



# Rheological and Structural Analysis of Hyaluronic Acid Fillers Used for Chin Augmentation

Ana Claudia Carbone · Maria Luiza Boechat Borges Neves · André Gaspar Zinco · Vasudev Vivekanand Nayak<sup>✉</sup> · Lucas Alexandre de Sousa Mendes · Andressa De Marchi El Assad · Mariana Barbosa Câmara-Souza · Stephanie Teixeira · Daniel Augusto Machado Filho · Fabio Seigi Murakami · Giancarlo De la Torre Canales

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## ABSTRACT

**Introduction:** Chin contouring and projection represent some of the most frequently requested procedures in aesthetic practice using hyaluronic acid (HA) fillers. Variations in the physicochemical and viscoelastic properties of HA fillers may directly influence clinical performance. This study aimed to compare four commercially available HA gels specifically indicated for chin projection: JUVÉDERM<sup>®</sup> VOLUX, RESTYLANE<sup>®</sup>

LYFT, PERFECTHA<sup>®</sup> SUBSKIN, and RESTYLANE<sup>®</sup> SHAYPE.

**Methods:** The samples were characterized using scanning electron microscopy, dynamic light scattering, zeta potential, and swelling factor (SF). Rheological assessments included frequency sweep, amplitude sweep, and cohesivity modulus (MOC). All tests were performed in triplicate.

**Results:** JUVÉDERM<sup>®</sup> VOLUX exhibited the highest SF values (3.28–3.37), indicating greater swelling capacity, whereas RESTYLANE<sup>®</sup> LYFT showed the lowest (1.53–1.66), reflecting a denser and less expansive profile. Rheological analysis revealed that RESTYLANE<sup>®</sup> LYFT and RESTYLANE<sup>®</sup> SHAYPE had higher storage

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Ana Claudia Carbone and Maria Luiza Boechat Borges Neves share first authorship.

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A. C. Carbone · S. Teixeira  
Private Practice, São Paulo, Brazil

M. L. B. B. Neves · L. A. de Sousa Mendes ·  
A. De Marchi El Assad · M. B. Câmara-Souza ·  
G. De la Torre Canales  
Department of Dentistry, Ingá University Center,  
Uningá, Maringá, Paraná, Brazil

A. G. Zinco · F. S. Murakami  
Aesthetic Research Laboratory, Postgraduate  
Program in Pharmaceutical Sciences, Department  
of Pharmacy, Federal University of Paraná, Curitiba,  
Paraná, Brazil

V. V. Nayak (✉)  
Department of Biochemistry and Molecular Biology,  
University of Miami Miller School of Medicine,  
1011 NW 15th St, Rm. 305, Miami, FL 33136, USA  
e-mail: vxn188@miami.edu

V. V. Nayak  
Dr. John T. Macdonald Biomedical Nanotechnology  
Institute (BioNIUM), University of Miami, Miami,  
FL, USA

D. A. Machado Filho  
Próspera Facial Institute, Sao Paulo, Brazil

G. De la Torre Canales  
Egas Moniz Center for Interdisciplinary Research  
(CiiEM), Egas Moniz School of Health and Science,  
Almada, Portugal

G. De la Torre Canales  
Division of Oral Diagnostics and Rehabilitation,  
Department of Dental Medicine, Karolinska,  
Huddinge, Sweden

modulus ( $G'$ ) values at elevated frequencies. MOC was significantly higher for RESTYLANE® SHAYPE and PERFECTHA® SUBSKIN compared with JUVÉDERM® VOLUX, suggesting greater resistance to deformation.

**Conclusions:** Overall, RESTYLANE® SHAYPE demonstrated the most favorable balance, combining moderate SF, high  $G'$  values, and elevated MOC. However, patient-specific anatomy, aesthetic goals, and injector expertise remain critical in determining the most appropriate product for chin contouring.

**Keywords:** Dermal filler; Rheology; Hyaluronic acid; Chin

### Key Summary Points

#### *Why carry out this study?*

This is the first systematic comparison of HA fillers designed for chin augmentation, integrating physicochemical and viscoelastic properties.

The study investigated whether chin-specific HA fillers differ in structural and viscoelastic properties, hypothesizing that RESTYLANE® SHAYPE would show a favorable balance of swelling, elasticity, and cohesivity.

#### *What was learned from the study?*

RESTYLANE® SHAYPE showed optimal balance of swelling factor, elasticity, and cohesivity, favoring supraperiosteal applications.

The fillers showed distinct structural and rheological behaviors despite similar clinical indications, supporting the importance of material-based selection for deep facial volumization.

including the skin, synovial fluid, and cartilage [1]. Its remarkable water-binding capacity contributes to dermal hydration and volumization with minimal inflammatory response, making it particularly suitable for aesthetic applications addressing aging-related changes [2, 3]. Owing to their biocompatibility, biodegradability, low toxicity, minimal immunogenicity, water retention capacity, and viscoelastic properties, HA-based dermal fillers are widely used in aesthetics medicine [4]. These injectable hydrogels restore facial volume, contour structures, and reduce visible signs of aging with minimal invasiveness, offering low procedural risk and short recovery time [5–7]. According to the International Society of Aesthetic Plastic Surgery, the global use of HA fillers increased by 56.4% between 2020 and 2024, underscoring their growing popularity and clinical demand [8].

Although HA fillers are broadly indicated for similar aesthetic outcomes, their in vivo behavior can vary significantly depending on formulation parameters [9]. Differences in HA concentration, particle size, crosslinking technology, and structural morphology strongly influence rheological and physicochemical gel performance [4, 10]. Comprehensive characterization of these parameters is essential, as they determine key clinical attributes such as injectability, tissue integration, and durability [4, 11].

For chin augmentation, fillers with high modulus of cohesion (MOC), elevated storage modulus ( $G'$ ), and firm yet flexible consistency are generally recommended. These characteristics provide projection, structural support, and resistance to mechanical forces in the chin—a dynamic and prominent facial region [7]. Products such as JUVÉDERM® VOLUX, RESTYLANE® LYFT, PERFECTHA® SUBSKIN, and RESTYLANE® SHAYPE (newly launched) have been developed for this indication, primarily owing to their elevated  $G'$  values [12–14]. Despite their widespread clinical use, no prior head-to-head rheological and physicochemical comparison of chin specific fillers has been published. Such analyses are critical to understanding product performance, influencing both handling characteristics during injection and biological behavior post-administration.

## INTRODUCTION

Hyaluronic acid (HA) is a naturally occurring, non-sulfated glycosaminoglycan found in the extracellular matrix of various human tissues,

This study aims to provide a comparative evaluation of the structural and viscoelastic profiles of four commercially available HA fillers indicated for chin augmentation. Specifically, we investigated their rheological behavior, particle morphology, swelling potential, and overall stability to support evidence-based product clinical selection and contribute to advancements in HA filler technology.

## METHODS

This study was conducted using four commercially available HA-based dermal fillers widely employed in aesthetic clinical practice for chin augmentation: RESTYLANE® SHAYPE (Galderma SA, Lausanne, Switzerland), RESTYLANE® LYFT (Galderma SA, Lausanne, Switzerland), JUVÉDERM® VOLUX (AbbVie Inc, Illinois, USA), and PERFECTHA® SUBSKIN (Sinclair France SAS, Dardilly, France). All products were acquired in their original commercial packaging and stored according to the manufacturers' recommendations. Fillers were used either as supplied or following standardized dilution procedures, depending on the specific requirements of each analysis. All experiments were performed in triplicate. This study did not involve human participants or human tissues; therefore, ethical approval was not required.

### Particle Size and Zeta Potential

Initial physicochemical characterization was performed using dynamic light scattering (Zetasizer NanoSeries ZS ZEN3600, Malvern Instruments, Egham, Surrey, UK). For particle size analysis, 0.1 mL of each filler was diluted into 0.9 mL sterile ultrapure water for a 1:10 (v/v) ratio and homogenized using a vortex mixer for 5 min each. Measurements were conducted at 25 °C and the evaluated parameters included the mean hydrodynamic diameter (Z-Ave, in nanometers), and polydispersity index (PDI).

### Swelling Factor

The swelling factor (SF) was determined by initially weighing the samples using a semi-analytical digital scale (precision  $\pm 0.01$  g). Approximately 0.5 g of each filler was then immersed in 25 mL of phosphate-buffered saline (PBS) at room temperature (25 °C) for 24 h. After incubation, excess liquid was removed using a quantitative filter paper (pore size 25  $\mu\text{m}$ ), and the samples were reweighed. The swelling factor was calculated as the ratio between the final ( $W_f$ ) and initial ( $W_i$ ) weights of the sample ( $W_f/W_i$ ).

### Scanning Electron Microscopy

Morphological evaluation was conducted using scanning electron microscopy (MIRA3, TESCAN ORSAY HOLDING, Brno, Czech Republic) operating at an acceleration voltage of 10.0 kV. Images were acquired at  $\times 4000$  magnification using a secondary electron detector, with a working distance between 7.0 and 8.0 mm. The samples were previously oven-dried for 48 h and mounted on metallic stubs using carbon conductive tape prior to imaging.

### Rheological Analysis

#### *Frequency Sweep Tests*

Rheological characterization was performed using a rotational rheometer (Discovery HR-10, TA Instruments, Delaware, USA) equipped with a 40 mm parallel plate geometry. Temperature was maintained at 25 °C using a Peltier system, with a fixed gap of 400  $\mu\text{m}$ . A 1 mL aliquot of each sample was tested. Frequency sweep test was performed under constant strain within the linear viscoelastic region, with the angular frequency ranging from 0.1 to 100 rad/s. The storage modulus ( $G'$ ), loss modulus ( $G''$ ), and loss factor ( $\tan \delta$ ) were recorded.

#### *Oscillation Amplitude*

Oscillation amplitude analyses were conducted using a rotational rheometer (Discovery HR-10, TA Instruments, New Castle, DE, USA) equipped

with a 50 mm parallel plate geometry. Temperature was maintained at 25 °C using a Peltier system and with a fixed gap of 300  $\mu\text{m}$ . A volume of 1 mL from each filler was used for testing. Measurements were conducted at a constant angular frequency of 10 rad/s, while the strain varied from  $10^{-1}$  to  $10^4\%$  in a logarithmic sweep; and five measurements per decade were obtained. The oscillation amplitude data was used to calculate the MOC - a measure of gel strength and ductility, and the energy required to induce solid-to-fluid phase transition, as described previously [15].

### Statistical Analysis

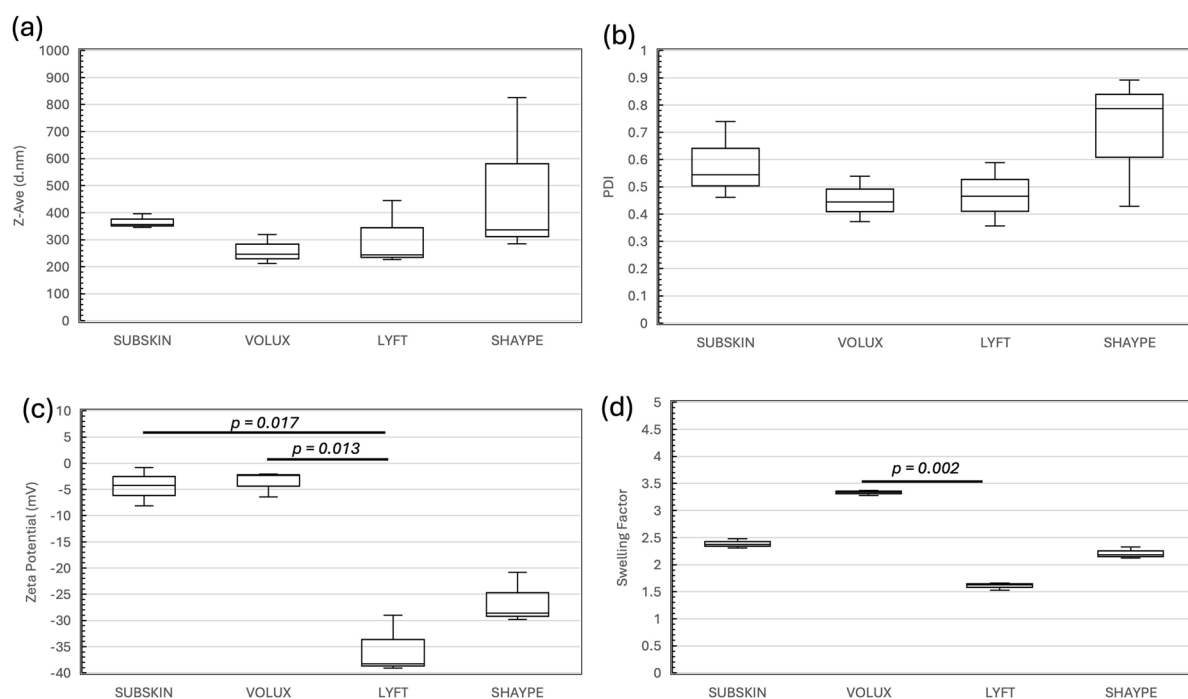
Data was tabulated and subjected to Kruskal–Wallis tests followed by post hoc comparisons, with significance level set at  $p < 0.05$ . Data are presented as estimated medians and corresponding interquartile ranges, unless

otherwise noted. All analyses were performed using a statistical software package (SPSS v29, IBM Corp., New York, USA).

## RESULTS

### Particle Size, Zeta Potential, and Swelling Factor Analysis

Marked variations in the mean hydrodynamic diameter (Z-Ave) were observed among the evaluated dermal fillers. RESTYLANE® SHAYPE exhibited the largest mean particle diameter and a high polydispersity index ( $\text{PDI} > 0.78$ ), indicative of a more heterogeneous particle size distribution. In contrast, JUVÉDERM® VOLUX displayed smaller particle diameters (212.1–319.0 nm) with PDI values below 0.54, suggesting a more uniform particle population. No statistically significant differences in Z-Ave or



**Fig. 1** Summary of the outcome variables: **a** mean hydrodynamic diameter (Z-Ave), **b** polydispersity index (PDI), **c** zeta potential, and **d** swelling factor of the study groups

presented as medians and corresponding interquartile ranges.  $p < 0.05$  is statistically significant

PDI were detected among groups ( $p > 0.070$  and  $p > 0.141$ , respectively; Fig. 1a, b).

The mean zeta potential of the evaluated fillers ranged from  $-0.828$  to  $-39.1$  mV, reflecting differences in colloidal stability. Significant differences were observed between RESTYLANE® LYFT, PERFECTHA® SUBSKIN, and JUVÉDERM® VOLUX ( $p = 0.017$  and  $p = 0.013$ , respectively, Fig. 1c).

Swelling factor analyses demonstrated distinct hydration capacities among formulations. JUVÉDERM® VOLUX exhibited the highest swelling factor values (3.28–3.37), indicating greater water absorption and a strong volumizing potential post-injection. In contrast, RESTYLANE® LYFT showed the lowest values (1.53–1.66), consistent with a denser gel with reduced expansion potential post-injection. Overall, JUVÉDERM® VOLUX presented significantly higher swelling factor values relative to RESTYLANE® LYFT ( $p = 0.002$ , Fig. 1d).

### Scanning Electron Microscopy

Scanning electron microscopy revealed distinct morphological differences among the tested fillers (Fig. 2). Fillers with lower PDI, such as JUVÉDERM® VOLUX, displayed a more homogeneous surface with minimal aggregation, indicative of uniform particle distribution. Conversely, RESTYLANE® SHAYPE presented a more irregular and low-porosity structure with visible aggregates, suggesting greater internal heterogeneity.

### Rheological Analysis

Oscillation amplitude analyses demonstrated  $G'$ – $G''$  crossover points at oscillation strains of approximately 100% for all fillers. Prior to the crossover,  $G'$  exceeded  $G''$ , whereas beyond that point,  $G''$  predominated in all fillers (Fig. 3). Frequency sweep analysis showed that  $G'$  was higher in RESTYLANE® LYFT and SHAYPE (Fig. 4a, b) at angular frequencies above 20 rad/s. In contrast, PERFECTHA® SUBSKIN and JUVÉDERM® VOLUX (Fig. 4c, d) exhibited lower  $G'$  values.  $G''$  showed similar trends across all groups, with no crossover between  $G'$  and  $G''$  observed. The  $\tan \delta$  increased with angular

frequency ( $> 20$  rad/s) for JUVÉDERM® VOLUX and RESTYLANE® LYFT, whereas RESTYLANE® SHAYPE and PERFECTHA® SUBSKIN presented a decrease in  $\tan \delta$  values between 0 and 40 rad/s, followed by a plateau up to 100 rad/s.

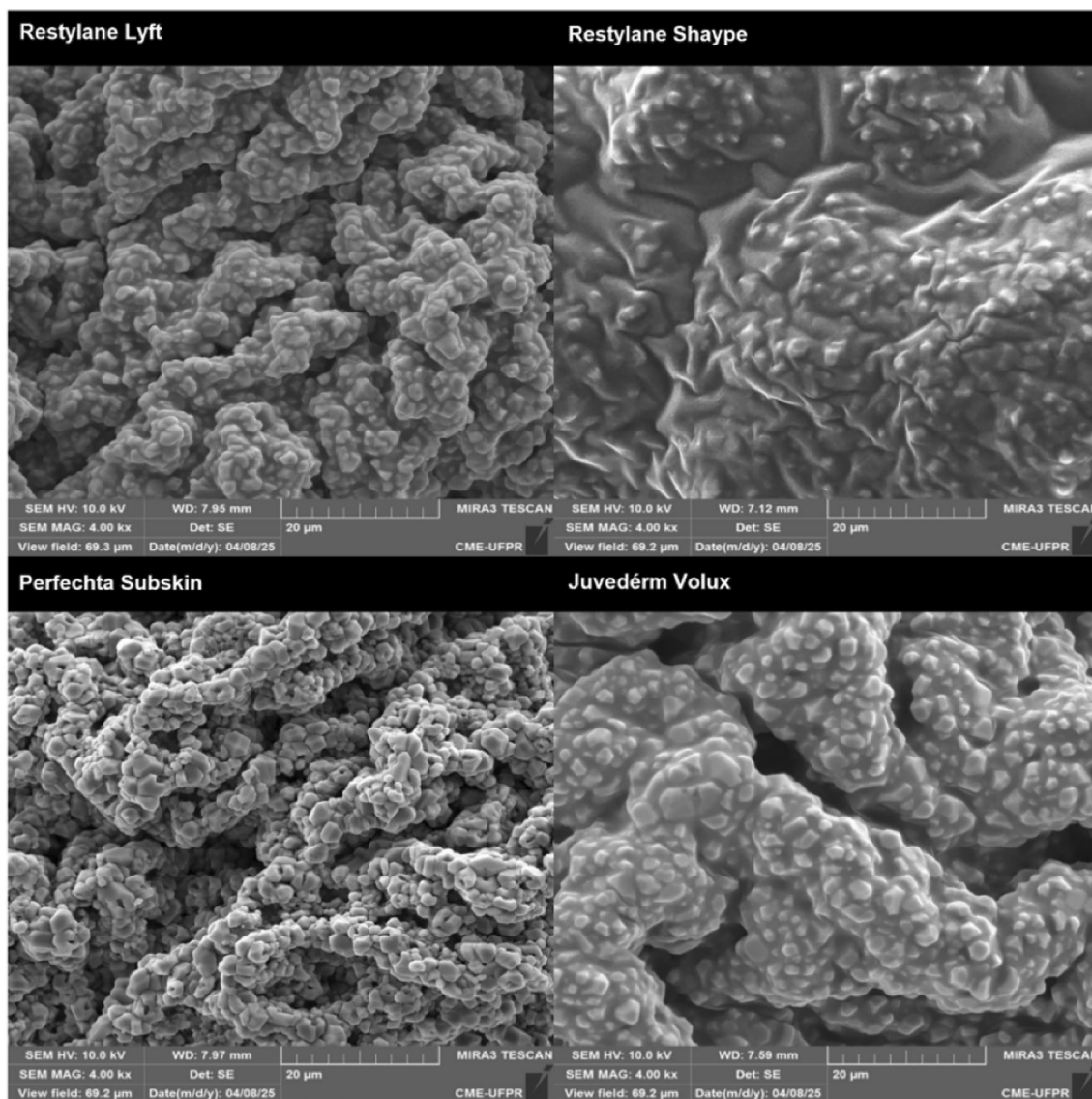
The MOC was significantly higher in RESTYLANE® SHAYPE compared to JUVÉDERM® VOLUX and RESTYLANE® LYFT ( $p = 0.002$  and  $p = 0.042$ , respectively; Fig. 5). PERFECTHA® SUBSKIN also presented higher MOC values than JUVÉDERM® VOLUX ( $p = 0.042$ ) (Fig. 5). No significant differences in MOC values were observed between RESTYLANE® SHAYPE and PERFECTHA® SUBSKIN ( $p > 0.05$ ) (Fig. 5).

Also, no direct relationships among fillers' chemical properties and the rheological parameters  $G'$ ,  $G''$ , and MOC were found (Fig. 6). However, an inverse relationship between MOC and swelling factor was observed.

## DISCUSSION

HA dermal fillers restore facial volume, define facial features, and reduce visible signs of aging with minimal risk and downtime. However, their clinical performance varies according to formulation parameters such as particle size, degree of crosslinking, and structural morphology. When selecting a filler, clinicians must consider intrinsic characteristics including HA concentration, SF,  $G'$ ,  $G''$ ,  $\tan \delta$ , and MOC. In this context, the SF in this study should be interpreted as a physicochemical parameter rather than a clinically validated indicator of volumetric outcomes, and future clinical investigations are required to confirm how these differences translate in vivo. This study provides a comparative structural and viscoelastic analysis of four commercial HA fillers for chin augmentation, assessing rheology, morphology, swelling behavior, and stability to inform both clinical decision-making and the continued innovation of filler technology.

Crosslinking of HA molecules is essential to enhance resistance against enzymatic and oxidative degradation. The degree of crosslinking reflects the average number of bonds between HA chain and defines the structural resilience

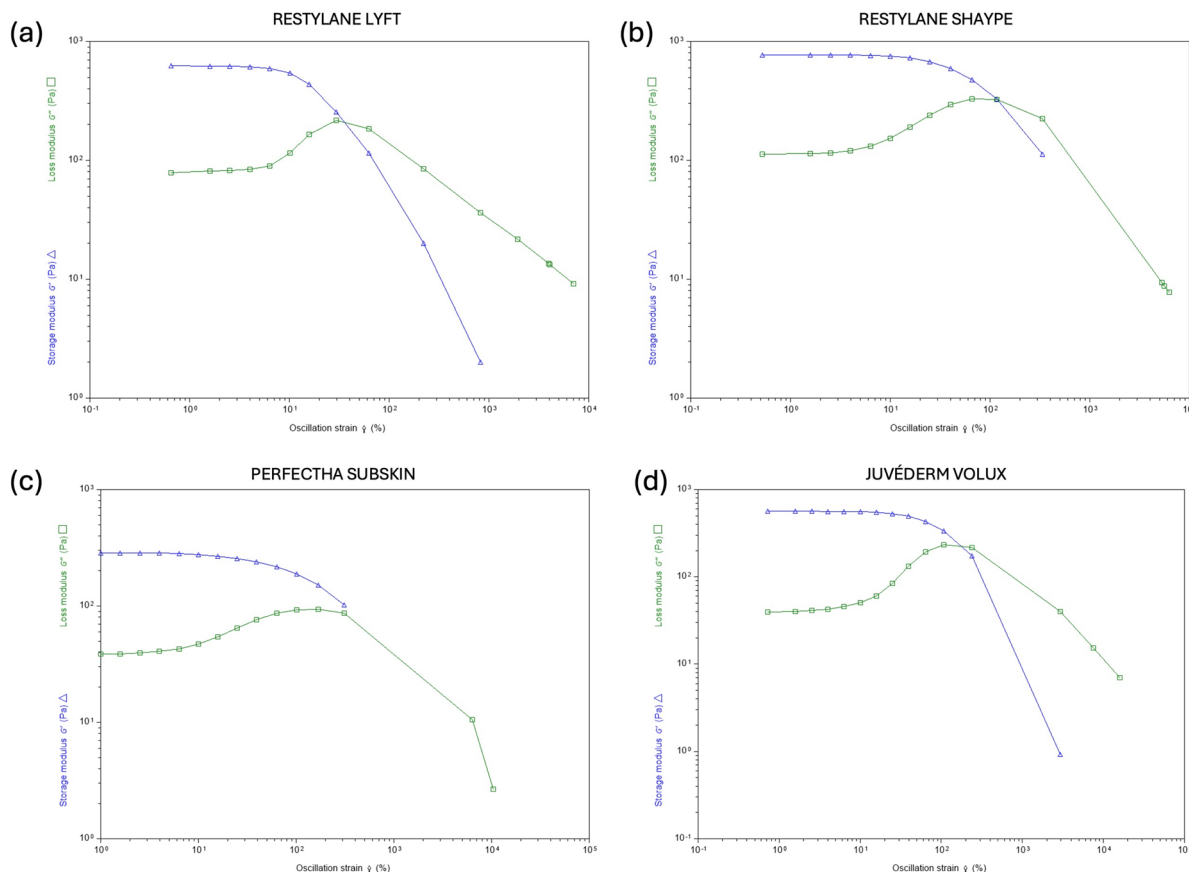


**Fig. 2** Representative scanning electron micrographs of the fillers used in this study

of the filler. All products evaluated in this study utilize 1,4-butanediol diglycidyl ether (BDDE) as a crosslinking agent, though at varying concentrations. Observed differences in particle sizes, PDI, and zeta potential among gels are likely attributable to proprietary manufacturing processes and directly affect the spatial organization and in vivo distribution of the gels. Kablik et al. [2] demonstrated that variations in particle size and distribution significantly influence filler homogeneity, injectability, and tissue response. Clinically, gels with

smaller particle sizes and lower PDI, such as JUVÉDERM® VOLUX, tend to exhibit superior moldability and tissue integration, making them advantageous for applications requiring contour refinement and structural volumization. Conversely, fillers with larger, more heterogeneous particles, such as RESTYLANE® SHAYPE, are better suited for deep-tissue injections where mechanical stability and projection are critical.

The present findings also demonstrate that fillers with more negative values of zeta



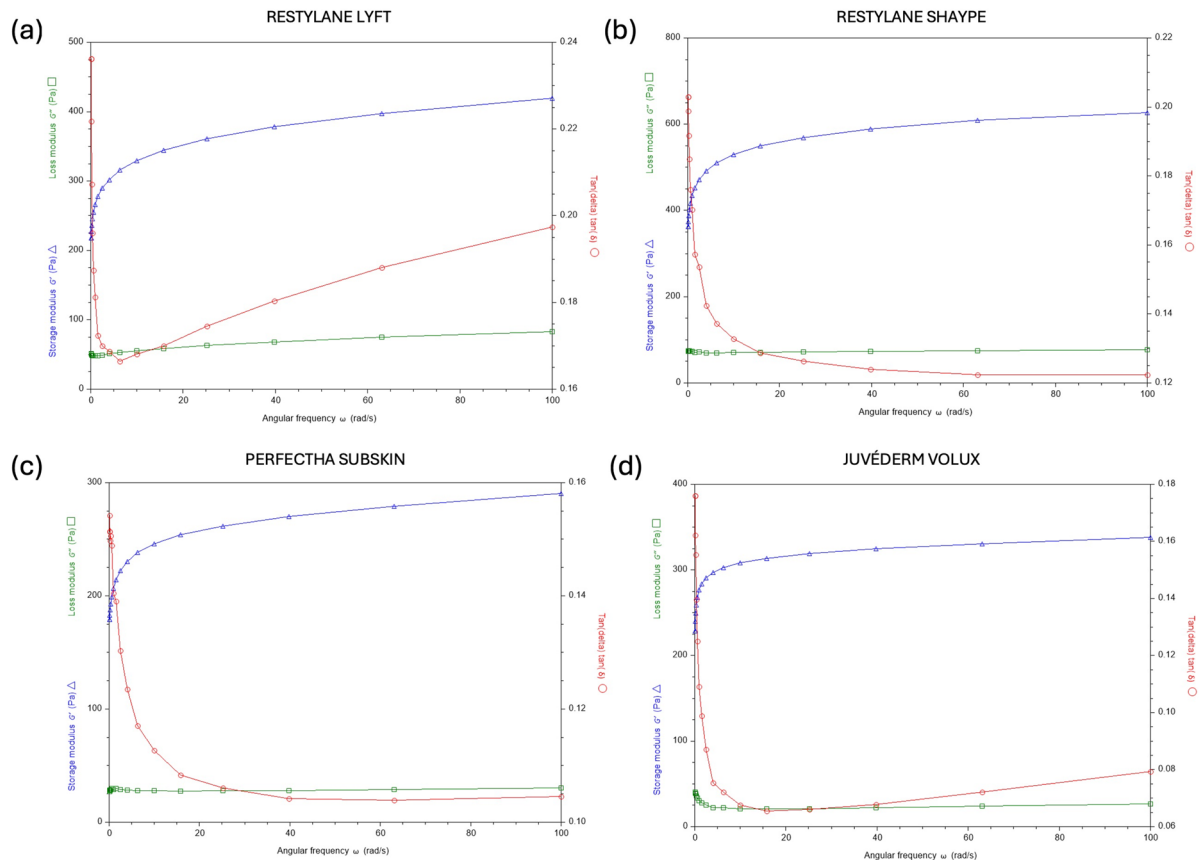
**Fig. 3** Representative oscillation amplitude measurements of the **a** RESTYLANE<sup>®</sup> LYFT, **b** RESTYLANE<sup>®</sup> SHAYPE, **c** PERFECTHA<sup>®</sup> SUBSKIN, and **d** JUVÉDERM<sup>®</sup> VOLUX fillers used in this study

potential values, such as RESTYLANE<sup>®</sup> LYFT, exhibit greater interparticle repulsion and reduced aggregation potential, supporting their use in dynamic or sensitive anatomical areas such as temples, malar region, nasolabial sulcus, and deeper areas such as chin and jawline. In contrast, fillers with lower surface charge, such as PERFECTHA<sup>®</sup> SUBSKIN, may display enhanced initial interaction with surrounding tissues, favoring rapid integration and immediate volumizing effects.

In terms of swelling behavior, the results align with those of Enright et al. [16] who reported low swelling capacity for RESTYLANE<sup>®</sup> LYFT, due to its NASHA-based manufacturing process. To elaborate, NASHA-derived (Bioventus LLC, North Carolina, USA) HA exhibits reduced hygroscopic expansion, yielding a more predictable and localized volumetric outcome. As

demonstrated by Enright et al. [16], fillers with higher SF, such as JUVÉDERM<sup>®</sup> VOLUX, are more suitable for regions such as the chin and mandibular contour, where gradual hydration and expansion contribute to progressive lifting effects. Conversely, gels with limited swelling capacity, such as RESTYLANE<sup>®</sup> LYFT, offer superior shape retention and reduced post-procedural edema, making them preferable for areas requiring immediate anatomical definition precision and stability.

Morphological differences observed by scanning electron microscopy further support these distinctions. As supported by Falcone et al. [9], structural attributes, including particle shape, surface porosity, and aggregation influence cohesivity and gel behavior. The present data demonstrate that more homogenous matrices, as seen in JUVÉDERM<sup>®</sup> VOLUX, promote smoother



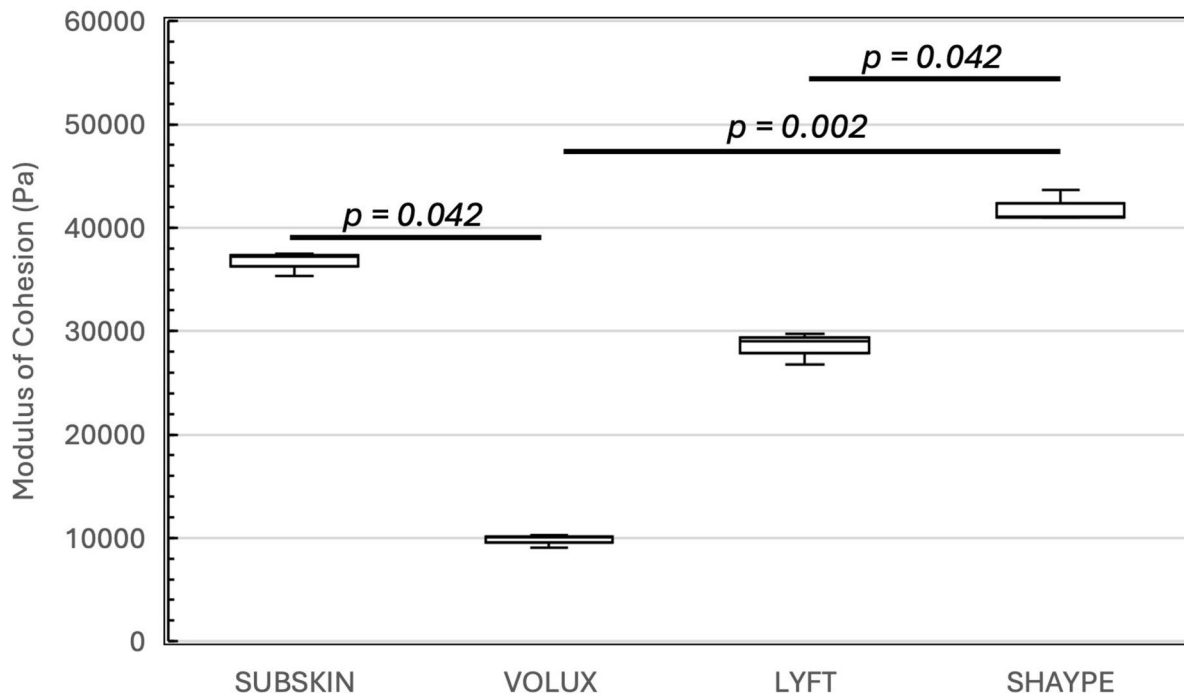
**Fig. 4** Representative frequency sweep measurements of the **a** RESTYLANE<sup>®</sup> LYFT, **b** RESTYLANE<sup>®</sup> SHAYPE, **c** PERFECTHA<sup>®</sup> SUBSKIN, and **d** JUVÉDERM<sup>®</sup> VOLUX fillers used in this study

tissue integration, while irregular and less porous structures, as observed in RESTYLANE<sup>®</sup> SHAYPE, confer enhanced internal rigidity, optimizing their use in deep structural enhancement.

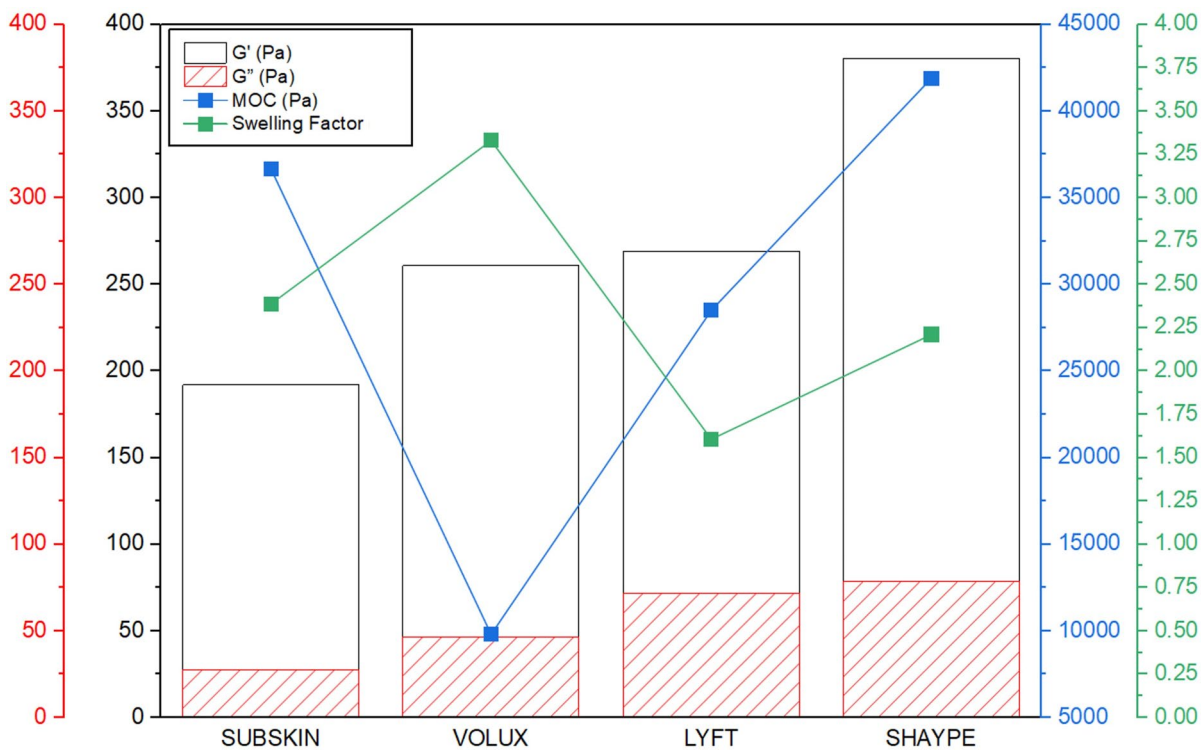
Rheologically, the predominance of  $G'$  over the  $G''$  at low frequencies indicates solid-like behavior essential for maintaining shape stability within tissues. Parallel  $G'$  and  $G''$  trends at lower frequencies suggest a stable rheological network and long-term storage stability (structural integrity), whereas curve divergence at higher frequencies, as observed in this study, reflects elasticity dominance and improved short-term stability. RESTYLANE<sup>®</sup> SHAYPE, RESTYLANE<sup>®</sup> LYFT, and PERFECTHA<sup>®</sup> SUBSKIN demonstrated high MOC values, confirming their cohesive and structured nature. Such characteristics make them particularly suitable for supraperiosteal applications, including the

chin and jawline, where mechanical support and resistance to deformation are required. Enright et al. [16] similarly characterized RESTYLANE<sup>®</sup> LYFT as a high- $G'$  filler, with strong structural integrity, consistent with our rheological findings.

As noted by Faivre et al. [11], understanding viscoelastic parameters such as  $G'$ ,  $G''$ , and  $\tan \delta$  is critical for predicting lifting performance and integration across anatomical planes. Reduced frequency dependence of the moduli curves ( $G'$  and  $G''$ ) reflects a robust three-dimensional gel network, while greater frequency sensitivity indicates a softer, more dynamic gel. The damping factor ( $\tan \delta$ ) further defines the elastic–viscous balance: lower values correspond to more elastic, moldable materials. In this study, RESTYLANE<sup>®</sup> SHAYPE and PERFECTHA<sup>®</sup> SUBSKIN displayed lower  $\tan \delta$  values, suggesting



**Fig. 5** Summary of the modulus of cohesion (MOC) of the study groups presented as medians and corresponding inter-quartile ranges.  $p < 0.05$  is statistically significant



**Fig. 6** Overlay of the storage modulus ( $G'$ ), loss modulus ( $G''$ ) (at 0.1 rad/s), modulus of cohesion (MOC), and swelling factor (SF) data of the study groups. Data presented as means of the three independent measurements obtained per group

high elasticity, reduced displacement tendencies, and greater resistance to displacement in high-mobility areas such as the chin, jawline, and perioral region.

Despite its strengths, this study has limitations. The relatively small sample size and the absence of long-term in vivo evaluation restrict generalizability. Additionally, rheological testing employed smooth parallel plate geometry without applied normal force, which may lead to potential sample slippage and slight variation in modulus measurements. Future analyses incorporating crosshatched geometries and controlled normal force would enhance measurement precision and reproducibility.

Overall, the findings demonstrate the value of rheological and structural profiling for guiding HA filler selection in chin augmentation. Among the evaluated fillers, RESTYLANE®SHAYPE, characterized by high MOC, elasticity, and cohesive structural properties, reducing displacement tendencies and minimizing application risks, demonstrated optimal performance for supra-periosteal procedures requiring projection and mechanical stability. Clinical trials are required to assess if these characteristics makes the mentioned filler clinically superior compared with other ones. Nevertheless, each filler presents unique advantages that may be leveraged according to patient anatomy, treatment goals, and practitioner preference. The present comparative analysis highlights the importance of evidence-based filler selection and contributes to a more nuanced understanding of HA gel performance in aesthetic medicine.

## CONCLUSIONS

Among the evaluated HA-based fillers, RESTYLANE® SHAYPE exhibited the highest MOC values, elevated  $G'$ , moderate SF, and favorable structural properties. These preclinical characteristics suggest potential suitability for chin augmentation procedures requiring projection and shape stability. Its high elasticity and resistance to deformation support its use in supra-periosteal applications requiring projection and long-term shape retention.

Nevertheless, filler selection should remain patient-specific, taking into account individual anatomical characteristics, aesthetic objectives, and practitioner expertise to achieve optimal outcomes.

**Author Contributions.** Ana Claudia Carbone: Investigation, Resources, Data Curation, Writing - Review & Editing. Maria Luiza Boechat Borges Neves: Methodology, Formal analysis, Writing - Review & Editing. André Gaspar Zinco: Conceptualization, Methodology, Formal analysis, Data Curation, Writing - Review & Editing, Visualization. Vasudev Vivekanand Nayak: Investigation, Formal analysis, Writing - Original Draft, Writing - Review & Editing. Lucas Alexandre de Sousa Mendes: Investigation, Writing - Review & Editing. Andressa De Marchi El Assad: Investigation, Writing - Review & Editing. Mariana Barbosa Câmara-Souza: Resources, Writing - Review & Editing, Visualization. Stephanie Teixeira: Conceptualization, Writing - Review & Editing, Supervision. Daniel Augusto Machado Filho: Investigation, Resources, Writing - Review & Editing. Fabio Seigi Murakami: Conceptualization, Formal analysis, Data Curation, Writing - Original Draft, Writing - Review & Editing, Supervision, Project administration. Giancarlo De la Torre Canales: Conceptualization, Formal analysis, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration.

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**Data Availability.** The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Conflict of Interest.** Ana Claudia Carbone reports serving as a speaker for Galderma, Brazil. Maria Luiza Boechat Borges Neves reports serving as a speaker for AbbVie – Allergan, Brazil. Stephanie Teixeira reports working as a senior

scientific manager for Galderma, Brazil. André Gaspar Zinco, Vasudev Vivekanand Nayak, Lucas Alexandre de Sousa Mendes, Andressa De Marchi El Assad, Mariana Barbosa Câmara-Souza, Daniel Augusto Machado Filho, Fabio Seigi Murakami, and Giancarlo De la Torre Canales declare that they have no conflicts of interest related to this work.

**Ethical Approval.** This study did not involve human participants or human tissues; therefore, ethical approval was not required.

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