ISOPROPYL ALCOHOL TO COUNTERACT EFFECTS OF FREEZING ON EXTENDED-STORAGE ALGINATES

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ABSTRACT

The purpose of the study was to evaluate the effects of freezing and isopropyl alcohol (IA) on two extended-storage alginates. Impressions were made of a custom stainless steel model of known dimensions and stored for 96 hours at room and freezing temperatures with or without IA and then poured with Type IV gypsum. Impression and cast clinical acceptability were evaluated based on 4 criteria: tray and impression separation, impression cracking, cast surface alterations, and residual alginate on casts. Percent differences in arch length and width between casts and the stainless steel model were also calculated. For both alginates, frozen impressions stored with or without IA and the resultant casts were all clinically unacceptable. There was high variability in cast dimensions with impressions exposed to freezing temperatures with or without IA. The evidence suggests that including IA during impression storage did not counteract the effects of freezing.

This abstract of 146 words is approved as to form and content.

The undersigned, appointed by the Dean of the School of Dentistry, have examined a thesis titled "Isopropyl Alcohol to Counteract Effects of Freezing on Extended-storage Alginates" presented by Dustin Christopher Wilson, candidate for the Master of Science in Oral Biology degree, and hereby certify that in their opinion it is worthy of acceptance.

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DEDICATION

I would like to dedicate this thesis to my remarkable wife, Julie. Her love and support throughout this entire process has been unwavering. She has made many sacrifices during my educational endeavors. Her strength as a person is humbling, she is my “rock” and words can not describe my gratitude.

CHAPTER 1

INTRODUCTION

Alignate Impression Material

History

One of the most widely used impression materials in dentistry, alginate (irreversible hydrocolloid), was invented for use in dentistry in the 1940s during World War II to find a suitable substitute for agar (reversible hydrocolloid) impression material which became short in supply at that time (Anusavice 2003). From these impressions, gypsum casts of the dentition and adjacent oral structures are fabricated and have many uses in dentistry, ranging from diagnostic and treatment planning for prosthodontics, orthodontics, periodontics, and restorative dentistry, as well as the fabrication of removable and fixed prostheses (Cook 1986; Anusavice 2003). Due to their relative inexpensiveness, patient comfort, acceptable taste, and ease of manipulation, alginates have stood the test of time and have become an integral aspect in the practice of dentistry (Cook 1986; Anusavice 2003; Powers and Wataha 2008; O'Brien 2008).

Composition and Chemical Reaction

Alginates are distributed in powder form and are mixed with water during use (McCabe and Walls 2008). The composition of alginates vary depending on the manufacturer, however there is a consistent relative concentration for each ingredient (McCabe and Walls 2008). The main reactive ingredient of irreversible hydrocolloids is one of the soluble alginates, such as sodium, potassium, or triethanolamine alginates with sodium alginate (NaAlg) being the most common (Anusavice 2003; McCabe and Walls 2008).

These soluble alginates make-up approximately eleven to sixteen percent of the composition of irreversible hydrocolloids and dissolve in water to first form a sol, eventually becoming cross-linked to form a gel (Anusavice 2003; McCabe and Walls 2008; Powers and Wataha 2008). Soluble alginates are derived anhydro-β-d-mannuronic acid (alginic acid) which is extracted from a specific type of brown seaweed (Anusavice 2003). Calcium sulfate dehydrate ($CaSO_4$ - $2H_2O$), approximately eleven to seventeen percent of alginate, is a reactor and serves as the source of Ca^{2+} ions responsible for the cross-linking of the alginate chains (Anusavice 2003; Powers and Sakaguchi 2006; McCabe and Walls 2008). One to three percent of alginate is sodium phosphate ($Na_4P_2O_7$), used to control and retard setting time (Anusavice 2003; Powers and Sakaguchi 2006). The largest component, approximately sixty percent, of dental alginates is diatomaceous earth which acts as filler particles (Anusavice 2003; McCabe and Walls 2008). The diatomaceous earth, if added in proper amounts can increase the strength and stiffness, produce a smooth texture, and aid in producing a firm gel that is not tacky (Anusavice 2003). Zinc oxide serves as an additional filler material which accounts for about four percent of the material (Anusavice 2003). To offset the inhibiting effect of alginate on setting of the gypsum stone model, potassium sulfate or potassium zinc fluoride is added consisting of about three percent of the alginate mixture (Anusavice 2003; Powers and Wataha 2008). Depending on the specific type of dental alginate, flavoring agents and pigments may be added to enhance taste and color (Powers and Wataha 2008).

The chemical reaction of alginates involves phase transitions from a powder to a sol to a gel (Anusavice 2003; McCabe and Walls 2008). This reaction begins with the addition of the appropriate amount of water to the powder to form a sol (McCabe and Walls 2008). Water (H_2O) combines with calcium sulfate ($CaSO_4$) forming calcium sulfate dehydrate ($CaSO_4$ - $2H_2O$) which dissociates into calcium ions (Ca^{2+}) and sulfate (SO_4^{2-}). The calcium ions (Ca^{2+}) replace the sodium ions in sodium alginate (NaAlg) to form a cross-linked complex or polymer network and a gel (Cook 1986; Anusavice 2003). Sodium phosphate ($Na_4P_2O_7$) dissociates to sodium ions (Na^+) and phosphate ($P_2O_7^{4-}$), the phosphate ions combine with the calcium ions to inhibit the cross-linking of calcium and alginate which extends the working time and controls the setting time of the alginate (Cook 1986). Once all of the phosphate from the sodium phosphate has combined with calcium, the calcium is now free to combine with alginate (Alg^-) to form calcium alginate ($CaAlg^+$). This step of the reaction is irreversible and completes the gelation process (Cook 1986; Anusavice 2003). The chemical reaction is shown below (Cook 1986; Powers and Sakaguchi 2006).

$CaSO_4 - 2H_2O(s) \rightarrow Ca^{2+}(aq) + SO_4^{2-}(aq)$ (1)

$NaAlg(s) \rightarrow Na^+(aq) + Alg^-(aq)$ (2)

$Na_4P_2O_7(s) \rightarrow 4Na^+(aq) + P_2O_7^{4-}(aq)$ (3)

$2Ca^{2+}(aq) + P_2O_7^{4-}(aq) \rightarrow Ca_2P_2O_7(s)$ (4)

$Ca^{2+}(aq) + Alg^-(aq) \rightarrow CaAlg^+ \rightarrow gel$ (5)

Colloidal Structure

Alginates are classified as colloids, a fourth state of matter separate from solid, liquid, or gas (Anusavice 2003). The structure of alginates is based on colloidal suspensions of polysaccharides in water (McCabe and Walls 2008). Colloidal suspensions are a state of matter which exists between two extremes. The first being a solution in which the solute is completely dissolved in a solvent and the second in which solid particles are suspended in a liquid forming a heterogeneous structure (McCabe and Walls 2008). In a colloidal suspension, no solid particle can be identified and the mixture does not perform as a simple solution (McCabe and Walls 2008). Alginates are composed of approximately 85% water acting as the fluid suspension medium and solvent, hence the name hydrocolloid (Giordano 2000; McCabe and Walls 2008).

During the setting or gelation process of alginates, the material can exist in two states: sol or gel (McCabe and Walls 2008). At the beginning of the setting process, the alginate is in the precursor fluid-like sol state. The sol state is characterized by a low viscosity and a random unorganized arrangement of the polysaccharides (McCabe and Walls 2008). During the completion of the gelation process and the transformation of the sol into a gel, the polysaccharides form irreversible links through the replacement of sodium ions with calcium ions and become more ordered (Cook 1986; Anusavice 2003; McCabe and Walls 2008).

Two different structures have been proposed for the gel state of alginates, the first structure of the alginate gel is described as an “egg box” configuration. In this configuration, calcium ions bridge polysacchrides (polygulronate) sequences with alternating mannuronate-guluronate sequences to form an organized polymer network (Cook 1986). The second consideration on structure is a randomly cross-linked filaments composed of many alginate chains (Cook 1986). SEM micrographs have been produced to support both of these structures, however the rubber-like character of alginates is best supported by the “egg box” configuration (Williams and Watkins 1983; Cook 1986).

The setting time of dental alginates according to American Dental Association (ADA) Specification No. 18 should not be less than 60 seconds nor more than 120 seconds for Type I, fast set alginates and not less than 120 seconds nor more than 4 minutes and 30 seconds for Type II , normal set alginates (ADA 1992). Controlling the setting time of alginates is a temperature dependant phenomenon. By increasing the temperature of the water added to the mixture, the setting time is shortened. The standard mixing temperature for alginates is normally around 20°C. In general, a 1 minute reduction in setting time is achieved for each 10°C of temperature increase of the water (Anusavice 2003; McCabe and Walls 2008). Water temperature does not have a significant effect on the dimensional accuracy of irreversible hydrocolloids (Harris 1969). Other methods can be performed to control the setting time such as changing the mixing time or water to powder ratio, thinner mixes have an increased setting time. However, these tactics produce unacceptable clinical inaccuracies (Anusavice 2003).

Dimensional Stability

Because the set alginate impression material is composed of mostly water, approximately 85%, this material is prone to inaccuracies after the final set (Giordano 2000). With the high water content, alginate impressions can distort due to syneresis and the associated extrusion of water onto the impression surface (Miller 1975; Powers and Sakaguchi 2006). Syneresis, described as contraction of the material, is caused by a reorganization of the polymer molecules within the alginate gel (Cook 1986). The primary mechanism of syneresis is due to the rupture of the calcium bonds cross-linking alginate chains which brings the polymer molecules closer together and causes an overall contraction of the material (Cook 1986). A secondary mechanism of syneresis is continued polymerization of the alginate chains and bonding of adjacent molecules by hydrogen bonding through the attraction of H and OH groups on adjacent molecules (Miller 1975; Cook 1986). This overall process causes the skeletal network of the gel to shrink or contract and in return forces the water within the gel to be pushed out on the surface of the material (Miller 1975).

The Gibbs Free Energy equation, [$\Delta G = \Delta H - T\Delta S$, where G = Gibbs Free Energy, H = enthalpy (total heat of the process), T = temperature (K°), and S = entropy (randomness of the process)], can also be used to further explain syneresis. The solubility of the alginate makes this process energetically favorable, ΔG is negative, at first. However, once the setting process begins with an increase in cross-linking of the alginate chains, the Entropy reduces driving the ΔG to be increasingly positive producing a system which is unstable. This instability forces water out of the set impression (Nallamuthu et al. 2006).

An additional cause of loss of water by alginates is the process of evaporation (Miller 1975; Coleman et al. 1979; Anusavice 2003). To counteract evaporation and syneresis, it is recommended that conventional irreversible hydrocolloid impressions be poured immediately or as soon as possible to obtain the most accurate gypsum model (Coleman et al. 1979). If an impression cannot be poured immediately, the impression should be stored at 100% relative humidity in a humidor or in a sealed plastic bag wrapped in a paper towel saturated with water (Skinner et al. 1950; Anusavice 2003). However, a moist environment does not totally prevent the process of syneresis (Skinner et al. 1950; Miller 1975; Anusavice 2003).

Dental alginates are also subject to imbibition, which is the reverse of syneresis and in the presence of excess water the gel absorbs the water and the material expands (McCabe and Walls 2008). This process of expansion occurs immediately after initial gelation when stored in 100% relative humidity followed by contraction of the set impression through syneresis and evaporation (Skinner and Pomes 1946). Inevitably with evaporation, syneresis, and imbibition occurring, alginates are not dimensionally stable over time and as a result are susceptible to distortion and inaccuracies. However, these processes are not the only factors which contribute to the dimensional instability of set alginate impressions; the use of disinfects on set impressions during storage prior to casting and the age of the alginate impression powder have an impact on the accuracy of the impression (Hondrum and Fernandez 1997; Saito et al. 1998; Taylor et al. 2002; Hiraguchi et al. 2007; Martin et al. 2007; Memarian et al. 2007; Kotsiomiti et al. 2008).

The dimensional stability of alginates is a function of time and is directly related to the expansion and contraction of the material due to imbibition, evaporation, and syneresis, which cannot in their entirety be prevented (Miller 1975; Coleman et al. 1979). The effects of storage time on the dimensional stability of conventional alginate impressions have been the focus of many previous investigations; these studies demonstrated a contraction in the set impression as time increased and continued loss of dimensional accuracy (Miller 1975; Coleman et al. 1979; Cohen et al. 1995; Chen et al. 2004). Therefore, the maximum recommended storage time prior to pouring for conventional irreversible hydrocolloid impressions is approximately 30 minutes after removal from the patient’s mouth (Powers and Sakaguchi 2006).

Extended-Storage Irreversible Hydrocolloids

Recently, extended-storage alginate impression materials have been introduced for use in dentistry. These materials are reported by the manufacturers to have a clinically acceptable dimensional stability up to 100 hours. The limited scientific investigations evaluating the dimensional stability of extended-storage alginates support manufacturers' claims demonstrating acceptable results at 100 hours (Sedda et al. 2008; Imbery et al. 2010; Walker et al. 2010). A recent investigation explained the increased dimensional stability of extended-storage alginates may be related to a higher degree of bound water compared to unbound water and higher ratios of Ca:Na in these materials (Fellows and Thomas 2009). During this study, no evidence of macroscopic syneresis was observed. It is speculated that the higher Ca concentration may result in the fixation of the gel early in the setting process in a configuration that is more open than the more compact configuration formed by the conventional setting process; thus leading to the extended dimensional stability of the impression (Fellows and Thomas 2009).

With the advent of extended-storage alginates, orthodontists can now make use of digital model systems such as OrthoCad, emodel by GeoDigm Corp, and Ortho Cast, Inc (Santoro et al. 2003; Rheude et al. 2005; Alcan et al. 2009; Dalstra and Melsen 2009). These companies generate a digitized set of 3-dimensional models by scanning gypsum casts created from impressions sent to the company (Joffe 2004; Dalstra and Melsen 2009). The digitized casts are then used by the orthodontist for treatment planning, patient consultation and as legal records (Joffe 2004). Moreover, companies such as OrthoCad have begun to do virtual set-ups, indirect bonding, and bracket placement for orthodontists using the digitized casts. Because the digitized casts are generated from impressions that are shipped to the companies, it is critical that the submitted impressions have a high degree of dimensional stability to produce clinically acceptable results (Joffe 2004).

Impression Shipment Considerations

While in transit, impressions are exposed to a wide range of temperatures from extreme heat to subfreezing depending on the method of shipping and season of the year (Purk et al. 1998). Previous investigations have studied the effects of extreme temperatures on elastomeric impression materials shipped to dental laboratories for the fabrication of fixed and removable prostheses (Arvidson and Johansson 1978; Corso et al. 1998; Purk et al. 1998).

With extended-storage alginate impressions being shipped to digital model companies and dental laboratories, these impression are very susceptible to freezing due to the high water content of alginate, approximately 85%, the impressions are susceptible to freezing (Giordano 2000). To date, one study has investigated the effects of freezing on conventional irreversible hydrocolloid impressions (Arvidson and Johansson 1978) . The authors reported that the frozen impressions were cracked and damaged making them clinically unacceptable with cast dimensional changes ranging from -12.1% to 5.6% (Arvidson and Johansson 1978). Currently, there are no studies present in the literature evaluating the effect of freezing on extended-storage alginates. In a recent presentation by a representative from the OrthoCad company, it was reported that the company has received frozen alginate impressions that are unacceptable due to cracks and distortions and as a result, new impressions must be requested (Phelps 2009). In an effort to resolve this problem, the digital model companies have made different recommendations ranging from faster shipping to the addition of isopropyl (rubbing) alcohol to the impression storage bag during the winter months from November to March. Specifically, OrthoCad recommends adding one tablespoon of rubbing alcohol to each bag prior to shipping for conventional alginates but does not recommended adding alcohol to extended-storage alginates impressions (OrthoCAD™ 2009). Emodel company recommends the use of extended-storage alginates with the addition of one tablespoon of rubbing alcohol and to include additional packaging materials to insulate the impressions during shipping (Emodel® 2009). OrthoCast does not have any alcohol recommendation and instead recommends faster shipping methods and avoiding shipment of impressions over the weekend to minimize the chance of freezing (Ortho Cast 2007).

Due to the different recommendations for shipping and lack of associated studies on extended-storage alginates, further investigation is necessary to determine the effects of freezing temperature on these materials.

Problem Statement

The purpose of this study was to evaluate the acceptability and dimensional stability of extended-storage alginate impressions as a function of storage temperature and the use of isopropyl alcohol to counteract the effects of freezing.

Hypothesis

There will be a differential effect of isopropyl alcohol use on impression acceptability and dimensional stability and this effect will vary depending on storage temperature.

CHAPTER 2

MATERIALS AND METHODS

Two extended-storage alginate impression materials[1] were used in this study. These materials purportedly have dimensional stability for up to at least 100 hours as reported by their manufacturer.

Specimen Preparation

Custom Stainless Steel Model

A custom stainless steel model that simulated intra-arch width and length and molar height and width was used (Fig.1). The model included two cylinders representing maxillary first molar clinical crowns. The cylinders were 10 mm in diameter and 7.5 mm in height representing a typical diameter and cervico-occlusal height of maxillary first molars (Ash and Nelson 2003). The two cylinders were 40 mm apart from their centers representing a typical intra-arch width of an 11-12 year old male (Sillman 1964). Arch length was signified by a 30-mm line that bisected the inter-molar width and extended to a cross mark representing the central incisor region on the base of the model. This line simulates the average arch length of an 11-12 year-old male (Moorrees and Reed 1965).

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[1] Alginmax, Lot # 9202, Major Prodotti Dentari S.p.A., Moncalieri (To), Italy;
Cavex Color Change, Lot# 091213 13:07, Cavex Holland B.V., Harmenjansweg 19-21, 2011 AZ Haarlem, Netherlands.

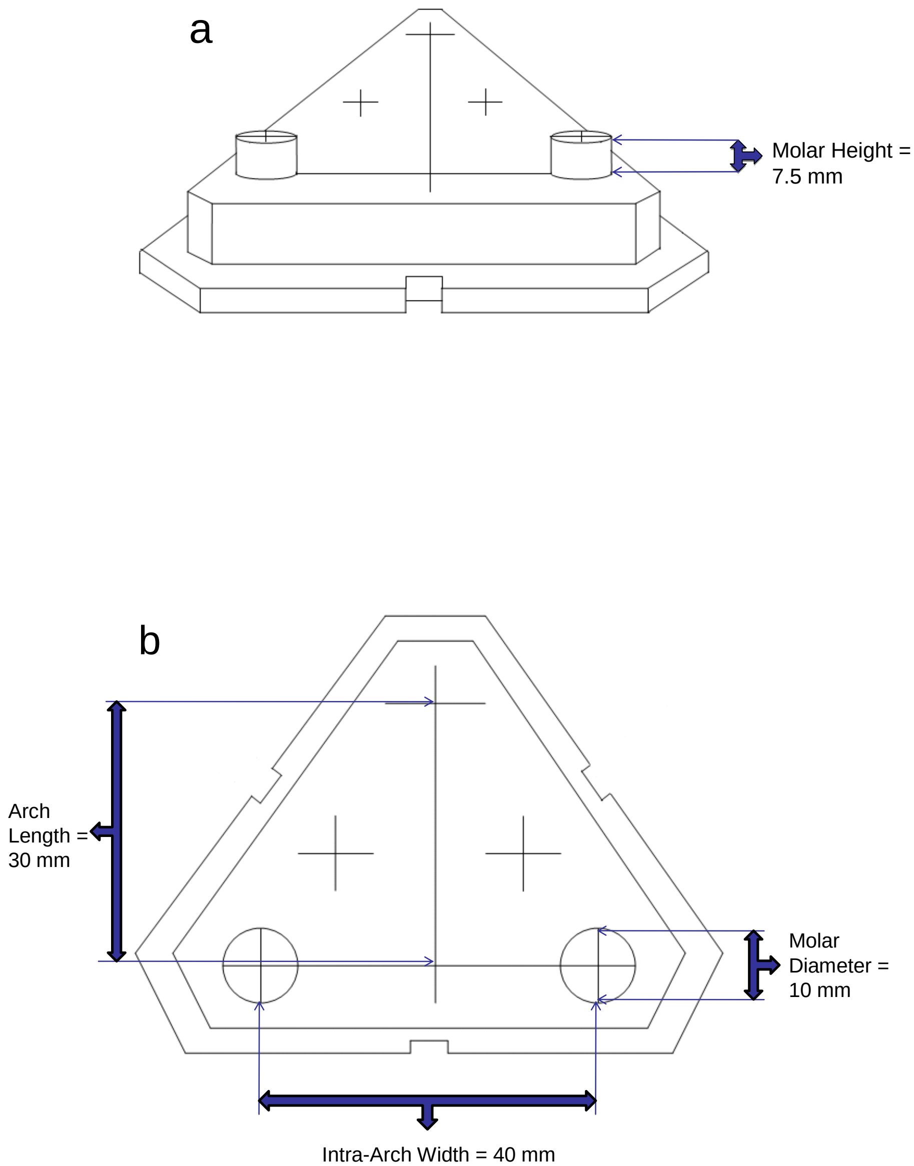

Fig. 1. Diagrams representing stainless steel master model. a. Side view, b. Superior surface view.

Impression Making

Impressions of the master model were made using a custom stainless steel impression tray (Fig. 2) with 3 mm of space for the alginate impression material and seating stops to allow consistent tray placement. The protocol for impression making followed the American Dental Association Specification No. 18 for alginate impression materials (ADA 1992).

With the utilization of an electric alginate mixer[2], the extended-storage alginate powder was mixed according to manufacturer's directions (35 seconds for Alginmax and 30 seconds for Cavex) using distilled water. The utilization of distilled water, instead of tap water, was to prevent the potential interaction of ions in tap water with the chemical reaction and setting of the alginate materials (Bradna and Cerna 2006). Alginate tray adhesive[3] was applied to the impression trays and allowed to dry for at least fifteen minutes prior to making the impression. After each impression, the trays were cleaned with alcohol to remove any residual tray adhesive prior to reapplication to ensure proper adhesion of subsequent impressions (Smith et al. 2002). The mixed alginate was then placed into the impression tray and slightly overfilled. The tray was then vibrated[4] for 10 seconds to reduce air incorporation into the impression material. Twenty seconds prior to the manufacturer's stated working time (1 minute for Algimax and 1 minute 10 seconds for Cavex) the impression tray was seated onto the model lightly coated with silicone emulsion[5]. To simulate oral conditions (as per ADA specification 18), the impression tray and model was placed into an

[2] Alginator, Cadco Dental Products, 600 East Hueneme RoadOxnard, CA 93033
[3] Hold Impression Tray Adhesive, Lot# R334JC, Water Pik, Inc., 1730 E Prospect Road Fort Collins, CO 80553; Cavex Alginate Adhesive, Lot# R334JC, Cavex Holland B.V., Harmenjansweg 19-21, 2011 AZ Haarlem, Netherlands
[4] HV-1, Healthco, Inc., 35 Otis Street Westborough, MA 01581-3311
[5] Mizzy Silicone Emulsion, Lot# YGA, Mizzy, Inc. , 616 Hollywood Avenue Cherry Hill, NJ 08002

850-ml water bath[6] of distilled water maintained at 35 +/- 1°C and loaded with a 1-kg mass conditioned at the same temperature. Three minutes after the manufacturer's stated setting time (5 minutes for Alginmax and 5 minutes 30 seconds for Cavex), the assembly was removed from the water bath and the set alginate impression was separated from the model.

[6] Teledyne Hanau, Water Pik, Inc., 1730 E Prospect Road Fort Collins, CO 80553

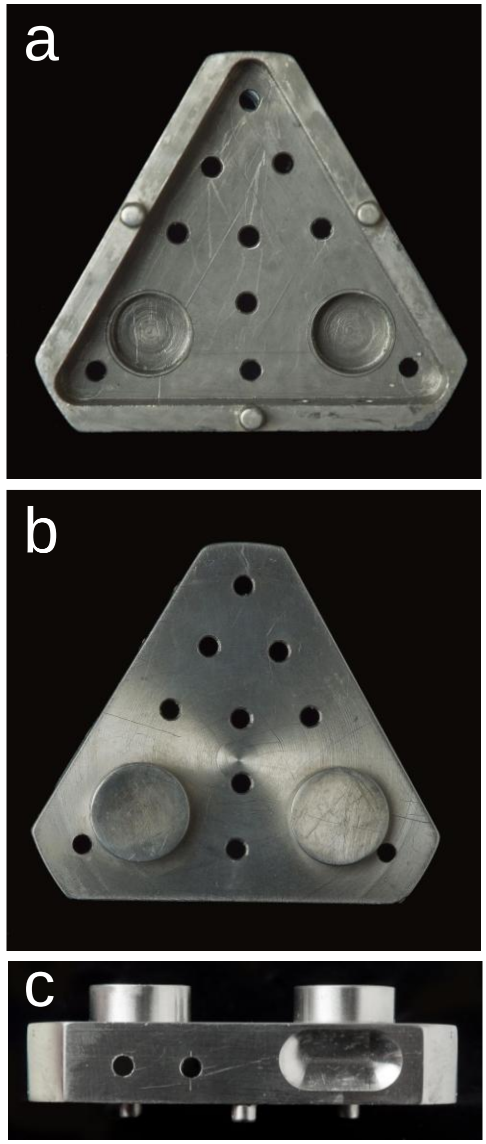

Fig. 2. Custom impression tray. a. Interior surface view. b. Superior surface view. c. Side view

Impression Storage

After the impressions were removed from the model, distilled water was used to rinse the impressions, and excess water was shaken from the impression. Impressions were stored according to manufacturer's directions in a 16.5 cm x 14.9 cm plastic bag[7].

For each impression material, there were four storage conditions that included varying temperatures with impressions stored for 96 hrs to account for the shipping time to digital model companies (Ortho Cast 2007; Emodel® 2009; OrthoCAD™ 2009; Phelps 2009). In addition, some of the impressions were stored with isopropyl alcohol[8] (IA) following the digital model recommendations for shipping impressions during the winter months (Emodel® 2009). Using this protocol, ten impressions of each brand were stored according to manufacturer's recommendations at room temperature. Five (half) of the impressions of each brand stored at room temperature had 15ml of IA added to the storage bags along with the impression.

In order to simulate what occurs when impressions are shipped during the winter months, an additional set of impressions of each brand were exposed to freezing temperatures. This aspect of the protocol included initial storage at room temperature for 24 hours simulating the storage of the impression in the clinician's office prior to shipping. The impressions were then frozen for 36 hours at -10° +/- 2°C to simulate shipping conditions. Finally, the impressions were stored at room temperature for an additional 36 hours representing the time the impressions are stored at the digital model company prior to being poured. A total of ten impressions of each brand were used with the freezing temperature

[7] Ziploc,Lot# 713189 or HO670504W1651, S.C. Johnson & Son, Inc., 1525 Howe Street, Racine, WI 53403
[8] Isopropyl Alcohol 70% Lot# 070572, Van R, Cadco, Clive Craig, 600 East Hueneme Road, Oxnard, CA 93033

protocol with five of those impressions having 15 ml of IA added to the storage bag at placement of the impression.

It's important to note that based on the manufacturers' recommendations Alginmax impressions require a humid environment during storage, while Cavex does not. To achieve this humid environment with Alginmax impressions, a saturated moist paper towel, which has absorbed 25 ml of distilled water, was included in the storage bags. This was done for all Alginmax impressions regardless of whether IA is also included in the bag.

Pouring the Impressions

After 96 hours of storage, the impressions were removed from the storage bags and excess moisture (water and/or IA) was removed using condensed air, being careful not to desiccate the impressions. Type IV dental stone[9] was mixed according to manufacturer's recommendations using 20ml of distilled water per 100g of gypsum powder. The gypsum and water was mixed using a vacuum mixer [10] for 30 seconds. The gypsum was then vibrated[11] into the impressions to reduce air incorporation into the gypsum casts. After 1 hour (final set), the gypsum cast was removed from the impression and examined for any critical voids that would prevent the cast from being used for subsequent measurements. The cast were stored for 48 hours prior to measuring. All procedures and storage were carried out at ambient laboratory conditions.

[9] Resin Rock Gypsum, Lot# 054031002, Whip Mix Corporation P.O. Box 17183 Louisville, KY 40217
[10] Vacuum Mixer Power Plus Whip Mix Corporation P.O. Box 17183 Louisville, KY 40217
[11] HV-1, Healthco, Inc., 35 Otis Street Westborough, MA 01581-3311

Instrumentation and Measurement

Forty-eight hours after casts were removed from impressions, intra-arch length and width measurements were made using a three-axis measuring microscope[12] at 20x magnification with 0.001 mm precision. Each measurement was performed three times to generate individual mean measures. Overall mean measurements of the model were used to determine percentage of change for each dimension using the following equation: [(mean cast measurement – standard model measurement / standard model measurement) x 100].

Sample Size

A power analysis was conducted to determine the sample size to test the primary interaction hypothesis that the effect of freezing on dimensional stability would differ depending on whether alcohol was used or not used. Effect size estimates for dimensional change were obtained from data reported in previous studies. Extended-storage alginates stored at room temperature had a mean percentage change of 0.30 (Walker et al. 2010). Conventional alginate impressions exposed to freezing temperatures had a mean percentage change of 3.7 (Arvidson and Johansson 1978). Conservative estimates of percentage change were made for extended-storage alginates exposed to IA at 1.25 for freezing temperatures and 0.75 for room temperature. Thus, marginal differences were computed and used as the interaction effect size estimates (between alcohol treated versus non-alcohol treated) as 2.4% for impressions stored at freezing temperatures and 0.3% for impressions stored at room temperature. An alpha level of 0.05 and a power of 0.80 were used for the analysis. Results of the power analysis proposed a sample size of five impressions for each group for a total of

[12] Quadra-Chek 200, Metronics, Inc., 30 Harvey Road, Bedford, NH 03110

40 impressions across all groups. At the proposed levels, it was determined that the study would have a power of 91% to yield a statistically significant result.

Impression and Cast Acceptability Composite Score

As the initial data measurements were made, it was evident that the effects of freezing temperatures and IA compromised the integrity of the impressions and associated casts making it impossible to make reasonable arch length and width measurements on those casts. Thus, it was determined that a qualitative analysis would also be required to determine impression and cast acceptability.

A composite scoring system for each impression and its cast was developed using four criteria: 1. Impression to tray separation, 2. Cracking of the impression, 3. Surface changes of the cast, and 4. Residual alginate on the cast. Impression to tray separation was evaluated with a score of 0 for no separation and a score of 1 if any separation occurred. Cracking of the impressions was scored in the following manner: 0 for no cracks, 1 for minimal cracks with dimensions of less than 1mm in height and/or depth, and 2 for large cracks greater than 1mm in height and/or depth. Cast surface changes, distortions and warping, were scored 0 for no changes and 1 if present. Residual alginate on casts were scored 0 for no residual alginate present and 1 if residual alginate was present. The scores for each impression and cast were totaled to produce a composite score that could range from 0-5 with 0 being best and 5 being worst.

Experimental Design

The experimental design was a two-factor non-repeated measures study design. The independent variables included: temperature conditions (frozen for 36 hours or not frozen) and with or without the addition of isopropyl alcohol. The dependent variables were impression and cast acceptability (composite score) and the percent change of arch width and length dimensions. While there were two extended-storage alginate impression materials evaluated, these were not compared statistically. The overall study design of impression storage conditions and impression/cast evaluations is presented in Table 1.

TABLE 1

STUDY DESIGN FOR TWO BRANDS OF EXTENDED-STORAGE ALGINATES, ALGINMAX AND CAVEX

Storage Conditions over 96 hours (N=5)	Impression Acceptability Evaluation	Cast Acceptability Evaluation	Cast Percent Dimensional Change	
			Arch Length	Arch Width
Room Temperature/No IA				
Room Temperature/IA				
Freezing Temperature/No IA				
Freezing Temperature/IA				

*N=5 Impressions of each material per storage condition to generate associated casts

Data Analysis

The impression and cast acceptability scores were analyzed using Fisher's Exact Test, with individual chi-squares used to detect significant differences among the main effects of temperature and IA use for each material. The percentage of change for each dimensional measurement was analyzed using an F-test via a two-factor ANOVA[13]. If the Omnibus test indicated significant differences among groups, a Fisher-Hayter Post Hoc analysis was used to assess pairwise comparisons and allow for control of type I error rate.

[13] SPSS Version 18, 223 S. Wacker Dr., Chicago, IL 60606

CHAPTER 3

RESULTS

Impression and Cast Acceptability

The impression and cast acceptability composite scores are presented in Tables 2 and 3. Representative photos of impressions and casts from each impression material brand and storage condition are shown in Figures 3 and 4, respectively.

Alginmax Alginate

The impression and cast acceptability scoring for Alginmax are presented in Table 2. There was a significant difference across both temperature ($p = 0.001$) and IA use ($p = 0.004$). With impressions stored at room temperature with no IA, there were no deficiencies with the evaluated quality criteria. While for impressions stored at room temperature with IA, the only problem was material separation from the tray (Fig. 3b) with all of the impressions, thus resulting in a composite score of 1 for each. All impressions and casts produced from impressions stored at freezing temperature with or without the addition of IA exhibited numerous problems such as impression/tray separation, large cracks in the impression (Fig. 3c and d), cast surface changes, and residual alginate on the casts (Fig. 4c and d), resulting in a composite score of 5 for each.

Cavex Alginate

The impression and cast acceptability scoring for Cavex are presented in Table 3. Similar to Alginmax, there were significant differences across both temperature ($p = 0.001$) and IA use ($p = 0.001$). Except for freezing temperatures with or without IA, Cavex Color Change performance was the same as Alginmax with no problems for impressions stored at room temperature without IA and tray separation for impressions at room temperature with IA (Fig. 3f). However, there were some differences with Cavex impressions stored at freezing temperature with and without IA as compared to Alginmax. Without the addition of IA, there were problems with tray separation and small cracks (Fig. 3g) in the impressions as well as cast surface effects (Fig. 4g) across test specimens with a composite score total of 3. All impressions and casts produced from impressions stored at freezing temperature with the addition of IA exhibited tray separation (Fig. 3h) and cast surface changes (Fig. 4h) for a composite score of 2. It's important to note that at freezing temperatures with or without IA, none of the casts from Cavex impressions demonstrated residual alginate as was the case with Alginmax impressions.

TABLE 2

ALGINMAX IMPRESSION AND CAST ACCEPTABILITY CRITERIA SCORE FREQUENCIES AND COMPOSITE SCORES

Storage Condition (N=5)	Impression/ Tray Separation	Impression Cracks	Cast Surface Change	Cast Residual Alginate	Composite Score*
Room Temperature/ No IA	0/5	0/5	0/5	0/5	0
Room Temperature/ IA	5/5	0/5	0/5	0/5	1
Freezing Temperature/ No IA	5/5	5/5	5/5	5/5	5
Freezing Temperature/ IA	5/5	5/5	5/5	5/5	5

*Chi-square indicated a significant effect of temperature and IA on impression and cast acceptability composite score.

TABLE 3

CAVEX IMPRESSION AND CAST ACCEPTABILITY CRITERIA SCORE FREQUENCIES AND COMPOSITE SCORES

Storage Condition (N=5)	Impression/ Tray Separation	Impression Cracks	Cast Surface Change	Cast Residual Alginate	Composite Score*
Room Temperature/ No IA	0/5	0/5	0/5	0/5	0
Room Temperature/ IA	5/5	0/5	0/5	0/5	1
Freezing Temperature/ No IA	5/5	5/5	5/5	0/5	3
Freezing Temperature/ IA	5/5	0/5	5/5	0/5	2

*Chi-square indicated a significant effect of temperature and IA on impression and cast acceptability score.

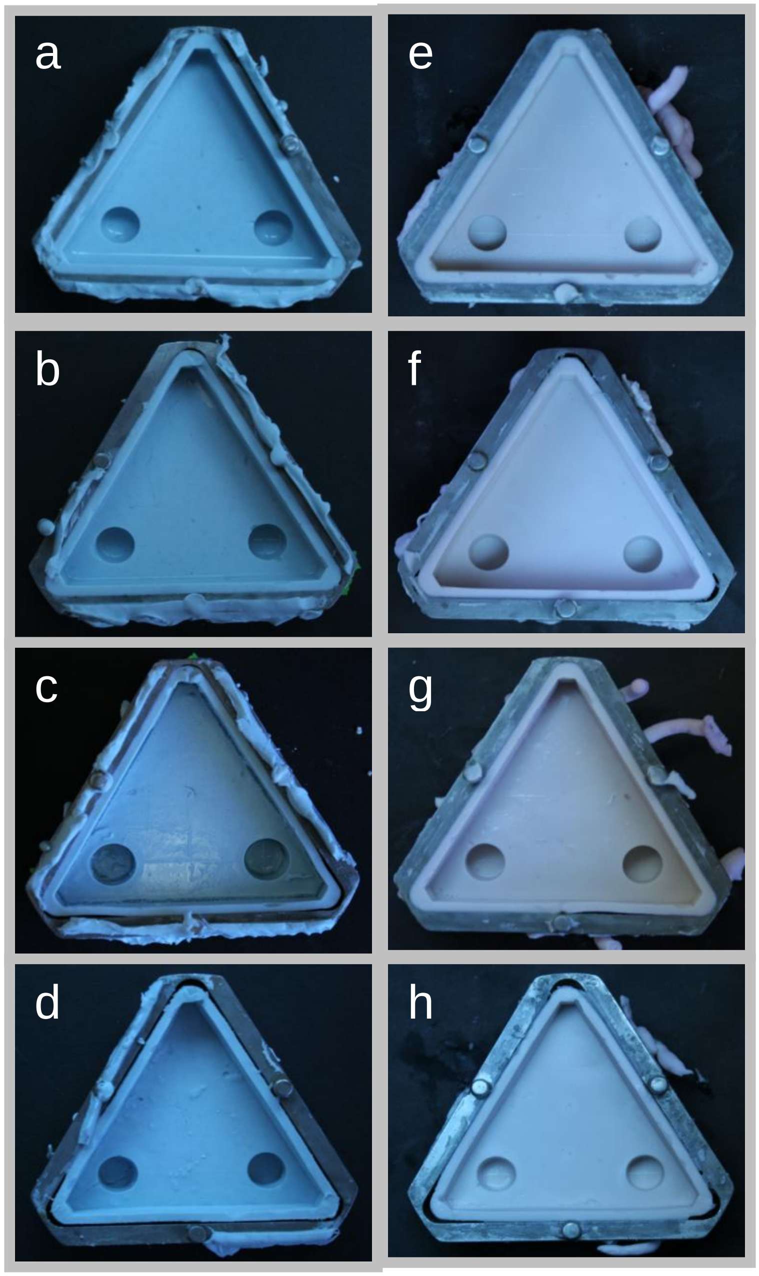

Fig. 3. Representative impressions from each impression material brand and storage condition. a. Alginmax – Room temperature/No IA. b. Alginmax – Room Temperature/IA. c. Alginmax – Freezing Temperature/No IA. d. Alginmax – Freezing temperature/IA. e. Cavex – Room temperature/No IA. f. Cavex – Room Temperature/IA. g. Cavex – Freezing Temperature/No IA. h. Cavex – Freezing temperature/IA.

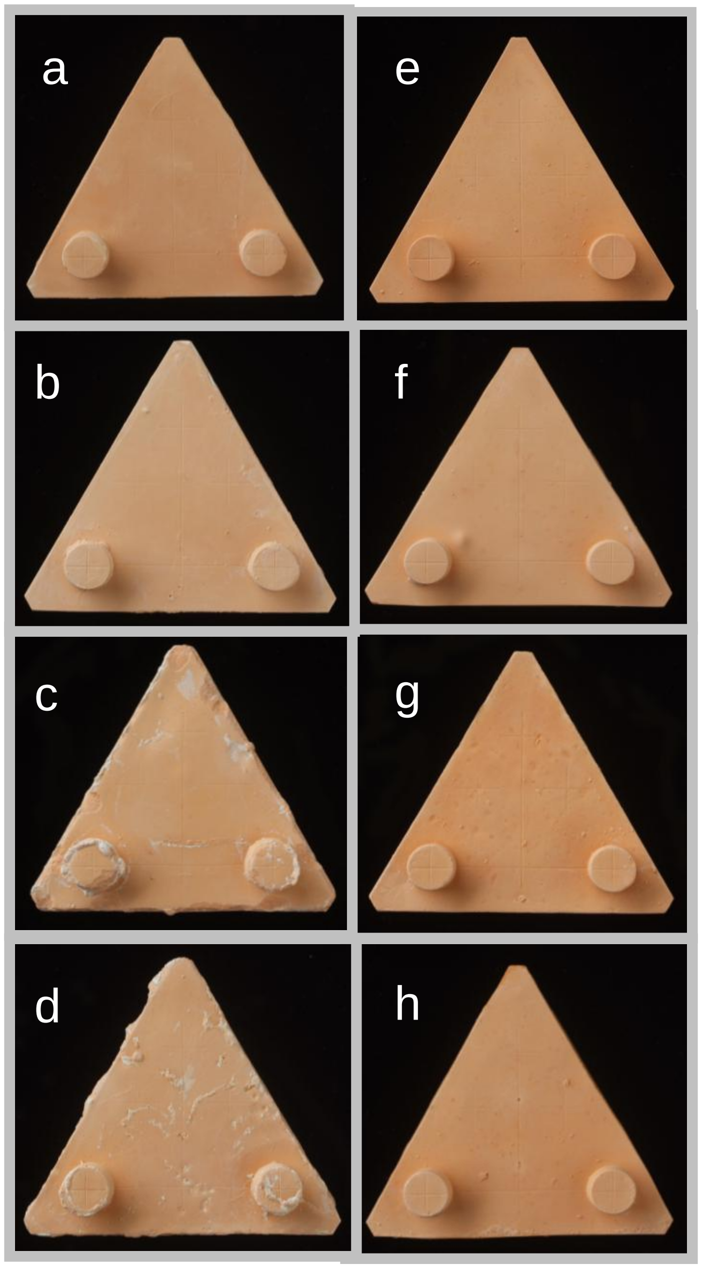

Fig. 4. Representative casts from each impression material brand and storage condition. a. Alginmax – Room temperature/No IA. b. Alginmax – Room Temperature/IA. c. Alginmax – Freezing Temperature/No IA. d. Alginmax – Freezing temperature/IA. e. Cavex – Room temperature/No IA. f. Cavex – Room Temperature/IA. g. Cavex – Freezing Temperature/No IA. h. Cavex – Freezing temperature/IA.

Arch Length and Arch Width Dimensional Change

The percentage change means and standard deviations of arch length and arch width for each impression material and storage condition are presented in Table 4. The dimensional measurement results for both Alginmax and Cavex indicated a significant effect of temperature and the use of IA on impression dimensional stability. However, this was not unexpected due to impression/tray separation with the inclusion of IA, impression cracking with freezing, and the resultant cast distortions. Thus, the dimensional measurements for all groups except impressions stored at room temperature with no IA were not meaningful.

TABLE 4

PERCENT CHANGE MEANS AND STANDARD DEVIATIONS (SD) OF ARCH LENGTH AND ARCH WIDTH FOR EACH IMPRESSION MATERIAL BRAND AND STORAGE CONDITION

	Alginmax		**Cavex**	
Storage Condition (N=5)	**Arch Length***	**Arch Width***	**Arch Length***	**Arch Width***
Room Temperature/No IA	-0.20 (0.03)	-0.21 (0.07)	0.06 (0.19)	-0.03 (0.09)
Room Temperature/IA	0.57 (0.24)	0.50 (0.16)	1.62 (0.38)	1.42 (0.37)
Freezing Temperature/No IA	0.22 (0.58)	-0.04 (0.53)	-0.01 (0.28)	-0.28 (0.45)
Freezing Temperature/IA	2.50 (0.71)	0.69 (0.30)	2.92 (0.73)	1.94 (0.45)

*There was a significant effect of temperature and IA on arch length and width percent change for both materials.

CHAPTER 4

DISCUSSION

With the advent of extended-storage alginates, it is now possible for clinicians to make impressions, which can be shipped directly to digital model companies and dental laboratories. It is important for impressions to maintain their integrity and dimensional stability during shipment regardless of environmental conditions to ensure accurate casts for producing dental appliances and digital models. A digital model company recommends the use of extended-storage alginates with the addition of one tablespoon of isopropyl alcohol (rubbing alcohol) and to include additional packaging materials to insulate the impressions during shipping (Emodel® 2009). This study looked at the effects of freezing temperatures with or without the addition of isopropyl alcohol (IA) on extended-storage alginates. The results of this study indicate freezing temperatures, regardless if alcohol is added to the storage bags as a preventive measure or not, have negative effects on the integrity and dimensional stability of extended-storage alginates.

For Alginmax, with impressions exposed to freezing with or without IA, there were problems with the impressions and the casts including: separation of the impression from the tray, cracking of the impressions, cast surface irregularities and distortions, and residual alginate on casts. Similar to Alginmax, Cavex impressions exposed to freezing temperatures exhibited impression/tray separation with cast surface irregularities and distortions also present. However, the impression cracking pattern was not the same with Cavex impressions; impressions exposed to freezing developed cracks while those frozen with IA did not. Moreover, casts made from frozen Cavex impressions with or without IA did not demonstrate residual alginate. Despite these differences between Alginmax and Cavex impressions exposed to freezing with or without IA, the resultant impressions and casts were not acceptable.

Alginates are composed mostly of water, approximately 85%, which makes them susceptible to freezing (Giordano 2000). The addition of IA to the storage bags was theorized to be a protective mechanism against freezing temperatures. As water freezes to form a solid, it expands and becomes less dense compared to its liquid state. The unpredictable formation of frozen water and subsequent expansion would result in forces within the impression material that could distort and crack the impression. All impressions exposed to freezing temperatures exhibited cracking except for Cavex stored with IA. Thus, it appears IA may have had a protective mechanism against cracking for Cavex impressions exposed to freezing temperatures; however, this was not the case for frozen Alginmax impressions.

However, in spite of this possible protective effect of IA against cracking with Cavex, there were numerous other problems with the impressions and casts with both alginate materials. For example, all impressions frozen with or without IA exhibited separation from the tray, which is likely the result of expansion and shrinkage associated with the freeze/thaw cycle. Impression/tray separation also occurred with all impressions that were stored with IA at room temperature. In this situation, the separation of the tray and the impression material is most likely linked to IA dissolving the tray adhesive, since alcohol is recommended to remove adhesive material from impression trays (Smith et al 2002). Thus, with impressions frozen with IA, tray separation was probably due to a combination of freezing effects and adhesive dissolution that might explain the larger dimensional changes exhibited with these impressions.

Beyond impression/tray separation, there were surface changes on all the casts from impressions that were frozen with or without IA. This effect might be related to the observation of a layer of ice on the surface of all impressions that were frozen. This occurred regardless if IA was included in the storage bags. After removal of the impressions from the freezer, the outer layer of ice thawed leaving a layer of liquid on the impression surface for the remainder of the storage time. The outer ice or water layer might have distorted the impression surface resulting in surface changes in the subsequent casts.

Finally, residual alginate was observed on casts generated from Alginmax impressions exposed to freezing temperatures with or without the addition of IA. Residual alginate was not present on any of the casts produced from Cavex impressions. Explanation of for this effect and the difference between materials is not known. It appears some type of alteration to the surface of Alginmax impressions occurred during freezing and resulted in the adhesion of the alginate to the gypsum cast. This effect not only made separation of the impression and gypsum cast difficult but rendered the cast unacceptable for use.

Due to the problems associated with impression/tray separation and impression cracking, the dimensional measurements were not meaningful for most of the casts in this study. However, the dimensional measurement results for Alginmax and Cavex exposed to room temperature without the addition of IA were comparable to results of previous studies (Imbery et al. 2010; Walker et al. 2010). With similar outcomes, this supports the validity of the measurement protocol along with the unpredictable effects of freezing temperatures and IA on extended-storage alginates.

Clinical Implications

The outcomes of this study indicate that extended-storage alginate impressions should not be shipped if the impressions might be exposed to freezing temperatures. To avoid this problem, the gypsum cast could be poured and shipped to the laboratory as an alternative. For those clinicians who prefer to send impressions directly to the digital model company, non-aqueous impressions materials such polyether or vinyl polysiloxane could be used. Although more costly than extended-storage alginate, non-aqueous elastomeric impression materials are not as susceptible to the effects of freezing and have been shown to maintain dimensional stability similar to impressions stored at room temperature (Arvidson and Johansson 1978).

Limitations of the Study

Being an in vitro study, there are certain limitations when comparisons are made to in vivo experiments and actual clinical situations. It is very difficult to replicate oral conditions in the laboratory. This study was based on impressions made of a stainless steel model, which is different from making intraoral impressions. The presence of saliva, plaque, and a pellicle on teeth alters the surface tension of teeth and facilitates the removal of the impression from the mouth by reducing the potential for adherence of the impression material to the oral structures. In this study, a silicone emulsion was applied to the stainless steel model prior to making each impression in order to try to prevent the adherence of the impression material and subsequent tearing during the removal of the impression from the model. Another consideration is the rigidity of the stainless steel model. Intraorally the periodontal ligament allows for a slight flexion of the teeth during removal of the impression from the mouth. The rigidity of the stainless steel model does not allow for this flexion and may result in distortion of the impression during removal from the model.

Future Studies

Future investigations in the area of extended-storage alginates and environmental shipping conditions should study the effects of extreme heat during the summer months on the dimensional stability of these alginates. Additional studies could investigate the effectiveness of insulated packaging on the acceptability and dimensional stability of extended-storage alginates exposed to both freezing and extreme heat temperatures. It is critical for clinicians to understand the effects of environmental conditions during shipment of extended-storage alginates to digital model companies and dental laboratories.

CHAPTER 5

CONCLUSIONS

1. The addition of isopropyl alcohol during impression storage did not counteract the effects of freezing on the acceptability or dimensional stability of extended-storage alginate impression material.

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