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RESEARCH **Open Access**

The role of surface electromyography in confirming the effect of blepharoplasty on strength of levator palpebrae superioris muscle in congenital blepharoptosis

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Abstract

Background Blepharoptosis is an abnormal drooping of the upper eyelid margin with the eye in the primary gaze position. The clinical evaluating tests of upper eyelid muscle function lack objectivity, while surface electromyography (SEMG) is an objective evaluating tool of muscle power. We aimed to confirm the effect of blepharoplasty on levator muscle power after its shortening via levator aponeurosis resection surgery in cases of congenital ptosis through electrophysiological and clinical studies.

The study included 40 patients aged ≥ 10 years with congenital blepharoptosis from the ophthalmology department of our university hospital, along with 40 age- and sex-matched healthy controls. All participants were subjected to clinical and electrophysiological assessment of levator muscle before and after blepharoplasty.

Results There was a significant improvement in clinical and electrophysiological findings among cases post-surgery compared with preoperative parameters. We recorded clinical improvement in 90% of patients postoperatively regarding eyelid morphology, symmetry, and visual field. Meanwhile, 82.5% of patients showed improvement in their muscle power using SEMG parameters in terms of improved muscle amplitude and firing characters compared with preoperative measures.

Conclusion SEMG provides a standardized, objective method of analysis of upper eyelid muscle power. It confirms that levator muscle shortening via levator aponeurosis resection surgery could increase its power based on its pre-surgical power and electrophysiological characteristics; so, it could be considered an indicator of post-operative improvement of ptosis based on electrophysiological measurements before surgery. The relatively short follow-up period and lack of quantitative analysis of EMG were limitations of this study.

Keywords Surface electromyography, Blepharoptosis, Margin-reflex distance levator muscle function

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Background

The eyelids protect the globe while providing essential elements of the corneal tear film and evenly distributing tears across the eye surfaces. The cornea is protected from injury and glare by constant voluntary and reflex eyelid movements [1].

The levator palpebrae and Müller's muscles are upper eyelid retractors, and their contraction elevates the eyelid. The upper eyelid margin lies at the superior corneal limbus in healthy children and 1.5–2 mm below the superior corneal limbus in the primary position in adults [2].

Blepharoptosis is an abnormal drooping of the upper eyelid margin with the eye in the primary gaze position caused by levator palpebrae superioris muscle dysfunction (either mechanical dysfunction as in acquired ptosis or muscle weakness as in congenital ptosis). Hence, the amount of cornea covered by the eyelid varies, causing vision problems and cosmetic issues [3].

Ptosis may be acquired or congenital; congenital ptosis is either caused by congenital dysplasia of the levator palpebrae superioris muscle or denervation of the oculomotor nerve, while acquired ptosis may be traumatic, mechanical, senile, neurogenic, or myogenic [4].

The reference values for measuring the degree of ptosis are clinically determined by the margin-reflex distance (MRD1, the distance between the upper eyelid margin and the site of pupillary light reflex on cornea (at the center of pupil)), vertical palpebral fissure (the distance between the upper and lower lid margins), and levator muscle function (the difference between the upper eyelid position in down-gaze and up-gaze, with the brow immobilized) [5–7].

Congenital ptosis is classified into three grades regarding levator muscle function: mild ptosis with good levator function (10 to 15 mm), moderate ptosis with fair levator function (6 to 10 mm), and severe ptosis with poor levator function (less than 4 mm) [8, 9].

Transcutaneous levator muscle resection with levator aponeurosis advancement is a well-established method for correcting blepharoptosis [9, 10].

Patient outcomes after surgical correction depend on clinical observations, which are inadequate, subjective, and non-quantitative tools for evaluating upper eyelid function [11, 12].

The electromyographic (EMG) study is an objective method of recording muscle function in many clinical situations. Surface electromyography (SEMG) is an electrodiagnostic method for measuring and recording the whole activity of muscles. It comprises the sum of all the motor unit action potentials (MUAPs) and is measured with the surface electrodes [12–16].

The SEMG signal amplitude examines the active muscle intensity assessed during maximum voluntary contractions. SEMG is preferred over needle EMG for superficial and easily accessible muscles and in conditions requiring a non-invasive maneuver for assessment. However, the inability to monitor deep muscles is a drawback of SEMG [16–18].

We aimed to confirm the effect of blepharoplasty on levator muscle power after its shortening via levator aponeurosis resection surgery in cases of congenital ptosis through electrophysiological and clinical studies.

Methods

This prospective cohort study was performed on 45 patients who were clinically diagnosed and evaluated with true congenital blepharoptosis, both sexes and aged $\geq$ 10 years. The study was approved by the ethics committee of our institutional university with IRB number 112022COM29. Each participant and their parents provided written informed consent for the study and publications.

Children aged < 10 years and patients with myasthenia gravis, acquired or pseudo-blepharoptosis, previous eyelid surgery, hepatic disease, chronic illness, and any disorder that interfered with anesthesia were excluded from the study.

Patients were enrolled in the outpatient ophthalmology clinic at our university hospital from January 2018 to March 2021. This study included 40 eligible patients (out of the 45 patients screened, 5 were missed during follow-up post-surgery), along with 40 age- and sex-matched healthy controls.

All patients were subjected to proper history taking (onset and duration of ptosis, constant or variable, family history, history of other ophthalmic or systemic diseases, history of probable bleeding tendencies, drug allergies, and a family history of anesthetic complications) and clinical examinations as regards routine ocular examination, with rolling out pseudoptosis in unilateral cases by examination of enophthalmos, contralateral exophthalmos, contralateral lid retraction, hypotropia, hemifacial spasm, and blepharospasm.

All the participants were subjected to a complete clinical evaluation that included the following criteria for measuring the function of the levator palpebrae superioris muscle and the degree of ptosis before surgery and at 1 week, 1 month, and 3 months after surgery.

– The upper lid margin-reflex distance (MRD1) was assessed by measuring the distance between the site of the corneal light reflex (on the center of the pupil) and the middle of the upper lid margin in the primary position. The normal MRD1 is 4–4.5 mm. Ptosis is graded based on margin-reflex distance 1 (MRD1) into mild-to-moderate ptosis (MRD1 > 1.5 mm) and severe ptosis (MRD1 ≤ 1.5 mm) [5, 18].

– The vertical palpebral fissure was assessed by measuring the distance between the upper and lower lid margins. Vertical palpebral fissure equals MRD1 and MRD2 (distance between the site of corneal light reflex on pupillary center and lower lid margin); vertically, the palpebral fissure measures 8–12 mm such that the upper eyelid rests 3–4 mm above the center of the pupil and the lower eyelid rests at the inferior of the limbus [6].
– Levator muscle function was assessed by measuring the difference between the position of the upper eyelid in the down-gaze and the up-gaze with the brow immobilized. Levator function was categorized as good (9–11 mm), fair (5–9 mm), poor (≤ 4 mm), and its standard value (> 14 mm) [7].

Electrophysiologic study

Enrollment was unified across cases and controls, as all participants underwent SEMG, which was standardized and performed by a single consultant with the same apparatus, technique, and data analysis method. The procedure was explained to participants before initiating the test. All patients underwent SEMG preoperatively and 3 months postoperatively.

The Nihon Kohden Europe apparatus was used to record the SEMG data. The amplitude sensitivity was set to 100–200 uV/division, and the upper and lower frequency filters were set to 20 Hz and 10 kHz, respectively. The electrode was adjusted to obtain optimum EMG signals.

Test technique

The area to be measured was cleaned, sterilized with alcohol, and dried before the study. The negative disc electrode (active) was placed in the middle of the upper eyelid above the lash line (E1), the positive disc electrode was placed on the forehead (E2), and the ground electrode was placed on the chin (G) [19] (Fig. 1).

SEMG recording was conducted while the patients attempted to open their eyes actively, and against resistance after abolishing the effects of the frontalis muscle with the head fixed, as shown in Fig. 1. The levator palpebrae superioris muscle amplitude was assessed at the maximal activity for controls, as in Fig. 2, for cases before surgery as in Fig. 3, and for cases after surgery as in Fig. 4.

The levator palpebrae superioris muscle firing (recruitment) frequency was assessed at minimal activity for controls and for cases before, and after surgery.

In this study, we analyzed the surface EMG parameters at maximal volitional activity by calculating the mean amplitude of the interfering waves at a fixed time unit; also, the firing (recruitment) frequency was evaluated at minimal activity by EMG2 in controls and cases before and after surgery [20, 21].

Most extremity muscles have a recruitment frequency of about 10–11 Hz. Facial muscles are an exception to this rough guide. MUAPs of facial muscles have higher recruitment frequencies (about 25 Hz) [22].

Surgical procedure

All patients underwent anterior approach transcutaneous levator muscle resection with levator aponeurosis advancement to shorten the weak levator muscle to improve its function [10].

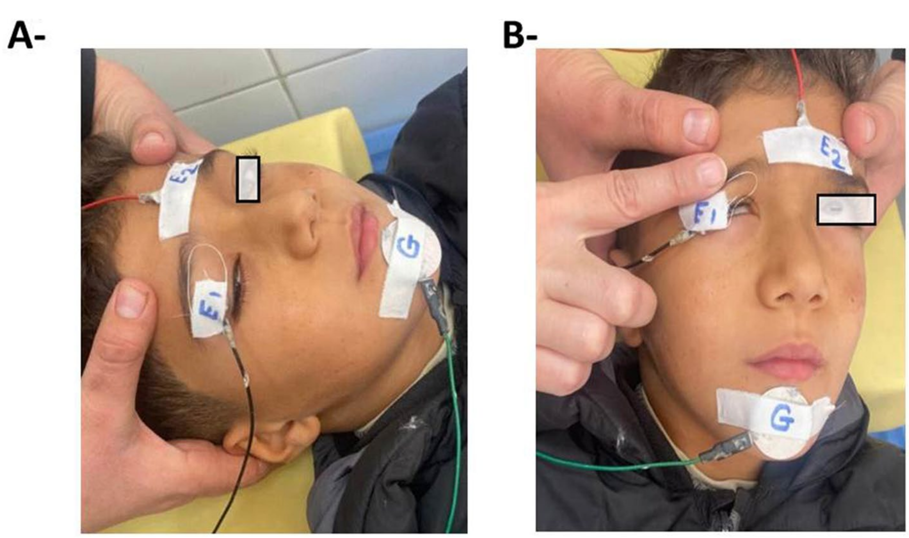

Fig. 1 Position of electrodes of SEMG on levator muscle while the patients attempted to open their eyes actively (**A**) and against resistance (**B**).

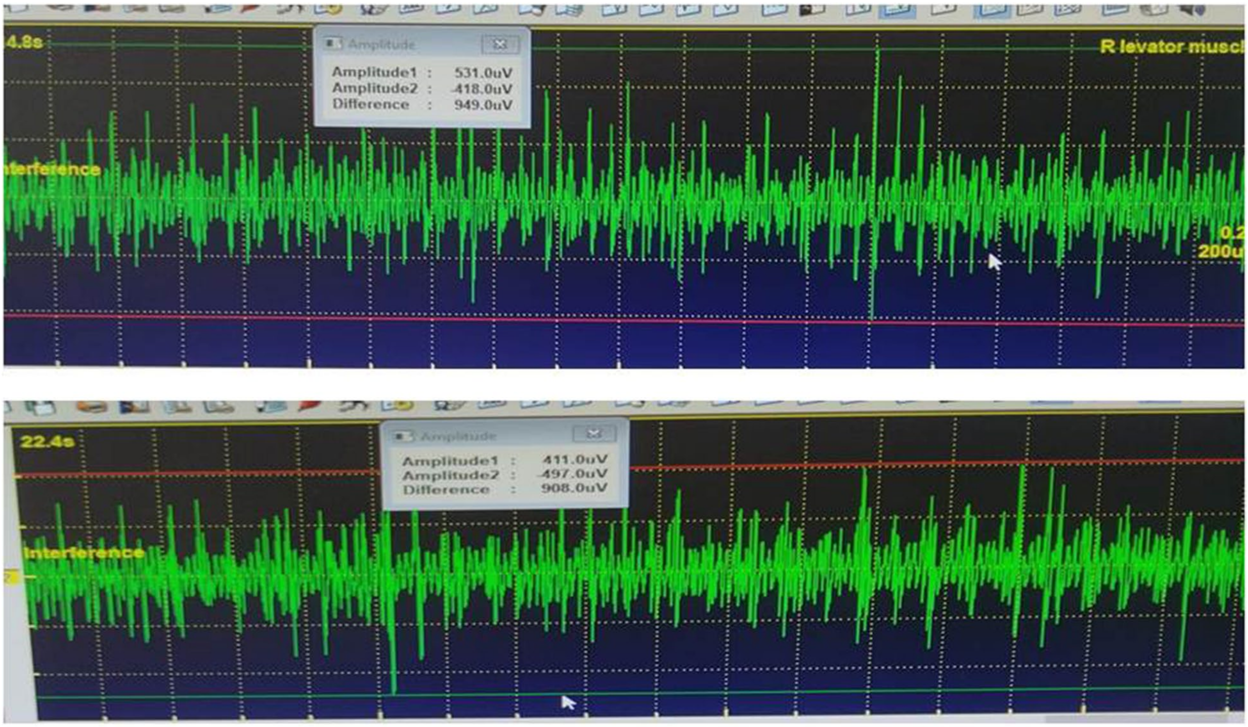

Fig. 2 Levator palpebrae superioris muscle amplitude at maximal activity in controls by SEMG recording

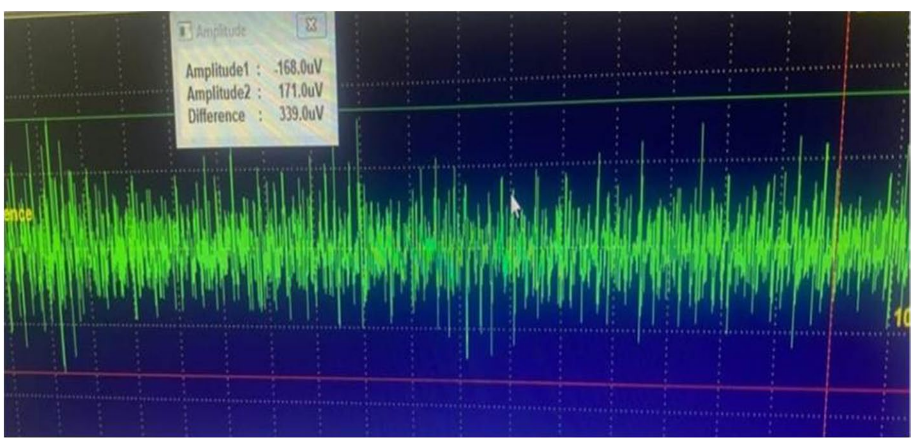

Fig. 3 Levator palpebrae superioris muscle amplitude at maximal activity in cases before surgery by SEMG recording

Statistical analysis

Data were analyzed using an IBM-compatible personal computer with Statistical Package for the Social Sciences (SPSS) version 26. Qualitative variables were expressed as numbers (*N*) and percentages (%) and analyzed using the chi-square test (χ^2) and the marginal homogeneity test (for paired categorical data measured only 2 times with > 2 outcomes), while quantitative data were expressed as mean, standard deviation (SD), and range (minimum–maximum) and analyzed using Student's *t* test (*t*) (for normally distributed data between two groups) and paired *t* test (for paired normally distributed data in the same group). A two-tailed *p*-value was judged significant at the 0.05 level [23].

Results

The present study included 40 patients with true congenital blepharoptosis with 40 age- and sex-matched healthy controls. The general demographic data of the enrolled participants in both groups were comparable, with a

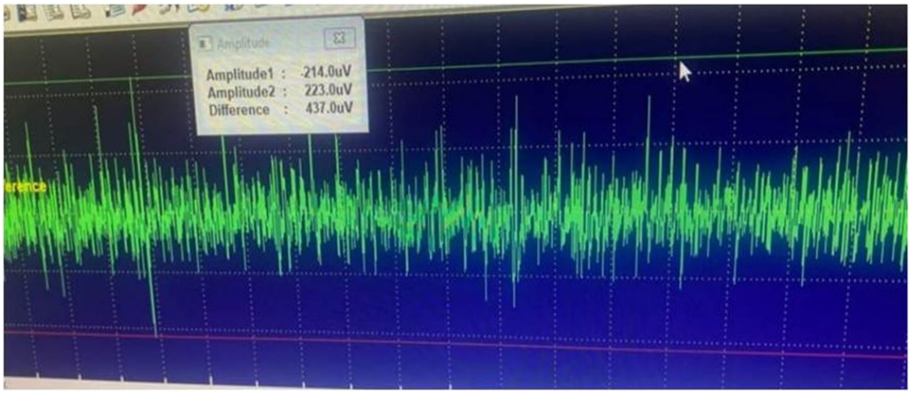

Fig. 4 Levator palpebrae superioris muscle amplitude at maximal activity in cases after surgery by SEMG recording

statistically significant difference regarding the mean amplitude of the interfering wave, firing frequency of levator muscle among cases before surgery (244.27 ± 56.4 uV) (29.8 ± 2.6 Hz), and controls (793.9 ± 131.7 uV) (22.3 ± 1.4 Hz) as shown in Table 1.

Table 2 shows the statistically significant improvement in SEMG measures postoperatively regarding amplitude (396.2 ± 110.4) compared with pre-surgery (244.27 ± 56.4 uV) and the firing frequency(26.9 ± 2.9) compared with pre-surgery (29.8 ± 2.6 Hz).

There was a significant clinical improvement in levator function degree, evaluation, MRD1 (mm), and palpebral fissure height (mm) in cases postoperatively compared with preoperative measures ($p < 0.001$) (Table 2).

Table 3 shows the SEMG findings (amplitude and firing frequency) in patients with different levator muscle functions before and after surgery.

Cases with good muscle function before surgery had a mean amplitude and firing frequency of 300.6 ± 51.2 and 28.4 ± 1.4, which became 455.5 ± 26.8 and 26.2 ± 0.9 after surgery, while cases with fair muscle function before surgery had a mean amplitude and firing frequency of 241.3 ± 38.2 and 29.7 ± 1.5 that became 374.5 ± 104.2 and 28.9 ± 2.4 after surgery. Finally, among those with poor levator function, the mean amplitude and firing frequency were 173.7 ± 17.6 and 33.9 ± 0.9 before surgery and became 172.3 ± 14.6 and 34.5 ± 0.6 post-surgery.

Table 4 shows the statistically significant postoperative electrophysiological improvement in cases whose mean amplitude and firing frequency were 259.2 ± 50.0 and 29.7 ± 1.4 pre-surgery, compared with those with mean amplitude and firing frequency of 173.7 ± 17.6 and 33.9 ± 0.9 before surgery ($p < 0.001$); the significant electrophysiological improvement observed among those classified as having good and fair levator muscle function (whose muscle amplitude ranged from 200 to 339 uV), before surgery, while all cases with poor LF (whose muscle amplitude ranged from 150 to 190 uV before surgery) show insignificant post-surgical electrophysiological improvement.

The statistically significant postoperative clinical improvement was observed in cases with mean amplitude and firing frequency of 253.7 ± 51.7 and 29.3 ± 2.2, respectively, before surgery, compared with those with

Table 1 Demographic data of the participants, and pre-operative SEMG parameters in cases versus control

	Cases (*N* = 40)	**Control (*N* = 40)**	**Student *t* test (t)**	***p*-value**
Age (years)	13.7 ± 3.0 10.0–19.0	14.1 ± 3.2 11.0–20.0	0.57	0.568
Sex: Male Female	18 (45.0) 22 (55.0)	16 (40.0) 24 (60.0)	**Chi square test** = 0.21	0.651
Amplitude (uV)	244.27 ± 56.4 150–339	793.9 ± 131.7 560–980	24.29	**< 0.001****
Firing frequency (Hz)	29.8 ± 2.6 27–35	22.3 ± 1.4 20–25	16.06	**< 0.001****

Amplitude Amplitude of interfering waves at maximal activity

** Highly significant ($P < 0.001$)

Table 2 Pre- and post-operative clinical and SEMG data among cases of the present study

		Cases (*N* = 40)		Paired *t* test	*p*-value
		Pre-operative	**Post-operative**		
Clinical data	**MRD1 (mm)**	2.0 ± 0.3 1.3–2.5	3.3 ± 0.8 1.3–4.0	12.32	**< 0.001****
	Palpebral fissure height (mm)	5.7 ± 0.9 4.0–6.9	8.9 ± 2.0 4.0–11.0	13.10	**< 0.001****
	Levator function degree mm	7.3 ± 1.6 4.0–10.0	10.6 ± 1.6 8.0–13.0	12.69	**< 0.001****
	LF evaluation **Good** **Fair** **Poor**	10 (25%) 23 (57.5%) 7(17.5%)	21 (52.5%) 15 (37.5%) 4(10.0%)	Marginal homogeneity test	**< 0.001****
S.EMG	**Amplitude (uV)**	244.27 ± 56.4 150–339	396.2 ± 110.4 156–500	11.83	**< 0.001****
	Firing frequency (Hz)	29.8 ± 2.6 27–35	26.9 ± 2.9 25–33	10.46	**< 0.001****

LF Levator function, *MRD1* upper lid margin-reflex distance, *Amplitude (uV)* Amplitude of interfering waves at maximal activity

** Highly significant ($p < 0.001$)

Table 3 SEMG findings (amplitude and firing frequency) in patients with different levator muscle function before and after surgery

Pre-operative SEMG	Pre-operative clinical parameters (levator muscle function)			Post-operative SEMG	Post-operative clinical parameters (levator muscle function)		
	Good (*N* = 10)	**Fair (*N* = 23)**	**Poor (*N* = 7)**		**Good (*N* = 21)**	**Fair (*N* = 15)**	**Poor (*N* = 4)**
Amplitude (uV)	300.6 ± 51.2 205–339	241.3 ± 38.2 200–330	173.7 ± 17.6 150–190	**Amplitude (uV)**	455.5 ± 26.8 410–500	374.5 ± 104.2 200–470	172.3 ± 14.6 160–189
Firing frequency (Hz)	28.4 ± 1.4 27–31	29.7 ± 1.5 28–32	33.9 ± 0.9 33–35	**Firing frequency (Hz)**	26.2 ± 0.9 25–27	28.9 ± 2.4 26–31	34.5 ± 0.6 34–35

Table 4 The electrophysiological and clinical improvement of cases post-blepharoplasty in relation to pre-operative SEMG parameters

Pre-operative SEMG	Clinical improvement		Student *t* test (*p*-value)	Electrophysiological improvement		Student *t* test (*p*-value)
	Improved (*N* = 36)	**Not-improved (*N* = 4)**		**Improved (*N* = 33)**	**Not-improved (*N* = 7)**	
Amplitude (uV)	253.7 ± 51.7 188–339	162.5 ± 15.3 150–180	7.65 (**< 0.001**)**	259.2 ± 50.0 200–339	173.7 ± 17.6 150–190	3.31 **(0.002)***
Firing frequency (Hz)	29.3 ± 2.2 27–33	34.5 ± 0.6 34–35	3.43 (**0.001**)*	29.7 ± 1.4 27–32	33.9 ± 0.9 33–35	4.27 (**< 0.001**)**

* Significant ($p < 0.05$)

** Highly significant ($p < 0.001$)

mean amplitude and frequency of 162.5 ± 15.3 and 34.5 ± 0.6, respectively, before surgery; the improvement included all good and fair cases and 3 out of the 7 cases with poor levator function, which proves that not all morphological improvement was associated with increment of muscle power (as those 3 cases did not improve electrophysiologically, and their muscle power was not improved).

Figure 5 shows that 90% (36) of patients with blepharoptosis improved clinically post blepharoplasty in terms of increasing palpebral fissure height, levator function degree, and evaluation, with improving eyelid morphology, symmetry, and visual field, while 82.5% (33) of patients showed improvement in their eyelid muscle power using surface EMG parameters in terms of increasing the amplitude of the interfering waves and

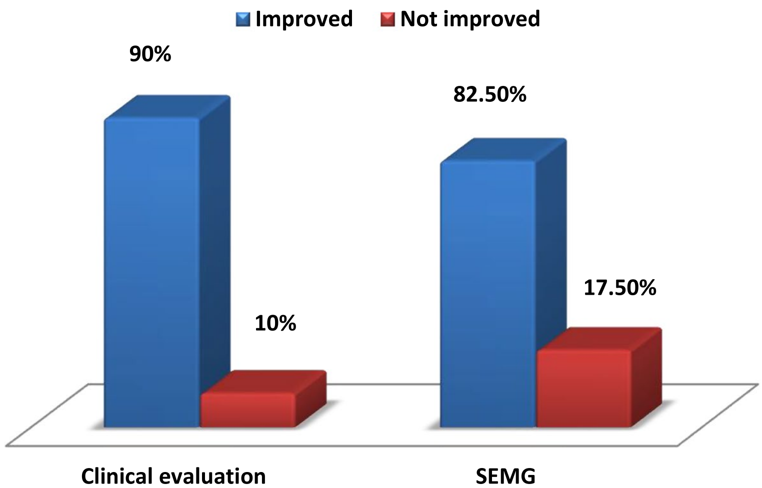

Fig. 5 The rate of post-surgical improvement assessed by clinical evaluation and SEMG parameters

improvement of their firing characters compared with their values before surgery.

Discussion

A few studies have discussed using SEMG to assess eyelid muscle function in blepharoptosis. One study relied on EMG data without relating it to the patient's clinical evaluation; it was conducted on 29 patients with involutional ptosis [24]. Another study focused on the function of the orbicularis oculi without examining levator muscle function [25].

Therefore, to our best knowledge, this is the first study conducted on cases with congenital blepharoptosis to study the role of SEMG in confirming the effect of blepharoplasty on muscle power after its shortening via levator aponeurosis resection surgery in an objective and standardized manner of analysis and correlates that with clinical examination results (regarding palpebral fissure height and levator muscle function, etc.) in those patients to ascertain whether postsurgical morphological improvement is accompanied by muscle power improvement; the study included 80 participants and a sizable number of patients with blepharoptosis (40 patients).

This study showed significant clinical improvements in levator muscle function degree, evaluation, MRD1 (mm), and palpebral fissure height (mm) among most cases postoperatively as well as statistically significant improvements in SEMG parameters regarding improvement of the amplitude of interfering waves at maximal activity and the firing frequency of levator muscle compared with preoperative parameters in most cases, indicating that muscle control improved in terms of clinical and electrophysiological findings following blepharoplasty.

Similar to those findings, Tu et al. [24] and Waqar et al. [10] found that the overall levator muscle function improved after blepharoplasty in their study cases, as shown by SEMG parameters and clinically by MRD1 (mm) and palpebral fissure height (mm).

The clinical and electrophysiological improvement of levator muscle power in cases of the present study after resection with levator aponeurosis advancement surgery could be explained as muscle shortening, increasing its tension and isometric force, resulting in greater contractions and strength [8].

Bouton's study [26] also documented that shortening the levator muscle in cases of congenital ptosis can increase its strength, depending on the amount of ptosis and pre-existing levator function, and power before surgery.

Therefore, the strength of the levator muscles improved after their surgical shortening in most cases of the current study, based on their good condition before surgery, as cases with good to fair levator muscle function, whose muscle amplitude ranged from 200 to 339 IF, and whose firing frequency ranged from 27 to 32 Hz before surgery, improved clinically regarding morphology and electrophysiologically regarding muscle power improvement. In contrast to cases with poor levator muscle function before surgery, whose amplitude ranged from 150 to 190 uV and whose firing frequency ranged from 33 to 35 Hz, they did not improve significantly regarding electrophysiological parameters, while 3 of them improved clinically (morphologically) without improvement in their muscle power.

In accordance with the current results, Mei and Li documented that the shortening of the levator palpebrae superioris muscle in cases of ptosis can enhance muscle strength, maintain the original walking and movement direction of the muscle, and conform to the physiological function of the human body [27].

In the current study, 90% of patients improved clinically after blepharoplasty (all cases were with good to fair levator power, 3 out of 7 cases were with poor levator function whose amplitude ranged from 188 to 339 uV, and firing frequency ranged from 27 to 33 Hz before surgery), in terms of increasing palpebral fissure height, levator function degree, and evaluation, with improving eyelid morphology, symmetry, and visual field.

While a significant electrophysiological improvement was recorded in 82.5% of cases (all cases were with good to fair levator function with amplitude ranging from 200 to 339 uV and firing frequency ranging from 27 to 32 Hz before surgery), in terms of improvement of their amplitude and firing frequencies, compared with their values before surgery, with subsequent improvement of their muscle power with non-significant electrophysiological improvement in those with poor levator muscle function (whose amplitude was equal to or less than 190 uV, and their firing frequency ranged from 33 to 35 Hz before surgery).

Therefore, SEMG can be considered as an indicator of post-surgical improvement of upper eyelid muscle power based on preoperative muscle strength and electrophysiological characteristics, as, in the current study, cases whose pre-operative levator muscle (LM) amplitude ranged from 200 to 339 uV, and their firing frequency was 27–32 Hz, which improved clinically and electrophysiologically post blepharoplasty, and their eyelid muscle power increased, which was not observed in those with levator muscle amplitude equal to or less than 190 uV, and their firing frequency ranged from 33 to 35 Hz.

Based on the current and other studies results, we can conclude that clinical assessment of the upper eyelid mainly evaluates the morphological and functional improvement in terms of palpebral fissure height, eyelid symmetry, and the field of vision, which is not necessarily associated with an increase in muscle strength. Therefore, it lacks the objective standardized analysis of upper eyelid muscle power and is insufficient to verify the improvement of levator muscle power after its shortening via levator aponeurosis resection surgery.

Servat and Mantilla's study, based only on clinical observations, agreed with ours as they reported that the pre-and post-operative clinical evaluation of eyelid muscles in blepharoptosis lacks the method of objective and quantitative analysis [11].

Similarly, other studies [5, 28] concluded that the levator function (LF) test is an imprecise and subjective clinical method of assessing the eyelid muscle function in blepharoptosis, as it cannot be consistently obtained in some clinical circumstances, such as in young, uncooperative patients and cases of mental disorders.

Ural et al. [5] reported that MRD1 determination is objective and more accessible than LF; however, it still requires proper brow relaxation before the examination, which some examiners may miss, and it cannot distinguish between mild and moderate levator muscle weakness.

Limitations

The relatively short follow-up period and the lack of quantitative EMG analysis were the main limitations of the present study.

Conclusion

SEMG provides a standardized, objective method of analysis of upper eyelid muscle power. It confirms that levator muscle shortening via levator aponeurosis resection surgery in cases of congenital ptosis could increase its power based on its pre-surgical power and electrophysiological characteristics; so, it could be considered an indicator of surgical success and postoperative improvement of ptosis based on electrophysiological measurements before surgery.

Abbreviations

EMG	Electromyography
LF	Levator muscle function
MRD	Margin-reflex distance
MUAP	Motor unit action potential
SEMG	Surface electromyography
t test	Student's *t* test
U test	Mann–Whitney *U* test
χ^2 test	Chi-square test

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Authors' contributions

SA was responsible for the following tasks: data collection, writing the first draft, reviewing it, contributing to the work's design, clinical work, and data interpretation. SS and EA completed the following tasks: placed the study design, followed the patients, performed the surgical procedure, and revised the draft paper. ES did the following: data collection, editing and reviewing of the draft, clinical work, and data interpretation. SHA participated in the conceptualization and formal and statistical analysis and revised the draft paper. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on request.

Declarations

Ethics approval and consent to participate
This study was approved by Menoufia University, Faculty of Medicine Research Ethics Committee (REC). IRB: 11/2022 COM 29. A written informed consent was obtained from the participants' legal guardians sharing in the study.

Consent for publication
Written consent was taken from the participants' legal guardians and available upon request.

Competing interests
The authors declare that they have no competing interests.

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