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Advancing Lip Augmentation: State-of-the-Art 2D and 3D Analysis for Assessing Volume Enhancement and Lip Line Redefinition

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Abstract: Over the preceding five decades, there has been a noticeable surge in the pursuit of achieving voluminous and well-defined lips. This trend has prompted an escalating number of individuals to undergo lip augmentation procedures, aiming for a natural three-dimensional enhancement of lip volume and distinct vermilion borders. Despite the proliferation of lip augmentation techniques, there remains a dearth of comprehensive investigations into their precise effects on the three-dimensional structural integrity of the lips. This research endeavors to address this gap by employing stereophotogrammetry as a quantitative tool to scrutinize lip augmentation outcomes and to appraise the efficacy of lip plumpers. The study methodology involves a comparative analysis of lip dimensions among subjects treated with a commercial lip plumper using multi-spectral imaging for lip dimension assessment, coupled with markerless tracking technology and 3D interpolating surface methodology to analyze lip volume and shape. Additionally, the study evaluated lip youth state, including moisture level, softness, firmness, and tissue density. The demand for lip augmentation procedures is driven by perceived advantages such as quick recovery and minimal risk. Therefore, it is crucial to substantiate their efficacy with robust findings. The investigation suggests that both 3D and 2D stereophotogrammetry techniques are reliable for evaluating lip size before and after augmentation, whether through cosmetic or aesthetic approaches. Overall, the study provides a comprehensive analysis of a lip treatment aimed at enhancing volume and redesigning lip lines. It demonstrates that stereophotogrammetry is effective for assessing 3D lip dimensions and their correlation with internal lip structure. This research could be particularly valuable for evaluating the efficacy and duration of various lip enhancement techniques, including dermal fillers, implants, and topical cosmetic formulations, offering quantitative and reproducible assessments over time.

Keywords: lip augmentation; volume; lip plumpers; stereophotogrammetry; 3D analysis; lip health

Citation: Di Lorenzo, R.; Ricci, L.; Vardaro, E.; Di Serio, T.; Morelli, E.; Laneri, S. Advancing Lip Augmentation: State-of-the-Art 2D and 3D Analysis for Assessing Volume Enhancement and Lip Line Redefinition. *Cosmetics* **2024**, *11*, 70. https://doi.org/10.3390/cosmetics11030070

Academic Editor: Enzo Berardesca

Received: 16 March 2024
Revised: 16 April 2024
Accepted: 30 April 2024
Published: 3 May 2024

1. Introduction

The lips are muscular–membranous skin folds that surround the mouth opening and anteriorly delimit the buccal vestibule [1]. On the face, lips occupy the lower third and play a key role in defining one's overall aesthetic appearance [2]. Lips perform important functions, as they facilitate the articulation of words and sounds, and allow food intake; lips express one's emotional status by conveying facial emotions, during verbal and psychological communication. Moreover, they can serve as a tactile organ, and being rich in sensory nerve endings, they are a very important erogenous zone, making them pivotal elements of human relationship life [3,4]. Lips are one of the most alluring features on the face, and thus, their dimension and youthfulness take on an important symbolic role in determining the overall perception and attractiveness of the face [5–7].

Throughout the last half-century, it has become increasingly common to undergo cosmetic and aesthetic procedures to increase lip volume and plumpness [8,9]. An increasing number of people undergo procedures to obtain an attractive appearance with a three-dimensional enhancement of lip volume and well-defined vermilion borders. These customs are a consequence of the importance given to the lips, through the filter of social customs, as a means of expression of social status, sexual proclivity, and amorous attitude. Full and well-defined lips impart a sense of youth, attractiveness, and health [4,10].

Aging often creates undesirable changes in our bodies, not least in the lips. The upper lip undergoes adipose tissue atrophy, leading to a thinner vermilion [3]. Other expected changes include the filter's flattening, Cupid's bow widening, and loss of the vermilion's natural protrusion [5]. Furthermore, studies reported lower lip ptosis with age, with consequent elongation, which causes an unwanted increase in lip length and vermillion height decrease [11], modifications that are related to significant muscular atrophy together with subcutaneous changes (dermal thinning and subcutaneous fat increase) [12]. All these factors push patients to seek lip beautification and rejuvenation procedures.

From this perspective, the nasolabial and labiomental angles are two key landmarks not to be overlooked when considering aesthetic pleasantness in the profile view [5]. Ideally, the nasolabial angle should be 95.5–100.1° in women and 93.4–98.5° in men [13], while the labiomental angle is appealing at 117–188° [14]. Demand for lip augmentation is rising because of its quick recovery and low risk, and the solutions come not only from the aesthetics but also from the cosmetic world, the latter of which is proposed as more cost-effective and less invasive than the former.

Cosmetic products known as lip plumpers are topical formulations based on active ingredients designed to stimulate lip protrusion and size temporarily [15]. They were developed to obtain noninvasive, low-cost, and, above all, painless effective lip augmentation and lip line mouth-filling redesign solutions [16], acting through stimulation of the matrix and dermis, replenishing from within. Lip plumpers thicken, strengthen, hydrate, and elasticize the supporting structure of the dermis and dermal–epidermal junction, while also stimulating the synthesis of new connective tissue. Still, they can include ingredients that act by inducing vasodilation, potentially resulting in either reversible irritant contact dermatitis or urticaria [15].

While lip augmentation is rising and becoming increasingly popular, there is a lack of clinical studies that evaluate with instruments the effects of lip-plumping products or procedures. To this end, this study aims to establish a quantitative analysis for lip augmentation and assess the efficacy of lip plumping through an innovative 2D and 3D technique. The study compared the lips of subjects before and after treatment with a commercial lip plumper for 30 days, by assessing lip volume and protrusion, moisture, softness, firmness, and tissue density of the lips.

2. Materials and Methods

2.1. Study Design

This study intended to propose an innovative and a multi-factorial analysis to assess lip volume boosting and lip line mouth-filling redesign, related to lip plumper applications or lip augmentation techniques. Specifically, the method is, for the first time, applied to a commercial lip plumper in a panel of 50 healthy women that had to apply approximately 1 mL of the test product once daily for 30 days. The product is investigated to promote lip volume, hydration, and softness, and improve the internal and superficial lip texture with a visible impact on lip shape, resulting in plump lips with a visible cushion effect. The lip plumper is a pomade produced by NECOS Srl (Crema, Italy); the list of ingredients is reported in Table 1.

Table 1. Lip pomade ingredient list.

Name	Ingredients (INCI Name)
Lip pomade	HYDROGENATED POLYDECENE, CAPRYLIC/CAPRIC TRIGLYCERIDE, C21-28 ALKANE, DIISOSTEARYL MALATE, STEARALKONIUM HECTORITE, HYDROGENATED STYRENE/BUTADIENE COPOLYMER, PHYTOSTERYL/OCTYLDODECYL LAUROYL GLUTAMATE, ETHYLHEXYL PALMITATE, PROPYLENE CARBONATE, CETEARYL ETHYLHEXANOATE, PARFUM, CI 77891, MICA, DECYLENE GLYCOL, PENTAERYTHRITYL TETRA-DI-T-BUTYL HYDROXYHYDROCINNAMATE, 1,2-HEXANEDIOL, CAPRYLYL GLYCOL, DIETHYLHEXYL SYRINGYLIDENEMALONATE, ECLIPTA PROSTRATA EXTRACT, SORBITAN ISOSTEARATE, TRIHYDROXYSTEARIN, LECITHIN, PORTULACA PILOSA EXTRACT, MELIA AZADIRACHTA LEAF EXTRACT, TIN OXIDE, TOCOPHEROL, ASCORBYL PALMITATE, SUCROSE COCOATE, SODIUM HYALURONATE, MORINGA OLEIFERA SEED OIL, PALMITOYL TRIPEPTIDE-38, CITRIC ACID, GLUCOMANNAN

The study was run from March 2022 to October 2022 at the RD Cosmetics laboratory, Pharmacy Department—University of Naples Federico II. The study protocol was reviewed and approved by qualified clinical, toxicology, and regulatory personnel of the university. The instrumental trial was conducted in accordance with Good Clinical Practices conforming to the ethical guidelines of the Helsinki Declaration.

Participants: Eligible subjects were women 20–45 years old with normal or thin lips and a desire to increase them. Written informed consent and release for audio–video–photo content was obtained from all participants before enrolling. Exclusion criteria included subjects with a history of sensitivity or allergy to any component of the topical lip care product and subjects with previous lip augmentation, lip surgery, or clinical evidence of orthognathic deformity. Only general health subjects were enrolled. At each check-up, subjects were asked if they complied with all pre-visit instructions and restrictions to determine whether they were qualified to continue the study. Protocol deviations were recorded to determine which subjects, endpoints, and time points should be excluded from subsequent data analysis.

Baseline measurements of the established lip parameters were carried out after enrollment (T_0). The test site identified is the test subjects' lips. Subjects were instructed verbally and in writing regarding the proper use of the test product, with instructions reinforced during each control time. The product application was conducted at the research lab to ensure all volunteers applied the same quantity of the test product.

Lip parameters were re-measured reliably after 30 days of once-daily 1 mL application (T_f). The comparative assessment of the cosmetic efficacy was based on the data obtained by instrumental measurements. Lip volumes and shapes were analyzed using VECTRA H2 (Canfield Scientific Inc., Parsippany, NJ, USA), which is a quantitative approach to soft tissue assessment that characterizes the degree of stretch, compression, lift, and volumization. Dense image-to-image correspondence enables fine-scale 3D biomechanical analysis; skin surfaces are automatically aligned, tracked, and mapped, while vector arrows provide a precise indication of the direction and magnitude of skin movement, which helps demonstrate cosmetic treatments. The Lip Index was assessed through VISIA® (Canfield Scientific Inc., Parsippany, NJ, USA), which works by using multi-spectral imaging and analysis to analyze data. Full-face photos were made under standardized illumination, focusing on the lip area. Lip youth states were determined through evaluation of the moisture level, softness, firmness, and tissue density, employing worldwide recognized tools for cosmetic efficacy evaluation, like Corneometer® CM 825, Cutometer® Dual MPA 580 and Indentometer® IDM 800 (C + K electronic GmbH, Köln, Germany), and Dermascan®

C (Cortex technology ApS, Aalborg, Denmark). The analysis compared before-and-after lip dimensions and status in treated subjects, setting the following primary endpoints. Lip augmentation is demonstrated by upper and lower lip dimension and surface increase (e.g., upper, lower, and overall lip), volume enhancement (total lip volume), and upper lip protusion and eversion. Furthermore, rejuvenating and beautification efficacy is defined by moisturizing, softening, firming, and dermal densifying action. Finally, lips had to appear visibly hydrated, soothed, plumped, filled, and lifted, pointing to improving the subcutaneous structures and their principal components.

2.1.1. Lip Analysis

The instrumental measurements were carried out in an air-conditioned room at T = 20 ± 2 °C and at controlled humidity (50 ± 5% RH) after a conditioning time of about 30 min. The detected lip parameters useful for assessing the product's ability in plumping, filling, and reshaping lip lines, extinguishing aging-related lip volume reduction, and satisfying the newest general demand for more extensive and fuller lips is reported as follows:

- 3D and 2D Lip dimension analysis:

Each subject was imaged using the VECTRA H2 and VISIA 7th (Canfield Scientific, Inc., Fairfield, NJ, USA), and analyzed with stereophotogrammetry manually and digitally, employing a 3D generated facial model through VAM® software version 7.4.6. To ensure more accurate results, the subjects were imaged according to Patient Preparation and Positioning methods for Capture Standardization described by Sawyer et al. [17]. All recordings were completed by a single investigator to ensure reliability. The following 3D analysis was performed after positioning lip landmarks according to those described by Farkas [11]: cheilion (Ch), Cupid's bow (Cb), labiale inferius (li), subnasale (Sn), sublabiale (sl), stomion (sto), alar (al), christa philtri (chp) (Figure 1).

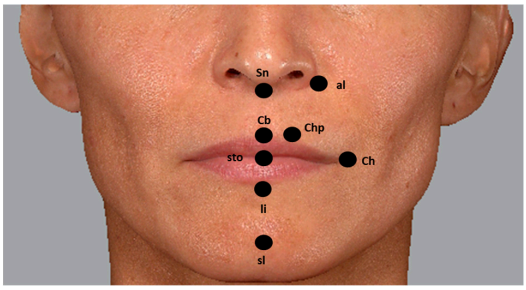

Figure 1. Facial and lip landmarks set with VAM® software for 3D lip dimensional analysis.

Furthermore, the Interpolating Surface method allows 3D surface volume analysis; the software first uses the area surrounding the bump to create an approximation of the base surface (interpolating surface). This surface will be shaped to match the shape of the face wall surrounding the lips. It cannot see what is under the lip mound and, therefore, will assume that the surface curve is consistent under the entire mouth (Figure 2).

Figure 2. VECTRA H2 Interpolating Surface Volume (cc) measurement.

The angle that originates from the columella and a line intersecting the Sn and the most anterior point of the upper lips is called the nasolabial angle (NlA). It is visible laterally (Figure 3), and it is associated with the upper lip and can promote disharmony in the adult face if not balanced. NlA is reduced by practicing lip eversion, resulting in a mouth with a more pronounced and protruding contour.

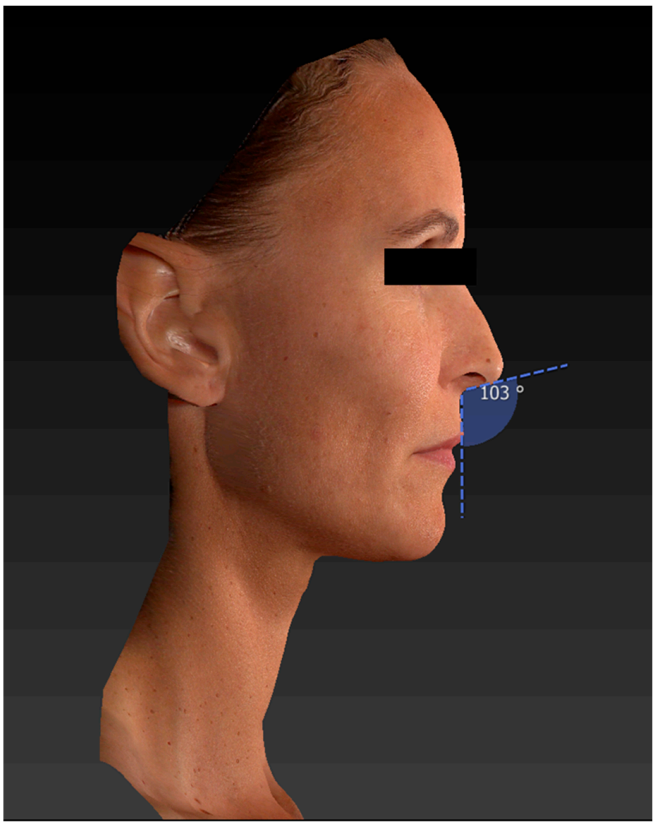

Figure 3. VECTRA H2 nasolabial angle detection.

Vectra H2 allows lip protrusion and eversion determination by calculating the distance (mm) from the lips to the nasomental angle (formed from the intersection of the line of the back of the nose and the nasomental line, also known as Ricketts line) [18], as shown in Figure 4a, and the average distance (mm) between Cupid's bow (Cb) and stomion (sto) (Figure 4b). If there is a lip size increase in terms of three-dimensionality, this can result in more significant protrusion and eversion of the lip itself. A greater protrusion can be indicated by the approach of the lip to the nasomental line, in which case a lesser distance has to be measured. Conversely, regarding eversion, the increase in the Cb-sto distance will indicate a greater torsion of the lip and thus an increase in its prominence. Still, as a further confirmation of eversion, the Upper Vermillion Height (UVH) was measured in mm. UVH is the distance (mm) from subnasale to Cupid's bow (Sn-Cb) [19].

Two-dimensional measurements were taken directly from standardized patient photos with the device designed by Lemperle [20], which allows reliable lip size analysis. The ruler enables sizing (in mm) of the vermilion height, indicated by Lemperle et al. as Upper Lip height (ULH) and Lower Lip height (LLH). Then, by lateral patient photos, as per Figure 5, the point of maximum protrusion was calculated (Upper Lip Protrusion [ULP] and Lower Lip Protrusion [LLP]).

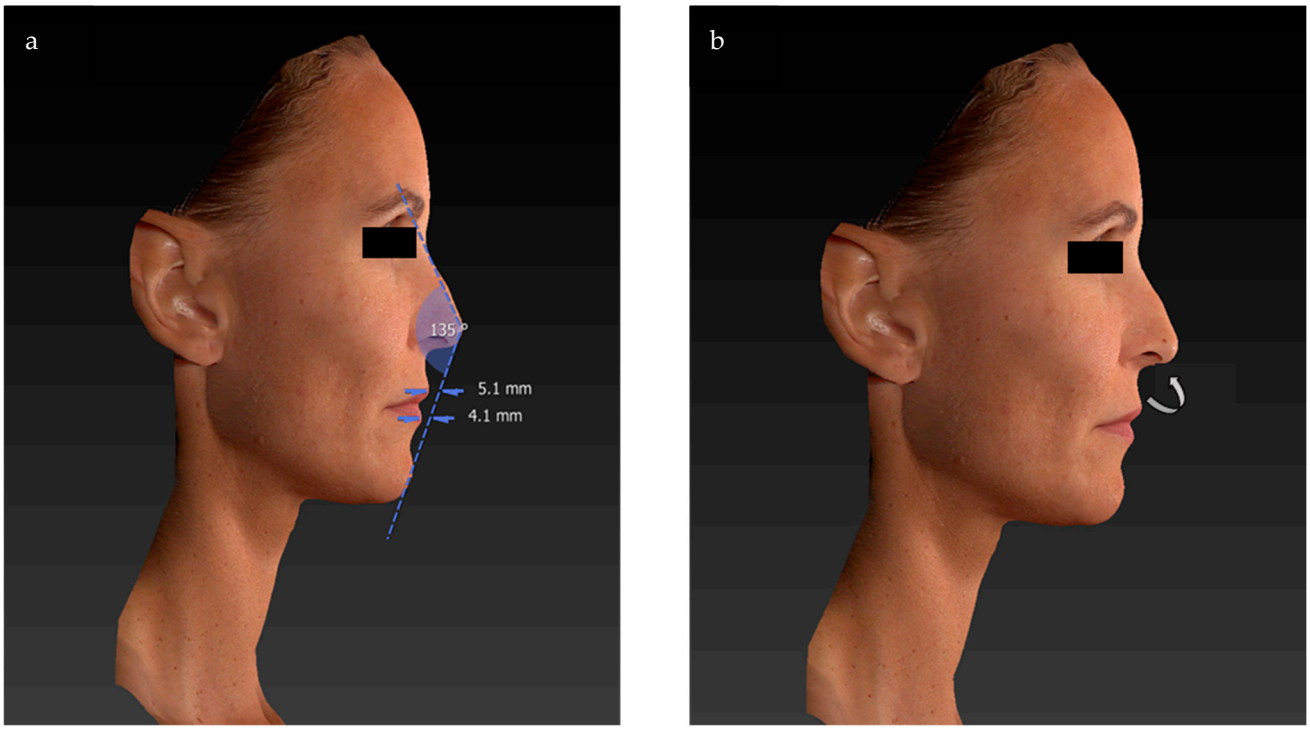

Figure 4. (**a**) Distance (mm) from the lips to the nasomental angle (lip protrusion). (**b**) Distance (mm) between Cupid's bow (Cb) and stomion (Sto) (lip eversion).

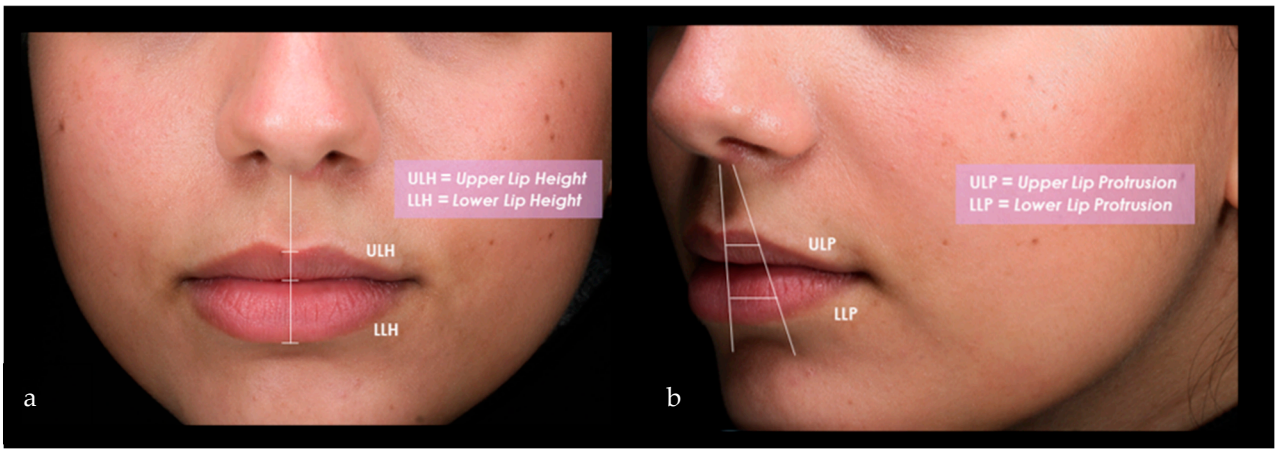

Figure 5. (**a**) Upper Lip Height [ULH] and Lower Lip Height [LLH] measured (in mm) frontally. (**b**) A line is drawn from the sub-nasale to the horizontal chin folds, and the lip protrusion is measured perpendicular to this line (ULP and LLP). The ratio was 1:1.

Finally, as suggested by Lemperle, the multiplication of the calculated ULH and ULP directly correlates with the upper lip area in mm^2. The same operation is performed for the lower lip by obtaining the patient's Upper Lip Index (ULI) and Lower Lip Index (LLI) in mm^2, respectively, whereas ULI and LLI addition results in the Overall Lip Index (mm^2).

ULI, LLI, and OLI became the baseline for comparative purposes following after-treatment augmentation.

- Lip youth state assessment:

Ultrasound imaging was performed with the subjects in an upright (90°) seated position employing a 20 MHz linear transducer (Dermascan®, Cortex Technology Aps, Aalborg, Denmark). Measurements were performed in the midline of the lower lip, without

applying pressure, allowing us to confirm the product's ability to plump lips by stimulating dermal and matrix modelling. Furthermore, the vermilion border is a body site particularly susceptible to water loss, with consequences in the surface smoothness, shape, tactile sensitivity, and healthy appearance [21]. Capacitance is a method recognized worldwide for establishing skin hydration [22–26]; therefore, since the skin is covered by an, albeit thinner, epithelial layer, it is possible to employ the same tool for assessing lip water content, as also shown in previous studies [27–29].

Lip fullness is ideally associated with softness and silky touch [30]. For the first time, the Indentometer IDM 800 was used to assess lip features, by measuring how the probe indenter displaces lips. The measurement principle is based on the force used by the tool to deform lips. The penetration depth of the pin (displacement) is measured in mm (0–3 mm). The softer the lips, the deeper the pin penetration.

2.1.2. Statistics

The recorded values were compared with intra-group analysis (T_0 vs. T_f) using Student's *t*-test, performed using SPSS software 15.0 for Windows (SPSS Science, Chicago, IL, USA). A *p*-value < 0.05 was considered significant.

3. Results

Lip dimension recorded values (mean ± SD and percentage variation) are shown in Table 2. The volume, ULI, LLI, OLI, area and NlA differences before and after treatment are highly significant ($p < 0.01$). Each patient's clinical response to treatment was assessed by comparing digital photographs taken before (baseline) and after treatment. The greater the values recorded, the higher the product-induced plump. So, a percentage increase is desirable to assess plumped, bigger, and filled lips. Figure 6 illustrates images of subjects treated with the tested lip plumper for 30 days.

Table 2. The trend of the lip dimension average values ± SD before and after the 30-day treatment with the commercial lip plumper (intra-group difference *t*-test * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

Parameter	T_0	T_f	Δ ($T_f - T_0$) %
Volume (cc)	72.3 ± 3.2	76.7 ± 5.1	6.5% ***
Upper Lip Index (cm^2)	31 ± 5	35 ± 5	15.0% ***
Lower Lip Index (cm^2)	64 ± 16	66 ± 15	12.0% ***
Overall Lip Index (cm^2)	95 ± 28	101 ± 20	13.0% ***
Area (cm^2)	8.7 ± 0.3	8.9 ± 0.3	5.3% ***
Eversion (mm)	9.1 ± 0.4	9.3 ± 0.4	2.8% *
Protrusion (mm)	7.1 ± 0.2	6.9 ± 0.3	−3.3% **
Upper Vermillion Height (mm)	19.7 ± 0.8	19.0 ± 0.9	−3.8% *
Nasolabial Angle (°)	115 ± 3	112 ± 2	−3° ***

The results reported in Table 3 show that after treatment for 30 days with the test product, the lips are not only more plumped, lifted, and defined, but also more moisturized and with a more turgid and denser appearance. As a consequence, corneometry, skin density, softness, and firmness were statistically increased by treatment with the lip plumper ($p < 0.05$). Hydration strongly influences lip health appearance. During the study, panelists experienced an increase in their lip hydration, partly due to the film-forming action of the lipgloss, which thus manages to maintain a good water content on the lips.

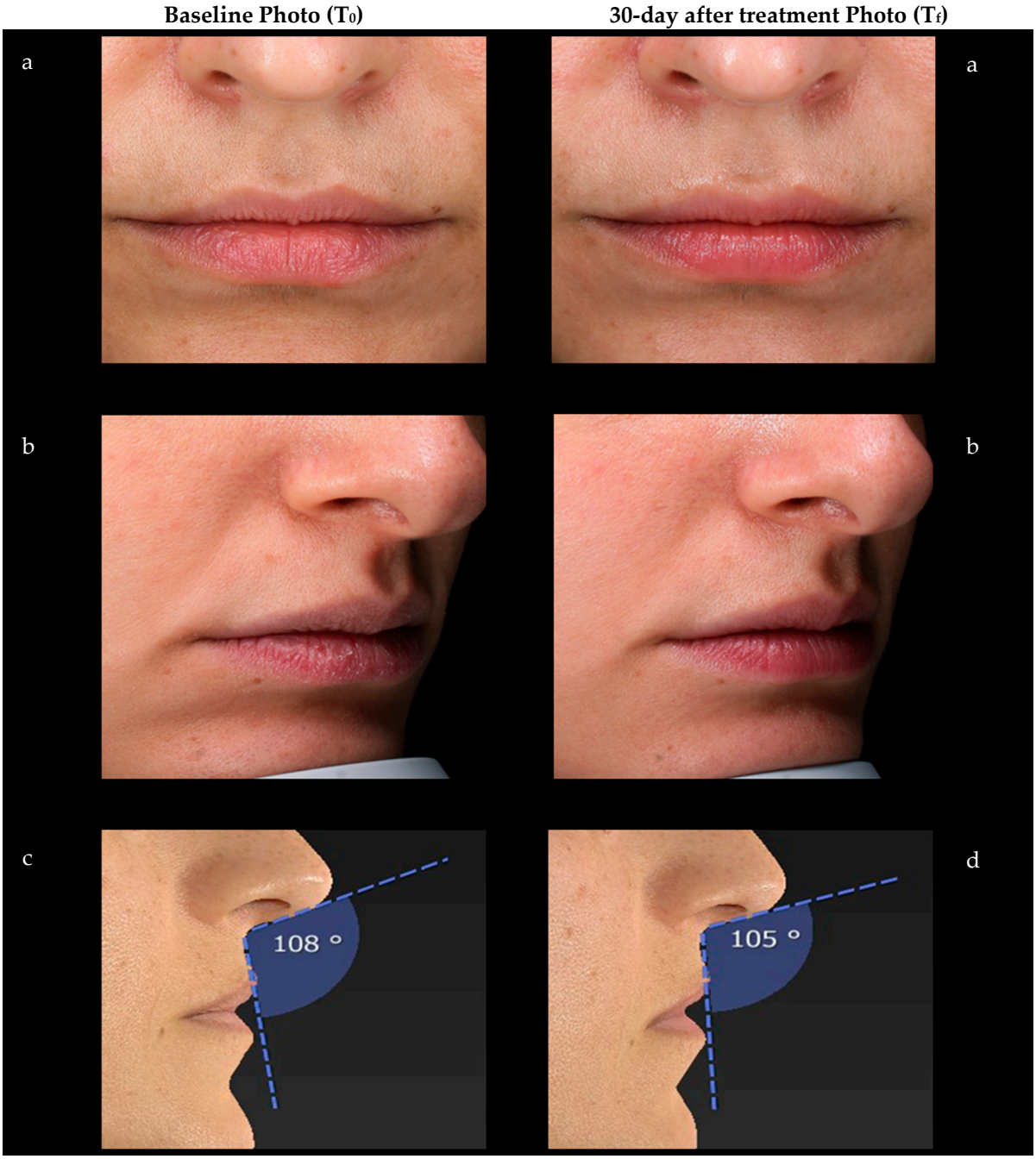

Figure 6. (**a**) Frontal and (**b**) lateral 2D panelist lip photos before (T_0) and after 30-day treatment (T_f) with the lip plumper; (**c**) 3D panelist lip photos and columella angle before (T_0) and (**d**) after 30-day treatment (T_f) with the lip plumper.

Table 3. The trend of the lip youth parameter average values ± *DS* before and after the 30-day treatment with the commercial lip plumper (intra-group difference *t*-test *** $p < 0.001$).

Skin Youth Parameter	T_0	T_f	Δ ($T_f - T_0$) %
Corneometry (A.U.)	44.1 ± 2.4	57.3 ± 5.9	30.4% ***
Lip Softness (mm)	2.832 ± 0.091	2.974 ± 0.052	5.0% ***
Lip firmness—R_0 (μm)	0.341 ± 0.067	0.275 ± 0.108	−17.0% ***
Collagen Index	34.0 ± 12.2	36.7 ± 12.5	11.0% ***

4. Discussion

In the 21st century, lips are protagonists of beauty that teach us how to transform it into a tool for empowerment. Over the past fifty years, full, plump, and pouty lips have been considered a desirable trait [6]. More and more young people undergo aesthetic surgical procedures for lip augmentation to obtain the commonly sought-after appearance [31–34]. In addition, aging creates a spectrum of undesirable changes in the lips, as for the rest of the face [11,12,35]. The upper lip undergoes dermal atrophy and stretches vertically, leading to a thinner and less visible vermilion border [18]. Other expected changes include flattening of the filter, a widening of the philtrum, and the loss of the natural lip protrusion [6,10–12,18]. Furthermore, the lower lip can also develop ptosis with age, resulting in an unattractive lower dental show [20,36]. All these factors contribute to pushing patients to seek lip augmentation. Lips become thin and stiff, and collagen and elastic fiber fragmentation occurs [12]. What is more, hyaluronic acid supply runs low, with the consequent appearance of wrinkles and fine lines on the lip surface [37]. In addition, excessive heat, pollution, and stress can affect the health of the skin and, thus, also lips [23,24]. Therefore, the goal of lip beautification and rejuvenation is a natural three-dimensional enhancement of lip volume with a well-defined vermilion border, accompanied by soft and nourished lips. Lip augmentation and rehydration is used to enhance the appearance of thin, aged, or asymmetrical lips, contributing to the ideal facial beauty. Therefore, good lip performance, whether induced by cosmetic or aesthetic treatment, requires a multifactorial approach involving all the elements that constitute the lips, which this method proposes to investigate.

Lip hydration is a technique used to improve the appearance of thin, aged, or asymmetrical lips. The health and size of lips largely depend on their hydration levels, which makes it crucial to use an intense moisturizing action while administering filler treatment. In our study, panelists observed an increase in their lip hydration, which could be attributed to the film-forming effect of the lip pomade as well as the presence of moisturizing ingredients such as Eclipta prostrata extract, Portulaca pilosa extract, Melia azadirachta leaf extract, Tocopherol, Sodium hyaluronate, Moringa oleifera seed oil, and Palmitoyl tripeptide-38. The intense moisturizing action is further related to the higher softness registered in the study population. Finally, the stimulation of the dermal elements was indicated by the collagen index and firmness increase. All these features were evaluated throughout the study to guarantee a complete understanding of the mechanism responsible for the recorded plumping effect. The NlA was monitored as confirmation of the recorded volumization treatment, because it is associated with the upper lip and can promote disharmony in the adult face if not balanced. While UVH is very useful in evaluating facial symmetries, in general, following lip-filling treatments, there is upper lip height increase, with a consequent reduction in the Cb distance from the Sn landmark. In this study, since it is a cosmetic treatment, the decrease recorded is far less than that obtainable through surgery, but not undetectable.

Despite several studies showed lip augmentation procedures [2,4,10,38–41] or investigated age-related lip disorders [3,11,12], there is a shortage of literature on the available noninvasive devices that can be employed for assessing the efficacy of anti-aging cosmetic or aesthetic lip treatment [14,37,42]. Many studies on lip filler injection efficacy and longevity have relied on subjective evaluation methods like patient satisfaction surveys and physician observation [43,44]. Some have used validated photonumeric lip fullness scales to compare augmentation results objectively [16,45,46]. However, only a handful have employed quantitative measurements to assess volume enhancement effects [19,47,48], and no one has related the volume enhancement to lip health amelioration. Our study lays the foundation for this kind of analysis, serving as a pioneer in determining the mechanisms of action underlying lip rejuvenation and beautification processes in accordance with the overwhelming desire to have more prominent and protruding lips. The main objective of this investigation was to provide a comprehensive analysis to assess lip treatment in order to gain valuable insights into the potential use of these innovative 2D and 3D techniques

for cosmetic, aesthetic surgical, and nonsurgical applications, through an observational in vivo study on healthy subjects treated for one month with a commercial topical cosmetic formulation with a plumping and filling action. The investigated lip pomade enhanced the volume, protrusion, and eversion of the lips by moisturizing them (+30.4% vs. T_0, $p < 0.001$) and inducing a dermis re-organization, as suggested by the increased density, softness, and firmness (collagen index: +11%, softness: +5% and R_0: −17% vs. T_0, $p < 0.001$). Nevertheless, our study presents some limitations. The short-term follow-up period (4 weeks) hinders our ability to assess long-term outcomes. The relatively small sample size reduces the statistical power of our results. Furthermore, the absence of a control group limits our ability to attribute observed changes solely to the tested product. Additionally, the study population comprised exclusively Italian females within a relatively narrow age range. Future research with larger, more diverse participant groups, encompassing various ages, ethnicities, and genders, would be recommended to corroborate our findings effectively.

5. Conclusions

In conclusion, the present investigation provided a comprehensive analysis for lip treatment designed to provide volume boosting and lip line mouth-filling redesign after cosmetic lip plumper applications or aesthetic lip augmentation techniques. Data showed that stereophotogrammetry produces a good approximation of 3D lip dimension analysis, and how it is correlated with the internal lip structure. This study may be particularly important in lip augmentation procedures, to provide a reliable method for the efficacy evaluation of the clinical effects or duration of lip enhancement dermal filler and implants, or topical cosmetic formulation. Moreover, quantitative and reproducible assessments over time are easy to calculate, with the most common worldwide skin testing devices.

Author Contributions: Conceptualization, R.D.L. and S.L.; methodology, R.D.L.; software, L.R. and E.V.; validation, R.D.L., L.R. and E.V.; formal analysis, R.D.L., L.R. and T.D.S.; investigation, R.D.L., E.V. and L.R.; data curation, E.V. and T.D.S.; writing—original draft preparation, R.D.L. and S.L.; writing—review and editing, R.D.L., E.M. and S.L.; visualization, S.L. and E.M.; supervision, S.L. and E.M.; All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board for non-pharmacological study of the University of Naples Federico II (protocol code CEA22M-01, date of approval 17 January 2022).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the patient(s) to publish this paper.

Data Availability Statement: The data presented in this study are available from the corresponding author upon request. The data are not publicly available due to privacy.

Conflicts of Interest: The authors declare no conflicts of interest.

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