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ORIGINAL RESEARCH

Motor Unit Number Index (MUNIX) as an Early Prognostic Biomarker in Acute Bell's Palsy: A Prospective Cohort Study

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Objective: Recovery from acute Bell's palsy (BP) is variable and there are few predictors of response. We evaluated the usefulness of motor unit number index (MUNIX) to predict outcome in BP.

Methods: This prospective study evaluated the prognostic utility of MUNIX in 64 consecutive patients with acute unilateral BP. Within 7 days of symptom onset, participants underwent bilateral MUNIX testing of three facial muscles: orbicularis oculi muscle, zygomatic muscle, and orbicularis oris muscle. Clinical outcomes were assessed using the House-Brackmann Grading System (HBGS) by two blinded neurologists at baseline, 1 month, and 3 months. All patients received prednisolone treatment and regular rehabilitation.

Results: At 1-month follow-up, 26 patients (65%) achieved good recovery (HBGS I–II). The zygomatic muscle demonstrated superior prognostic performance, with absolute value of affected-to-unaffected side MUNIX difference in the zygomatic muscle (ΔMUNIX zygomatic muscle) >14 predicting poor recovery (AUC =0.804, 95% CI 0.667–0.940; p =0.002), showing 85% sensitivity and 79% specificity. Three-month outcomes (n=20) confirmed ΔMUNIX zygomatic muscle >16 as the optimal cutoff (AUC =0.893, 95% CI 0.748–1.000; p =0.006).

Conclusion: These findings establish MUNIX, particularly zygomatic muscle measurements, as an objective, non-invasive prognostic tool for early BP management.

Plain Language Summary:

- MUNIX was evaluated for predicting outcomes in BP.
- ΔMUNIX values in the zygomatic muscle were identified as the most significant predictive indicator of BP recovery.
- Zygomatic muscle MUNIX serves as a sensitive prognostic tool for acute BP recovery, aiding in the development of effective management strategies.

Keywords: facial nerve, Bell's palsy, MUNIX, zygomatic muscle, prognosis

Introduction

Bell's palsy (BP) is a rapid, unilateral, partial, or complete lower motor neuron paralysis of the facial nerve[1] with highest incidence in people aged 15 to 45 years,[2] an annual incidence of 20 per 100,000.[3] While 70% of patients recover spontaneously, 30% experience incomplete recovery leading to permanent disfigurement and impaired quality of life.[2] Current prognostic tools face significant limitations: electroneurography (ENoG) requires precise timing (48–72 hours post-onset) and causes patient discomfort,[4] while clinical grading systems [eg, House–Brackmann Grading System (HBGS), Sunnybrook Facial Grading System (SFGS)][5] suffer from subjectivity.

Given the limitations of current prognostic methods, there is a clear need for objective, quantitative tools that can reliably predict recovery early in the disease course. The motor unit number index (MUNIX) presents a promising

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candidate, as it provides a non-invasive, electrophysiological measure of motor unit integrity that could potentially address this clinical gap. The MUNIX offers a novel approach by quantifying functional motor units through analysis of compound muscle action potentials (CMAP) and surface EMG (sEMG) interference patterns (SIP).[6] MUSIX is derived from the ratio of CMAP amplitude to MUNIX. Originally developed for amyotrophic lateral sclerosis monitoring,[7] MUNIX provides several advantages for BP assessment: non-invasiveness, rapid administration (<5 minutes), and technical simplicity.[6] This study investigates whether early (3–7 days post-onset) MUNIX measurements can predict recovery patterns in acute BP. To our knowledge, this is the first prospective study to systematically evaluate MUNIX as an early prognostic biomarker for recovery in patients with acute BP.

Methods

Participants

From August 2021 to August 2023, we screened 64 consecutive BP patients at Beijing Tsinghua Changgung Hospital. Inclusion criteria were: (1) unilateral BP diagnosis ≤7 days, (2) age ≥18 years, and (3) no treatment before the MUNIX examination. Exclusion criteria included herpes zoster infection, trauma, or other secondary causes. Flow diagram of BP cohort selection is shown in Figure 1.All consecutive eligible patients presenting to our hospital during the recruitment period were invited to participate. Patients who declined to participate were excluded from our study but continued to receive standard medical care.

All participants gave informed consent before participation in the study and after explanation of the investigation and the treatment that they would receive. In accordance with the requirements of the journal's editorial policy, we hereby confirm that the study protocol for this research has been reviewed and formally approved by our Institutional Review Board prior to the commencement of the study.

Clinical Assessments

Two fellowship-trained neurologists independently evaluated patients using the HBGS (I=normal, VI=complete paralysis), demonstrating excellent inter-rater reliability. The two neurologists served as external assessors and were blinded to the MUNIX measurements during their clinical assessments. However, they were aware of the overall study hypothesis. Good recovery was defined as HBGS I–II at follow-up.[8,9] Assessments occurred at baseline, 1 month (n=40, with loss due to follow-up refusal), and 3 months (n=20, with loss due to follow-up refusal). The baseline, 1-month, and 3-month assessment time points were selected to align with the typical trajectory of recovery for this condition. The baseline assessment was essential to establish the pre-intervention status. The 1-month timepoint was chosen to capture the initial phase of recovery, where the most dynamic changes are often observed, allowing for the assessment of early efficacy or safety signals. Finally, the 3-month follow-up is a conventional and critical medium-term endpoint in neurological studies, as it is sufficient to determine whether an intervention has a sustained effect beyond the immediate post-treatment period.[10]

MUNIX

To prevent assessment bias, the technician performing all MUNIX and MUSIX measurements was blinded to the patients' clinical outcomes and HBGS outcomes throughout the study. MUNIX technique was performed according to well-described protocols.[11] Before testing, the face temperature of each participant was checked and confirmed to be maintained at approximately 32°C. The greatest stimulation of the facial nerve was applied in the anterior tragus, in front of the lower ear. The maximal CMAP was recorded bilaterally from the orbicularis oculi, zygomatic, and orbicularis oris muscles, adjusting the position of the active electrode (ie, G1 was placed on the affected side of the corresponding facial muscle and G2 on the healthy side) (Figure 2). Informed consent was obtained from the patient following the demonstration using an electrode position placement chart. The MUNIX calculations were not performed when the CMAP amplitude was < 0.5 mV. The SIP was recorded under five different forces during the muscle contractions of the tested participants (10% or slight, 25%, 50%, submaximal, and maximal contraction). At least 20 SIP recordings were obtained. The orbicularis oculi, zygomatic, and orbicularis oris muscles were activated by eye closing, mouth grinning, and mouth pouting, respectively.

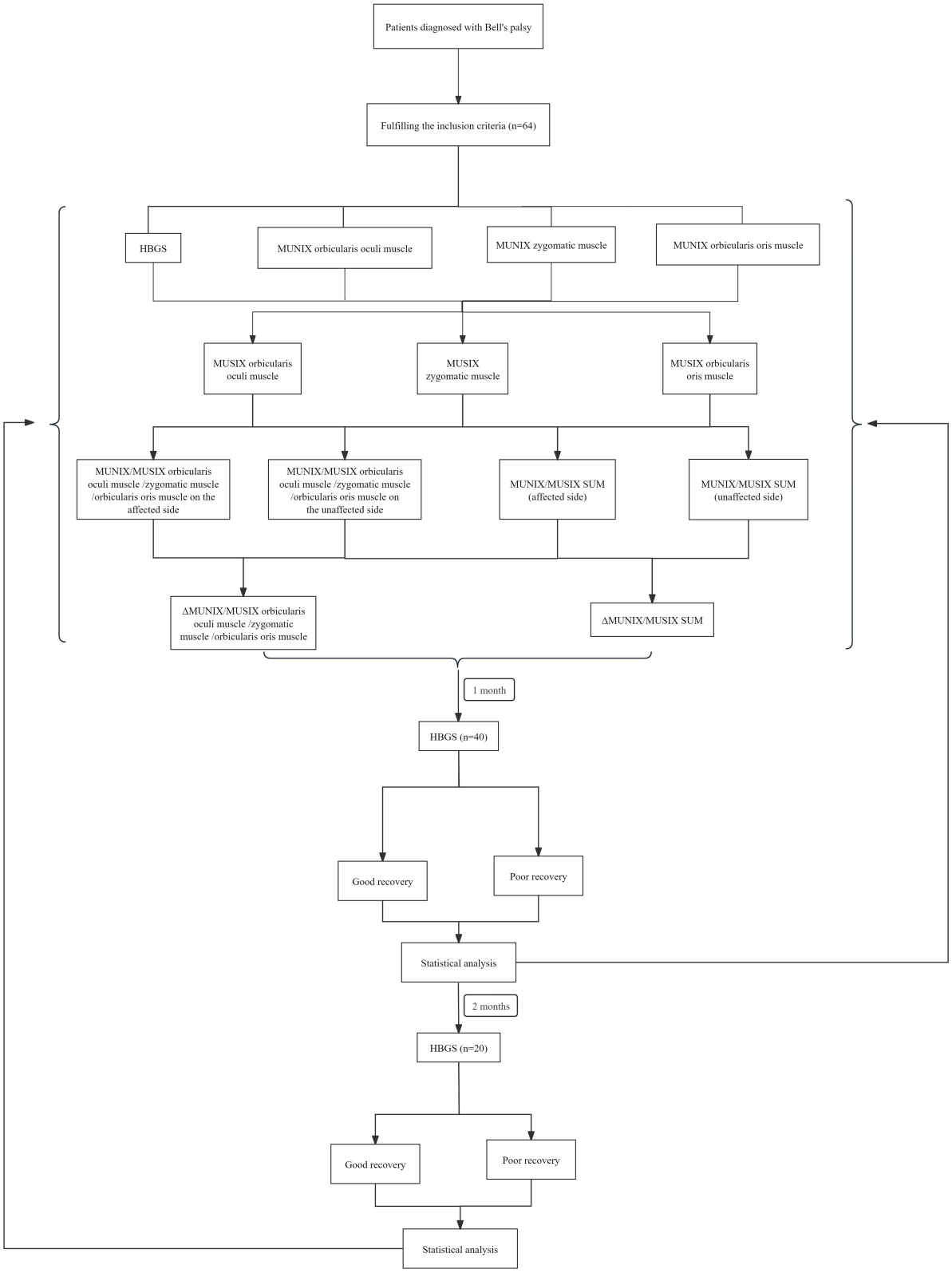

Figure 1 Flow diagram of BP cohort selection.
Abbreviation: BP, Bell's palsy.

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Figure 2 Cross-side electrode placement for bilateral maximal CMAP in facial muscles [cited from,[11] both studies were performed by Professor Feng's research group]. (**a**) The placement of the EMG G1/G2 electrodes on the orbicularis oculi muscle. (**b**) The placement of the EMG G1/G2 electrodes on the zygomatic muscle. (**c**) The placement of the EMG G1/G2 electrodes on the orbicularis oris muscle.

The data were exported to an Excel file and used to calculate the MUNIX and MUSIX values (automated analysis is shown in Figure 3). We obtained MUNIX = (CMAP × SIP area)/SIP power, MUSIX = CMAP amplitude/MUNIX, MUNIX/MUSIX orbicularis oculi muscle [a]/zygomatic muscle [a]/orbicularis oris muscle [a] = MUNIX/MUSIX orbicularis oculi muscle / zygomatic muscle /orbicularis oris muscle on the affected side, MUNIX/MUSIX orbicularis oculi muscle [b]/zygomatic muscle [b]/orbicularis oris muscle [b] = MUNIX/MUSIX orbicularis oculi muscle /zygomatic muscle /orbicularis oris muscle on the unaffected side; ΔMUNIX/MUSIX orbicularis oculi muscle /zygomatic muscle /orbicularis oris muscle = absolute value of affected-to-unaffected side MUNIX/MUSIX difference in the orbicularis oculi muscle/zygomatic muscle/orbicularis oris muscle, MUNIX/MUSIX SUM [a] = MUNIX/MUSIX orbicularis oculi muscle + MUNIX/MUSIX zygomatic muscle + MUNIX/MUSIX orbicularis oris muscle (affected side), MUNIX/MUSIX SUM [b] = MUNIX/MUSIX orbicularis oculi muscle + MUNIX/MUSIX zygomatic muscle + MUNIX/MUSIX orbicularis oris muscle (unaffected side), ΔMUNIX/MUSIX SUM = absolute value of affected-to-unaffected side difference of MUNIX/MUSIX SUM. The detailed calculation methods can be found in the Supplementary Material 1.

Statistical Analysis

All statistical analysis was performed using IBM SPSS statistical software (version 25). No a priori power analysis was performed as this study was designed as an exploratory, hypothesis-generating investigation. The sample size was determined by the number of eligible patients consecutively recruited during the defined study period. Given the exploratory nature of the multiple ROC and regression analyses performed, p-values should be interpreted with caution, and the findings require validation in future, adequately powered studies.

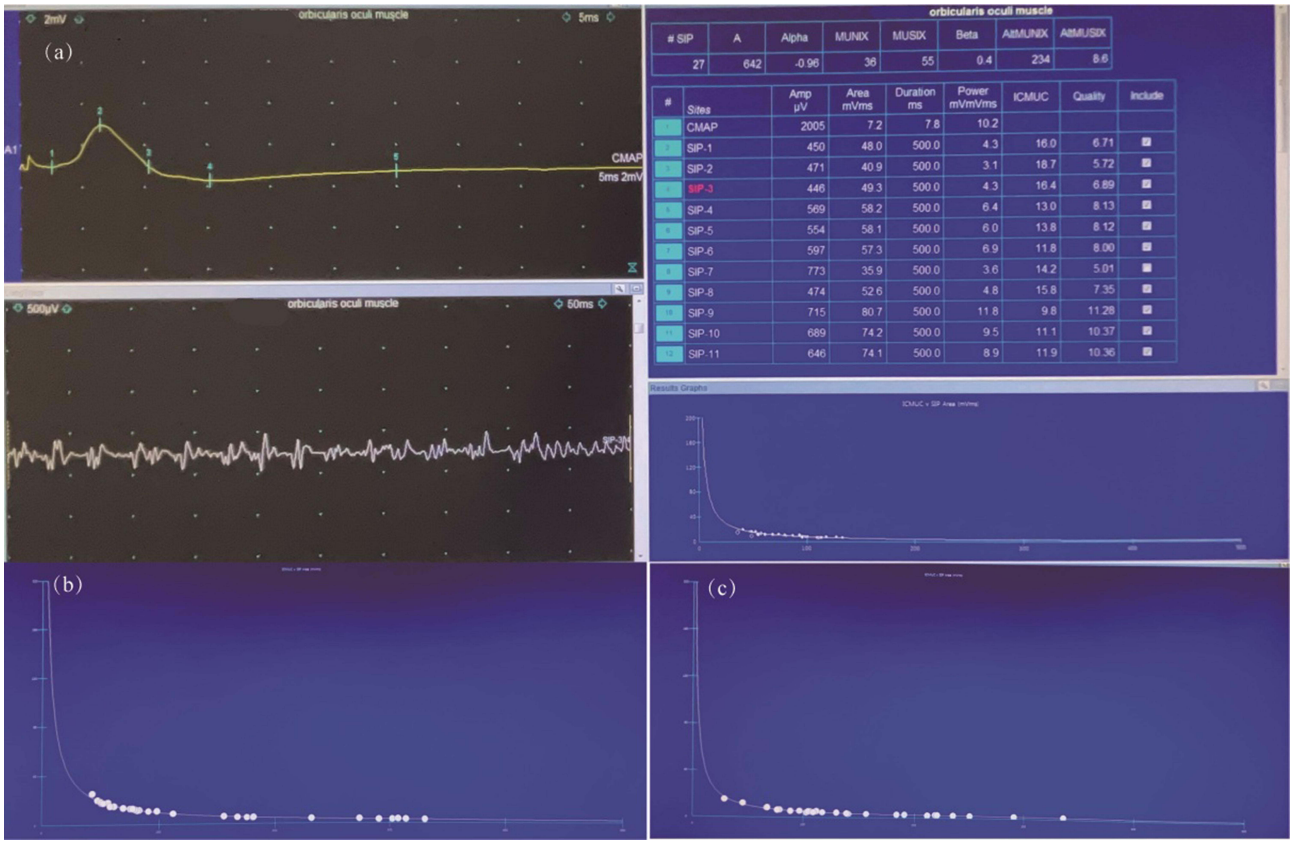

Figure 3 Calculation of MUNIX and MUSIX values: methodology and automated analysis [cited from,[11] both studies were performed by Professor Feng's research group]. Left facial nerve: (**a**) MUNIX operating page. (**b**) ICMUC v SIP Area (mV x ms) of unaffected side on the zygomatic muscle (ICMUC is the vertical coordinate and the distance of each frame is 40; SIP Area is the horizontal coordinate and the distance of each frame is 100). (**c**) ICMUC v SIP Area (mV x ms) of affected side on the zygomatic muscle. (ICMUC is the vertical coordinate and the distance of each frame is 40; SIP Area is the horizontal coordinate and the distance of each frame is 100).
Abbreviation: MUNIX, motor unit number index.

According to HBGS grade at 1-month and 3-month follow up, the patients were classified into good recovery (grade I and II) or poor recovery (grade III and IV). A favorable recovery was defined as achieving a House-Brackmann grade of I or II at follow-up. This cutoff was selected because grades I and II represent "excellent" to "good" recovery, characterized by normal or near-normal facial function with, at most, minor synkinesis. In contrast, grade III represents "fair" recovery and is frequently associated with obvious synkinesis and/or hemifacial spasm, which are considered clinically significant sequelae.[3] The primary therapeutic goal in BP management is to achieve outcomes without such sequelae, justifying the use of this dichotomization. Distribution of all variables was assessed using the Shapiro−Wilk test. Differences between groups were assessed using independent, two-tailed Student's *t*-test for parametric variables and Mann–Whitney *U*-test for nonparametric variables. If *p* value less than 0.05, it was considered significant.

The receiver operating characteristic (ROC) curves were built for ΔMUNIX orbicularis oculi muscle/ zygomatic muscle / orbicularis oris muscle, ΔMUSIX orbicularis oculi muscle, MUNIX SUM on the affected side and ΔMUNIX SUM at 1 month. They were built for ΔMUSIX orbicularis oculi muscle, ΔMUNIX zygomatic muscle, and ΔMUNIX SUM at 3 months. Finally, we conducted a linear regression analysis to define prognostic indicators of recovery at the end of the 1st and 3rd month.

Results

Demographics

64 patients were included, all patients had untreated BP within 7 days of onset. No significant differences existed in age, sex, or baseline HBGS.

MUNIX and MUSIX Values

MUNIX were performed in patients. MUNIX and MUSIX values in patients are summarized in Table 1. MUNIX values were significantly higher in unaffected side than affected side at baseline and MUSIX values were significantly lower in the unaffected side.

All muscles showed reduced MUNIX on affected sides, with zygomatic muscle both demonstrating the strongest prognostic value in 1-month and 3-month prediction ($p = 0.002$, $p = 0.002$, respectively)

ROC Curve Analysis

ROC Curve Analysis Was Used for Diagnostic Test Accuracy Studies at 1-month Interval

At the end of 1st month after the onset, 26 patients (65.0%) had good recovery, while 14 patients (35.0%) had poor recovery according to the HBGS. There was no significant association between recovery rate and demographic data as regards patients' age, sex, and side of involvement, as well as no significant association between recovery and degree of facial palsy (HBGS grade) at baseline (Table 2).

Table 3 summarizes the baseline electrophysiological data according to the clinical outcome at 1 month. The ΔMUNIX orbicularis oculi muscle and ΔMUNIX zygomatic muscle both were significantly lower in patients with good recovery compared with poor recovery patients (p =0.007 and 0.002, respectively). The ΔMUSIX orbicularis oculi muscle was significantly higher in patients with good recovery compared with poor recovery patients (p =0.008). The MUNIX SUM on the affected side, on the unaffected side, as well as the difference between these two sides were significantly different in patients with good recovery than those with poor recovery (p = 0.029, 0.02 and 0.001, respectively).

We used the preferred approach for diagnostic test accuracy studies—ROC curve analysis to analyze the ΔMUNIX orbicularis oculi muscle, ΔMUNIX zygomatic muscle, ΔMUSIX orbicularis oculi muscle, MUNIX SUM on the affected side, on the unaffected side, as well as ΔMUNIX SUM in Figure 4. The meaningful indicators for ROC curves are as follows: the ΔMUNIX orbicularis oculi muscle/ zygomatic muscle had a cutoff value of 23.5, 14 with an area under the

Table 1 Neurophysiological Data (Affected and Unaffected Facial Nerves)

Neurophysiological Parameters	Affected Side (mean ± SD)	Unaffected Side (mean ± SD)	*p* value
MUNIX orbicularis oculi muscle	17.47±8.34	45.75±25.57	< 0.001***
MUSIX orbicularis oculi muscle	77.85±44.37	57.05±24.90	0.003**
MUNIX zygomatic muscle	20.55±10.92	42.27±24.32	< 0.001***
MUSIX zygomatic muscle	73.85±28.14	58.15±31.01	0.001**
MUNIX orbicularis oris muscle	16.78±9.07	37.75±13.72	< 0.001***
MUSIX orbicularis oris muscle	72.90±37.96	57.15±19.84	0.01*
MUNIX SUM	54.80±20.90	125.78±49.50	< 0.001***
MUSIX SUM	224.60±77.08	172.35±57.39	< 0.001***

Notes: *, p <0.05; **, p <0.01, ***, p <0.001.

Table 2 Relationship Between Clinical Data at Baseline and Recovery at 1 month According to HBGS

	Good Recovery (HB Grade: I–II) (n = 26)	Poor Recovery (HB Grade: III–IV) (n = 14)	t	*p*
Age	44.35±5.77	50.36±18.94	−1.071	0.291
Gender			−0.65	0.520
Male	14	6		
Female	12	8		
Side of facial palsy			0.397	0.694
Right	11	5		
Left	15	9		
HB grade at baseline	3.04±0.72	4.07±0.73	−1.896	0.058

Table 3 Relationship Between Electrophysiological Data at Baseline and Recovery at 1 month According to HBGS

	Good Recovery (HB Grade: I–II) (n = 26)	Poor Recovery (HB Grade: III–IV) (n = 14)	t	*p* value
MUNIX orbicularis oculi muscle[a]	18.88±7.79	14.86±8.97	1.48	0.147
MUNIX orbicularis oculi muscle[b]	39.81±22.74	56.79±27.57	−2.088	0.062
ΔMUNIX orbicularis oculi muscle	21.15±20.43	41.93±25.45	−2.695	0.007**
MUSIX orbicularis oculi muscle[a]	78.27±31.54	77.07±63.18	0.08	0.094
MUSIX orbicularis oculi muscle[b]	60.69±28.20	50.29±15.96	1.271	0.145
ΔMUSIX orbicularis oculi muscle	60.65±33.67	43.86±62.73	−2.638	0.008**
MUNIX zygomatic muscle[a]	22.92±12.21	16.14±6.24	1.938	0.060
MUNIX zygomatic muscle[b]	37.42±17.63	51.29±32.28	−1.765	0.154
ΔMUNIX zygomatic muscle	14.96±13.07	35.14±29.80	−3.140	0.002**
MUSIX zygomatic muscle[a]	71.08±27.94	79.00±28.81	−0.846	0.409
MUSIX zygomatic muscle[b]	62.96±37.12	49.21±10.17	1.351	0.087
ΔMUSIX zygomatic muscle	19.88±17.51	31.64±22.22	−1.842	0.101
MUNIX orbicularis oris muscle[a]	18.23±9.20	35.42±12.02	1.401	0.162
MUNIX orbicularis oris muscle[b]	17.27±9.91	69.81±35.66	−1.484	0.188
ΔMUNIX orbicularis oris muscle	17.27±9.91	28.00±16.78	−1.930	0.054
MUSIX orbicularis oris muscle[a]	14.07±8.47	42.07±16.00	−0.698	0.516
MUSIX orbicularis oris muscle[b]	28.00±16.78	78.64±42.68	0.749	0.369
ΔMUSIX orbicularis oris muscle	53.93±11.22	32.00±33.98	−0.886	0.411
MUNIX SUM[a]	60.04±22.96	45.07±11.80	2.273	0.029*
MUNIX SUM[b]	112.65±37.66	150.14±60.34	−2.423	0.020*
ΔMUNIX SUM	52.62±34.18	105.07±57.95	−3.614	0.001**
MUSIX SUM[a]	219.15±67.20	234.71±94.71	−0.604	0.592
MUSIX SUM[b]	182.54±67.85	153.43±20.81	1.558	0.128
ΔMUSIX SUM	59.08±50.82	85.86±79.83	−1.007	0.314

Notes: *, $p < 0.05$; **, $p < 0.01$.

Abbreviations: MUNIX/MUSIX orbicularis oculi muscle [a]/zygomatic muscle [a]/orbicularis oris muscle [a], MUNIX/MUSIX orbicularis oculi muscle /zygomatic muscle / orbicularis oris muscle on the affected side; MUNIX/MUSIX orbicularis oculi muscle [b]/zygomatic muscle [b]/orbicularis oris muscle [b], MUNIX/MUSIX orbicularis oculi muscle / zygomatic muscle /orbicularis oris muscle on the unaffected side; ΔMUNIX/MUSIX orbicularis oculi muscle /zygomatic muscle /orbicularis oris muscle, absolute value of affected-to-unaffected side MUNIX/MUSIX difference in the orbicularis oculi muscle/zygomatic muscle/orbicularis oris muscle; MUNIX/MUSIX SUM [a], = MUNIX/MUSIX orbicularis oculi muscle + MUNIX/MUSIX zygomatic muscle + MUNIX/MUSIX orbicularis oris muscle (affected side); MUNIX/MUSIX SUM [b], = MUNIX/MUSIX orbicularis oculi muscle + MUNIX/MUSIX zygomatic muscle + MUNIX/MUSIX orbicularis oris muscle (unaffected side); ΔMUNIX/MUSIX SUM, absolute value of affected-to-unaffected side difference of MUNIX/MUSIX SUM.

curve of 0.761 ($p = 0.007$; 95% CI: 0.604–0.918), 0.804 ($p = 0.002$; 95% CI: 0.667–0.940), respectively. The cutoff value of ΔMUNIX SUM was 85.5 with an area under the curve of 0.819 ($p = 0.001$; 95% CI = 0.681–0.957). Patients who had side difference of MUNIX SUM < 85.5 (33 cases) had a higher percent of good recovery (73.68% versus 26.32% of poor recovery), while patients who had facial nerve excitability or side difference > 85.5 (9 cases) had 11.11% of good recovery versus 88.89% of poor recovery ($p < 0.001$).

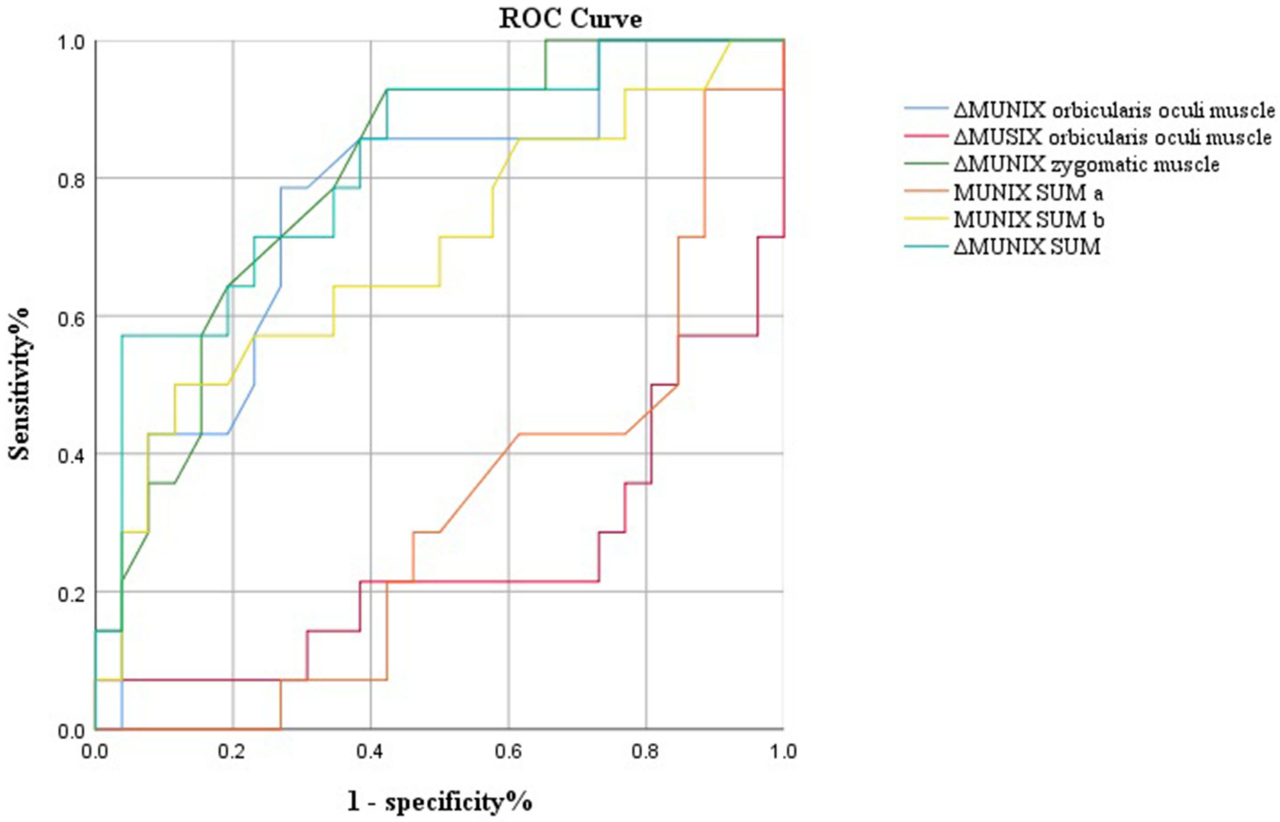

Figure 4 ROC curve analysis was used for testing prognostic validity after 1 month of BP.
Abbreviations: ROC, receiver operating characteristic; ΔMUNIX/MUSIX orbicularis oculi muscle /zygomatic muscle, absolute value of affected-to-unaffected side MUNIX/MUSIX difference in the orbicularis oculi muscle/zygomatic muscle; MUNIX SUM [a], = MUNIX orbicularis oculi muscle + MUNIX zygomatic muscle + MUNIX orbicularis oris muscle (affected side); MUNIX SUM [b], = MUNIX orbicularis oculi muscle + MUNIX zygomatic muscle + MUNIX orbicularis oris muscle (unaffected side); ΔMUNIX SUM, absolute value of affected-to-unaffected side difference of MUNIX SUM; BP, Bell's palsy.

ROC Curve Analysis Was Used for Diagnostic Test Accuracy Studies at 3-month Interval

At the end of the third month after the onset of the illness, 20 patients were followed up. During the three-month follow-up period, a number of participants were lost to follow-up. The primary reasons for attrition included: loss of contact after initial hospital discharge, relocation to another city, and inability to attend scheduled follow-up appointments due to work commitments. According to the HBGS criteria, 15 patients (75.0%) had good recovery, while 5 patients (25.0%) had poor recovery. Table 4 summarizes the baseline electrophysiological data according to the clinical outcome at 3 months. The MUNIX zygomatic muscle as well as the MUNIX SUM difference between sides were significantly lower in patients with good recovery than those with poor recovery ($p = 0.002$ and 0.042, respectively). The ΔMUSIX orbicularis oculi muscle was significantly higher in patients with good recovery compared with poor recovery patients ($p = 0.03$).

We used the preferred approach for diagnostic test accuracy studies—ROC curve analysis to analyze the ΔMUNIX zygomatic muscle, ΔMUNIX SUM, and ΔMUSIX orbicularis oculi muscle in Figure 5. The meaningful indicators for ROC curves are as follows: a critical cutoff value of ΔMUNIX zygomatic muscle was considered for poor-recovery at 3rd month follow up with an area under the curve of 0.893 ($p = 0.01$; 95% CI: 0.748–1.000). Patients with ΔMUNIX zygomatic muscle < 16 (11 cases) had a higher percent of good recovery (100.0% versus 0% of poor recovery), while patients with ΔMUNIX zygomatic muscle > 16 (9 cases) had 44.4% of good recovery versus 55.6% of poor recovery ($p < 0.001$). The same result was observed for ΔMUNIX SUM recordings (cutoff value of degeneration rate > 50%) with an area under the curve of 0.8 ($p = 0.05$; 95% CI: 0.593–1.000).

Table 4 Relationship Between Electrophysiological Data at Baseline and Recovery at 3 months According to HBGS

	Good Recovery (HB Grade: I–II) (n = 15)	Poor Recovery (HB Grade: III–IV) (n = 5)	*t*	*p* value
MUNIX orbicularis oculi muscle[a]	16.07±1.77	16.80±4.59	−0.149	0.887
MUNIX orbicularis oculi muscle[b]	31.93±3.49	49.40±10.64	−2.067	0.053
ΔMUNIX orbicularis oculi muscle	15.87±2.89	32.60±9.07	−1.758	0.141
MUSIX orbicularis oculi muscle[a]	84.93±9.67	59.20±2.15	1.506	0.149
MUSIX orbicularis oculi muscle[b]	66.87±7.00	51.80±6.14	1.618	0.128
ΔMUSIX orbicularis oculi muscle	69.07±9.66	28.20±6.51	2.348	0.030*
MUNIX zygomatic muscle[a]	21.07±11.06	12.40±4.22	−1.841	0.066
MUNIX zygomatic muscle[b]	31.47±3.09	34.80±2.96	−0.780	0.450
ΔMUNIX zygomatic muscle	11.20±2.13	22.40±1.94	−3.893	0.002**
MUSIX zygomatic muscle[a]	77.27±8.27	93.40±18.32	−0.803	0.454
MUSIX zygomatic muscle[b]	70.13±11.53	53.20±4.45	1.370	0.188
ΔMUSIX zygomatic muscle	25.40±5.39	40.20±13.97	−0.988	0.366
MUNIX orbicularis oris muscle[a]	19.53±1.98	16.00±4.32	0.743	0.487
MUNIX orbicularis oris muscle[b]	39.33±3.09	34.40±5.64	0.766	0.470
ΔMUNIX orbicularis oris muscle	19.93±2.91	18.40±5.45	0.248	0.812
MUSIX orbicularis oris muscle[a]	58.07±4.69	60.40±6.34	−0.296	0.774
MUSIX orbicularis oris muscle[b]	54.87±3.39	54.80±6.05	0.010	0.993
ΔMUSIX orbicularis oris muscle	16.27±2.69	9.20±1.24	1.474	0.158
MUNIX SUM[a]	56.67±5.03	45.20±6.57	1.386	0.199
MUNIX SUM[b]	102.73±7.11	118.60±13.90	−1.016	0.347
ΔMUNIX SUM	46.07±6.14	73.40±11.41	−2.191	0.042*
MUSIX SUM[a]	220.27±19.52	213.00±23.83	0.236	0.818
MUSIX SUM[b]	191.87±17.67	159.80±6.41	1.706	0.106
ΔMUSIX SUM	51.33±49.12	53.20±43.78	−0.568	0.570

Notes: *, p <0.05; **, p <0.01.

Abbreviations: MUNIX/MUSIX orbicularis oculi muscle[a]/zygomatic muscle[a]/orbicularis oris muscle[a], MUNIX/MUSIX orbicularis oculi muscle /zygomatic muscle /orbicularis oris muscle on the affected side; MUNIX/MUSIX orbicularis oculi muscle[b]/zygomatic muscle[b]/orbicularis oris muscle[b], MUNIX/MUSIX orbicularis oculi muscle / zygomatic muscle /orbicularis oris muscle on the unaffected side; ΔMUNIX/MUSIX orbicularis oculi muscle /zygomatic muscle /orbicularis oris muscle, absolute value of affected-to-unaffected side MUNIX/MUSIX difference in the orbicularis oculi muscle/zygomatic muscle/orbicularis oris muscle; MUNIX/MUSIX SUM[a], = MUNIX/MUSIX orbicularis oculi muscle + MUNIX/MUSIX zygomatic muscle + MUNIX/MUSIX orbicularis oris muscle (affected side); MUNIX/MUSIX SUM[b], = MUNIX/MUSIX orbicularis oculi muscle + MUNIX/MUSIX zygomatic muscle + MUNIX/MUSIX orbicularis oris muscle (unaffected side); ΔMUNIX/MUSIX SUM, absolute value of affected-to-unaffected side difference of MUNIX/MUSIX SUM.

Correlations Between MUNIX and Clinical Assessments

ΔMUNIX orbicularis oculi muscle: positively correlated with HBGS scores 1 month later (r = 0.474, p = 0.002)
ΔMUNIX zygomatic muscle: positively correlated with HBGS scores1 month later (r = 0.511, p = 0.001)
ΔMUNIX SUM: positively correlated with HBGS scores 1 month later (r = 0.526, p < 0.001)
ΔMUNIX zygomatic muscle: positively correlated with HBGS scores 3 months later (r = 0.592, p =0.006)
According to ROC curve and Pearson correlation analysis, the best predictive indicator of 1-month poor recovery was the ΔMUNIX zygomatic muscle > 14 (p = 0.001), and for 3 months, it is ΔMUNIX zygomatic muscle > 16 (p = 0.006).

Discussion

There are a variety of clinical predictors for BP prognosis;[4,12] nevertheless, effective and noninvasive predictive factors are still lacking at present. Our prior research has revealed that in patients with BP, there is a notable decline in the MUNIX values of individual muscles and the MUNIX SUM values on the affected side when compared to the healthy side. Moreover, the diminished MUNIX SUM values were found to be associated with the clinical assessment scales used for patients with BP, clearly demonstrating a significant correlation between the MUNIX SUM values and the extent of facial nerve damage. Subsequently, the present study demonstrates that MUNIX, particularly when measured in the zygomatic muscle within 3–7 days of BP onset, serves as a reliable and noninvasive prognostic biomarker. Our findings

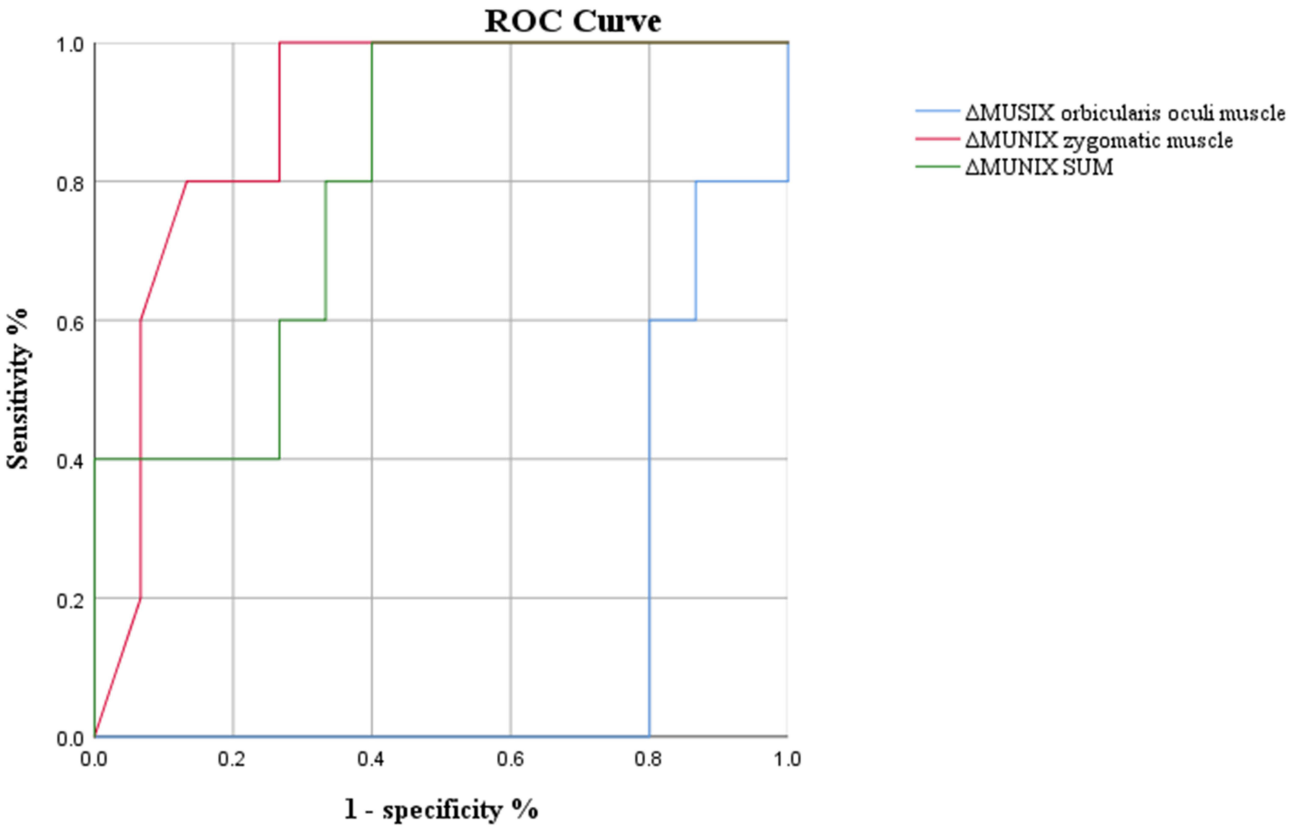

Figure 5 ROC curve analysis was used for testing prognostic validity after 3 months of BP.
Abbreviations: ROC, receiver operating characteristic; ΔMUNIX/MUSIX orbicularis oculi muscle /zygomatic muscle, absolute value of affected-to-unaffected side MUNIX/MUSIX difference in the orbicularis oculi muscle/zygomatic muscle; MUNIX SUM [a], = MUNIX orbicularis oculi muscle + MUNIX zygomatic muscle + MUNIX orbicularis oris muscle (affected side); MUNIX SUM [b], = MUNIX orbicularis oculi muscle + MUNIX zygomatic muscle + MUNIX orbicularis oris muscle (unaffected side); ΔMUNIX SUM, absolute value of affected-to-unaffected side difference of MUNIX SUM; BP, Bell's palsy.

reveal that the difference in MUNIX values between affected and unaffected sides (ΔMUNIX zygomatic muscle) strongly correlates with clinical recovery at both 1-month and 3-month follow-ups. Specifically, a ΔMUNIX zygomatic muscle >14 at baseline predicted poor recovery (HBGS III–IV) with an AUC of 0.804 (95% CI: 0.667–0.940), demonstrating good discriminatory power (sensitivity: 85%, specificity: 79%). By 3 months, a ΔMUNIX zygomatic muscle >16 further refined prognostic accuracy (AUC = 0.893, 95% CI: 0.748–1.000), highlighting its potential for long-term outcome prediction.

These results hold significant clinical implications. Unlike conventional electroneurography (ENoG), which requires precise timing (48–72 hours post-onset) and is often uncomfortable for patients, MUNIX offers a practical alternative with several advantages: (1) it can be performed within a broader therapeutic window (3–7 days), (2) it is painless and quick (<5 minutes per muscle), and (3) it provides quantitative data on functional motor unit loss. The zygomatic muscle emerged as the most prognostically relevant, likely due to its anatomical representation of the midface—a region where persistent weakness leads to noticeable functional and cosmetic deficits. Therefore, MUNIX is a useful prognostic evaluation parameter in predicting 1-month or 3-month outcome, breaking the previous dilemma where there was no objective and noninvasive electrophysiological evidence available for evaluating the short-term prognosis of patients. Since the diagnostic accuracy is affected by different degrees of intra-observer and inter-observer variability, future relevant research still needs to be improved to provide guidance for early clinical intervention and prognosis judgment.

In the present study, good recovery was observed in 15 (75.0%) patients while 5 patients (25.0%) had poor recovery. Similar results were seen by Peitersen, who found that about 70% of patients recovered completely within 3 months after the onset of BP.[2] Our study also introduces clinically actionable thresholds. Patients with ΔMUNIX zygomatic muscle >16 at baseline may benefit from early treatment intensification, such as extended corticosteroid regimens or adjuvant

therapies, while those below this cutoff could be reassured of a favorable prognosis. Furthermore, serial MUNIX assessments could objectively track recovery progression, addressing a critical gap in current BP management, which relies heavily on subjective grading scales.

Several limitations warrant consideration. First, not only as a single-center design and recruitment from a single ethnic population, but the relatively high attrition rate, particularly at the 3-month follow-up (n=20), may introduce attrition bias and affect the generalizability of the long-term findings. The 3-month results should be interpreted with caution and that future studies with larger, retained cohorts are needed for validation. While a formal sensitivity analysis was not feasible due to the lack of outcome data for dropouts, we acknowledge that this may affect the generalizability and long-term validity of our findings. Future studies with strategies to improve participant retention are needed. Second, while our electrode placement followed standardized protocols, future studies should validate these findings across different EMG systems and operators. Thirdly, a limitation of this study is the lack of an a priori power analysis. As an exploratory investigation, the sample size was not predetermined based on a specific effect size, which may affect the reliability of the finding. Therefore, the results, especially from the regression analyses, should be interpreted as generating hypotheses for future validation in larger, adequately powered studies. Finally, further research is needed to explore the relationship between early MUNIX values and long-term complications, such as synkinesis.

In conclusion, this study establishes ΔMUNIX zygomatic muscle as a sensitive and specific prognostic tool for BP, offering objective data to guide early therapeutic decision-making. Its noninvasive nature, combined with strong predictive accuracy, positions MUNIX as a viable alternative to traditional electrophysiological tests. To our knowledge, our study is the first to investigate the prognostic utility of MUNIX in BP, and consequently, the specific ΔMUNIX zygomatic muscle cutoffs (1 month >14, 3 months >16) identified for predicting recovery are novel findings. Direct comparison with existing literature is not currently possible, as no prior studies have established similar threshold values in this patient population, underscores the exploratory nature of our work. Multicenter validation studies are now needed to confirm these findings and refine cutoff values for widespread clinical adoption.

Conclusion

Zygomatic muscle MUNIX difference measured 3–7 days post-onset represents a sensitive, specific prognostic biomarker for BP. This technique provides clinicians with an objective tool for early risk stratification and personalized treatment planning. The proposed ΔMUNIX cut-offs show potential for practical integration into clinical pathways as an early objective test to identify high-risk patients who may benefit from more intensive monitoring or adjunctive therapies. Implementation in clinical practice could significantly improve outcomes for the 30% of patients at risk for poor recovery.

Project Number and IRB Approval Number

YCLX202331 and 24039-0-02.

Compliance with Declaration of Helsinki

This prospective study was conducted in accordance with the ethical principles of the Declaration of Helsinki. In accordance with the requirements of the journal's editorial policy, we hereby confirm that the study protocol for this research has been reviewed and formally approved by our Institutional Review Board prior to the commencement of the study, and all patient data were de-identified prior to analysis to ensure confidentiality. The study protocol maintains compliance with all relevant components of the Declaration, including protection of patient privacy through strict data anonymization, exclusion of vulnerable populations, adherence to principles of scientific integrity and data transparency. No treatment interventions were modified for research purposes, and all clinical management decisions were made independently of this evaluation.

Written Consent for Publication

Written informed consent for publication of data was obtained from all participants included in the study. The participants grant permission for their information being used in this publication and potentially in future editions and reprints of the work.

Abbreviations

BP, Bell's palsy; VZV, varicella-zoster virus; HBGS, House–Brackmann Grading System; SFGS, Sunnybrook Facial Grading System; ENoG, electroneurography; nEMG, needle electromyography; nENoG, needle electroneurography; MUNIX, motor unit number index; CMAP, compound muscle action potential; sEMG, surface EMG; SIP, interference pattern; MUNIX/MUSIX orbicularis oculi muscle [a]/zygomatic muscle [a]/orbicularis oris muscle [a], MUNIX/MUSIX orbicularis oculi muscle /zygomatic muscle /orbicularis oris muscle on the affected side; MUNIX/MUSIX orbicularis oculi muscle [b]/zygomatic muscle [b]/orbicularis oris muscle [b], MUNIX/MUSIX orbicularis oculi muscle /zygomatic muscle /orbicularis oris muscle on the unaffected side; ΔMUNIX/MUSIX orbicularis oculi muscle /zygomatic muscle /orbicularis oris muscle, absolute value of affected-to-unaffected side MUNIX/MUSIX difference in the orbicularis oculi muscle/zygomatic muscle/orbicularis oris muscle; MUNIX/MUSIX SUM [a], = MUNIX/MUSIX orbicularis oculi muscle + MUNIX/MUSIX zygomatic muscle + MUNIX/MUSIX orbicularis oris muscle (affected side); MUNIX/MUSIX SUM [b], = MUNIX/MUSIX orbicularis oculi muscle + MUNIX/MUSIX zygomatic muscle + MUNIX/MUSIX orbicularis oris muscle (unaffected side); ΔMUNIX/MUSIX SUM, absolute value of affected-to-unaffected side difference of MUNIX/MUSIX SUM; ROC, receiver operating characteristic.

Data Sharing Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Ethics Approval

All enrolled patients provided written, informed consent to be included in the study. All methods were performed in accordance with the relevant guidelines and regulations.

Consent to Participate

Informed consent was obtained from all individual participants included in the study. We are grateful to all study participants and their family. We confirm that written informed consent for the publication of Figures has been provided by the patient.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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