

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

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Article #: 2026-02-02-07

Paper ID: IJOMAHIP_Kh4KXBR

International Journal of Medicine and Health Innovations Perspectives Vol. 2, No.2 (2026)

DOI: 10.69481/KYJQ7227

Page No.: 129-143

Pages: 15

Submitted: 15 July 2026

Resubmitted: 11 September 2026

Accepted: 12 September 2026

Similarity Index: <10.00%

Originality: 90.00%

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 β_2 -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 a two-puff daily exposure condition, and artificial saliva with a four-puff daily exposure condition using the tested 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

the clinical significance of these findings.

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

Cite this Article (APA): Basubeit, Khaled Mubarak (2026). Effect of levosalbutamol bronchodilator inhaler on the tensile strength of orthodontic elastomeric modules: An in vitro study. *International Journal of Medicine and Health Innovations Perspectives*, 2(2), 129-143. DOI: 10.69481/KYJQ7227.

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.

INTRODUCTION

Orthodontic treatment depends on controlled forces to achieve predictable tooth movement. Orthodontic elastomeric materials are widely used because of their elasticity, ease of application, and ability to provide sustained force during treatment (Proffit et al., 2018; Singh et al., 2012). Their mechanical behavior can change during clinical use, and recent in vitro and in vivo work has shown that elastomeric force behavior is influenced by material and environmental conditions (Yang et al., 2023; Viridi et al., 2024).

Environmental and mechanical factors can alter orthodontic elastomeric behavior. Storage temperature and oral conditions may affect force retention (Piradhiba et al., 2021; Viridi et al., 2024), while stretching extent, morphology, filament configuration, and material formulation can influence initial force and subsequent force degradation (Mousavi et al., 2020; Zheng et al., 2023). Chemical exposures have also been studied separately: acidic solutions can alter force decay (Khaleghi et al., 2021), disinfecting solutions can affect tensile strength (Ebrahiminik et al., 2021; Evangelista et al., 2007; Osorio et al., 2022), and mouthwashes can influence force decay (Menon et al., 2019; Mirhashemi et al., 2017; Castelló et al., 2023). Beverage exposure has likewise been associated with changes in force decay and elongation (Torres-Rosas et al., 2023; Nobahari et al., 2024), while cigarette smoke and electromagnetic radiation have been investigated as additional environmental stressors (Ferraz et al., 2020; Bhatia et al., 2023).

These effects are relevant to polyurethane materials because environmental stress can alter intermolecular interactions, moisture uptake, polymer-chain mobility, hydrolysis, oxidation, and chain scission, potentially reducing mechanical performance (Xie et al., 2019). Such mechanisms provide a materials-science framework for interpreting changes in elastomeric properties, but the present study did not directly measure polymer chemistry or degradation products. Importantly, tensile strength is a material failure property and should be distinguished from clinical force degradation, which depends on activation, elongation, elastic recovery, and clinical configuration (Yang et al., 2023; Viridi et al., 2024).

Asthma is commonly managed with inhaled medications, including short-acting β_2 -adrenergic agonists such as salbutamol and levosalbutamol. During administration, aerosolized medication and formulation components may contact oral tissues and dental materials. Previous studies have reported effects of antiasthmatic inhalers on dental restorative materials and orthodontic archwires (Alemran et al., 2024; Candan & Ünal, 2024; Subramaniam et al., 2024; Attia et al., 2025), suggesting that inhaler-derived exposures can interact with dental and orthodontic biomaterials.

The potential interaction is particularly relevant to orthodontic elastomeric modules because these polyurethane-based materials are exposed directly within the oral cavity. The tested inhaler contains the active medication together with formulation components and a propellant; therefore, any material response should be interpreted as an effect associated with the complete tested formulation rather than attributed exclusively to levosalbutamol. This formulation-specific distinction is important when interpreting biomaterial responses to inhaled medications.

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

elastomeric modules.

The clinical significance of any material change requires cautious interpretation because the present model evaluates tensile strength rather than clinical force delivery or patient outcomes. Thus, any observed change should be considered evidence of a material response under the tested conditions and not as direct evidence of altered treatment duration, replacement intervals, or clinical effectiveness.

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

Environmental and Mechanical Factors

Orthodontic elastomeric materials are exposed to moisture, temperature changes, saliva, mechanical loading, and chemical agents during clinical use. These conditions can influence polymer structure and force behavior (Khaleghi et al., 2021; Viridi et al., 2024). Material composition, manufacturing characteristics, filament configuration, stretching extent, and morphology also contribute to differences in initial force and force degradation among products (Mousavi et al., 2020; Zheng et al., 2023).

Recent studies illustrate that these factors affect elastomeric performance through different pathways. Simulated oral conditions can produce progressive force decay, while in vivo and in vitro comparisons show that force behavior may differ according to the environment and material tested (Yang et al., 2023; Viridi et al., 2024; Ptáčková et al., 2025). These findings support the need to distinguish the effects of environmental exposure from the effects of material configuration and loading history when interpreting elastomeric degradation.

Chemical and Dietary Exposures

Chemical exposures represent a separate group of environmental stressors. Acidic solutions can alter force decay (Khaleghi et al., 2021), disinfecting solutions can affect tensile strength (Ebrahiminik et al., 2021; Evangelista et al., 2007; Osorio et al., 2022), and mouthwashes can alter force decay, with the magnitude depending on the formulation and elastomeric material (Menon et al., 2019; Mirhashemi et al., 2017; Castelló et al., 2023). These findings suggest that chemical composition and repeated exposure can influence mechanical behavior, but the response is not necessarily uniform across materials or exposure conditions.

Dietary exposures provide another example of formulation-specific effects. Torres-Rosas et al. (2023) reported changes in force decay and elongation after exposure to commonly consumed beverages, while Nobahari et al. (2024) found changes in force decay after exposure to hot beverages over 28 days. Together, these studies indicate that repeated contact with chemically different substances can modify elastomeric behavior, supporting the need to evaluate specific exposures rather than assume a common response across all substances.

Polyurethane Degradation Mechanisms

Polyurethane degradation may involve physical, chemical, and mechanical changes under environmental stress. Proposed processes include moisture uptake, changes in intermolecular interactions and polymer-chain mobility, hydrolysis, oxidation, and chain scission, which can reduce mechanical performance (Xie et al., 2019). These mechanisms provide a plausible framework for interpreting changes in polyurethane elastomers, but they were not directly measured in the present study. Therefore, any mechanistic explanation for the observed tensile-strength reduction remains provisional.

Inhaled Medications and Specific Research Gap

Inhaled medications represent a less investigated form of oral chemical exposure. Bronchodilator aerosols can contact oral tissues and dental materials during administration, making inhaler use relevant to dental care (Godara et al., 2011; Pasternak, 2023; Vincken et al., 2018). Existing studies have reported changes in restorative-material surface characteristics and orthodontic archwire surfaces following antiasthmatic inhaler exposure (Alemran et al., 2024; Candan & Ünal, 2024; Subramaniam et al., 2024; Attia et al., 2025), but these outcomes differ from tensile-strength testing of polyurethane elastomeric modules.

Levosalbutamol is a selective β_2 -adrenergic agonist used for bronchodilation. The tested Airlevo inhalation aerosol contains levosalbutamol tartrate together with anhydrous ethanol, oleic acid, and norflurane (HFA-134a). Because the experiment exposed elastomers to the complete inhaler formulation, the material response cannot be assigned to levosalbutamol alone. Formulation components may interact with polyurethane through changes in intermolecular interactions or moisture-related behavior, although these processes were not directly assessed in this study (Lee et al., 2019; Xie et al., 2019).

Force degradation also needs to be distinguished from tensile strength. Yang et al. (2023) demonstrated force degradation of orthodontic accessories using in vivo and in vitro models, illustrating that force delivery can change over time under oral conditions. Thus, tensile strength provides information about resistance to failure, whereas force degradation reflects changes in the force delivered during activation. This distinction is important when relating the present material-testing results to orthodontic biomechanics and tooth movement (Proffit et al., 2018; Yang et al., 2023; Viridi et al., 2024).

The specific research gap identified in this review was the lack of a direct evaluation of repeated exposure to the tested levosalbutamol inhaler formulation and tensile strength of E-link orthodontic elastics. The present experiment therefore evaluated this material response under standardized simulated intraoral conditions.

METHODOLOGY

Design

This in vitro randomized controlled experimental design evaluated the effect of the tested levosalbutamol bronchodilator inhaler formulation on E-link orthodontic elastics. Controlled exposure conditions and random allocation were used to improve comparability among the four groups. During tensile testing, the laboratory technician was blinded to group allocation; samples were coded, and the same trained technician performed all measurements. Randomization used Microsoft Excel's RAND function, with specimens assigned to groups according to the randomized sequence.

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, α = 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 (CaCl₂·2H₂O) at 0.795 g/L, monosodium phosphate dihydrate (NaH₂PO₄·2H₂O) at 0.69 g/L, sodium sulfide nonahydrate (Na₂S·9H₂O) 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 conditions were selected to provide two experimentally defined levels of contact with the tested Airlevo inhalation aerosol rather than to reproduce a complete therapeutic dosing regimen. Each actuation delivered 45 µg of levosalbutamol; Group C received two consecutive puffs (90 µg) and Group D received four consecutive puffs (180 µg) during a single daily exposure session. The exposure procedure was repeated once daily for 21 days. Before immersion, Groups C and D were exposed according to their assigned condition; the specimens were then immersed in Fusayama–Meyer artificial saliva and maintained at 37°C. The artificial saliva was replaced every 24 hours, while Groups A and B remained 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

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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	<i>n</i>	Tensile Strength (MPa)
Baseline	17	47.03 ± 1.54
Artificial Saliva Control	17	37.06 ± 1.58
Levosolbutamol Bronchodilator (2 puffs)	17	26.03 ± 1.76
Levosolbutamol 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 ($p < .001$).

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 a clear exposure-associated reduction in tensile strength of the tested E-link polyurethane elastomeric modules. Mean tensile strength was 47.03 ± 1.54 MPa in the baseline group, 37.06 ± 1.58 MPa in the artificial-saliva control, 26.03 ± 1.76 MPa after the two-puff condition, and 20.23 ± 2.44 MPa after the four-puff condition. One-way ANOVA showed a significant difference among groups ($F = 689.81$, $p < .001$, $\eta^2 = .970$), and all Tukey HSD pairwise comparisons were significant ($p < .001$). The graded reduction across the experimental conditions supports an association between increasing exposure to the tested inhaler formulation and lower tensile strength under the study conditions.

No closely comparable study identified in the present literature review directly evaluated repeated levosalbutamol inhaler exposure and tensile strength of polyurethane orthodontic elastomeric modules. The present findings therefore extend, rather than directly replicate, evidence from other chemical exposures. Acidic solutions, mouthwashes, disinfectants, and beverages have been associated with changes in force decay or tensile properties of orthodontic elastomers (Khaleghi et al., 2021; Menon et al., 2019; Mirhashemi et al., 2017; Ebrahiminik et al., 2021; Osorio et al., 2022; Castelló et al., 2023; Torres-Rosas et al., 2023; Nobahari et al., 2024). Studies of antiasthmatic inhalers have likewise reported changes in dental restorative materials and orthodontic archwires (Alemran et al., 2024; Subramaniam et al., 2024; Attia et al., 2025), but these outcomes are not equivalent to tensile-strength failure testing.

A plausible materials-science explanation is that repeated exposure to chemical and environmental stressors can alter polyurethane through moisture uptake, changes in intermolecular interactions and polymer-chain mobility, hydrolysis, oxidation, or chain scission (Xie et al., 2019). These processes could reduce the integrity of the polymer network and thereby lower resistance to tensile failure. However, the present study did not measure polymer chemistry, surface morphology, mass change, or degradation products; therefore, these mechanisms remain possible explanations rather than demonstrated causal pathways.

The observed effect should not be attributed exclusively to levosalbutamol. The tested Airlevo formulation contained levosalbutamol tartrate, anhydrous ethanol, oleic acid, and norflurane (HFA-134a). Because these components were delivered together, the result represents the response of the elastomer to the complete tested inhaler formulation. Separate testing of the active ingredient and individual excipients would be required to determine their relative contributions.

Clinical interpretation also requires a clear distinction between tensile strength and force degradation. Yang et al. (2023) showed that force degradation of orthodontic accessories can be evaluated in vivo and in vitro, whereas the present study measured tensile strength at failure. Tensile strength therefore cannot be used as a direct surrogate for the force delivered during orthodontic treatment. Clinical force behavior also depends on activation, elongation, elastic recovery, configuration, oral conditions, and time (Proffit et al., 2018; Yang et al., 2023; Viridi et al., 2024). Accordingly, the present findings do not establish changes in clinical force delivery, tooth movement, treatment duration, or patient outcomes.

The strengths of this study include random allocation, standardized exposure conditions, blinded tensile testing, a calibrated testing machine, and a controlled laboratory environment. Limitations include evaluation of one orthodontic elastomeric brand and one inhaler formulation, a 21-day exposure period, and the absence of direct measurements of force decay, elastic recovery, polymer chemistry, surface changes, and clinical outcomes. Normal oral clearance, swallowing, drinking, rinsing, masticatory

forces, salivary enzymes, microbiota, and patient-specific factors were also not reproduced. Future work should therefore evaluate multiple materials and inhaler formulations, clinically realistic exposure patterns, additional mechanical properties, and in vivo conditions.

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 recommendations from this study are directed primarily toward further research because tensile strength was the only mechanical outcome measured. The following priorities are proposed:

1. Clinically realistic exposure studies. Future experiments should reproduce more realistic inhaler-use patterns, oral clearance, and intermittent exposure rather than relying on a single daily laboratory exposure session.
2. Mechanical-property studies. Future studies should measure force degradation, elongation, elastic recovery, and other clinically relevant properties alongside tensile strength to determine whether material changes correspond to changes in force delivery.
3. Formulation and material comparisons. Studies should compare multiple orthodontic elastomeric brands and multiple inhaler formulations and, where feasible, test the active drug and formulation components separately to identify formulation-specific effects.
4. Mechanistic and clinical validation. Polymer-science investigations should assess surface and chemical changes associated with degradation, while appropriately designed in vivo studies should determine whether tensile-strength changes are accompanied by measurable changes in force delivery, tooth movement, or treatment outcomes.
5. Evidence synthesis. Future systematic or comparative studies should integrate material testing with force-degradation and clinical evidence to determine the clinical significance of inhaler–elastomer interactions before any changes to patient management or replacement intervals are considered.

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.

Funding

This research received no external funding.

Acknowledgements

Not applicable.

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**
- * Methodology: **K.M.B**
- * Formal Analysis: **K.M.B.**
- * Writing – Original Draft: **K.M.B**
- * Visualization: **K.M.B**
- *Project Administration: **K.M.B.**

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