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Original Article

Dynamic Evaluation of Glabellar Area Muscles Movement and Skin Displacement Using 3D Skin Displacement Vector Analysis

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ABSTRACT

Background: Three-dimensional (3D) skin displacement vector analysis method provides a deeper understanding of dynamic muscle anatomy. Understanding the dynamic muscle anatomy in the glabellar area during frowning can facilitate safer and effective botulinum toxin injections for treating glabellar wrinkles.
Objective: We aimed to investigate the skin displacement patterns of the glabellar area and adjacent skin during contraction of the glabellar muscles using 3D skin vector displacement analysis.
Methods: Twenty-nine healthy individuals (26 female, 3 male; median age 40.5 years) participated in the study. Photographs of the face were taken at rest and during maximal contraction of the glabellar muscles. Each expression image was aligned to its respective static image to compute the differences in the skin position.
Results: Two skin displacement patterns were identified during frowning: lateral pattern (89.66%), in which main skin vector displacement located on the eyebrow area and central pattern (10.34%), in which skin vector displacement mostly located between eyebrows. 62.07% showed asymmetric skin displacement. Analysis of the glabellar patterns showed that the 'U', '11', 'X', and 'π' patterns were observed in 38%, 38%, 14%, and 10% of cases, respectively, with corresponding skin vector displacement angles of 48°, 32°, 74°, and 24°. Additionally, 20.69% of subjects exhibited upward skin movement in the medial frontalis area during frowning. In 48% of subjects, the lateral and inferior portions of the orbicularis oculi muscle contracted, along with the upper medial portion.
Conclusion: This data will serve as an important guide for Botulinum Toxin treatment of glabella wrinkles in Korean patients.

Keywords: Biomechanical phenomena; Botulinum toxins; Facial muscles; Muscle contraction; Skin

INTRODUCTION

The glabellar lines are the most common target for botulinum toxin treatment on the face. The muscles of the glabella complex responsible for frown line formation include the corrugator supercilii, depressor supercilii, procerus, and the orbicularis oculi muscles adjacent to the frontalis. These muscles merge with the superior portions of the glabella complex, extending upward beneath the forehead. A single injection of botulinum toxin can cause local diffusion up to 3 cm in diameter from the injection point, which may result in unintended effects on neighboring muscles, potentially leading to undesirable outcomes[1,2]. Additionally, if botulinum toxin treatment targets only one muscle without considering the dynamic relationships between muscles and the overlying skin, wrinkles in surrounding areas, such as the forehead or around the eyes, may worsen. Thus, for effective and safe botulinum toxin treatment of glabellar lines, it is important to understand not only the static anatomy but also the interaction between muscles that elevate and depress the brow.

Previous studies on three-dimensional (3D) skin displacement analysis have proven useful in providing a deeper understanding of skin movement through objective quantification, by illustrating the direction and strength of skin vectors as well as muscle contraction[3]. By applying 3D skin vector displacement analysis, muscles that contribute to wrinkle formation during specific facial expressions and the relationship between muscle contraction and the resulting skin displacement during different facial expressions can be identified[4].

In this study, we aimed to investigate in greater detail the skin displacement patterns and muscle contraction characteristics in the glabella area during frowning expressions among individuals in the Korean population

MATERIALS AND METHODS

This study complied with the Declaration of Helsinki and good clinical practice. Study protocol and informed consent were reviewed and approved by Institutional Review Board (IRB) of Gangnam Severance Hospital (IRB No.3-2021-0156). Subjects aged 30–80 years without history of botulinum toxin injection, filler injections or surgical procedures on the face within 6 months are included in the study. Subject were given enough explanation on procedure and purpose of the study, and each participant voluntarily provided written informed consent was obtained prior to the study.

Subjects were trained until they are fully able to create a frowning expression related to glabella muscle movement. Photographs were taken two times, at rest (static image) and at frowning expression (upon request) chronologically. The environments (lighting, distance, camera) were remained constant during the whole process. Photographs were taken using Vectra H1 camera system (Canfield Scientific, Inc., Fairfield, NJ, USA). Each expression image was aligned to its respective static image to compute the difference in skin position and thus to calculate skin displacement vectors.

By applying automated algorithms of Vectra Software Suite® on skin displacement vectors, value for local changes were calculated and visualized using color and size of the arrow. The degree of skin displacement of is gradually increase as it goes towards blue, green, yellow, red, and also proportional to the length of the arrow. We measured the average angle between the horizontal axis of the face running through the medial eyebrow (parallel from the medial canthus) and the direction of the mean skin displacement vector (**Fig. 1**). We also classified the wrinkles pattern into 5 groups according to previous studies[5], and analyzed the relationship between the wrinkles pattern and the skin vector motion angle.

RESULTS

A total of 29 healthy individuals aged 30–62 years (median age, 40.5 years) were enrolled in this study. Twenty-six female and 3 male participants were included.

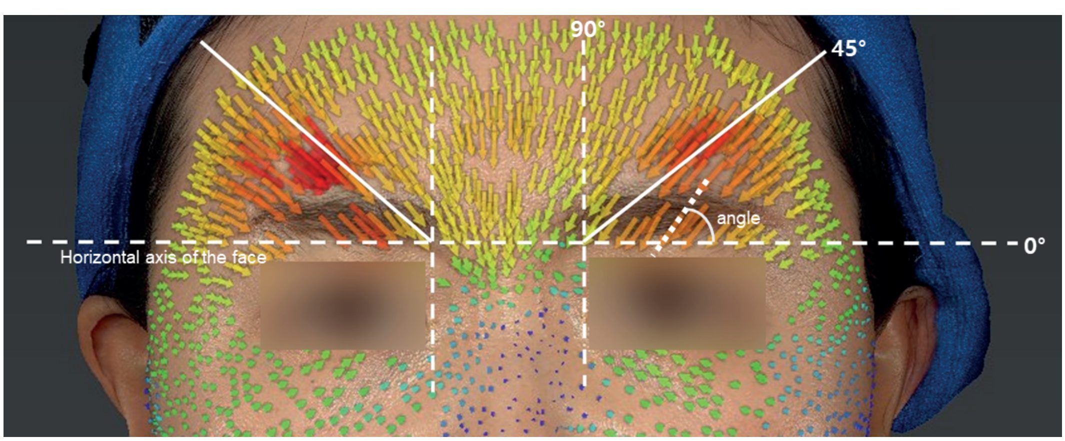

Fig. 1. Angle measurement of average skin vector displacement during a frowning expression. The horizontal axis of the face (white long dashed line) was defined by connecting the inferior medial points of both eyebrows. Skin displacement vectors (colored arrows) were derived from three-dimensional facial images captured during facial expression using the Vectra H1 system and analyzed with the Vectra Software Suite. The direction and magnitude of displacement were visualized using arrows, with color and size corresponding to vector angle and magnitude, respectively. The mean skin displacement vector (white short dotted line) was calculated, and the angle between this vector and the facial horizontal axis was measured in degrees (°) to quantify the directional pattern of skin movement during frowning.

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Skin displacement pattern

Two types of skin displacement pattern were identified at making frown expression; 1) central pattern where skin vector displacement mostly located in the procerus area between eyebrows (**Fig. 2A**), and 2) lateral pattern in which main skin vector displacement located on the eyebrow area (**Fig. 2B**). Upon making frowning facial expression, 26 subjects showed lateral pattern (89.66%) and 3 subjects showed central pattern (10.34%) skin displacement.

In addition, the symmetry of skin displacement was also analyzed. Among 29 subjects, 11 subjects (37.93%) showed symmetric skin displacement, while 18 subjects (62.07%) showed asymmetric skin displacement, with 12 (41.38%) showed more dominancy on the right side and 6 (20.69%) showed more dominancy on the left side (**Fig. 3**).

The relationship between glabella wrinkles pattern and skin vector displacement

Upon making frown expression, procerus, orbicularis oculi, depressor supercilii and corrugator supercilii muscles all contract in a different degree resulting different pattern of glabella wrinkles. First, classified the subjects based on glabellar wrinkle patterns, which were categorized into five types: 'U,' '11,' 'X,' 'π,' and 'I,' as previously reported[5], and then calculated the average skin displacement vector angle for each wrinkle pattern (**Fig. 4**). The 'U' and '11' patterns were the most common, each observed in 38% of cases, followed by the 'X' and 'π' patterns, observed in 14% and 10% of cases, respectively (**Fig. 4** and **Table 1**). Eleven subjects with the 'U' pattern had a mean glabella motion angle of 48.38°, while eleven subjects with the '11' pattern had a mean glabella motion angle of 32.30°. Three subjects with the 'π' pattern had a mean glabella motion angle of 24.07°, and four subjects with the 'X' pattern had a mean glabella motion angle of 74.35° (**Fig. 4** and **Table 1**).

Medial frontalis contraction during frowning expression

The frontalis muscle is connected inferomedially to the procerus, depressor supercilii, inferolateral orbicularis oculi, and corrugator supercilii muscles. During a frowning expression, the procerus, orbicularis oculi, depressor supercilii, and corrugator supercilii muscles all contract. This contraction theoretically elongates the frontalis muscle, resulting in the inferomedial movement of the forehead skin. As expected, 80% of subjects (n=23) displayed downward forehead movement during a frowning expression (**Fig. 5A**), while 20.69% (n=6) exhibited skin vector displacement indicating upward movement in the medial frontalis area (**Fig. 5B**).

Contraction of oblique oculi muscle

It is well known that during a frowning expression, the corrugator, depressor, procerus, and upper medial portion of the orbicularis oculi muscles contract, collectively contributing to the formation

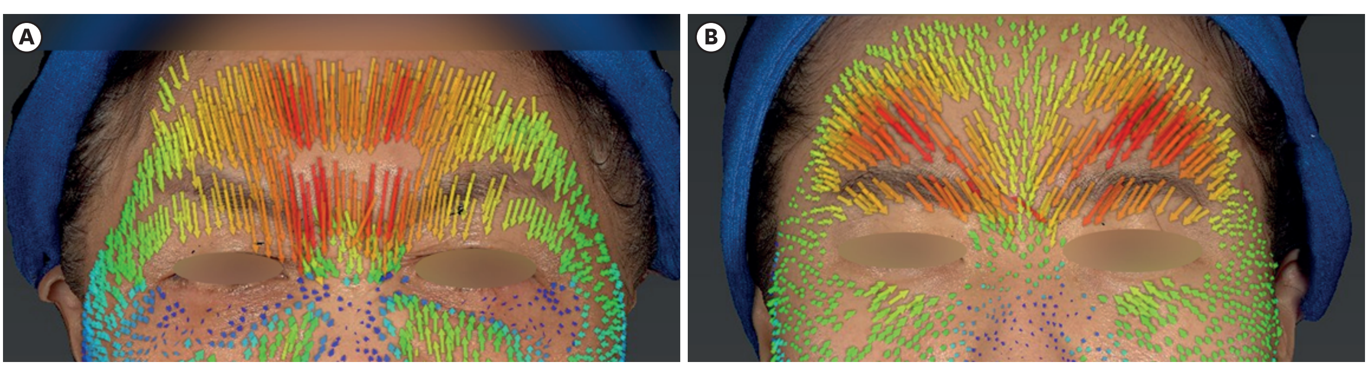

Fig. 2. Two patterns of skin displacement during frowning. Central pattern (A) and lateral pattern (B).

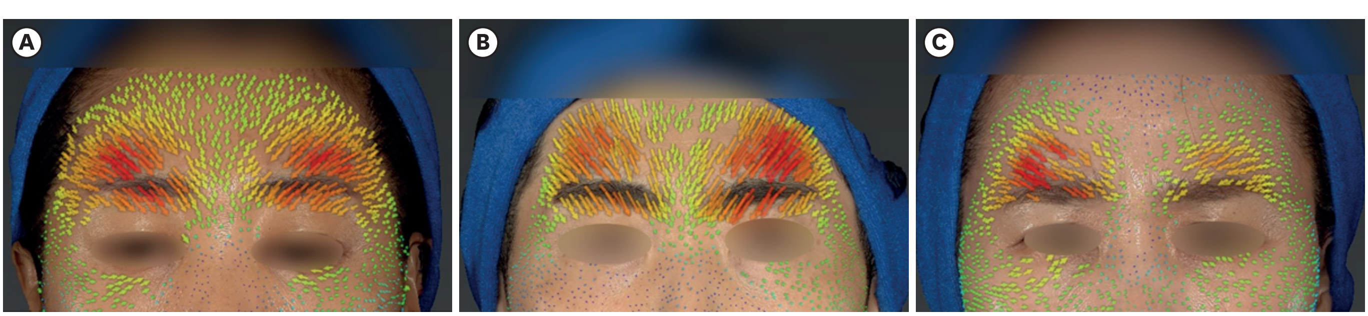

Fig. 3. The symmetry of skin displacement during frowning. Symmetrical (A), asymmetrical, left-dominant (B), and asymmetrical, right-dominant (C).

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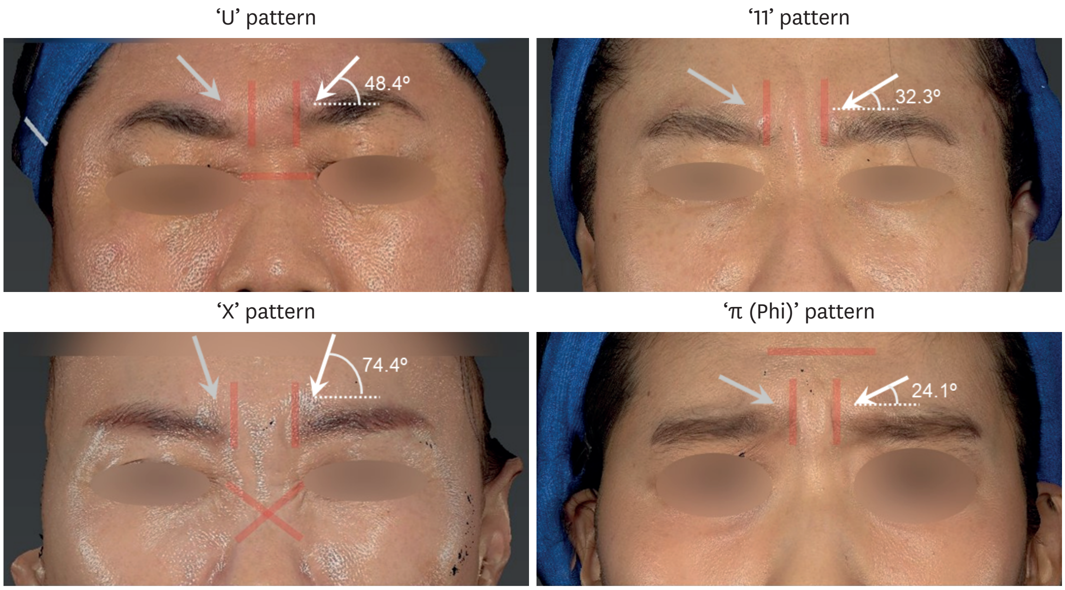

Fig. 4. Representative images of four distinct glabellar wrinkle patterns, 'U,' '11,' 'X,' and 'π (Phi),' observed during frowning, along with corresponding average skin displacement angles. The red markings indicate the characteristic wrinkle pattern observed in each subject. The white short dotted line represents the facial horizontal axis, defined by connecting the medial lower edges of both eyebrows. The white arrows indicate the direction and angle of the average skin displacement vector, measured relative to the facial horizontal axis. 'U' pattern (top left): Wrinkles form a curved 'U'-shape, and the average skin displacement angle was 48.4°. '11' pattern (top right): two vertical parallel lines appear between the brows, with a displacement angle of 32.3°. 'X' pattern (bottom left): crossing wrinkles in the shape of an 'X', with an angle of 74.4°. 'π (Phi)' pattern (bottom right): a central vertical wrinkle with a horizontal line above, resembling the Greek letter π, showing an angle of 24.1°.

Table 1. The frequency and the average skin movement angle for each wrinkle pattern

Glabellar wrinkle pattern	Frequency (%)		Average skin displacement angle
	Our study	Previous study[5]	
'U' pattern	37.90%	44.60%	48.4°
'11' pattern	37.90%	29.50%	32.3°
'X' pattern	13.80%	14.40%	74.4°
'π (Phi)' pattern	10.30%	10.80%	24.1°

of dynamic facial wrinkles. In 48% of cases, not only does the upper medial portion of the orbicularis oculi muscle contract (**Fig. 5C**), but the lateral and inferior portions of the orbicularis oculi muscle also contract (**Fig. 5D**).

DISCUSSION

We investigated the relationship between glabella muscle movement and dynamic wrinkle formation using 3D skin vector displacement analysis. Glabella frown lines consist of vertical, oblique, and horizontal lines. Vertical lines result from the contraction of the corrugator supercilii's transverse belly, while oblique lines form from the depressor supercilii and the oblique head of the corrugator supercilii. The procerus muscle creates horizontal or curved lines on the radix below the glabella by pulling down the inner eyebrow[4,6]. Based on this, we can postulate that glabella frown expressions typically produce a skin vector that is oblique, directing medially and inferiorly. In this study, nearly 90% of cases showed a dominant inferior medial oblique pattern, which we classified as the lateral pattern, while 10% exhibited dominant vertical skin displacement vectors, classified as the central pattern, indicating a strong dominance of the procerus muscle. When treating glabella wrinkles, subjects with a central pattern require higher doses of botulinum toxin into the procerus muscle. However, it is important to discuss with patients that procerus injections of high dose botulinum toxin may increase glabella height due to diffusion of botulinum toxin into and partial inactivation of the medial fibers of the frontalis[7].

In addition, we also found that more than 60% of cases showed asymmetric skin displacement. This finding suggests that different dosage should be performed in each sides, the dominant side needs a higher dose of botulinum toxin to correct glabella wrinkles[8].

We analyzed the relationship between glabella wrinkle patterns and skin vector displacement. Among the 29 subjects, the '11 pattern' and 'U pattern' were the most common glabellar wrinkle patterns, each occurring in 38% of cases, followed by the 'X pattern' (13.8%) and the 'phi pattern' (10.3%). These findings align with a previous study by Kim et al.[5], which also showed that the 'U pattern' and '11 pattern' were two of the most common patterns, followed by the 'X pattern' and 'phi pattern' in the Korean population. While previous studies[5,9,10] analyzed only glabellar

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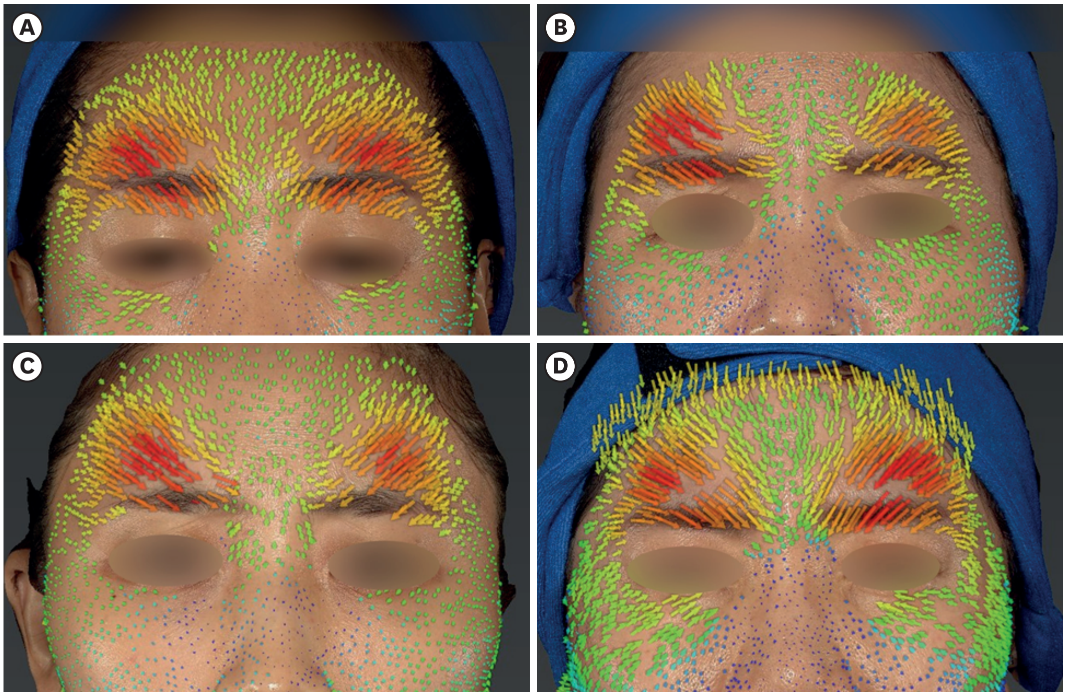

Fig. 5. Direction of frontalis and orbicularis oculi muscle contraction during frowning. (A) Full downward contraction of the frontalis muscle. (B) Upward contraction localized to the medial frontalis area. (C) Contraction of the upper medial portion of the orbicularis oculi muscle. (D) Contraction of the upper medial, lateral, and inferior portions of the orbicularis oculi muscle.

wrinkle patterns, our study investigated the skin displacement vector for each pattern, allowing us to predict the muscles involved in forming each wrinkle pattern. In subjects showing the 'U pattern,' the skin displacement angle was found to be nearly 45°, which is likely caused by similar contraction forces of the corrugator muscle (medial) and the procerus muscle (vertical). In glabellar wrinkles with the U pattern, the skin displacement vector was observed in both the eyebrow and glabellar areas, indicating that botulinum toxin injections are necessary in both the corrugator and procerus muscles. The average skin displacement angle in subjects showing the '11 pattern' was 32°, indicating minimal vertical skin displacement but prominent lateral skin displacement. This suggests minor skin displacement associated with the procerus muscle and a stronger corrugator contraction. Therefore, when treating glabellar wrinkles with the '11 pattern' using botulinum toxin, a more medial injection along the corrugator muscle is needed, while injection into the procerus muscle may not be necessary. In subjects with the X pattern, our data showed a greater skin displacement angle of 74.4°, with skin vector displacements primarily observed in the medial glabellar area, possibly resulting from the contraction of the procerus, corrugator, and nasalis muscles. These findings suggest that for optimal results, it is recommended to inject botulinum toxin not only into the glabellar frown area but also into the nasalis muscle in subjects with the X pattern. Lastly, in subjects with the 'Phi π pattern,' the average skin displacement angle was very narrow (24.1°), with skin vectors directed upward. This narrow skin displacement angle can be explained by minimal or no contraction of the procerus muscle, which normally pulls the skin downward. Instead, the contraction of the frontalis muscle pulls the medial glabellar area upward, causing skin displacement in the medial frontalis area. In this case, if the frontalis muscle is not injected as well, the glabellar frown may improve, but the glabellar area could appear oddly furrowed due to the influence of the frontalis muscle.

Our facial expressions result from the complex contraction of various muscles. Although glabellar frown lines primarily arise from the contractions of the procerus, orbicularis oculi, depressor supercilii, and corrugator supercilii muscles, the frontalis muscle also plays a role. We found that 20% of subjects exhibited upward skin vector displacement in the medial frontalis area during glabellar frowning, indicating contraction of the frontalis muscle. In individuals with this frowning habit, it is advisable to avoid botulinum toxin injections in the procerus muscle, as this may lead to hyperfunction of the frontalis muscle; instead, treatment should focus on the medial part of the frontalis muscle.

The glabella, forehead, and periocular muscles share interrelated fibers, and muscle contractions influence the contraction of adjacent muscles to a greater or lesser extent[11]. The superomedial fibers of the orbicularis oculi are connected to the corrugator supercilii and procerus muscles (also known as depressor supercilii). Therefore, contraction of the superomedial orbicularis oculi muscle leads to eyebrow lowering, while contraction of the lateral portion contributes to periocular rhytids[12]. According to our data, 48% of subjects exhibited contraction not only in the upper part of the orbicularis oculi but also in the lateral and inferior parts on frowning. Moreover, subjects with the X wrinkle pattern showed an association with contraction in the upper, lateral, and inferior parts of the orbicularis oculi muscle.

This study, while limited by its relatively small sample size of 29 participants, represents the first report to study skin displacement pattern in the glabellar area based on patterns of glabellar wrinkles in Koreans using a 3D skin vector displacement analysis method. Based on our study, future research with a larger cohort could provide evidence that offers more personalized and precise guidance for botulinum toxin injections for glabellar frown lines in clinical practice.

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CONFLICTS OF INTEREST

H.M., the first author of this manuscript, is the Chief Executive Officer of Hugel, the funding source. The other authors declare no conflicts of interest.

DATA SHARING STATEMENT

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

REFERENCES

1. Huang W, Foster JA, Rogachefsky AS. Pharmacology of botulinum toxin. J Am Acad Dermatol 2000;43:249-259. PUBMED | CROSSREF
2. Aoki KR. Pharmacology and immunology of botulinum neurotoxins. Int Ophthalmol Clin 2005;45:25-37. PUBMED | CROSSREF
3. Cotofana S, Freytag DL, Frank K, Sattler S, Landau M, Pavicic T, et al. The bidirectional movement of the frontalis muscle: introducing the line of convergence and its potential clinical relevance. Plast Reconstr Surg 2020;145:1155-1162. PUBMED | CROSSREF
4. Moon HJ, Lee W, Choi JY. Dynamic evaluation of facial muscles: 3D skin displacement vector analysis using a facial painting model. Laryngoscope Investig Otolaryngol 2021;6:650-656. PUBMED | CROSSREF
5. Kim HS, Kim C, Cho H, Hwang JY, Kim YS. A study on glabellar wrinkle patterns in Koreans. J Eur Acad Dermatol Venereol 2014;28:1332-1339. PUBMED | CROSSREF
6. Kim SB, Kim HM, Ahn H, Choi YJ, Hu KS, Oh W, et al. Anatomical injection guidelines for glabellar frown lines based on ultrasonographic evaluation. Toxins (Basel) 2021;14:17. PUBMED | CROSSREF
7. Carruthers A, Carruthers J. Eyebrow height after botulinum toxin type A to the glabella. Dermatol Surg 2007;33:S26-S31. PUBMED | CROSSREF
8. Weeden JC, Trotman CA, Faraway JJ. Three dimensional analysis of facial movement in normal adults: influence of sex and facial shape. Angle Orthod 2001;71:132-140. PUBMED
9. Trindade de Almeida AR, da Costa Marques ERM, Kadunc BV. Glabellar wrinkles: a pilot study of contraction patterns. Surg Cosmet Dermatol 2010;2:23-28.
10. de Almeida AR, da Costa Marques ER, Banegas R, Kadunc BV. Glabellar contraction patterns: a tool to optimize botulinum toxin treatment. Dermatol Surg 2012;38:1506-1515. PUBMED | CROSSREF
11. Tamura BM, Odo MY. Classification of periorbital wrinkles and treatment with botulinum toxin type A. Surg Cosmet Dermatol 2011;3:129-134.
12. Lima ASD, Gubert M, Lyra T, Sardagna CF. Muscle contraction patterns and their associations in the upper third of the face: a clinical and epidemiological study. Surg Cosmet Dermatol 2022;14:1-10. CROSSREF