

Comparative Evaluation of Weight Variation and Mechanical Properties of Thermoplastic Materials Post Salivary Storage

Dr Shubhaker Rao Juvvadi^{*1}, Dr Himabindu², Dr Shivangi Gupta³, Dr Pradeep Raghav⁴, Dr Munish Reddy⁵, Dr Ashish Chauhan⁶

¹PhD Research Scholar, Department of Orthodontics and Dentofacial Orthopaedics, Subharti Dental College & Hospital Swami Vivekanand Subharti University, Meerut– 250005, Uttar Pradesh.

²MDS – Orthodontics & Dentofacial Orthopedics, Private Practitioner, Adilabad

³MDS – Orthodontics & Dentofacial Orthopedics, Reader, Department of Orthodontics & Dentofacial Orthopedics, Sri Balaji Dental College, Hyderabad.

⁴MDS – Orthodontics & Dentofacial Orthopedics, Professor & Head, Department of Orthodontics & Dentofacial Orthopedics Subharti Dental College & Hospital Swami Vivekanand Subharti University, Meerut– 250005, Uttar Pradesh.

⁵MDS – Orthodontics & Dentofacial Orthopedics, Professor, Department of Orthodontics & Dentofacial Orthopedics, Subharti Dental College & Hospital Swami Vivekanand Subharti University, Meerut– 250005, Uttar Pradesh.

⁶Reader, Department of Orthodontics and Dentofacial Orthopedics, Saraswati Dental College Lucknow, Uttar Pradesh.

*Corresponding Author:

Dr Shubhaker Rao Juvvadi, PhD Research Scholar, Department of Orthodontics and Dentofacial Orthopaedics, Subharti Dental College & Hospital Swami Vivekanand Subharti University, Meerut– 250005, Uttar Pradesh.

Email ID: shubhaker@gmail.com

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ABSTRACT

The increasing demand for clear aligner treatments has highlighted the importance of metal-free thermoplastic materials in orthodontics. Materials such as Erkodur, Duran+, Imprelon, CA Pro+, Monoflex, and Leone are commonly used for fabricating these aligners. A study was conducted to evaluate the effect of storage in artificial saliva on the weight variation of specimens with different thicknesses (0.5, 0.6, 0.75, and 1 mm). The results indicated that immersion in artificial saliva leads to an increase in weight due to water absorption, which can affect the mechanical properties and fit of the aligners.

Thermoplastic materials like PETG and TPU are known to absorb water when exposed to saliva, leading to dimensional changes and potential alterations in mechanical properties. For instance, a study found that TPU exhibited higher water absorption compared to PETG, with TPU showing a 1.45% weight increase after one week of water storage, while PETG showed a 0.84% increase. These changes can impact the force exerted by the aligners, potentially affecting treatment outcomes.

In conclusion, while metal-free thermoplastic materials are essential in clear aligner therapy, their interaction with artificial saliva can lead to weight gain due to water absorption. This underscores the need for careful selection and testing of materials to ensure the effectiveness and longevity of orthodontic treatments.

Keywords: Clear aligners, Thermoforming process, Artificial saliva, Weight variation.

1. INTRODUCTION

For years the term ‘Orthodontics’ conjured the images of metal wires, brackets and middle school chants of “braceface”, all of which are effective deterrents from the orthodontist’s office. However, orthodontics is more than just braces. The trend in clinical field has shown a paradigm shift from conventional braces to innovative technologies like clear aligners¹.

In recent years, there has been increase in numbers of adult patients seeking orthodontic treatment with enhanced esthetics and comfortable appliance as an alternative to the fixed appliances². This higher demand led to the

introduction of clear aligners. Clear aligners are thin clear flexible ‘mouth guards’ which fits closely over the teeth³. A series of aligners is used to move the teeth incrementally according to the treatment plan of Orthodontist. Aligners are ideally suited for adult patients because of their life-style, work pressure makes it difficult to wear more visible conventional fixed appliances.

Clear aligners involves a series of thermoformed appliances which uses computerized 3D technology to visualize and move the teeth in a virtual model made from a transparent, thin (less than 1 mm) plastic material formed with CAD-CAM laboratory techniques³. These aligners are similar to the splints that cover the clinical crowns and the marginal gingiva. Each aligner is designed to move the teeth a maximum of about 0.25 to 0.3 mm over a two-week period⁴. Excellent compliance is mandatory since the appliance has to be worn a minimum of 20 to 22 hours a day⁵. The aligners available today are vastly different than those available earlier. Various types of aligners are available today throughout the world and marketed to treat everything from mild to more complex malocclusions⁶. Thermoplastic materials like PETG and TPU are commonly used in clear aligners, but their interaction with saliva can affect their performance. Both materials are hygroscopic, meaning they absorb water when exposed to saliva, which can lead to dimensional changes and alterations in mechanical properties.

AIM: To evaluate the influence of artificial saliva on mechanical properties as well as weight variation of the various thermoplastic materials used in the present study.

2. MATERIALS AND METHODS:

The procedure is designed to inspect the influence of thermoforming process and the possible effects of material degradation due to a simulated intraoral environment. The materials investigated were: Erkodur, Duran+, Imprelon, CA Pro+, Monoflex, Leone.

Tests were carried out on material after thermoforming (T0), after storage in saliva for a week (T1) and after storage in artificial saliva for 14 days (T2)⁷. The materials are supplied as circular sheets with a diameter of 125 mm and various thicknesses. For the sample preparation of all the materials to be investigated, a thermoforming process was performed normally adopted to fabricate clear aligners under manufacturer’s recommendations for pressure, heating and cooling time⁷.

The thermoforming machine used is Biostar, (Scheu-Dental, Iserlohn, Germany)(Figure 1a). In the present study, a dumbbell shaped wooden disk of 25mm diameter and 80 mm height was used as template for the thermoforming process⁷ (Figure 1b). The geometry of the mould is designed to provide a flat area where the material could be thermoformed and the samples could be cut. Each type of thermoplastic material sheet was thermoformed using a dumbbell disk. After thermoforming, the cross section dimensions of each sample are accurately trimmed and finished with burs using a micromotor.

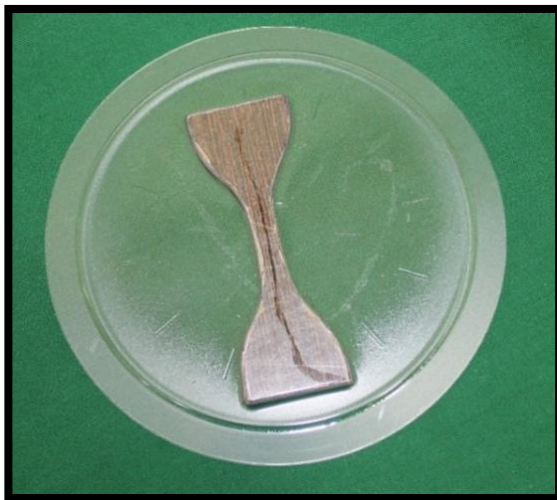


Figure- 1b. Dumbell Disk



Figure 1a. Thermoforming process



Figure- 2. Artificial Saliva



Figure- 3 Falcon tube with Saliva



Figure- 4. Incubator



Figure- 5. Weighing Scale

The experimental tests were designed for determining the weight variation after storage in artificial saliva⁷ (Table-1). To correspond, as suggested by the normative ISO527-1^{8,9} was adopted and the 5 samples of each size from each type of thermoplastic material at varying stages were tested.

Table-1: Chemical composition of artificial saliva (pH =6.5) used to recreate the biochemical environment of human saliva.

COMPOUND	CONTENT(g/L)
Nacl	0.35
Kcl	0.0466
NaHco3	0.1785
C2H6O2	13.125

3. RESULTS:

The materials analyzed under different testing conditions namely, thermoformed (T0), after storage in saliva for a week (T1) and in two weeks (T2) were compared and the results for change were tabulated in table 2.

Table 2: Weight variation of material specimen due to fluid absorption, before and after storage in artificial saliva.				
Material	0.5mm	Variation % T0 - T1	Variation % T0 - T2	Variation % T1 - T2
DURAN +	Single dumbbell	11.8	15.8	3.5
	Double dumbbell	14.7	18.7	3.5
ERKODUR	Single dumbbell	1.4	1.4	0.0
	Double dumbbell	1.4	2.7	1.4
TAGLUS PREMIUM	Single dumbbell	4.2	8.3	4.0
	Double dumbbell	4.1	6.8	2.6
NATURALIGNER	Single dumbbell	1.4	1.4	0.0
	Double dumbbell	1.4	2.8	1.4
CA Pro+	Single dumbbell	9.2	10.5	1.2
	Double dumbbell	9.0	9.0	0.0
Material	0.6	Variation % T0 - T1	Variation % T0 - T2	Variation % T1 - T2
DURAN +	Single dumbbell	11.1	13.6	2.2
	Double dumbbell	10.0	10.0	0.0
ERKODUR	Single dumbbell	2.2	3.3	1.1
	Double dumbbell	2.2	4.3	2.1
Material	0.75mm	Variation % T0 - T1	Variation % T0 - T2	Variation % T1 - T2
DURAN +	Single dumbbell	15.9	14.8	-1.0

	Double dumbbell	14.1	16.2	1.8
ERKODUR	Single dumbbell	1.8	2.7	0.9
	Double dumbbell	2.6	2.6	0.0
TAGLUS PREMIUM	Single dumbbell	5.0	5.9	0.9
	Double dumbbell	6.7	8.7	1.8
NATURALIGNER	Single dumbbell	2.2	2.2	0.0
	Double dumbbell	3.1	3.1	0.0
TRACK	Single dumbbell	6.8	15.4	8.0
	Double dumbbell	11.7	15.8	3.7
IMPRILON	Single dumbbell	6.5	10.4	3.7
	Double dumbbell	5.4	10.8	5.1
MONOFLEX	Single dumbbell	5.4	6.5	1.0
	Double dumbbell	5.4	6.5	1.0
LEONE	Single dumbbell	10.7	16.1	4.8
	Double dumbbell	12.7	14.3	1.4
ZENDURA	Single dumbbell	6.3	7.4	1.0
	Double dumbbell	5.1	6.1	1.0
TAGLUS PU	Single dumbbell	11.5	19.5	7.1
	Double dumbbell	10.5	13.7	2.9
GT FLEX	Single dumbbell	12.3	18.9	5.8
	Double dumbbell	10.8	17.5	6.0
Material 1mm		Variation % T0 - T1	Variation % T0 - T2	Variation % T1 - T2
DURAN +	Single dumbbell	15.7	18.3	2.3
	Double dumbbell	15.9	17.4	1.3
ERKODUR	Single dumbbell	1.5	2.2	0.7
	Double dumbbell	1.4	2.1	0.7
TAGLUS PREMIUM	Single dumbbell	4.3	5.8	1.4
	Double dumbbell	4.3	7.1	2.7
NATURALIGNER	Single dumbbell	1.8	3.5	1.7
	Double dumbbell	1.7	2.6	0.8
TRACK	Single dumbbell	9.9	12.8	2.6
	Double dumbbell	11.1	13.9	2.5

4. DISCUSSION:

Study compared exhibited higher water absorption, with a 15.9% to as low as 1.4% weight increase after one week of immersion in saliva and 18.7% and 1.2% after 14 days. The weight variation % between the two weeks varied from as little as 0 to as high as 8%

This higher water absorption can lead to increased molecular mobility and plasticization, weakening the internal structure and potentially causing internal cracks in the aligners.

A part of this study is in accordance with the study done by Bucci et al¹⁰, who evaluated the thickness changes of PET-G sheets used for fabricating clear aligners, before and after 10 days of intraoral use with no significant results but concluded that thermoforming process reduces the thickness of aligners compared to original dimension of thermoplastic material.

Duran+ in comparison with Imprelon results showed increase in thickness. This is in accordance with the study done by Ryokawa et al¹¹ who concluded that Duran+ showed increase in thickness after storage in saliva compared to Imprelon while it is similar with the present study in which Duran+ also showed increase in thickness after storage in saliva. The thickness changes were more in thermoformed materials compared to pre-thermoformed sheets, this difference may be attributed to the changes in the thermoforming procedures¹² which is under manufacturer's recommended pressure, heating and cooling time of materials.

Structurally, polymer materials are either amorphous or partly crystalline. Many amorphous plastics are clear because visible light can pass through polymers. In contrast, many crystalline plastics are opaque because they contain mixtures of crystalline and amorphous polymers with different refractive indexes. So, thermoplastic materials crystallize from the amorphous state because of the high temperature and pressure applied to the material, with the regular polymer chains closely arranged over a relatively long distance. Thus, the surface hardness may increase with transformation of the amorphous regions into crystalline regions.^{11,13}

This is contradicting the study done by Ryu et al¹⁴ and Liu et al¹⁵ who evaluated elongation at break for different kinds of thermoplastic materials (PET-G) and concluded that decrease in elongation after immersion in saliva.

Furthermore, the absorption of water can reduce the glass transition temperature (T_g) of the material, promoting molecular movement within the polymer matrix and leading to degradation. This degradation can result in a decrease in the elastic modulus, flattening of the stress-strain curve, and a reduction in the material's ability to maintain its shape and force application over time.

In summary, while PETG and TPU are popular choices for clear aligners, their water absorption properties can impact their mechanical performance and longevity. Understanding these effects is crucial for optimizing aligner materials and ensuring effective orthodontic treatment outcomes.

5. CONCLUSIONS:

- The thickness decreases after thermoforming and increases after storage in artificial saliva.
- Thermoforming process does affect mechanical properties of thermoplastic materials.
- Noticeable increase in weight is observed after salivary storage and it increase drastically at the end of week 1 but increases slightly by week 2 compared to 1st week.

There could be deterioration of thermoplastic materials in simulated intraoral environment

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