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ORIGINAL ARTICLE

Increasing precision during neuromodulator injections for frontal rhytids—Using ultrasound imaging to identify the line of convergence

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Abstract

Background: Recent research introduced the concept of the "line of convergence" as a guide for injectors to enhance precision and avoid complications when treating the frontalis muscle with toxins. However, currently, no pre-injection ultrasound scanning is employed to increase precision and reduce adverse events when searching for the line of convergence.

Objective: To explore the feasibility and practicality of implementing pre-injection ultrasound scanning into aesthetic neuromodulator treatments of the forehead.

Methods: The sample of this study consisted of $n = 55$ volunteers (42 females and 13 males), with a mean age of 42.24 (10.3) years and a mean BMI of 25.07 (4.0) kg/m^2. High-frequency ultrasound imaging was utilized to measure the thickness, length, and contractility of the frontal soft tissue and to determine the precise location of the line of convergence during maximal frontalis muscle contraction.

Michael Alfertshofer and Sebastian Cotofana contributed equally to this study.

Results: The results revealed that the line of convergence was located at 58.43% (8.7) of the total forehead height above the superior border of the eyebrow cilia without a statistically significant difference between sex, age, or BMI. With frontalis muscle contraction, the forehead shortens in males by 25.90% (6.5), whereas in females it shortens only by 21.74% (5.1), with $p < 0.001$ for sex differences.
Conclusion: This study demonstrated the feasibility and practicality of pre-injection ultrasound scanning for facial aesthetic neuromodulator treatments. Knowing the location of the line of convergence, injectors can determine precisely and on an individual basis where to administer the neuromodulator deep or superficial or when the injection location is at risk to cause eyebrow ptosis.

KEYWORDS
facial anatomy, forehead, line of convergence, neuromodulator injections, ultrasound

1 | INTRODUCTION

According to annual statistics released by The Aesthetic Society, in 2022, a total of 3 945 282 neuromodulator procedures were performed in the US, revealing an increase of 24% when compared to 2021.[1,2] Despite being one of the most challenging facial regions to treat with neuromodulators, the forehead is most frequently requested by aesthetic patients. Removing horizontal forehead rhytids and adjusting the height as well as the shape of eyebrows is a desired outcome when administering toxins.[3,4]

Recent anatomic research has introduced the *line of convergence* as a guide for injectors to avoid adverse events and to increase precision when treating the frontalis muscle with toxins.[5,6] The line of convergence is a horizontally oriented area of the forehead in which two opposing movements of the frontalis muscle converge: eyebrow elevation produced by the lower portion of the frontalis muscle versus hairline depression produced by the upper frontalis muscle. These two antagonistic movements (eyebrow elevation vs. hairline depression) converge into a static area of the forehead in which no movement is visible. The authors calculated in their 3D imaging study that the line of convergence is located approximately at 60% of the total forehead length above the superior margin of the eyebrow cilia, or alternatively, was located at the second horizontal forehead rhytid when counting from superior to inferior; these measurements were independent of sex or ethnic background of the volunteers investigated.[5]

Targeting the frontalis muscle below the line of convergence with the same amount of neuromodulator product as in the upper frontalis muscle carries an increased risk for eyebrow ptosis due to its involvement in eyebrow elevation. Therefore, recent research has suggested to either limit the amount of toxins administered in the lower forehead[7] or to inject more superficially to reduce the risk for eyebrow ptosis-related adverse events.[6,8]

However, the study initially describing the *line of convergence* investigated only 27 volunteers, and the results presented were based on the calculations conducted in that specific sample. It is therefore questionable if those results are applicable to different samples or the general population. To improve the precision of injections and decrease the risk of adverse events, it is advisable to conduct individual assessments of the *line of convergence* for each patient prior to administering neuromodulators by using a reliable and reproducible method.

Therefore, the authors propose to employ non-invasive ultrasound imaging prior to frontal neuromodulator treatments to precisely and individually identify the line of convergence. The aim of this study is to demonstrate the feasibility and precision of pre-toxin-injection ultrasound imaging for forehead toxin treatments. It is hoped that the results of this study open the path to pre-injection ultrasound imaging for toxin treatments to ultimately increase precision and reduce neuromodulator-related adverse events.

2 | MATERIALS AND METHODS

This observational study used real-time ultrasound imaging and was conducted from April to August 2023 in São Paulo, Brazil. Patients from the private practice of the first author (C.C.B.M.) and from the Sially Institute, São Paulo, Brazil, were recruited into this study. Patients were not included if they received neuromodulator treatments of their upper face sooner than 6 months prior to the beginning of this study or if they had received any other surgical or non-surgical treatment of their forehead or periorbital region that could influence normal forehead and periorbital anatomy. No other exclusion criteria were applied.

The study received ethics approval from the respective Brazilian ethics committee board under the number 6.593.958.

All participants provided written, informed consent for the use of their images and demographic data for the purposes of this research project. The study adhered to the Declaration of Helsinki

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(1996) and regional laws and good clinical practice guidelines for human subject research.[9]

2.1 | Ultrasound imaging

To ensure accuracy and consistency throughout the study, all measurements were carried out by the same investigator (C.C.B.M.). As a value of measurement accuracy, the interclass correlation coefficient (ICC) was calculated based on a two-way mixed effect model with absolute agreement and was identified to be >0.989 for all measurements, which equals excellent reliability.[10]

Patients were examined in an upright position using a PHILIPS LUMIFY ultrasound device (Philips Ultrasound, Inc., Bothell, WA, USA) with an L4–L12 MHz linear hockey stick probe. The following settings were utilized: B-mode grayscale images with a gain of 50, Doppler frequency at 12 MHz, and depth at 1.5 cm. The device had a low-wall filter with an average of 112, and the pulse repetition frequency (PRF) averaged 1.7. A generous layer of Aquasonic Clear Ultrasound Gel (Parker Laboratories Inc., Fairfield, NJ, USA) was applied to avoid direct skin contact and to minimize soft tissue compression and measurement artifacts. The transducer was held at a 90-degree angle to the skin surface (Figure 1).

2.2 | Conducted measurements

Measurements of the forehead were performed bilaterally in the vertical midpupillary line, either by ultrasound imaging or by using a flexible surgical ruler to account for the curvature of the forehead:

- Forehead thickness [in mm]
- Total forehead length, relaxed (i.e., distance between the upper margin of eyebrow cilia and hairline) [in mm]
- Total forehead length, maximal frowning (i.e., distance between the upper margin of eyebrow cilia and hairline) [in mm]
- Upper forehead length (i.e., distance between the line of convergence and hairline) [in mm]
- Lower forehead length (i.e., distance between the upper margin of eyebrow cilia and the line of convergence) [in mm] (Figures 1 and 2)

The typical assessment time for ultrasonographic pre-injection evaluation was approximately 4 min.

2.3 | Statistical analysis

Bilaterally conducted measurements were averaged, and the respective mean value is reported. Ordinal variables were computed via the chi-square test, and bivariate correlations (Spearman, Pearson, depending on variable scaling) were used to identify relationships between groups. All calculations were run using SPSS Statistics 27 (IBM, Armonk, NY, USA), and differences were considered statistically significant at a probability level of ≤0.05 to guide conclusions. Results are presented as mean values and their respective 1× standard deviation (mean [SD]).

3 | RESULTS

3.1 | Patient demographic data

The sample of this study consisted of $n = 55$ volunteers (42 females and 13 males), with a mean age of 42.24 (10.3) years [range: 23–66] and a mean body mass index (BMI) of 25.07 (4.0) kg/m^2 [range: 19.0–39.3]. No statistically significant correlation was identified between age and BMI, with $r_p = -0.089$, $p = 0.356$.

3.2 | Forehead soft tissue thickness (as measured with ultrasound imaging)

The thickness of the frontal soft tissues was on average 4.33 (0.8) mm [range: 2.77–6.36], with females having a reduced soft tissue thickness when compared to males with 4.19 (0.7) mm [range: 2.77–6.06] versus 4.77 (0.9) mm [range: 3.17–6.36] and $p < 0.001$.

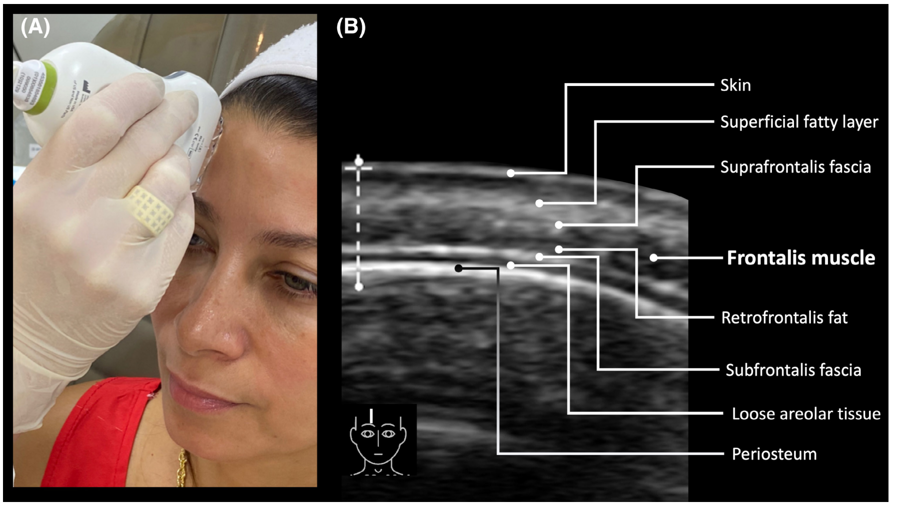

FIGURE 1 Photograph (A) of a 41-year-old female study participant showcasing the ultrasound examination technique. The ultrasound probe was placed in a generous layer of ultrasound visualization gel while avoiding compression of the underlying soft tissues. The respective ultrasound image (B) depicts the layered anatomy of the forehead.

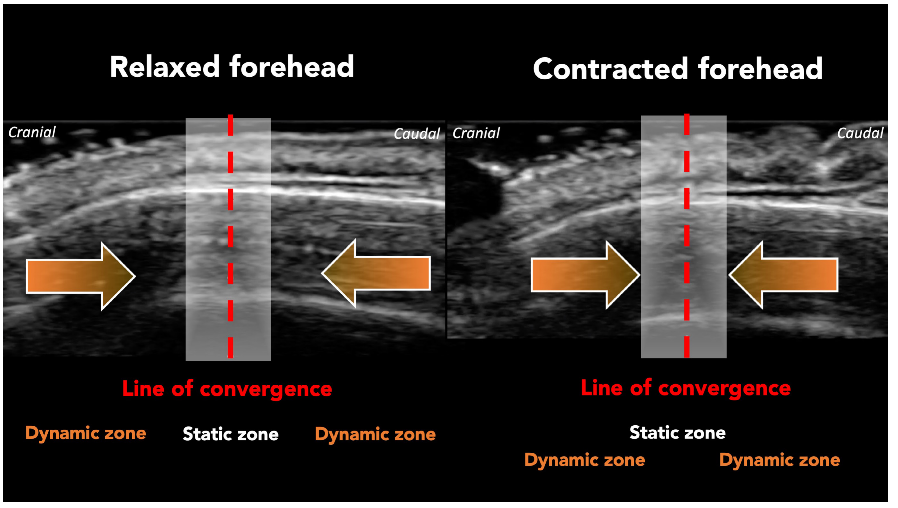

FIGURE 2 Ultrasound image series obtained in a 31-year-old female study participant showing the bidirectional movement of the frontal soft tissues toward a static zone, clinically seen as the *line of convergence*.

Higher age was inversely correlated to the frontal soft tissue thickness with $r_p = -0.218$, $p = 0.022$, indicating that at higher age the frontal soft tissues reduce in their thickness, whereas higher BMI was directly correlated with an increase in soft tissue thickness with $r_p = 0.275$, $p = 0.004$.

3.3 | Forehead length (relaxed vs. contracted)

The total length of the forehead was on average 54.13 (9.1) mm [range: 35–78], with females having a shorter forehead when compared to males with 51.83 (8.1) mm [range: 35–71] versus 61.54 (0.82) mm [range: 49–78] and $p < 0.001$. The average reduction in forehead length upon maximal frontalis muscle contraction was 22.73% (5.7) [range: 5–36] to the average contracted length of 41.65 (6.6) mm [range: 28–58]. Interestingly, the calculated reduction in forehead length was greater in males with 25.90% (6.5) [range: 5–36] when compared to females with 21.74% (5.1) [range: 11–33] with $p < 0.001$ (Figure 3).

3.4 | Location of the line of convergence (as measured with ultrasound imaging)

The location of the line of convergence was visualized via ultrasound imaging in all study volunteers successfully and without exception. The line of convergence was identified during the scanning procedure as the location within the frontal soft tissues that did not move during maximal frontalis muscle contraction. In reference, the soft tissues of the upper forehead moved caudally, whereas the soft tissues of the lower forehead moved cranially; both movements converged toward a static, non-mobile area of the forehead: the line of convergence.

The line of convergence was located on average at 58.08% (8.6) [range: 33–77] of the forehead height above the superior brow cilia without a statistically significant difference between sex ($p = 0.447$) or without influence of age ($p = 0.375$) or BMI ($p = 0.106$) (Table 1, Figure 4).

3.5 | Anatomic observations

From superficial to deep, the following anatomic layers were observed on the forehead: skin, superficial (subdermal) fatty layer, suprafrontalis fascia, frontalis muscle, retrofrontalis fat, including the retrofrontalis fat compartments, subfrontalis fascia, loose connective tissue, including the deep compartments of the forehead, and frontal periosteum. Great emphasis was placed on identifying a structure that could potentially act as a zone of attachment deep to the line of convergence, allowing for the frontal soft tissues to be tethered toward one specific non-mobile location. However, no such zone of adhesion was identified deep to the line of convergence in any of the investigated volunteers.

4 | DISCUSSION

This study was designed as a pilot study to explore the feasibility and practicality of implementing pre-injection ultrasound scanning into aesthetic neuromodulator treatments. Pre-treatment ultrasound is starting to become or has already become the standard of care in several countries for soft tissue filler injections.[11–19] When used in conjunction with soft tissue filler administration, the patient receives pre-treatment facial scanning to identify the 2D and 3D location of facial arteries and to evaluate previous aesthetic filler treatments.[12,15,17,20–23] This information is crucial for the injector to determine the plane of product placement in relation to the respective facial vessel and to obtain knowledge about the type and location of a possible previous soft tissue filler treatment, ultimately aiming to increase patient safety and to improve aesthetic outcomes.

However, pre-treatment scanning is not routinely practiced for neuromodulator treatments. Reasons for this may include the

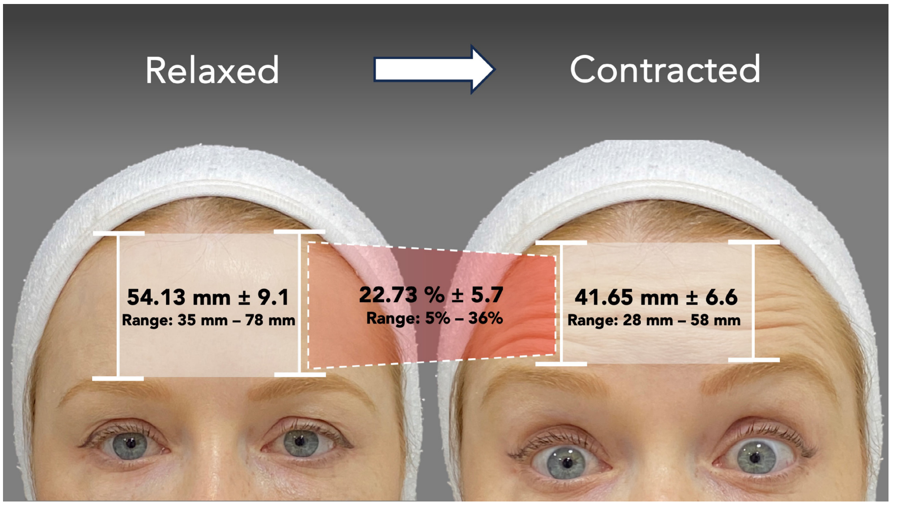

FIGURE 3 Three-dimensional surface scans of a 37-year-old female study participant summarizing total forehead length in a relaxed facial expression and upon frontalis muscle contraction. Upon frontalis muscle contraction, the total forehead length was reduced by approximately 22.73% on average.

TABLE 1 Summary of the measurements conducted in our study.

Measurement	Overall	Male	Female	*p* value
Total forehead length (relaxed)	54.13 (9.1) mm [35.0–78.0]	61.54 (8.2) mm [49.0–78.0]	51.83 (8.1) mm [35.0–71.0]	**<0.001**
Total forehead length (contracted)	41.65 (6.6) mm [28.0–58.0]	45.58 (7.0) mm [35.0–58.0]	40.43 (6.0) mm [28.0–52.0]	**<0.001**
Forehead thickness	4.33 (0.8) mm [2.77–6.36]	4.77 (0.9) mm [3.17–6.36]	4.19 (0.7) mm [2.77–6.06]	**<0.001**
Upper forehead length	22.59 (5.7) mm [10.0–39.0]	25.73 (4.9) mm [15.0–35.0]	21.62 (5.6) mm [10.0–39.0]	**<0.001**
Lower forehead length	31.36 (6.6) mm [14.0–49.0]	35.04 (6.7) mm [22.0–49.0]	30.23 (6.2) mm [14.0–42.0]	**<0.001**
Line of convergence (percentage of total forehead length)	58.08 (8.6) % [33.0–77.0]	56.95 (8.2) % [42.0–76.0]	58.43 (8.7) % [33.0–77.0]	0.447
Percentage shortening forehead	22.73 (5.7) % [5.0–36.0]	25.90 (6.5) % [5.0–36.0]	21.74 (5.1) % [11.0–33.0]	**<0.001**

Note: *p* values are calculated via independent Student's *t*-test for differences between sex. Bold *p* values indicate statistical significance (i.e., $p < 0.05$).

FIGURE 4 Three-dimensional surface scans of a 37-year-old female study participant illustrating the *line of convergence* and how it is formed by the bidirectional movement of the forehead. The total forehead length (as measured between the hairline and upper margin of the eyebrow) is divided by the line of convergence into an upper and lower forehead.

time requirement for ultrasound evaluation relative to toxin treatment time, the relative safety of neuromodulator versus soft tissue filler, the relatively shorter duration of neuromodulator adverse events should they occur or a lack of perceived need for more precise anatomic knowledge of facial muscle to achieve desired treatment outcomes, or a lack of comfort using ultrasound technologies. Whichever reasons might be applicable, the current study tried to investigate whether it is feasible to utilize pre-injection ultrasound scanning to readily and precisely identify frontalis muscle anatomy, as this knowledge may be extremely helpful in enhancing the outcome of forehead neuromodulator treatments.

The results of this study revealed that, with ultrasound imaging, it is possible to reliably and precisely identify the location of the line of convergence. This is an important marker for frontal neuromodulator treatments, which helps to reduce eyebrow ptosis and to determine where in the forehead superficial or deep toxin injections can be performed.[5,7] In the initial introductory 3D imaging study, the line of convergence was located at 60.9% (10.2) in males and 60.6% (9.6) in females, with a standard deviation of approximately 10% for both sexes.[5] The current study identified that the line of convergence is located at 58.43% (8.7) [range: 33–77] without a statistically significant difference between sexes ($p=0.447$) and without influence of age ($p=0.375$) or BMI ($p=0.106$). These results confirm the previous findings in a larger sample size (27 vs. 55 volunteers) but also show that the variation in its location can vary between 33% and 77%. This data range showcases the need for an individual line of convergence assessment, as some patients might not follow the average value (approximately 60%) but might be outliers. These patients might benefit from individual pre-treatment ultrasound scanning to optimize their outcome and to reduce their possibility of toxin-related adverse events.

The benefit of real-time ultrasound imaging lies in the ability to investigate (facial) tissues in both static and dynamic motion, an advantage that was realized in the current study. The results revealed that the forehead shortens in males by 25.90% (6.5) [range: 5–36], whereas in females the forehead shortens only by 21.74% (5.1) [range: 11–33], with $p<0.001$ for sex differences. This information is novel and allows the injector to appreciate the change in frontal soft tissue shortening with its respective effects on eyebrow elevation and hairline depression.

The results of the current study also showcased that the average frontal soft tissue thickness was 4.33 (0.8) mm [range: 2.77–6.36], with females having a reduced soft tissue thickness when compared to men with 4.19 (0.7) mm [range: 2.77–6.06] versus 4.77 (0.9) mm [range: 3.17–6.36] and $p<0.001$. These values demonstrate the complexity of frontalis muscle toxin injections into a tissue that is only 4 mm thin and that requires precise product administration. A recent study has revealed that injections deep into the frontal soft tissues and penetrating the subfrontalis fascia provide more effective toxin treatment outcomes when compared to subdermal product placement.[7] The authors explained their findings with the location of the neuromuscular junction, which is located on the underside of the frontalis muscle. Ultrasound imaging can support the individual assessment of frontal soft tissue thickness and can guide injectors to know their injection territory rather than treating the forehead blindly and entrusting the neuromodulator effect to product spread and diffusion.

Utilizing pre-injection ultrasound scanning allows the injector not only to know the thickness of the frontal soft tissue planes but also to reliably and individually determine the location of the line of convergence. The practitioner or a well-trained designee needs to perform a mobile assessment of the patient, which requires the patient to contract their forehead under constant ultrasound scanning. This will reveal an area of the frontal soft tissues that does not move (either cranially or caudally), thereby determining the precise location of the line of convergence as a static zone. Ultrasound imaging is hereby superior to just observing skin movements (with or without markings) or even superior to 3D imaging. The latter can capture movements of the skin surface only but is unable to capture small movements or twitching's of the underlying frontalis muscle fibers. These circumstances might have prompted the results of a recent 3D imaging study investigating forehead skin movements in an Asian (Korean) population, in which the authors identified the line of convergence in only 40% ($n=12$) of their study population.[24] Using ultrasound imaging allows the injector to precisely determine the line of convergence and to guide the toxin treatment accordingly.

This study is not free of limitations: First, the study sample consisted of Caucasian (Brazilian) volunteers only, which might offer a different representation of the line of convergence when compared to other ethnic groups. This may be true despite a recent study that suggested that the line of convergence can be identified via 3D imaging in various ethnic groups.[24] Second, this study was designed as a pilot study to determine whether the line of convergence can be identified with ultrasound imaging. Future studies will need to utilize the information provided herein to correlate the ultrasound findings of the true line of convergence with clinical topographic landmarks and to assess clinical outcomes with respect to eyebrow position and contour when neuromodulators are injected with and without ultrasound pre-injection scanning.

5 | CONCLUSION

This study demonstrated the feasibility and practicability of pre-injection ultrasound scanning for facial aesthetic neuromodulator treatments. By utilizing high-frequency non-invasive ultrasound assessment, the line of convergence was reliably identified and confirmed previous findings in which the non-mobile area of the forehead was located at approximately 60% of the total forehead length. Knowing the location of the line of convergence, injectors can determine precisely and on an individual basis where to administer the neuromodulator deep or superficial or when the injection location is at risk to cause eyebrow ptosis.

CONFLICT OF INTEREST STATEMENT

The authors declared no potential conflicts of interest with respect to the research, authorship, and publication of this article. AP is an employee of Evolus Inc., a company distributing neuromodulator products. SC is CEO of Cotofana Anatomy Corp., a company specialized in anatomical education.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The study received ethics approval from the respective Brazilian ethics committee board under the number 6.593.958.

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