Viscoelasticity, cohesive energy, and viscosity of new hyaluronic acid-based fillers

Viscoelasticidade, energia coesiva e viscosidade de novos preenchedores à base de ácido hialurônico

Viscoelasticidad, energía cohesiva y viscosidad de nuevos rellenos a base de ácido hialurónico

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Abstract
The storage and loss modulus (G'; G"), cohesive energy, and viscosity of Hyaluronic Acids (HA) are key factors to be considered in aesthetic volumizing. Objective. This study aims to assess the properties of three HAs indicated for facial volumization: Gahya Volume, Gahya Light, and Gahya Classic. Methodology. Those rheological properties were performed in a rotational rheometer (TA-Instruments AR-1500ex). The sample volume for analysis was 1.0 mL. The frequency sweep was performed in the range of 10.0 to 0.01 Hz with 15 points. The following parameters were evaluated: viscoelasticity (G' and G") considering the frequency variation, cohesive energy, and viscosity. The statistical method used to compare the results two by two was the unpaired t-test with significance level (p=0.05). Results. The results showed that G' was statistically different when comparing Gahya Classic® and Gahya Light® samples and between Gahya Classic® and Gahya Volume® (p<0.05). Gahya Classic® and Gahya Volume® showed a significant difference from Gahya Volume® for G" (p<0.05). There was no significant difference between the samples for viscosity. Gahya Light® and Gahya Classic® have better elasticity and viscosity, and Gahya Light® and Gahya Volume® have better cohesive energy. Conclusion. Gahya Light® had the best behavior for the analyzed properties.
Keywords: Hyaluronic acid; Rheology; Physical property; Cohesive; Viscoelasticity.

Resumo
O módulo de armazenamento e perda (G'; G"), a energia coesiva e a viscosidade dos Ácidos Hialurônicos (HA) são fatores-chave a serem considerados na volumização estética. Objetivo. O objetivo deste estudo foi avaliar as propriedades estudadas em três HAs indicados para volumização facial: Gahya Volume, Gahya Light e Gahya Classic. Metodologia. Essas propriedades reológicas foram realizadas em um reômetro rotacional (TA-Instruments AR-1500ex). O volume da amostra para análise foi de 1,0 mL. A varredura de frequência foi realizada na faixa de 10,0 a 0,01 Hz com 15 pontos. Os seguintes parâmetros foram avaliados: viscoelasticidade (G' e G") considerando a variação de frequência, energia coesiva e viscosidade. O método estatístico usado para comparar os resultados dois a dois foi o teste t não pareado com nível de significância (p=0,05). Resultados. Os resultados mostraram que G' foi estatisticamente diferente na comparação entre as amostras Gahya Classic® e Gahya Light® e entre Gahya Classic® e Gahya Volume® (p<0,05). O Gahya Classic® e o Gahya Volume® apresentaram uma diferença significativa em relação ao Gahya Volume® para G” (p<0,05). Não houve diferença significativa entre as amostras quanto à viscosidade. O Gahya Light® e o Gahya Classic® têm melhor elasticidade e viscosidade, e o Gahya Light® e o Gahya Volume® têm melhor energia coesiva. Conclusão. O Gahya Light® apresentou o melhor comportamento para as propriedades analisadas.
Palavras-chave: Ácido hialurônico; Reologia; Propriedade física; Coesivo; Viscoelasticidade.

Resumen
El módulo de almacenamiento y de pérdida (G'; G"), la energía cohesiva y la viscosidad de los Ácidos Hialurónicos (AH) son factores clave a tener en cuenta en la voluminización estética. Objetivo. Se estudiaron estas propiedades en

tres AH indicados para la voluminización facial: Gahya Volume, Gahya Light y Gahya Classic. Metodología. Dichas propiedades reológicas se realizaron en un reómetro rotacional (TA-Instruments AR-1500ex). El volumen de muestra para el análisis fue de 1,0 mL. El barrido de frecuencia se realizó en el rango de 10,0 a 0,01 Hz con 15 puntos. Se evaluaron los siguientes parámetros: viscoelasticidad (G' y G") considerando la variación de frecuencia, energía cohesiva y viscosidad. El método estadístico utilizado para comparar los resultados fue la prueba t no apareada con nivel de significación (p=0,05). Resultados. Los resultados mostraron que G' era estadísticamente diferente al comparar las muestras de Gahya Classic® y Gahya Light® y entre Gahya Classic® y Gahya Volume® (p<0,05). Gahya Classic® y Gahya Volume® mostraron una diferencia significativa con Gahya Volume® para G» (p<0,05). No hubo diferencias significativas entre las muestras en cuanto a la viscosidad. Gahya Light® y Gahya Classic® tienen mejor elasticidad y viscosidad, y Gahya Light® y Gahya Volume® tienen mejor energía cohesiva. Conclusión. Gahya Light® tuvo el mejor comportamiento para las propiedades analizadas.
Palabras clave: Ácido hialurónico; Reología; Propiedades físicas; Cohesividad; Viscoelasticidad.

1. Introduction

Facial appearance changes due to a combination of changes in soft tissues and bone. It is well known that there is a strong correlation between a healthy facial structure and the appearance of the face. (Shaw & Kahn, 2007). With increasing age, bone loss occurs, resulting in an aging appearance of the face. These patterns are well-established and can be confidently identified. The superotemporal and inferotemporal areas of the orbital rims are particularly prone to resorption. Whereas changes in the inferolateral rim can be observed in middle age, superotemporal regression is typically seen in old age (Shaw & Kahn, 2007; Kahn & Shaw 2008). Besides that, the inferomedial quadrant of the orbit tends to recede with age, particularly in males (Pessa & Chen,2002).

The contour of the midface skeleton, defined primarily by the maxilla and zygomatic arch, undergoes midface retrusion during ageing, (Pessa, 2000) with the maxilla more susceptible to age-related loss than the zygoma. The absence of dental elements or impairment of the vertical dimension of the face may accelerate this process (Flowers, 1991). Changes in the bony base that supports the nasal structures cause the nose to lengthen and the tip to droop, resulting in the columella and lateral flaps moving posteriorly due to the increase in the piriform opening (Rohrich et al. 2004). In general, however, the lower jaw fails to resorb at the same rate as the middle one, (Shaw et al. 2010) leading to the appearance of protrusions in elderly people (Pecora et al, 2006).

In recent years, a minimally invasive procedure to volumize resorbed areas of the facial skeleton has been widely used as a corrective strategy. However, only a few materials have been proven to be effective for this purpose and we can confidently recommend their use. When considering the use of volumizing materials, it is important to take certain characteristics into account. These factors are critical in ensuring the best possible outcome for the patient. These include durability, low potential for adverse events, ease of manipulation, predictability, reversibility, and cost-effectiveness (Gold, 2009).

Hyaluronic acid (HA) is found naturally in the extracellular matrix, vitreous humor and cartilage. It is an essential component of connective tissue. It is involved in cell adhesion, cell division and the transport of nutrients (Abatangelo et al. 2020). The diverse and complex biological functions of the compound have stimulated innovative research, and the interest of the pharmaceutical industry in developing new derivatives with distinct properties to improve human health has been stimulated by clinical interest in a variety of health areas, including aesthetics, ophthalmology, joint lubrication, skin repair and remodeling, prosthetics, adipocyte engineering and neurology.

Chemical modifications of the molecule have enabled the production of insoluble or partially water-soluble polymers, which are ideal for use in tissue volumizing gels and other applications (Sciabica et al. 2021). Localized infiltrations of hyaluronic acid (HA) in the form of a synthetic volumizing gel are essential for the restructuring of the tissues in the areas where re-absorption has taken place. It is highly biocompatible and is primarily derived from bacterial culture. Its nonimmunogenic properties promote fibrovascular development, which in turn contributes to long-term tissue stability. Any technical abbreviations are clearly explained at first use. HA consists of a long-chained polysaccharide, divided into repeated disaccharide units of hyaluronic acid and N-acetyl-glucosamine (Fundarò et al, 2022; De Boulle et al, 2013). The density of polymers is determined by the cross-linking process, and the activity of natural hyaluronidase is inhibited by this process, which prolongs the effectiveness of the polymer at the implantation site.

Density can be classified as high, medium or low. This is based on the number and quality of cross-links. Low density HA is the most fluid and suitable for joint viscosupplementation, fine wrinkle correction, skin hydration and dark circles. Medium density hyaluronic acid is used to correct and control deeper wrinkles and furrows and to increase the volume of the lips. High Density Hyaluronic Acid is recommended for adding volume to areas where there has been tissue resorption, providing a lifting effect to the treated area. The cross-linking of the polymer chains leads to a change in the physical and rheological properties of the molecule, resulting in an increase in the firmness of the gel and a greater resistance to enzymatic degradation. 1,4-Butanediol diglyceryl ether (BDDE) is the primary crosslinking agent used in the production of HA gels. A hygroscopic viscous liquid, it reacts safely with amines, esters, amides, hydroxyls and sulfhydryl groups (Kenne et al, 2013).

The biodegradable nature of this product has made it a popular choice in the pharmaceutical industry. Furthermore, its toxicity levels are significantly lower than other chemical agents based on either cross-linking, such as divinyl sulfone (Volpi et al, 2009; Rees et al, 2004). The cross-linking capacity of the molecule is due to the reactivity of its epoxy groups, which react selectively with the more accessible primary alcohol in the HA structure to form an ether bond. The superior stability of the ether linkage, compared to ester or amid linkage, gives BDDE cross-linked HA fillers a clinical duration of one year or more (Volpi et al, 1991). However, it is important to note that not all crosslinking agents will react with HA polymers, resulting in residual chemicals that may become harmful when metabolized. To ensure safety as an HA binder, the Food and Drug Administration (FDA) recommends a residual BDDE level of two parts per million (ppm).

The purity of the HA gel is ensured by successive washes to eliminate any remaining BDDE, which results in less than 0.002 mg of BDDE per 1 mL of gel. The degree of purity is determined by the analysis of the parameter of contamination. The manufacturer achieves a balance between the amount of crosslinker added to the HA and its toxicity level. A lower cross-linking agent will result in a lower density, making it more suitable for tissues that are less dense and more mobile. In the same way, an average cross-linking index will result in an average density, mobility, and depth of application. To achieve a higher level of support, a higher number of cross-linking agents are required. (Di Gregorio et al, 2022; Philipp-Dormston, 2018).

Rheological properties and degree of aggressiveness of HA gel can be determined by different properties. The quality of an HA can also be assessed by the high quality of the raw materials of which it is composed. Products approved by both the FDA and EDQM usually are highly trustworthy.

HA is considered safe if its composition contains low levels of heavy metals, not exceeding 20 ppm according to the standards set by the FDA and EDQM, the minimum residual protein level should not be greater than 0.3% and the maximum endotoxin level should be less than 0.05 IU/mg. Several brands of HA are available, each with unique characteristics that may have a major impact on the indication depending on where it is injected. It is important to understand these differences, which many users may be unaware of. It is important to note that HA's rheology and physicochemical properties will determine whether they will be suitable for any given clinical application.

HA rheology is an important tool for the assessment and differentiation of HA fillers. Although manufacturers do not always describe these properties, it is essential to consider rheological properties such as modulus, viscosity, tan delta, complex modulus G* and cohesiveness when evaluating HA quality. A reliable measure of a material's ability to return to its original shape or strength is the modulus of elasticity, or G-prime (G'). It gives a clear indication of the ability of the gel to withstand deformation or to resist changes in shape when subjected to external forces.

HA with a high G' value has a greater capacity for projection or volumization as a structural support for the replacement of resorbed bone structures. HA with a high G' is ideal for implants in supraperiostal layers that are not subject to large movements. Clinically, the HA strength is defined by its G' property, with a higher G' indicates a firmer HA (Edsman et al 2012). The viscous modulus or G double prime (G") refers to the deformation of the gel under dynamic forces. Viscous hyaluronic acids can be difficult to extrude from the inside of cannula. A good HA should have a low and constant extrusion force upon injection into the tissue, a property that has a direct relationship with the uniformity of the gel, its high quality and its purification process (Fagien et al, 2019). The extrusion force of an HA should be in the range of 10 N to 23 N. Tan Delta (ɗ) refers to the elasticity of the material (G"/G'). It defines the consistency of the gel. The G* complex modulus reflects the ability of the gel to resist deformation. These materials must remain stable under the pressure of the external environment. When balanced with G*, HA gels usually show good viscoelasticity. Materials with good viscoelastic properties are easy to mold and allow the material to flow smoothly. The appropriate values for this property range from 310 to 330 Pa at 0.1Hz agitation frequency, and from 350 to 400 Pa at 1.0Hz (Borrell et al, 2011). Cohesiveness is the force of attraction between particles, which holds them together. The correct texture of the cohesive gel is determined by its ability to retain its initial shape and to resist migration under pressure. The lifting capacity of the HA can be determined with confidence from this property. It is linked to G' (Faivre et al, 2021).

HA has more physicochemical properties, which include swelling factors (SWF), cross-linking, concentration, and production technology. SWF depends on polymer network thickness, degree of crosslinking and concentration of HA polymers. This is inversely proportional to the hydrophilic properties of the HA gel. As the binder index increases, the hydrophilicity of the HA decreases resulting in a lower wetting factor. HAs containing high levels of SWF should be used with caution in critical areas and in thin skin as they tend to retain more water over time.

The degree of cross-linking is determined by the number of cross-linking agents in the gel formulation. Long-term adverse reactions are more likely to occur when there is a greater amount of free cross-linking agents present in the gel. The number of polymers present in the formulation will be dictated by the concentration of HA. Fillers can be either insoluble or soluble, insoluble being long-acting fillers, while soluble, which are easily metabolized, do not contribute significantly to a filler's purpose. Manufacturing technology determines the quality of HA. The more advanced the technology, the greater the tendency to optimize the product (Kablik et al, 2009). In general, properties such as viscoelasticity, cohesive energy and viscosity are important to define the quality of a HA gel to be used in volumization.

AH Gahya has launched three versions for tissue volumization lifting in the market: Gahya Volume®, Gahya Classic®, and Gahya Light®. They are presented by the manufacturer as volumizers, but with different indications. According to the manufacturer, these materials are single-phase products consisting of small particles called volumizers that undergo a long-lasting, low-temperature cross-linking process that significantly increases their complete cross-linking rate through the cross-linking bonds associated with the ring bonds of the polymer itself. The material retains its original shape after passing through the cannula and reduces the risk of migration under pressure due to its cohesiveness and texture (Lee et al,2015; Chun et al, 2016).

In addition, the washing polymer technology is highly precise and can effectively remove significant amounts of residual BDDE (at levels of 500ppm) and contaminants, while causing minimal deformation of the HA (less than 5%), resulting in a reduction in the long-term toxicity of the HA without altering the rheological properties of the gel (Sciabica et al. 2021; Kahn & Shaw, 2007). This method produces a soft hyaluronic acid gel with fine particles, good viscoelasticity, and natural volume. The gel can be easily injected with a 27G cannula, providing a gentle injection sensation of about 3 to 7 N. It can also be easily molded after injection, making it an excellent volumizer for regions with limited tissue mobility (Lee et al,2015; Chun et al, 2016). These findings are supported by Lee et al (2015) and Chun et al (2016).

Literature on the rheology of AH Gahya Volume®, Gahya Classic® and Gahya Light® is lacking, but it is important to note that they are volumizing devices with different indications.

The objective of this study was to evaluate properties that were studied in three HAs indicated for facial volumization: Gahya Volume, Gahya Light and Gahya Classic. This study reliably evaluated the viscosity, viscoelasticity, and cohesive energy parameters of three hyaluronic acid-based dermal volumizers: Gahya Volume®, Gahya Classic®, and Gahya Light®.

2. Methodology

Experimental, laboratory research of a quantitative nature (Fagien et al., 2019) was carried out with the support of statistics and, in the following lines, the materials and methods used in the studies are presented.

Identification of samples

The hyaluronic acid samples, Gahya Light®, Gahya Volume® and Gahya Classic®, were stored under the conditions recommended by the manufacturer, as detailed in Table 1.

Table 1 - Identification of the samples received and their batch.

Hyaluronic Acid	Batch
Gahya Volume®	RAHC2922K
Ghaya Classic®	RAHP0122K
Gahya Light®	RAHV0822K

Source: Authors.

Equipment – Rotational Rheometer

Rheological analyses to determine viscoelastic parameters were performed in a rotational rheometer of TA-Instruments AR-1500ex (New Castle, NE, USA) at 25ºC, with a parallel plate geometry, sandblasted with a diameter of 40 mm and a 500 μm gap between the geometry and the fixed plate. The sample volume for was 1.0 mL.

Frequency sweep: determination of viscoelasticity parameters

Frequency scanning ranged from 10.0 to 0.01 Hz, with 15 points per decade. The following parameters were evaluated: storage modulus (G') and loss modulus (G") as a function of frequency variation.

Cohesiveness

Cohesiveness was analyzed by scanning the amplitude curve over a range of 0.01 to 1000% with a fixed frequency of 1 Hz and 15 points per decade. The cohesive energy was then calculated using the provided formula:

$$E\ coe = 1/2\ x\ G'_{RLV\ x\ \gamma}{}^{2}$$

where, G'RLV is the storage modulus of the viscoelastic linear region and γ is the critical strain stress.

Viscosity

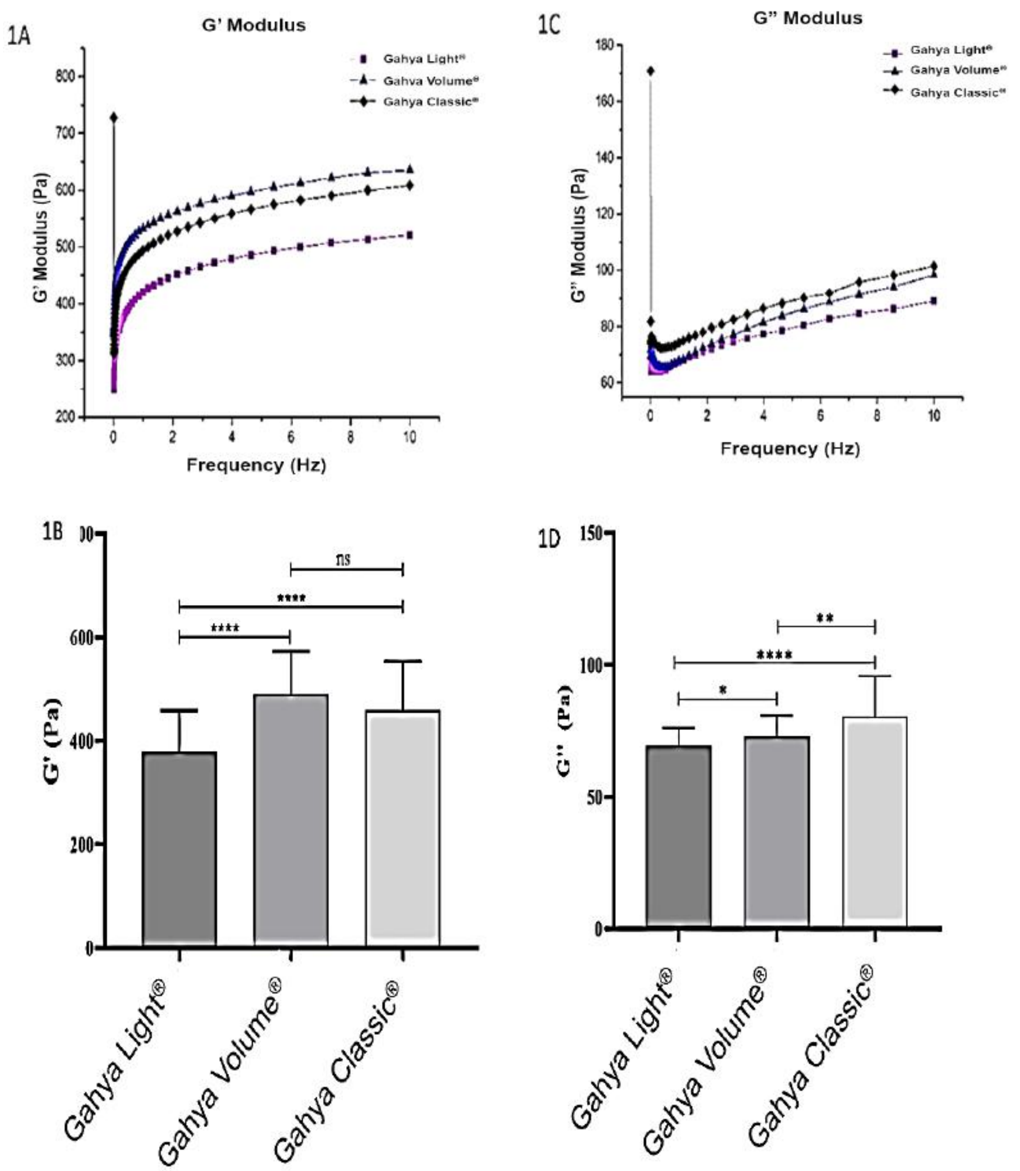
Flow curve tests were performed under the shear rate from 0.01 to 1000s-1

3. Results

Viscoelasticity

Figure 1 shows the elastic modulus (G') and viscous modulus (G") for Gahya Volume®, Gahya Classic® and Gahya Light®. The behavior of G' for the three HA is shown in Figure 1A, and Figure 1B shows the corresponding G' statistics. Statistical analysis shows a significant difference between Gahya Volume® and Gahya Classic®, as well as between Gahya Volume® and Gahya Light® ($p<0.05$). No statistical difference was found between Gahya Classic® and Gahya Light®. The behavior of "G" for the three HA is shown in Figure 1C. Figure 1D shows the corresponding statistical results for module "G". There was no significant difference between the samples of Gahya Volume® and the samples of Gahya Classic®. There was a statistically significant difference ($p<0.05$) between Gahya Volume® and Gahya Light®, as well as between Gahya Classic® and Gahya Light®.

Figure 1 – Elastic modulus.



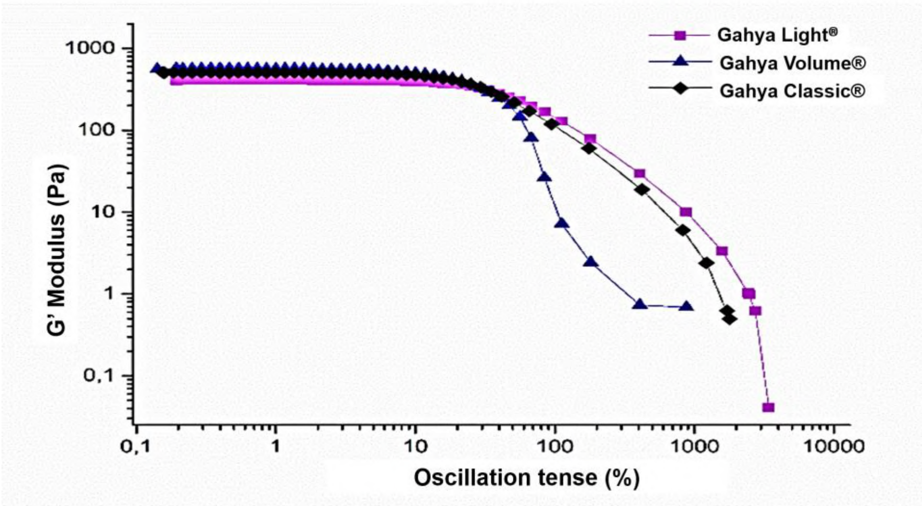
Source: Authors.

As can be seen in Figure 1, above: (A) Elastic modulus (G') for Gahya Volume®, Gahya Classic®, and Gahya Light® HA. (C) Viscous modulus (G") for Gahya Volume®, Gahya Classic® and Gahya Light® HA. (B) Statistical analysis of G' values using the t-test not paired with the significance level ($p<0.05$). (Gahya Volume® sample compared to Gahya Classic® sample p= 0.0048, Gahya Volume® compared to Gahya Light® p <0.0001; sample Gahya Classic® compared to Gahya Light® p= 0.391. (D) Statistical analysis of G" values using the t-test not paired with the significance level ($p<0.05$). (Gahya Volume® sample compared to Gahya Classic® sample p = 0.1952; Gahya Volume® sample compared to Gahya Light® p <0.0001 and Gahya Classic® sample compared to Gahya Light® p<0.0001).

Cohesive energy

Cohesive energy was calculated from the amplitude sweep plot considering Modulus G', and oscillation tense (Figure 2). Table 2 shows G'_{LRV}, strain (%) and cohesive energy (J/m3) values for each HA.

Figure 2 - Cohesive energy considering G' modulus and oscillation tense (%) for Gahya Light®, Gahya Volume® and Gahya Classic® HA.



Source: Authors.

Table 2 - G'_{LRV} (Pa), Strain (%) and Cohesive Energy (J/m^3) for HA Gahya Volume®, Gahya Classic®, and Gahya Light®.

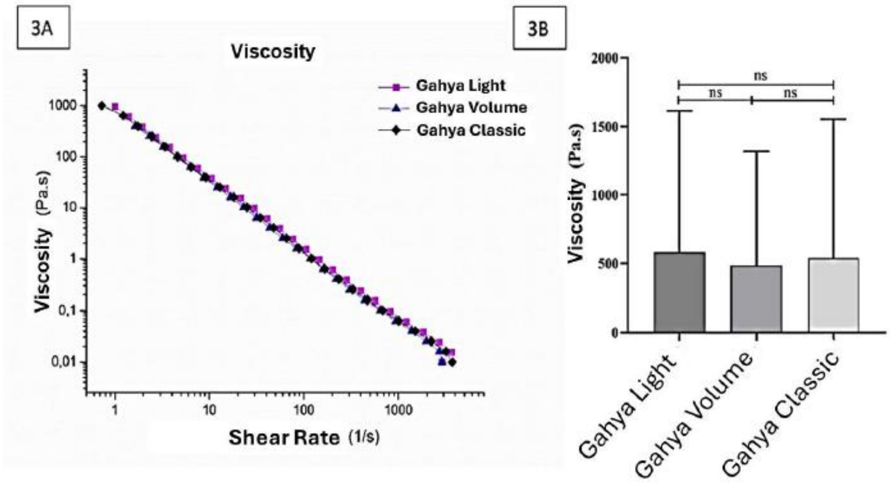
Sample	G'_{LRV} (Pa)	Strain (%)	Cohesive Energy (J/m^3)
Gahya Volume®	406,52	1,36	375,94
Gahya Classic®	568,93	0,86	210,39
Gahya Light®	507,97	1,58	634,05

Source: Authors.

Viscosity

The viscosity of the HA is shown in Figure 3A, and the corresponding statistical results are shown in Figure 3B. There were no significant differences between the samples.

Figure 3A – Viscosity and Figure 3B Statistical results.



Source: Authors.

As can be seen in Figure 3, above: (A) Viscosity for Gahya Volume®, Gahya Classic®, and Gahya Light® HA. (B) Statistical analysis using the t-test not paired ($p<0.05$). The statistical analysis indicates that there is no significant difference between the Gahya Volume® sample and the Gahya Classic® sample ($p = 0.2861$), nor between the Gahya Volume® sample and the Gahya Light® sample ($p = 0.925$). Similarly, there is no significant difference between the Gahya Classic® sample and the Gahya Light® sample ($p = 0.3303$.

4. Discussion

Physicochemical properties measure HA rheology, one of the most important properties to evaluate the viscoelastic of those materials. The study found statistically significant differences ($p<0.05$) in G' between the Gahya Volume®, Gahya Classic®, and Gahya Light® samples. There was a statistically significant difference ($p<0.05$) between the Gahya Volume® and Gahya Light® samples, as well as between the Gahya Classic® and Gahya Light® samples. The viscosity test did not show any statistically significant differences between the samples tested.

For this reason, research into the rheology of HA gels has become increasingly common. Understanding the physicochemical characteristics of intradermal filler materials can help professionals select the most appropriate option, improving the effectiveness and durability of clinical procedures. When selecting a filler, it is important to consider the dynamic and weight conditions of each region of the face, as this affects the distinct characteristics of each filler.

The storage modulus (G') defines the stiffness and elasticity of the HA gel. Cross-linking between the polymers of the gel increases its degree of cohesion and resistance to deformation. The parameter G' can be used to assess the effectiveness of cross-linking in viscoelastic materials. Materials with a high G′ are described as having a high load bearing capacity of the tissue. This is an important parameter as it indicates that these materials can be used at deeper levels where greater post-implantation precision and contour maintenance are required. These materials are more resistant to deformation, allowing greater definition and correcting deep tissue. Materials with intermediate G' provide a better balance between elasticity and fluidity, making them suitable for applications in the subcutaneous and supraperiostal tissues in areas of greater mobility, where there is a need to support the tissue.

The study found that all three materials investigated had adequate G' for volumization. Although there was a small difference between Gahya Classic® and Gaya Light®, their values were considered the same, with Gahya Classic® presenting a slightly higher value. Gahya Classic® and Gahya Light® can be considered high cross-link AH due to their composition's cross-links. This parameter demonstrates the ability of both materials to withstand pressure, suggesting deeper implantation sites. Gahya Volume® exhibited lower G' values compared to other HA products available in the market, (Furtado et al 2023) indicating its suitability for use in intermediate tissue layers rather than supraperiostal layers. This is due to its lower number of cross-linked polymers.

The loss modulus (G”) is a measure of the flow competence of viscoelastic materials, indicating the fluidity of the gel. This information suggests that the volumetric fraction of cross-linked HA microspheres is a key factor in determining the flow competence of viscoelastic materials. Previous studies have shown that the volumetric fraction of cross-linked HA microspheres in a material like Gahya Classic® can affect G”, with an increase from 211 to 700 Pa observed when the fraction increased from 65% to 95%.

Samples with percentages between 65% and 85% showed G values between 175 Pa and 430 Pa, which can be extruded through a 29-30G needle. In this study, the G values of Gahya Light® and Gahya Classic® were considered equal, but lower than those observed by Chung et al. (2016).

The differences in experimental conditions and materials investigated may have contributed to the lack of chemical similarity between the Gahya Classic® and the product being studied. Additionally, the size of the spherical particles was not controlled for in all three products. The results indicate that Gahya Volume® has vertical filling characteristics and less lateral flow.

Table 2 shows that Gahya Light® and Gahya Classic® are highly malleable due to their horizontal filling properties, making them versatile in adapting to different anatomies, especially those with age-related tissue degradation. Table 2 shows that the Gahya Light® and Gahya Classic® have good 'moldability' due to their horizontal filling characteristics.

Ghaya Classic® has the lowest energy dissipation during deformation compared to other products. This is due to its high crosslinking values resulting in low deformation, whereas Gahya Light® has higher deformation values and dissipates more energy. Correlating the high G' of the Gahya Light®, it is possible to conclude that it supports greater weight and pressure, but its projection is horizontal.

Gahya Volume® is in an intermediate state of deformation and dissipation energy, indicating that it is a firmer gel. However, due to its lower G', it can support less weight and pressure than other gels. It has good vertical structuring and may be useful in clinical cases that require lip contouring or tear duct filling. From a statistical point of view, the three types of HA examined did not differ significantly because they all had very close viscosities. However, it was observed that Gahya Light® had a slightly higher viscosity than Gahya Classic® and Gahya Volume®. These results suggest that the flow resistance (extrusion) of the three types of HA studied is similar.

All rheological conditions were like those already existing on the market, such as Gahya Volume®, Gahya Classic®, and Gahya Light® (Furtado et al, 2023). However, to confirm this hypothesis, it is necessary to conduct comparative studies that compare these materials clinically.

The inclusion of characteristics such as BDDE concentration, tan Delta, and Complex Module G* can provide a better understanding of the products and help to define parameters related to the gel's uniformity, quality, purification process, and clinical selection.

This study clarified information on the behavior of the products that were studied regarding viscosity, viscoelasticity, and cohesive energy. Understanding these properties improves the indication, use, and quality of the results of their clinical application. Further studies could investigate these properties by comparing the three products with others available on the market.

5. Conclusion and Suggestions

Gahya Classic and Gahya Light exhibit superior elastic and viscous moduli, while Gahya Light and Gahya Volume demonstrate better cohesiveness. Of the three materials examined, Gahya Light performed the best results in the tested properties.

Further clinical, controlled and randomized studies should be carried out to validate the quality of the products investigated, confirming the viability of the properties presented here.

Conflict of Interest statement

The authors declare that they have no conflicts of interest to disclose.

Statement of human and animal rights, or ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent

For this study informed consent is not required.

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