15	0.07	0.36	0.21	0.22	0.17
	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)
72 h	0.19	0.08	0.16	0.09	0.16	0.07	0.36	0.21	0.23	0.17
	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
96 h	0.19	0.05	0.15	0.07	0.17	0.05	0.36	0.18	0.24	0.16
	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)
1 week	0.17	0.04	0.13	0.05	0.15	0.04	0.34	0.17	0.25	0.13
	(0.02)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)
2 weeks	0.09	-0.03	0.09	-0.01	0.11	-0.04	0.28	0.12	0.22	0.11
	(0.01)	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)
3 weeks	0.09	-0.03	0.09	-0.01	0.11	-0.04	0.28	0.12	0.22	0.10
	(0.01)	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)

Table II. Two-way repeated-measures ANOVA Tests of within-subjects effects

Tests of within-subjects effects					
Source	**Type III Squares**	***df***	**Mean Square**	**F**	***P***
Time	1.26	3.2	0.40	1348	<.001
Greenhouse-Geisser	0.17	12.9	0.01	45	<.001
Time × material	0.58	3.2	0.18	619	<.001
Greenhouse-Geisser	0.05	12.9	0.004	12.5	<.001
Time × condition	0.08	289	0.000		
Greenhouse-Geisser					
Time × material × condition					
Greenhouse-Geisser					
Error (time)					
Tests of within-subjects effects					
Intercept	17.62	1	17.62	8733	<.001
Material	4.28	4	1.06	529	<.001
Condition	1.32	1	1.32	658	<.001
Material × condition	0.09	4	0.02	11.5	<.001
Error	0.18	90	0.002		

weeks. Hard Rock (Type V stone) also presented a contraction at the 1-week and 2-week measurements. Jade Stone (Type V stone) continued to expand until the first week. Thereafter a contraction was noticed. No difference was registered between the second and the third week. All Type IV dental stones in the experimental group presented a contraction after 24 hours, a contraction which continued at a slow rate for 2 weeks. However, no difference in the measurements was noticed between the second and the third week. The same phenomena were noted for the Type V dental stones included in the study. An important finding was that the 3-week percentage contraction of Type IV and V dental stone specimens in the control group did not fall below the 2-hour expansion level required by the ANSI/ADA Specification No. 25.[4] Two-way repeated measures ANOVA revealed significant differences (P<.001) among different Type IV and V dental stone products, time, and storage conditions (Table II).

DISCUSSION

The study investigated the effect of time and storage under conditions of increased temperature and decreased humidity on 3 Type IV and 2 Type V dental stones used routinely for the fabrication of definitive casts. The results of this study indicate that both time and different storage conditions significantly affect linear dimensional stability values. Therefore, the null hypothesis was rejected.

Only the linear dimensional stability values of Type IV and Type V dental stones were measured in this study. These measurements provide only a partial indication as to what occurs 3-dimensionally. As expected, Type V gypsum products demonstrated higher expansion values than Type IV stone. All gypsum products, with the exception of Vel-Mix (Kerr Corp), showed continuous setting expansion for all time intervals up to 96 hours when stored in normal storage conditions (21 ±1°C temperature and 50 ±10% relative humidity). Vel-Mix (Kerr Corp) presented its highest expansion value at the 72-hour measurement. These results are in partial agreement with those of Heshmati et al,[24] who reported that at 96 hours, gypsum expansion was complete. It should be mentioned, however, that the Type IV and Type V gypsum specimens included in that study were stored at room temperature (21 ±3°C) with no control of environmental humidity in an attempt to simulate a realistic clinical and laboratory setting. In addition, the setting expansion of the specimens was not recorded after 120 hours. In the present study contraction was noticed between the 96th hour and the 2-week measurements.

Specimens that were stored in an environment with increased temperature and decreased humidity demonstrated a continuous setting expansion only in the first 24 hours. Thereafter, a contraction which continued for 2 weeks was registered. The dimensional changes were completed

after a 2-week period for both the control and the experimental group specimen.

The results of the present study indicate that prolonged storage of the gypsum specimens for 2 or more weeks has a negative effect on the expansion values. The results of the present study also suggest that the combination of prolonged storage with high temperature and low humidity can cause contraction of the stone specimens. These results are in agreement with those reported by Sweeney and Taylor,[15] who reported that a contraction occurred when specimens were heated in an electric oven with temperatures ranging between 90°C and 110°C. Additionally, Docking et al[16] and Toreskog et al[7] reported on contraction of gypsum products. The data of the present study suggest that even a temperature of only 40°C in combination with a humidity of less than 20% may cause a significant contraction of the dental stone specimens. The explanation for this phenomenon may be the chemistry of $CaSO_4$. It is known that the reaction of calcium sulfate hemihydrate (dental stone powder) with water results in the formation of calcium sulfate dihydrate (dental stone) and release of heat. Storage of dental stone specimens in an environment of elevated temperature and decreased humidity has the effect of removing water and transforming the specimens from $CaSO_4 \cdot 2H_2O$ to $CaSO_4 \cdot \frac{1}{2}H_2O$. This transformation is accompanied by a contraction of the specimens, which is first observed after 48 hours.[15] Storage of the specimens for longer periods in an environment of elevated temperature and decreased humidity can result in additional contraction of the specimens.

The mechanism of stone expansion has been described in the past.[15,16,18,20,21] Based on scanning electron microscopy and x-ray diffraction data, Winkler et al[22] have shown that the conversion of calcium sulfate hemihydrate to calcium sulfate dihydrate was accompanied by crystal transformation (from prismatic hemihydrate to needle-like), crystal growth, and adjacent crystal impingement, which result in the expansion of the stone. However, no data are available to explain the contraction of the stone. Scanning electron microscopy may be a helpful tool for detecting qualitative and/or quantitative changes of the stone crystals over prolonged time periods.[22]

Contraction of the definitive casts is undesirable since the dies will be smaller than the prepared teeth. This could result in unacceptable castings, which would not seat on the abutment teeth unless the dental technician compensated for this discrepancy with additional coatings of die spacer. It should be mentioned, however, that the result of this compensatory laboratory technique is not predictable and as such is undesirable.

The results of the present study indicate that the risk of stone contraction is greater in geographical regions with elevated temperatures and decreased humidity. It is recommended that in these geographical regions, the framework waxing and casting procedures should be completed as soon as possible to avoid shrinkage of die stones, which will affect the fit of the casting on prepared teeth. Alternatively, the definitive casts should be stored in temperature and moisture controlled areas to prevent their contraction.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. The highest expansion values for all specimens in the control group were recorded between 72 and 96 hours. A contraction was noticed thereafter, until the 2-week measurements.

2. The highest expansion values for all specimens in the experimental group were recorded at 24 hours. A contraction was noticed thereafter, until the 2-week measurements.

3. No difference was noticed between the measurements of the second and the third week.

4. All the examined factors (dental stone, time, storage condition) significantly affected the linear dimensional changes.

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Noteworthy Abstracts of the Current Literature

Influence of tooth mobility on critical stresses in all-ceramic inlay-retained fixed dental prostheses: A finite element study

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Dent Mater 2012;28;146-51

Objectives: Inlay-retained fixed partial dentures are conservative prosthetic restorations. Their failure resistance is influenced by the stress distribution that depends on the material properties as well as the loading conditions. Finite element analysis provides the ability to estimate the loading capacity by simulating the stress distribution in all-ceramic dental restorations. The null-hypothesis of this study was that tooth mobility or tooth bearing condition significantly influences the stress distribution and therefore the failure resistance of all-ceramic inlay-retained fixed dental prostheses. Therefore, the stress distribution under different loading and bearing conditions of the teeth was analyzed using the finite element method.

Methods: Three different bearing conditions, one fixed and two flexible were chosen to simulate tooth mobility. The flexible models were constrained with spring elements to a virtual center of rotation. In addition, loading conditions were varied.

Results: The influence of tooth mobility on the stress distribution depended on the degree of modeled tooth mobility, as well as the loading conditions. The maximum first principal stresses differed significantly in magnitude and location depending on the modeled bearing condition and the simulated load case. The maximum difference between fixed and flexible model was more than 100%.

Significance: Tooth mobility and occlusal loading conditions have to be considered in finite element analyses as the simulated stress distribution is strongly influenced by these factors.

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