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EFFECT OF LEVOSALBUTAMOL BRONCHODILATOR INHALER ON THE TENSILE STRENGTH OF ORTHODONTIC ELASTOMERIC MODULES: AN IN VITRO STUDY

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Abstract

Background. Orthodontic elastomeric modules are widely used to deliver continuous forces during orthodontic treatment but may undergo mechanical degradation when exposed to chemical and environmental conditions in the oral cavity. Levosalbutamol is a selective β2-adrenergic agonist commonly administered through inhalers for asthma management. During inhaler use, aerosolized medication and formulation components may contact the oral cavity and potentially interact with orthodontic elastomeric materials. Because these materials are polyurethane-based, repeated exposure to inhaler aerosols may alter their mechanical properties, including tensile strength. However, the effect of repeated levosalbutamol inhaler exposure on the tensile strength of orthodontic elastomeric modules has not been specifically established, warranting further investigation under simulated intraoral conditions.

Methods. An in vitro randomized controlled experimental study was conducted using 68 unused clear E-link polyurethane orthodontic elastics randomly allocated into four groups ($n = 17$): baseline, artificial saliva control, artificial saliva with two puffs/day of levosalbutamol bronchodilator inhaler, and artificial saliva with four puffs/day of levosalbutamol bronchodilator inhaler. Tensile strength was measured using a calibrated Universal Testing Machine. Data were analyzed using one-way analysis of variance (ANOVA) followed by Tukey's Honestly Significant Difference (HSD) post hoc test, with statistical significance set at $p < .05$.

Results. Repeated levosalbutamol bronchodilator inhaler exposure significantly reduced the tensile strength of E-link orthodontic elastics. The baseline group demonstrated the highest mean tensile strength, whereas the four-puff exposure group showed the lowest. One-way ANOVA revealed significant differences among the four experimental groups ($p< .001$), and Tukey's HSD test demonstrated significant pairwise differences between all groups.

Conclusion. Repeated exposure to levosalbutamol bronchodilator inhaler aerosols significantly reduced the tensile strength of the tested polyurethane orthodontic elastomeric modules under simulated intraoral conditions. These findings indicate a potential effect of inhaler exposure on the mechanical integrity of the tested material in vitro. However, the findings cannot establish effects on clinical force delivery, replacement intervals, or patient outcomes. Further in vivo studies are needed to determine

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the clinical significance of these findings.

Keywords: *Bronchodilator inhaler; in vitro; levosalbutamol; orthodontic elastomeric module; orthodontic materials; polymer degradation; tensile strength*

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Research Highlights

What is the current knowledge?

- Orthodontic elastomeric materials are susceptible to mechanical degradation under environmental conditions, including variations in temperature and storage conditions.
- Chemical and environmental exposures, including cigarette smoke, electromagnetic radiation, mouthwashes, disinfectants, acidic solutions, and commonly consumed beverages, can alter the mechanical properties and force behavior of orthodontic elastomeric materials.
- Previous studies have demonstrated that chemical exposure can contribute to force decay and changes in the tensile or mechanical properties of orthodontic elastomers.
- Antiasthmatic inhalers have been reported to affect the surface characteristics of dental and orthodontic materials; however, their effects on the tensile strength of orthodontic elastomeric modules remain insufficiently investigated.

What is new in this study?

- This study evaluated the effect of repeated exposure to the tested levosalbutamol bronchodilator inhaler formulation on the tensile strength of orthodontic elastomeric modules under simulated intraoral conditions.
- Increasing exposure to the tested inhaler formulation was associated with progressively lower tensile strength across the experimental conditions.
- Significant differences were observed among the baseline, artificial-saliva control, low-exposure, and high-exposure groups.
- The findings provide in vitro evidence of an association between repeated exposure to the tested bronchodilator inhaler formulation and reduced tensile strength of orthodontic elastomeric modules.
- The study identifies an underexplored interaction between the complete tested inhaler formulation and orthodontic elastomeric materials, providing a basis for further investigation under clinically representative conditions.

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INTRODUCTION

Orthodontic treatment relies on the application of light, continuous, and biologically compatible forces to achieve controlled tooth movement while minimizing undesirable biological effects (Singh et al., 2012). Orthodontic elastomeric materials, including polyurethane-based elastomeric modules and chains, are widely used in clinical practice because of their elasticity, ease of application, and ability to provide continuous force during orthodontic treatment. However, their mechanical performance may deteriorate during exposure to the oral environment. Changes in force delivery and mechanical properties may affect the consistency of orthodontic mechanics and potentially influence treatment efficiency.

The mechanical behavior of orthodontic elastomeric materials is influenced by multiple environmental and chemical factors. Temperature, storage conditions, moisture, saliva, pH changes, acidic solutions, beverages, mouthwashes, disinfectants, and other chemical exposures have been investigated as potential contributors to force degradation and changes in the mechanical properties of orthodontic elastomers (Singh et al., 2012; Piradhiba et al., 2021; Khaleghi et al., 2021; Ebrahiminik et al., 2021; Osorio et al., 2022; Castelló et al., 2023; Nobahari et al., 2024; Torres-Rosas et al., 2023). Additional studies have examined the effects of cigarette smoke and electromagnetic radiation on orthodontic elastomeric materials (Ferraz et al., 2020; Bhatia et al., 2023). Collectively, these findings demonstrate that orthodontic elastomeric materials are susceptible to changes in their surrounding chemical and environmental conditions.

Because orthodontic elastomeric materials are primarily polyurethane-based, their mechanical properties may be affected by chemical and environmental processes such as hydrolysis, oxidation, swelling, and polymer-chain scission (Xie et al., 2019). These processes may contribute to deterioration of the polymer matrix and changes in mechanical performance. Therefore, identifying clinically relevant environmental exposures that may interact with orthodontic elastomeric materials is important for understanding variations in their mechanical behavior.

Asthma is commonly managed with inhaled medications, including short-acting β2-adrenergic agonists such as salbutamol and levosalbutamol. Orthodontic patients may therefore be repeatedly exposed to inhaled medications during treatment. During administration, inhaler-derived substances may come into contact with the oral cavity and potentially with orthodontic materials. Previous investigations have demonstrated that inhaled antiasthmatic medications may affect dental and orthodontic materials. For example, salbutamol exposure has been investigated for its effects on orthodontic archwires, while inhaled asthma medications have also been studied in relation to restorative dental materials (Alemran et al., 2024; Candan & Ünal, 2024). These findings suggest that inhaled medications may interact with dental and orthodontic biomaterials, although the effects may vary according to the material and exposure conditions.

Recent evidence has reported effects of antiasthmatic inhalers on dental and orthodontic materials (Attia et al., 2025). However, available evidence has focused primarily on restorative materials and orthodontic archwires rather than orthodontic elastomeric modules. The effect of repeated inhaler exposure on the tensile strength of orthodontic elastomeric materials therefore remains insufficiently established.

levosalbutamol inhaler exposure warrants specific investigation because the orthodontic material may be exposed not only to the active medication but also to other components of the inhaler formulation. The tested inhaler formulation contains the active medication together with formulation components

and propellants. Therefore, any observed material response should be interpreted in relation to the complete tested inhaler formulation, rather than being attributed exclusively to levosalbutamol. This distinction is important when evaluating potential interactions between inhaled medications and polyurethane-based orthodontic materials.

The clinical relevance of this issue lies in the role of elastomeric materials in orthodontic force delivery. If repeated exposure to inhaler-derived substances alters the tensile strength or mechanical integrity of orthodontic elastomeric modules, this may indicate a potential interaction that warrants further investigation. However, because the present study is conducted under controlled in vitro conditions and evaluates tensile strength rather than clinical force delivery or patient outcomes, the findings cannot by themselves establish effects on treatment duration, replacement intervals, or clinical outcomes.

Therefore, the present in vitro experimental study was conducted to determine whether repeated exposure to the tested levosalbutamol bronchodilator inhaler formulation affects the tensile strength of orthodontic elastomeric modules under simulated intraoral conditions. Specifically, the study compared the tensile strength of untreated modules, modules maintained in artificial saliva, and modules exposed to two levels of inhaler exposure under controlled laboratory conditions. The null hypothesis was that repeated exposure to the tested levosalbutamol bronchodilator inhaler formulation would not significantly affect the tensile strength of the orthodontic elastomeric modules.

LITERATURE REVIEW

Orthodontic treatment depends on the application of controlled forces to achieve predictable tooth movement. Among the commonly used force-delivery systems are orthodontic elastomeric chains, which are valued for their elasticity, ease of application, and ability to provide continuous force during orthodontic treatment (Singh et al., 2012). However, elastomeric materials undergo progressive changes in their mechanical properties during clinical use. Because these materials are exposed to the oral environment, factors such as moisture, temperature fluctuations, pH changes, mechanical loading, and chemical agents may influence their polymer structure and force-delivery characteristics (Khaleghi et al., 2021; Virdi et al., 2024). Variations in polymer composition, manufacturing processes, filament configuration, and material formulation may further contribute to differences in force degradation among commercially available orthodontic elastomeric products (Mousavi et al., 2020; Zheng et al., 2023).

The mechanical degradation of orthodontic elastomeric materials has been extensively investigated under different environmental conditions. Saliva and simulated oral conditions can contribute to progressive force decay, while the extent of degradation may vary according to the characteristics of the elastomeric material and the duration of exposure (Virdi et al., 2024). The degree of stretching and the configuration of elastomeric chains also influence their initial force and subsequent force decay (Mousavi et al., 2020; Zheng et al., 2023). Recent research has further demonstrated that elastomeric materials may exhibit measurable changes in mechanical performance following prolonged exposure under clinically relevant conditions, emphasizing the importance of evaluating orthodontic elastomers under standardized and controlled environments (Ptáčková et al., 2025).

Chemical exposure is another important factor affecting the mechanical integrity of orthodontic elastomers. Previous studies have demonstrated that acidic solutions, mouthwashes, and disinfecting agents can alter the force or tensile properties of orthodontic elastomeric materials (Khaleghi et al., 2021; Menon et al., 2019; Mirhashemi et al., 2017; Ebrahiminik et al., 2021; Evangelista et al., 2007; Osorio et al., 2022). A systematic review and meta-analysis also confirmed that mouthwashes can

influence the force decay of polymeric orthodontic ligature chains, although the magnitude of the effect may vary according to the formulation of the mouthwash and the characteristics of the elastomeric material (Castelló et al., 2023). These findings indicate that repeated chemical exposure may contribute to changes in the mechanical behavior and force-retention capacity of orthodontic elastomers.

Dietary substances may similarly influence orthodontic elastomeric materials. Studies investigating commonly consumed beverages have reported changes in force decay and elongation following repeated exposure. Torres-Rosas et al. (2023) found that exposure to different beverages affected the force decay and elongation of orthodontic elastomeric chains, while Nobahari et al. (2024) demonstrated changes in the force decay of elastomeric chains following exposure to common hot beverages over a 28-day period. These findings suggest that repeated contact with chemically different substances in the oral environment can contribute to the progressive deterioration of orthodontic elastomeric materials.

The susceptibility of orthodontic elastomers to chemical and environmental degradation can be explained by the structure of polyurethane polymers. Polyurethane degradation may involve physical, chemical, and mechanical changes when the polymer is exposed to environmental stressors. Such degradation mechanisms may include changes in intermolecular interactions, moisture uptake, polymer-chain mobility, hydrolysis, oxidation, and chain scission, ultimately resulting in reduced mechanical performance (Xie et al., 2019). Polyurethane-based materials are particularly relevant to these mechanisms because changes in their polymer structure can affect their integrity and force-delivery characteristics. Since E-link orthodontic elastics are manufactured from polyurethane, repeated exposure to chemical substances may potentially alter their tensile strength and mechanical reliability.
Inhaled medications represent a less investigated form of chemical exposure within the oral environment. Bronchodilator inhalers are commonly used in the management of asthma, and inhaled aerosol may come into contact with oral tissues and dental materials during administration. The use of inhaled therapy has therefore been recognized as relevant to oral health and dental care (Godara et al., 2011; Pasternak, 2023). Vincken et al. (2018) also described the deposition and delivery characteristics of inhaled medications within the respiratory and oral pathways. Because orthodontic materials are positioned within the oral cavity, repeated exposure to inhaler aerosols may provide an additional source of chemical interaction that has not been extensively investigated in orthodontic biomaterials.

levosalbutamol is a selective β2-adrenergic agonist used for bronchodilation in patients with asthma. The tested bronchodilator was Airlevo inhalation aerosol 45 μg/actuation (Glenmark), containing levosalbutamol tartrate as the active pharmaceutical ingredient. The inactive ingredients were anhydrous ethanol, oleic acid, and norflurane (hydrofluoroalkane [HFA]-134a) as the propellant. From a materials-science perspective, exposure to these formulation components may influence polymer structure, intermolecular interactions, and moisture-related behavior, potentially affecting the mechanical properties of polyurethane-based materials (Lee et al., 2019; Xie et al., 2019).
Recent investigations have provided evidence that antiasthmatic inhalers may affect dental and orthodontic materials. Subramaniam et al. (2024) reported changes in the color stability and surface roughness of dental restorative materials following exposure to antiasthmatic inhalers. Attia et al. (2025) similarly demonstrated changes in the surface roughness and color stability of hybrid ceramic materials exposed to salbutamol-based antiasthmatic medication. Furthermore, Alemran et al. (2024) reported alterations in the surface characteristics of orthodontic archwires following exposure to salbutamol sulfate inhalation. These findings suggest that inhaled antiasthmatic medications can interact with dental and orthodontic biomaterials; however, the outcomes investigated in these studies primarily involved surface characteristics rather than the tensile properties of orthodontic elastomeric chains.

Although considerable research has examined the effects of saliva, beverages, mouth rinses, disinfectants, acidic solutions, and other environmental factors on orthodontic elastomeric materials, the available evidence concerning inhaled bronchodilator medications remains limited. Similarly,

existing studies involving antiasthmatic inhalers have primarily evaluated restorative materials and orthodontic archwires rather than polyurethane-based orthodontic elastics. Therefore, there remains a specific gap concerning the potential effect of repeated bronchodilator inhaler exposure on the tensile strength of orthodontic elastomeric materials.

Given the documented susceptibility of polyurethane polymers to chemical and environmental degradation, the repeated intraoral exposure associated with inhaler use, and the demonstrated effects of antiasthmatic inhalers on other dental and orthodontic materials, further investigation is warranted. In particular, no published study identified in the present literature review has specifically evaluated the effect of repeated daily levosalbutamol bronchodilator inhaler aerosol exposure on the tensile strength of E-link orthodontic elastics. Therefore, the present study was undertaken to evaluate the effect of repeated levosalbutamol bronchodilator inhaler exposure on the tensile strength of E-link orthodontic elastics under standardized simulated intraoral conditions. This investigation aims to provide evidence regarding inhaler–material interactions and their potential relevance to orthodontic material selection and patient management.

METHODOLOGY

Design

This study utilized an *in vitro* randomized controlled experimental design to evaluate the effect of levosalbutamol bronchodilator inhaler exposure on the tensile strength of E-link orthodontic elastics. This design was appropriate because it allowed the exposure conditions to be controlled and standardized, thereby isolating the effect of inhaler exposure on the tested elastics while minimizing the influence of other environmental factors. Random allocation of samples to the experimental groups helped minimize selection bias and improve comparability among the groups (Cox, 2009).

To minimize measurement bias, a single-blind approach was implemented during tensile strength testing. The laboratory technician responsible for operating the Universal Testing Machine (UTM) was blinded to the group allocation. Each sample was assigned a coded identification number that did not reveal its corresponding group, and the same trained laboratory technician performed all measurements to ensure consistency and standardization.

Randomization was performed using a computer-generated method through Microsoft Excel (RAND function). Each sample was assigned a unique identification number, and random values were generated and arranged in ascending order. Samples were then equally allocated into four groups (Group A, Group B, Group C, and Group D) according to the randomized sequence.

Environment

The experimental procedures were conducted in April 2026 at the Institute of Chemistry Research Building, National Science Complex, University of the Philippines–Diliman, Quezon City, Philippines. Laboratory procedures were performed following institutional laboratory safety protocols. Samples were incubated at 37°C to simulate intraoral temperature conditions throughout the 21-day experimental period.

Data Sources

A total of 68 unused clear E-link polyurethane orthodontic elastics were obtained from a licensed dental supplier and inspected for visible defects before testing. Sample size was determined through power analysis using one-way analysis of variance (ANOVA) (effect size = 0.418, $\alpha = 0.05$, power = 80%), yielding 17 specimens per group. The specimens were randomly allocated into four experimental groups:

- Baseline group (n= 17): Unexposed E-link orthodontic elastics used to determine baseline tensile strength.
- Artificial saliva control group (n= 17): E-link orthodontic elastics maintained in Fusayama–Meyer artificial saliva throughout the 21-day experimental period.
- Two-puff inhaler group (n= 17): E-link orthodontic elastics receiving daily exposure to two puffs of the levosalbutamol bronchodilator inhaler and subsequently maintained in Fusayama–Meyer artificial saliva.
- Four-puff inhaler group (n= 17): E-link orthodontic elastics receiving daily exposure to four puffs of the levosalbutamol bronchodilator inhaler and subsequently maintained in Fusayama–Meyer artificial saliva.

Instruments

The materials used in this study included 68 unused, clear polyurethane orthodontic elastomeric modules (E-Links Modules; TP Orthodontics, Inc.; clear; size E-7; REF 389-007), Fusayama–Meyer artificial saliva, Airlevo inhalation aerosol 45 µg/actuation (Glenmark), a laboratory incubator maintained at 37°C, and a calibrated Universal Testing Machine (UTM). Tensile strength was evaluated using an Instron 34SC Single Column, Model 3343, equipped with a 100-N load cell and a least count of 0.0001 N. The elastomeric modules were mounted using rectangular acrylic plates measuring 100 mm × 40 mm × 3 mm, with stainless-steel pins positioned at a standardized distance of 29 mm. A 0.40-mm stainless-steel wire was used to secure the specimens during testing. A constant crosshead speed of 98 mm/min was applied until rupture occurred. The tensile testing procedure was based on previously published methods for evaluating the tensile properties of orthodontic elastomeric materials (Eliades et al., 2004). Tensile strength at failure was recorded and expressed in megapascals (MPa). The UTM was calibrated according to the manufacturer's recommendations before testing to ensure measurement accuracy and reliability.

Fusayama–Meyer artificial saliva was used as the immersion medium to simulate intraoral conditions. The artificial saliva consisted of potassium chloride (KCl) at 0.4 g/L, sodium chloride (NaCl) at 0.4 g/L, calcium chloride dihydrate ($CaCl_2 \cdot 2H_2O$) at 0.795 g/L, monosodium phosphate dihydrate ($NaH_2PO_4 \cdot 2H_2O$) at 0.69 g/L, sodium sulfide nonahydrate ($Na_2S \cdot 9H_2O$) at 0.005 g/L, and urea at 1.0 g/L. The artificial saliva was maintained at 37°C throughout the experimental period and replaced every 24 hours to maintain consistent exposure conditions.

Data Collection Procedure

The exposure schedule was based on the recommended dosing of Airlevo inhalation aerosol. Each actuation delivered 45 µg of levosalbutamol, with two inhalations (90 µg) representing the standard recommended dose. Accordingly, Group C received two consecutive puffs (90 µg), whereas Group D received four consecutive puffs (180 µg) during a single daily exposure session to represent a higher exposure condition. The exposure procedure was repeated once daily throughout the 21-day experimental period. Before immersion, the assigned elastomeric modules in Groups C and D were exposed to the levosalbutamol bronchodilator inhaler according to their respective exposure groups. Following each daily exposure, the specimens were immersed in Fusayama–Meyer artificial saliva and

maintained at 37°C. The artificial saliva was replaced every 24 hours. Groups A and B were maintained in their respective conditions throughout the experimental period.

After the 21-day experimental period, the specimens were removed from the artificial saliva, gently dried, and subjected to the standardized tensile-strength testing protocol using the calibrated Universal Testing Machine. Each specimen was mounted using the standardized acrylic-and-pin apparatus and tested at a crosshead speed of 98 mm/min until rupture. Tensile strength at failure was recorded and expressed in megapascals (MPa).

Data Analysis

Descriptive statistics, including the mean and standard deviation, were calculated for tensile strength values in each experimental group. Prior to inferential analysis, the Kolmogorov–Smirnov test was used to assess the normality of the standardized residuals, which indicated no significant departure from normality ($D = 0.089$, $p = .200$). Levene's test indicated that the assumption of homogeneity of variances was also satisfied, $F(3, 64) = 2.692$, $p = .054$.

Because these assumptions were satisfied, one-way analysis of variance (ANOVA) was used to determine whether significant differences existed in tensile strength among the four experimental groups. Tukey's Honestly Significant Difference (HSD) post hoc test was performed for pairwise comparisons following a significant ANOVA result. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS), version 29.0 (IBM Corp., Armonk, NY, USA), with statistical significance set at $\alpha = .05$.

Ethical Considerations

Ethical approval was obtained from the Cebu Doctors' University Institutional Biosafety Committee before the experimental procedures. Because the study involved only in vitro orthodontic materials and commercial chemical solutions and did not involve human or animal participants, informed consent was not applicable.

Laboratory procedures followed institutional biosafety and chemical-safety protocols. Personal protective equipment was used during sample preparation and chemical handling, and chemical waste was handled and disposed of according to institutional Environmental Health and Safety procedures.

RESULTS

Tensile Strength (MPa) of E-link Orthodontic Elastics

Table 1 presents the mean tensile strength of E-link orthodontic elastics in the four experimental groups. The baseline group demonstrated the highest mean tensile strength, whereas the four-puff levosalbutamol bronchodilator inhaler group demonstrated the lowest.

Table 1.

Tensile Strength (MPa) of Orthodontic Elastomeric Modules Under Different Experimental Conditions

Experimental Conditions	*n*	Tensile Strength (MPa)
Baseline	17	47.03 ± 1.54
Artificial Saliva Control	17	37.06 ± 1.58
Levosalbutamol Bronchodilator (2 puffs)	17	26.03 ± 1.76
Levosalbutamol Bronchodilator (4 puffs)	17	20.23 ± 2.44

Difference in Tensile Strength (MPa) Among the Experimental Groups

Table 2 presents the one-way analysis of variance (ANOVA). A statistically significant difference in tensile strength was observed among the four experimental groups (*p* < 0.001).

Table 2.

One-Way ANOVA for Tensile Strength (MPa) of Orthodontic Elastomeric Modules Under Different Experimental Conditions

Source of Variation	Type III Sum of Squares	df	Mean Square	F-value	*p*-value	Partial Eta Squared
Experimental condition	7213.21	3	2404.40	689.81	< .001	.970
Error	223.08	64	3.49			
Total	7436.29	67				

Table 3 presents the results of Tukey's Honestly Significant Difference (HSD) post hoc test. Significant pairwise differences were observed among all experimental groups (*p* < .001).

Table 3.

Tukey's Honestly Significant Difference (HSD) Post Hoc Test for the Tensile Strength of E-link Orthodontic Elastics

Group Comparison	Mean Difference	*p*-value	95% CI of the Mean Difference	
			Lower Bound	Upper Bound
Baseline vs Artificial saliva	9.96	< .001	8.27	11.65
Baseline vs Levosalbutamol bronchodilator (2 puffs)	21.00	< .001	19.31	22.69
Baseline vs Levosalbutamol bronchodilator (4 puffs)	26.80	< .001	25.11	28.49
Artificial saliva vs Levosalbutamol bronchodilator (2 puffs)	11.04	< .001	9.35	12.72
Artificial saliva vs Levosalbutamol bronchodilator (4 puffs)	16.84	< .001	15.15	18.53
2 puffs vs 4 puffs Levosalbutamol bronchodilator	5.80	< .001	4.11	7.49

DISCUSSION

The present study demonstrated that repeated exposure to levosalbutamol bronchodilator inhaler aerosols significantly reduced the tensile strength of polyurethane orthodontic elastomeric modules under simulated intraoral conditions. These findings suggest that repeated exposure to a bronchodilator inhaler formulation may affect the mechanical integrity of polyurethane orthodontic elastomeric materials. Tensile strength progressively decreased with increasing inhaler exposure, suggesting that repeated exposure to the complete inhaler formulation may adversely affect the mechanical properties of the tested elastomeric material. Polyurethane elastomers may undergo degradation through mechanisms such as hydrolysis, oxidation, chain scission, and swelling when exposed to chemical and environmental stressors (Khaleghi et al., 2021; Xie et al., 2019). However, these mechanisms were not directly investigated in the present study and therefore should be considered possible explanations rather than confirmed mechanisms.

The findings are consistent with previous investigations reporting changes in the mechanical properties of orthodontic elastomeric materials following exposure to acidic solutions, mouthrinses, disinfectants, beverages, and other environmental conditions (Khaleghi et al., 2021; Castelló et al., 2023; Ebrahiminik et al., 2021; Osorio et al., 2022; Nobahari et al., 2024; Torres-Rosas et al., 2023). Studies examining antiasthmatic inhalers have also reported changes in dental restorative materials and orthodontic archwires following inhaler exposure (Attia et al., 2025; Subramaniam et al., 2024; Alemran et al.,

2024). These studies provide indirect supporting evidence for the present findings but do not directly establish the mechanism responsible for the reduction in tensile strength observed in the current study.

The magnitude of the observed reduction was substantial, and the analysis demonstrated a very large effect size ($\eta^2 = .970$), indicating that experimental condition accounted for a large proportion of the variability in tensile strength. Nevertheless, this effect should be interpreted within the context of the in vitro experimental design. Tensile strength is a material failure property and should not be equated directly with clinical orthodontic force delivery. Clinical force delivery is influenced by additional factors, including the degree of activation, force decay, elongation, elastic recovery, and the clinical configuration of the elastomeric material. Therefore, the reduction in tensile strength observed in this study does not by itself establish a corresponding reduction in clinical orthodontic force or treatment effectiveness.

The observed effect should also not be attributed exclusively to levosalbutamol. Airlevo contains levosalbutamol tartrate as the active pharmaceutical ingredient, together with anhydrous ethanol, oleic acid, and norflurane (HFA-134a) as formulation components. Therefore, the effects observed in the present study should be interpreted as an interaction with the complete inhaler formulation rather than being attributed exclusively to levosalbutamol. Because the study did not separately test the active ingredient and other excipients, the observed changes may have resulted from the combined interaction of the complete inhaler formulation with the polyurethane material. Accordingly, the present findings should be interpreted as an effect associated with exposure to the complete inhaler formulation rather than as evidence of an isolated effect of levosalbutamol.

The clinical relevance of these findings should also be interpreted cautiously. Although the experimental model simulated selected intraoral conditions, it did not reproduce normal oral clearance through saliva flow, swallowing, drinking, or rinsing. Other clinical factors, including masticatory forces, salivary enzymes, oral microbiota, and patient-specific conditions, were also not simulated. Consequently, the extent of tensile-strength reduction observed under controlled laboratory conditions may differ from that occurring clinically.

The strengths of this study include its randomized experimental design, standardized exposure conditions, calibrated mechanical testing, and controlled laboratory environment. However, the study evaluated only one brand of orthodontic elastomeric module and one inhaler formulation, and the exposure period was limited to 21 days. Future studies should evaluate multiple orthodontic elastomeric materials and inhaler formulations, longer exposure periods, additional mechanical properties such as force decay and elastic recovery, and in vivo conditions. Such studies would help determine whether the observed changes in tensile strength translate into clinically meaningful alterations in orthodontic force delivery.

CONCLUSION

The present study demonstrated that exposure to the complete levosalbutamol bronchodilator inhaler formulation was associated with a significant reduction in the tensile strength of the tested polyurethane orthodontic elastomeric modules under simulated intraoral conditions. The findings indicate that inhaler exposure may affect the mechanical integrity of the tested elastomeric material in vitro. However, these findings should not be interpreted as evidence of altered clinical force delivery or patient outcomes, as these parameters were not measured. Further in vivo research is needed to determine the clinical significance of the observed changes.

RECOMMENDATIONS

The following in vitro-informed considerations are presented as provisional, research-based hypotheses rather than established clinical standards.

1. Practice considerations. Orthodontists may consider the potential effects of regular bronchodilator inhaler exposure when monitoring patients who use orthodontic elastomeric components. Patients who regularly use bronchodilator inhalers may be advised to inform their orthodontist about their inhaler use, allowing appropriate monitoring of elastomeric components during treatment. However, the present in vitro findings should not be used to routinely recommend earlier replacement intervals or changes in orthodontic treatment protocols, as tensile strength was the only mechanical property evaluated and clinical force delivery and patient outcomes were not assessed.
2. Material-management considerations. Manufacturers and orthodontic professionals should consider formulation-specific compatibility when evaluating the effects of inhaled medications on orthodontic elastomeric materials. Because the present study evaluated a specific levosalbutamol inhaler formulation and a single brand of clear polyurethane elastomeric modules, the findings should not be generalized to all bronchodilator inhalers or orthodontic elastomeric materials. Material-selection and management decisions should therefore be guided by product-specific evidence, standardized laboratory testing, and subsequent clinical validation.
3. Education and training considerations. Postgraduate orthodontic and dental training programs may use this study as an example of the cautious interpretation of biomaterial evidence in clinical practice. Trainees should be taught to distinguish tensile strength from other mechanical properties, such as force decay, elongation, and elastic recovery, and to recognize the importance of formulation-specific evidence when counseling patients who use inhaled medications during orthodontic treatment.
4. Theoretical and research-framework considerations. The findings may be interpreted in relation to polyurethane degradation mechanisms, including hydrolysis, oxidation, and polymer chain scission, rather than a single formal “Polymer Degradation Theory.” The observed reduction in tensile strength indicates altered mechanical behavior under the tested exposure conditions; however, the specific chemical mechanisms responsible should not be assumed without direct polymer-science investigation.
5. Future research directions. Future studies should compare multiple brands and types of orthodontic elastomeric materials, different bronchodilator inhaler formulations, and longer exposure periods. Additional mechanical properties, including force decay, elongation, and elastic recovery, should be evaluated. Studies should also investigate the contribution of complete inhaler formulation components and exposure conditions to changes in polyurethane materials. Direct investigation of polymer degradation and surface or chemical changes may further clarify the underlying mechanisms. Multi-center mechanical testing and appropriately designed in vivo clinical studies are needed to determine whether reductions in tensile strength observed under controlled laboratory conditions translate into clinically meaningful changes in orthodontic force delivery or treatment outcomes.

List of Abbreviations

ANOVA – Analysis of Variance
CDU – Cebu Doctors' University
IBC – Institutional Biosafety Committee
MPa – Megapascal
UTM – Universal Testing Machine

Declarations

Ethical approval and consent to participate

This study was approved by the Cebu Doctors' University Institutional Biosafety Committee (IBC) before the conduct of the experiment. All experimental procedures were performed in accordance with the approved research protocol and institutional laboratory safety guidelines. As this was an in vitro experimental study involving orthodontic materials only, informed consent from human participants was not applicable.

Consent for publication

Not applicable. No individual participant data are reported.

Availability of data and materials

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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Declaration of Generative AI and AI-assisted Technologies

The authors used ChatGPT (OpenAI) and Grammarly AI solely for language editing and readability enhancement. All scientific content, analyses, interpretations, and conclusions were developed, reviewed, and approved by the authors, who take full responsibility for the content of this manuscript.

Competing Interests

The authors declare no competing interests.

Author's Contributions

K.M.B. conceived and designed the study, developed the research methodology, conducted the experimental procedures, performed the formal statistical analysis, interpreted the data, prepared the original manuscript draft, developed the tables, and managed the overall execution and administration of the project. The author read and approved the final manuscript.

Contributor Roles (CRediT):

* Conceptualization: **K.M.B**
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