Disinfectant-Induced Surface Changes in Injectable Denture Base Polymer

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Abstract

Introduction:

A variety of challenges confront dentists, including the requirement for optimal materials to successfully provide dental care to their patients. To create functional prosthetics with pleasing aesthetics, these materials need to be biologically compatible, cost-effective, easy to manipulate using controlled technological processes, and readily usable. Within the realm of removable prosthodontics, a multitude of tools and versatile materials are utilized, but they present difficulties in terms of sterilization and cleaning. Prostheses, impressions, and stone casts are examples of such items that increase the likelihood of cross-contamination occurrence among dental clinics and laboratories.

Materials and methods: Polycarbonate and polyamide specimens were immersed in Sodium Hypochlorite (NaOCl) and chlorhexidine solutions at concentrations (0.5% and 2% respectively). In total, 60 specimens were prepared and divided into 3 groups, a control group, 2% chlorhexidine group, and 0.5% NaOCl group. 30 specimens for each of the materials. 10 specimens for each test (Hardness and roughness). The specimens were immersed in the disinfection solutions for five minutes, three times a day, for 12 days. One way ANOVA was utilized for each material followed by independent t test to compare between polycarbonate and polyamide.

Results: The results revealed a significant decrease in hardness of both polycarbonate and polyamide after immersion, while surface roughness was increased.

Conclusions: It was concluded that the immersion of polycarbonate and polyamide in 0.5% sodium hypochlorite and 2% Chlorhexidine solutions can alter surface properties of the injectable denture base materials.

1. Introduction

Numerous materials are employed in the construction of dentures, and each of these materials has an impact on the dimensions of the denture base during fabrication, as well as

various factors relevant to clinical utilization. These elements include stability, support, retention, adaptability, resistance to impact, texture of the surface, and additional aspects. Denture base materials are categorized into various categories and groups depending on their manufacturing method, chemical structure, and processing techniques.

Some thermoplastic polymers like PMMA can be processed by different processing technique such as compression molded and injected molded technique. However, the compression molding of PMMA is the most widely used technique to produce acrylic denture base but change in dimension and shrinkage of the denture base throughout the polymerization, and the presence of residual monomer are the main limitations of this technique. Regarding the fact that the qualities of the denture can be altered not only by the material type used to produce the denture, but also affected by the processing techniques selected, new processing technique were developed to overcome the limitation in conventional compression molded technique such as injected molded technique to improve dentures' efficiency and properties **[1].**

Since its introduction in 1937, polymethyl methacrylate has remained the most widely favored material for denture fabrication. In recent years, thermoplastic materials crafted through injection molding techniques had become popular for denture base fabrication due to their favorable qualities, which include having a higher degree of flexibility than heat-polymerizing base resins and the ability to help retain dentures by making use of the undercuts present in the design of the denture base around abutment teeth. **[2]**

In the 1950s, polyamide emerged as a suggested material for denture base construction **[3]**. Polyamide is a crystalline polymer, whereas PMMA is amorphous. The crystalline nature of polyamide contributes to its resistance to solvents, along with its notable attributes of elevated heat resistance and strong durability. However, this material is not without challenges. Issues such as water absorption, surface roughness, susceptibility to bacterial presence, warping, fading color, and challenges in achieving a polished finish have been reported **[4].**

Crafted from high-quality lightweight plastic, polycarbonate is an amorphous polymer that displays occasional crystalline regions **[5].** Its translucent nature is coupled with exceptional mechanical properties, including remarkable resistance to impacts and structural stability. However, polycarbonate does come with certain property-related drawbacks. These

include low tolerance to chemicals, restricted ability to withstand scratches, and a responsiveness to ultraviolet (UV) rays that initiates alterations in color. **[6].**

The ideal denture base material should be able to withstand masticatory forces, be easy to handle and disinfect, and be biocompatible with oral tissues **[7,8].** For individuals utilizing fixed and partial removable dentures, ensuring denture hygiene, and preserving the well-being of oral mucosa holds significant importance. **[9].** Disinfection involves the application of chemical agents to eliminate or eradicate potentially infectious organisms, and this category encompasses heat-based techniques as well. Various mechanical and chemical methods have been employed to cleanse and disinfect the surfaces of dentures, removing accumulated microorganisms. 0.5% Sodium hypochlorite (NaOCl), 2% chlorhexidine, and denture brushing are among the chemicals utilized for this purpose. Nevertheless, these measures have proven to have adverse effects on the structural integrity of the denture foundation. Sodium hypochlorite is an excellent disinfectant with excellent cleaning properties. The effectiveness of sodium hypochlorite in cleaning and disinfection operations is controlled by the amount of accessible chlorine and the pH of the disinfectant solution **[10].**

2% Chlorhexidine has become one of the best studied antimicrobial agents in recent years. It is the antiseptic of choice for dental biofilm control, and it is important in the prevention of dental caries, gingivitis, and stomatitis. It is also recommended for antisepsis of the hands **[11]**

2. Materials and methods

2.1 Materials used in the study

1. Polycarbonate (Extra rigid polymer M10 XR, Deflex, Argentina. (Figure 2-1B).
2. Polyamide injectable material (Sabilex, Argentina).
3. Isodent gypsum separating solution (Spofa Dental Czechoslovakian Europe).
4. Dental stone (Zermach, EXTRA HARD HIGH DENSITY DIESTONE, Spain).
5. Sodium hypochlorite 3% (PREVEST DENPRO, India).
6. Chlorhexidine 2% (CERKAMED Medical co., Poland).

2.2 Specimens grouping

60 specimens were prepared, 30 polyamide (PA) specimens and 30 polycarbonate (PC) specimens. 10 specimens were control kept in distilled water as control, 10 were immersed in NaOCl, and 10 immersed in Chx for each material.

NaOCl 3% was mitigated to 0.5% by the formula: Concentration before Vs Volume before = concentration after Vs Volume after.

2.3 Test specimens' preparation

The acrylic pattern measurements, designed using computer software (Auto CAD, 2015), was subsequently fabricated utilizing a laser cutting machine. A specialized cutting of clear acrylic sheets (Glass-look acrylic, Clairvauxles Lacsrance, France) was performed as bar shaped specimen with dimensions of (65mm x 10 mm x2.5 ± 0.1 mm) length, width, thickness respectively **[12],** used for surface roughness test and Vickers microhardness test **(Figure 1)**.

Figure 1: Plastic pattern cut using CNC.

2.4 Mold preparation for PC and PA

Separating medium was used to cover the pieces of the metallic dental flask, and then a stone mixture was made according to the manufacturer's recommendations, using 100 g/25ml (powder/water) to fill the lower half of the flask. Meanwhile, it was vigorously vibrated to remove air bubbles. The plastic patterns were then put, with care taken not to fully embed the plastic patterns in the dental stone in order to enable their removal after the flasking procedure is completed. Wax tubes (sprue) were affixed to the plastic pattern to facilitate the injection of material **(Figure 2).**
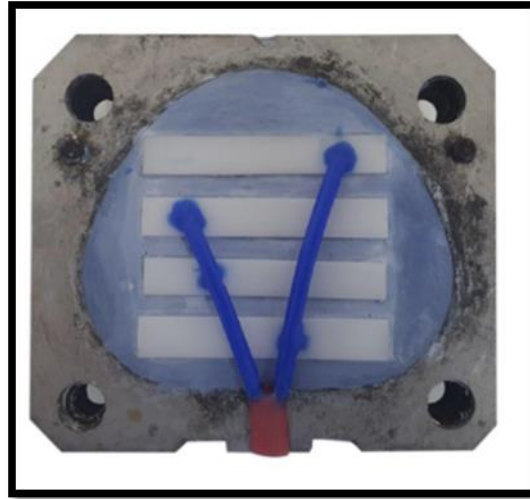
Figure 2: Wax sprue attached.

Both the stone surface and the plastic patterns were covered with separating medium and allowed to dry after the dental stone was fully set. Since assembling the flask's equivalent, the flask was filled by pouring another mix of stone and vibrating it again. The flask's upper lid was mounted, and the flask was tightly clamped until the stone was fully set. Then, the flask placed in boiled water bath for wax elimination.

2.5 Injecting, packing, and finishing of the test specimens.

Polycarbonate and polyamide capsules were placed in the automatic programmable device DEFLEX MAD (for polycarbonate), and Sabelix 2AD (for polyamide), respectively and injected into the flask according to manufacturer's instruction as following:

1. Polycarbonate was injected under pressure (5-7 Bar) and subjected to heat (305°C ± 10°C) for a duration of 15 minutes.

2. Injectable PA was introduced under pressure (5-7 Bar) and exposed to heat (240°C ± 10°C) for 15 minutes. Prior to the injection process, the pressure was verified in accordance with procedural requirements (5-7 bars). Preheating temperature and duration were also scrutinized based on manufacturer's instructions. The appropriate material cartridge for injection was chosen.

The injection process was executed using an automatic programmable device with the

following specifications: digital control, preset programs, user-defined programs, and a pressure gauge (manometer). Before commencing the injection, the pressure for injection was assessed to align with procedural requirements. Similarly, preheating temperature and duration were verified in accordance with the manufacturer's instructions. The appropriate injection material cartridge was selected. To facilitate the process, a Vaseline-based lubricant was applied to the closed end of the cartridge. Subsequently, the cartridge was placed into either of the two heating cylinders, directed towards the flask chamber (Figure 3A). Any excess lubricant on the heating cylinder's edge was removed using absorbent paper. The preheating process was initiated, and an audible signal indicated the end of the preheating duration as chosen.

Once the two halves of the flask were assembled and secured with screws, the flask was positioned within the injecting unit and fixed in place (Figure 3B). The opening of the flask was aligned directly with the cartridge and the heating cylinder. The injection process was initiated by pressing the start key on the control panel, activating the injection procedure.
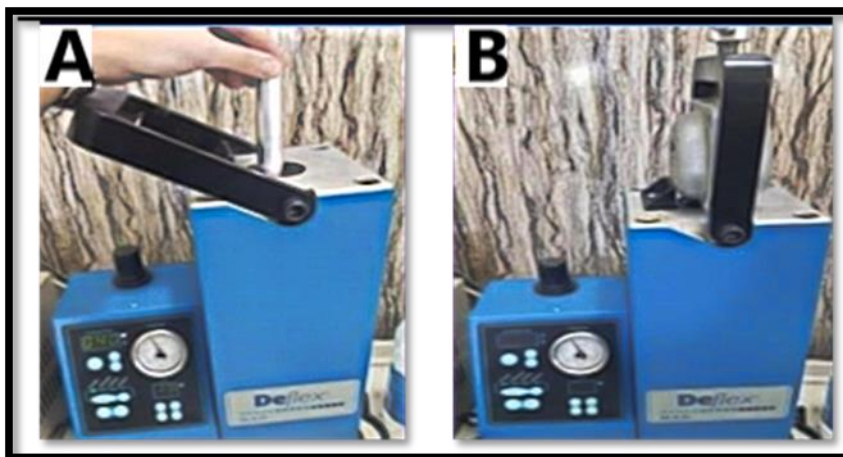

Figure 3: Injection of thermoplastic material; A: Cartilage placed in Automatic programmable device DEFLEX MAD; B: Flask attached to the device DEFLEX MAD.

The setting contraction was compensated for by automatically keeping the pressure constant for (1) minute. The cylinder was then moved about 3 to 4 mm away from the flask so that the cartridge could be separated. Subsequently, the flask was taken out, and the utilized cartridge was automatically released by pressing the evacuation button. To ensure the attainment of optimal material quality, the flask was subjected to gradual cooling over a period

of approximately 8 to 9 hours. Following the cooling process, the screws securing the flask were loosened, and the two halves of the flask were carefully separated. This allowed for the removal of the specimens from the molds (Figure 4).
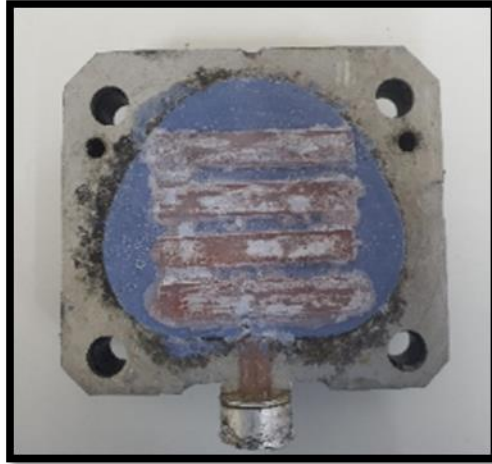

Figure 4: Specimens after de-flasking.

2.6 Finishing and polishing

After the process of removing the specimens from the molds (de-flasking), any excess material was carefully removed to achieve a clean finish. The specimens made from polycarbonate and Polyamide were separated, and the sprue was eliminated using a metal disk for cutting. Subsequently, each individual specimen underwent finishing using specialized plastic burs tailored for this purpose. The removal of excess material was performed with an acrylic bur. Following this, all specimens underwent a finishing process involving sandpaper with a grain size of 120. To prevent overheating, the specimens were periodically cooled by immersing them in a rubber bowl filled with distilled water. This cooling process involved a 15-second interval of finishing followed by a 15-second immersion in water.

The completed specimens of each test group were collected and housed within plastic containers. These containers were filled with distilled water and subsequently placed within an incubator set at 37°C for a period of 48 hours, adhering to the specifications outlined in the ADA 1999 standard [12]. The purpose of this incubation was to eliminate any residual byproducts from the specimens.

2.7 Disinfection procedure

Each specimen will be immersed in the disinfecting solutions for 5 minutes, 30 times a day for 12 days to simulate 1-year interval and after each immersion the specimen will be taken out and rinsed with running water and dried with absorbent paper and the procedure of immersion will be repeated simulating the patient denture cleaning **[9].**

2.8 Vickers hardness and surface roughness tests

The Vickers hardness test was performed with (laryee hvs-5Manufacturing Limited, Beijing, China), specimens were submitted to a 25-g load for 30 second. Three places were utilized on the specimen. One in the center and two on either end. The average of three readings was calculated (Figure 5).

Figure 5: Vickers hardness tester.

Surface roughness test was performed using a profilometer (Figure 6). This tester contains a diamond sensible needle (stylus) used to track the irregularities on the surface. Using a stylus, the surface of the specimen is engaged at three distinct points across its surface to obtain three readings from each specimen. The specimen is positioned on a stable and firm surface, and the stylus is allowed to make contact with the first point. Subsequently, the stylus is moved along the surface for a distance of 11 mm. The readings are automatically displayed

on a digital scale as they are generated. The average of the three readings is then calculated to determine the roughness value of the specimen.

Figure 6: Surface roughness testing Profilometer.

2.9 Statistical analysis

An ANOVA test was used to compare the mean values of the tested groups (one-way analysis of variance). Levene's test was used to assess the homogeneity of variance in each test. To see if there was a significant difference between the groups, Tukey's post-hoc test (multiple comparisons) was used.

3. Results and discussion

3.1 Surface hardness

Hardness refers to a material's capacity to withstand wear and abrasion from adjacent dental structures. It serves as an indicator of a material's resilience and its ability to resist damage. The concept of hardness is frequently employed to investigate various factors that impact the extent of resin conversion. Because of the simplicity of the process, it is possible to characterize the mechanical properties of a polymer. In addition to the availability of the specimen preparation and test procedure equipment **[13].** This experiment used a Vickers microhardness tester, which is appropriate for determining the hardness of denture bases. The Vickers microhardness tester eliminates the problem of elastic recovery due to its design. The application of a technology that directly measures the depth of the loaded indentation by a screen that displays the number of them **[14].**

Following immersion, a statistically significant reduction in surface hardness was observed in both the PC and PA groups when compared to the control groups **(Table 1).** This change can be attributed to the degradation induced by the concentrations of NaOCL and Chx.

Subsequent to immersion, the damage acquired by the material matrix intensifies the mechanism of water transport, thereby increasing water absorption **[15].** The presence of oxygen within carbonate groups (CO3) in PC and PA renders them vulnerable to water absorption. As water molecules accumulate around the polymer chains of PC and PA, the structure of the polymer becomes distorted and more open, leading to an increased free volume. This enhanced diffusion of water molecules into the polymers has a plasticizing effect, gradually relaxing the polymer chains, and consequently causing a decline in hardness **[16,17].**

Table 1: Descriptive statistics, one way ANOVA and Tuckey test of hardness for PC and PA.

Polycarbonate PC			Post-hoc test	Polyamide PA		
Groups PC	**Mean PC**	**ANOVA**	**P value**	**Groups PA**	**Mean PA**	**ANOVA**
Control (A)	**83.758**	**0.000 H. S**	**A and B 0.025 H. S**	**Control (A)**	**67.860**	**0.801 N.S**
Chx (B)	**82.051**		**A and C 0.000 H. S**	**Chx (B)**	**67.740**	
NaOCl (C)	**80.286**		**B and C 0.020 H. S**	**NaOCl (C)**	**67.660**	
Levene's test P-value: 0.192				**Levene's test P-value: 0.625**		

Independent t test was then conducted to evaluate the differences between the means of the groups (Pc and Pa). There were highly significant differences between all the groups in the study **(Table 2).**

Table 2: Independent T test of hardness test between PC and PA.

Material \ Solution	PC		PA		**P–value**	**Sig.**
	Mean	**S.D.**	**Mean**	**S.D.**		

Distilled	**83.7580**	**1.10368**	**67.8600**	**0.73060**	**0.000**	**H.S.**
Chx	**82.0510**	**1.68362**	**67.7400**	**0.56608**	**0.000**	**H.S.**
NaOCl	**80.2860**	**1.23996**	**67.6600**	**0.71212**	**0.000**	**H.S.**

3.2 Surface roughness

The profilometer device was used in this study which was reported to be an excellent device for studying the surface roughness of restorative materials and giving measurements that can be evaluated and compared. Surface texture plays a crucial role as it can lead to the accumulation of bacteria on uneven denture surfaces, influencing oral well-being **[18].** The coarseness of denture surfaces is influenced by factors such as material properties, polishing methods, and the proficiency of the practitioner **[19].** All resin materials should aim for a smooth, scratch-free surface, because an increase in surface roughness can decrease denture esthetics, while a decrease in surface roughness can improve denture esthetics, Surface roughness helps to prevent bacterial build-up and plaque formation accumulation **[20].**

The results revealed an increase in surface roughness of both PC and PA after the immersion in disinfecting solutions **(Table 3).**

Table 3: Descriptive statistics, one way ANOVA and Tuckey test of roughness for PC and PA.

Polycarbonate		ANOVA	Post-hoc test	Polyamide		ANOVA
Groups PC	**Mean PC**	**ANOVA**	**P value**	**Groups PA**	**Mean PA**	**ANOVA**
Control(A)	**3.393**	**0.000 H. S**	**A and B 0.024 H. S**	**Control(A)**	**1.794**	**0.297 N. S**
Chx (B)	**3.559**		**A and C 0.000 H. S**	**Chx (B)**	**1.982**	
NaOCl (C)	**3.794**		**B and C 0.002 H. S**	**NaOCl (C)**	**1.994**	
Levene's test P-value: 0.113				**Levene's test P-value: 0.201**		

The observed increase in surface hardness with the presence of sodium hypochlorite (NaOCl) and chlorhexidine (Chx) can be attributed to their induced increase in hydrophilicity and the presence of ester bonds in the material. Ester bonds are susceptible to degradation by water, particularly under alkaline conditions. This degradation process may involve the hydrolysis of a polyester chain into two sub-chains with carboxyl and hydroxyl terminations [21].

Increase the number of the molecular chain per unit cross section and increase in the junction number will cause increase in surface roughness [21], this agrees with Wang et al. in 2019 [23]. An alternative explanation suggests that the observed increase could stem from the phenomenon where a polymer, upon exposure to a solution, undergoes hydrolytic breakdown. This breakdown is a consequence of the chemical interaction occurring between the solution and the organic matrix present within the interstitial spaces between the polymer chains [24].

Independent t test was conducted to reveal the differences between PC and PA groups in the immersion solutions, there were highly significant differences between all the groups (**Table 4**).

Table 2: Independent t test between PC and PA.

Material / Solution	PC		PA		P–value	Sig.
	Mean	S.D.	Mean	S.D.		
Distilled	3.392	0.1410	1.794	0.208592	0.000	H.S.
Chx	3.560	0.0939	1.982	0.372922	0.000	H.S.
NaOCl	3.794	0.1570	1.994	0.340424	0.000	H.S.

4. Conclusions

The study highlighted how sodium hypochlorite and chlorhexidine influenced surface hardness and roughness through hydrophilicity and ester bond interactions. This research contributes to our understanding of surface properties in dental materials and their implications for denture aesthetics and hygiene.

Conflict of interest

None

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