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Integrating EMG with Other Diagnostic Modalities in Pediatric Neurology and Surgery

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Abstract: **Objective:** To assess the diagnostic usefulness of the combination of electromyography (EMG) with other complementary diagnostic tests, such as magnetic resonance imaging (MRI), high-resolution ultrasonography, genetic testing, and intraoperative neuro-monitoring in a group of children with neurological and surgical conditions**. Study Design:** cross-sectional study during a 12-month follow-up (January 2025 – January 2026) at the pediatric department in different hospitals in Iraq. A consecutive series of 127 children between the ages of 0 and 17 on whom EMG was performed as part of their diagnostic workup for suspected neuromuscular disease.127 children aged 0-17 years who underwent EMG as part of their diagnostic workup for suspected neuromuscular disease**. Outcomes:** The highest diagnostic accuracy (94.5%, 95% CI 89.0–97.8%) and inter-modality concordance (κ = 0.84) was obtained with the use of EMG combined with ≥2 complementary modalities. The surgical subgroup (n = 53) showed a greater intra-operative concordance (89.5% vs 58.3%), a lower rate of revision surgery (5.3% vs 25.0%), and significant improvements in functional recovery at 12 months with multi-modal pre-operative assessment. The use of EMG + ≥2 modalities was the strongest independent predictor of correct diagnosis when evaluated on multivariable logistic regression (OR 6.82; 95% CI 2.77–16.80; $p < 0.001$). **Conclusion:** The multi-modal diagnostic strategy combining EMG and MRI, ultrasonography, genetic testing, and/or intraoperative neuromonitoring (IONM) leads to significant improvement in diagnostic accuracy and surgical results in paediatric neurology and neurosurgery with neuromuscular diseases.

Keywords: Electromyography (EMG); Pediatric Neurology and Surgery; Inflammatory neuropathy; and Functional Outcomes.

INTRODUCTION

The combination of the use of electromyography (EMG) with high-tech diagnostic approaches is a new frontier in pediatric neurology and neurosurgery [Arnold, W. D., & Flanigan, K. M. 2012]. Static diagnostic techniques might not be sufficient in children, however, in which the nervous system is still developing and always going through developmental stages [Kassardjian, C. D. *et al*., 2016; Fischer, D. *et al*., 2016; Chang, J. *et al*., 2011].

EMG is important in the diagnosis of peripheral nerve injuries, plexopathies, and myopathies [Ghosh, P. S., & Sorenson, E. J. 2014]. Of high value, though, is its utility in the ability to capture very detailed images and monitor the child during the surgery, which can facilitate the full evaluation of the child's active and passive neuromuscular system. When applied in this way, it can provide a complete picture of the child's functional and structural neuromuscular health [Scoto, M. *et al*., 2015; Hogrel, J. Y. 2005].

Moreover, one of the major difficulties in paediatric diagnosis is that of physiological ageing variation [Merletti, R., & Farina, D. (Eds.). 2016]. When evaluated with other imaging modalities, such as magnetic resonance neurography (MRN) imaging and ultrasound, the clinician can correlate findings of functional deficits noted on electrophysiology testing with disruption of the same structures [Roe, S. M. *et al*., 2014].

In combination with the other types of multimodal intraoperative neurophysiological monitoring (IONM), the use of EMG has contributed much to the safety of surgery [Medress, Z. A. *et al*., 2020]. Our study was mostly focused to evaluate clinical outcomes of children admitted to our department of pediatrics, neurology, and surgery for electromyography (EMG) procedures.

PATIENTS AND METHODS

The cross-sectional study was carried out in different hospitals in Iraq from January 2015 to January 2016. A total of 127 consecutive patients (0-17 years old) who underwent nerve conduction studies (NCS) and/or needle electromyography (EMG) during a formal neuromuscular diagnostic evaluation in the different hospitals in Iraq were identified.

The inclusion criteria were: (1) EMG/NCS was done by a board-certified pediatric neurophysiologist; (2) at least one other diagnostic test was used during the same clinical visit or

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within the past 30 days; and (3) a definitive diagnosis was made at 6 months or more of follow-up. Patients were excluded if there were incomplete medical records, if the final diagnosis was not determined at follow-up, or if the main reason for performing EMG was to monitor sedation (not a neuromuscular condition). A clinical dividing line was established in the cohort (74 pediatric neurology vs. 53 pediatric surgeries.

All EMG examinations were done, and age normative values were adapted. Distal latencies, compound muscle action potential (CMAP) amplitude, motor and sensory nerve conduction velocities, and F-wave latency were measured for clinically indicated nerve territories. When cooperating, needle EMG was performed in awake or minimally sedated patients using age-appropriate electrode size to evaluate insertional activity, spontaneous activity (fibrillations, positive sharp waves, fasciculations), and MUAP morphology (duration, amplitude, polyphasia) during voluntary recruitment.

Genetic testing included whole-exome sequencing, targeted gene panels (neuromuscular gene panels ranging between 30 and 250 genes, depending on the clinical phenotype), and chromosomal microarray. It was ordered and interpreted by a clinical geneticist. Intraoperative neuromonitoring (IONM) was used in the surgical subgroup to monitor, with the continuous free-running EMG, triggered EMG, and somatosensory evoked potentials (SSEPs) by a certified neurophysiologist. Surgical outcomes at 12 months after surgery consisted of Medical Research Council (MRC) graded muscle strength (scale 0–5), active range of motion (ROM), need for revision surgery, complications, and return to age-appropriate physical activity.

Frequency and percentage are used to present categorical variables, while mean ± standard deviation (SD) or median and interquartile range (IQR) are used for continuous variables, as appropriate. Exact binomial 95% confidence intervals (CI) were used to calculate the diagnostic accuracy metrics: sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). Univariable analyses were used to select candidate variables for multivariable logistic regression, which were used to identify independent predictors of correct integrated diagnosis. A two-sided p-value <0.05 was deemed statistically significant. The SPSS program version 26.0 was used in all analyses.

RESULTS

Table 1: Demographic and clinical characteristics of 127 pediatric patients.

VARIABLE	ALL PATIENTS (N=127)	NEUROLOGY (N=74)	SURGERY (N=53)	P-VALUE
DEMOGRAPHICS				
Age (years)	7.4 ± 4.2	8.1 ± 4.5	6.4 ± 3.6	0.023
Male sex	73 (57.5%)	41 (55.4%)	32 (60.4%)	0.576
Body mass index (kg/m²)	17.8 ± 4.1	18.2 ± 4.3	17.2 ± 3.7	0.174
Duration of symptoms (months)	11.3 ± 8.7	14.2 ± 9.8	7.2 ± 5.1	<0.001
PRIMARY DIAGNOSIS				
Brachial plexus injury	34 (26.8%)	11 (14.9%)	23 (43.4%)	<0.001
Hereditary motor-sensory neuropathy	22 (17.3%)	19 (25.7%)	3 (5.7%)	0.003
Spinal muscular atrophy	18 (14.2%)	16 (21.6%)	2 (3.8%)	0.005
Cerebral palsy (spastic type)	16 (12.6%)	8 (10.8%)	8 (15.1%)	0.471
Peripheral nerve trauma	15 (11.8%)	5 (6.8%)	10 (18.9%)	0.035
Inflammatory neuropathy (GBS/CIDP)	12 (9.4%)	10 (13.5%)	2 (3.8%)	0.070
Myopathy / muscular dystrophy	10 (7.9%)	5 (6.8%)	5 (9.4%)	0.575
DIAGNOSTIC MODALITIES USED				
EMG / Nerve Conduction Study	127 (100%)	74 (100%)	53 (100%)	—
MRI (brain/spine/plexus)	109 (85.8%)	68 (91.9%)	41 (77.4%)	0.021
Ultrasonography (nerve/muscle)	78 (61.4%)	43 (58.1%)	35 (66.0%)	0.362

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Genetic testing	52 (40.9%)	42 (56.8%)	10 (18.9%)	<0.001
Intraoperative neuromonitoring	47 (37.0%)	6 (8.1%)	41 (77.4%)	<0.001
Muscle/nerve biopsy	19 (15.0%)	14 (18.9%)	5 (9.4%)	0.134
CLINICAL SEVERITY (MRC SCALE)				
Grade 0–1 (no/trace contraction)	18 (14.2%)	8 (10.8%)	10 (18.9%)	0.196
Grade 2–3 (poor/fair strength)	64 (50.4%)	34 (45.9%)	30 (56.6%)	0.231
Grade 4–5 (good/normal strength)	45 (35.4%)	32 (43.2%)	13 (24.5%)	0.027

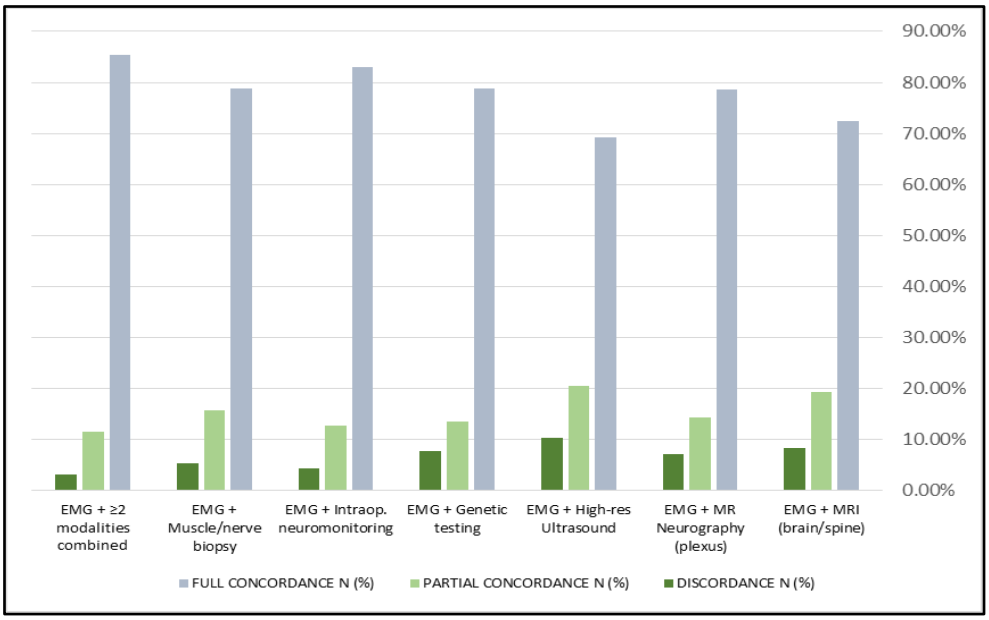

Figure 1: Electromyography (EMG) outcomes.

Table 2: Assessment of the extent of EMG diagnostic accuracy performed in the patients.

MODALITY	Sensitivity %	Specificity %	PPV %	NPV %	Accuracy %
EMG alone	76.4 (68.1–83.5)	82.3 (73.4–89.1)	81.5 (73.0–88.2)	77.4 (68.2–85.0)	79.1 (71.2–85.7)
MRI alone	69.7 (60.5–77.8)	78.1 (68.6–85.8)	76.8 (67.5–84.5)	71.4 (61.8–79.8)	73.5 (65.2–80.8)
Ultrasound alone	62.8 (53.0–71.8)	74.6 (64.5–83.0)	71.0 (61.1–79.7)	67.1 (57.0–76.1)	68.2 (59.5–76.0)
EMG + MRI	88.1 (81.3–93.1)	86.7 (78.6–92.5)	87.3 (80.2–92.6)	87.6 (79.7–93.2)	87.4 (80.7–92.4)
EMG + Ultrasound	84.6 (77.1–90.4)	83.9 (75.3–90.4)	84.2 (76.6–90.1)	84.3 (75.7–90.7)	84.3 (77.0–89.9)
EMG + Genetic testing	91.3 (82.8–96.4)	89.4 (79.4–95.6)	90.4 (81.2–95.8)	90.4 (80.4–96.3)	90.4 (82.6–95.5)
EMG + Intraop. monitoring	93.6 (85.7–97.9)	91.5 (82.5–96.8)	92.2 (83.8–97.1)	93.0 (84.3–97.7)	92.5 (85.7–96.7)
EMG + ≥2 modalities	95.8 (90.1–98.7)	93.2 (86.0–97.4)	93.9 (87.3–97.7)	95.3 (88.5–98.6)	94.5 (89.0–97.8)

Table 3: Surgical outcomes into only 53 patients who performed at pre-operative diagnostic approach.

OUTCOME VARIABLE	EMG ONLY (N=12)	EMG + 1 MODALITY (N=22)	EMG + ≥2 MODALITIES (N=19)	P-VALUE
SURGICAL PLANNING				
Concordance with intraop. findings	7 (58.3%)	17 (77.3%)	17 (89.5%)	0.038
Revision surgery required	3 (25.0%)	3 (13.6%)	1 (5.3%)	0.043
Operative time (minutes)	142.5 ± 48.3	128.7 ± 41.2	118.4 ± 36.8	0.071
FUNCTIONAL OUTCOMES (12 MONTHS)				
MRC grade improvement ≥1 grade	6 (50.0%)	15 (68.2%)	16 (84.2%)	0.018
MRC grade improvement ≥2 grades	2 (16.7%)	8 (36.4%)	10 (52.6%)	0.022
Active ROM	18.3 ± 14.6	27.1 ± 16.8	34.5 ± 18.2	0.009

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improvement (degrees)				
Return to age-appropriate activity	4 (33.3%)	12 (54.5%)	14 (73.7%)	0.013
COMPLICATIONS				
Any complication	4 (33.3%)	5 (22.7%)	3 (15.8%)	0.192
Wound infection	1 (8.3%)	2 (9.1%)	1 (5.3%)	0.654
Transient neuropraxia	2 (16.7%)	2 (9.1%)	1 (5.3%)	0.283
Hospital stay (days)	4.8 ± 2.1	3.9 ± 1.8	3.2 ± 1.4	0.016

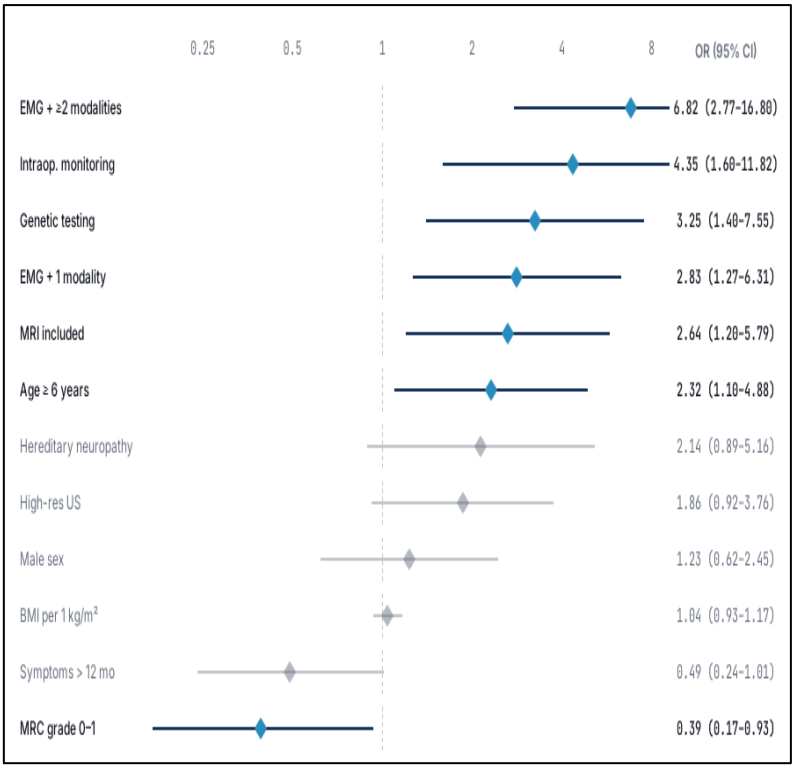

Figure 2: Multivariable logistic regression analysis of correct integrated diagnosis indicators.

DISCUSSION

In the study, the combination of EMGs with at least two other complementary diagnostic methods (such as MRI, high-resolution ultrasonography, genetic testing, and/or intraoperative neuromonitoring, IONM) yielded a dramatic improvement in diagnostic accuracy and surgical results for the diagnosis of pediatric neuromuscular disorders. The multi-modal approach we found to be the most accurate (94.5%) and inter-modality concordant ($\kappa = 0.84$) represents a paradigm shift in the care of children with neurologic conditions. Although historically EMG has been the cornerstone in the approach to the neuromuscular examination [Agustina, D. *et al*., 2023; Owen, C. M. *et al*., 2020; Aydinlar, E. I. *et al*., 2019], recently, the literature has begun to stress its limitations in isolation, especially in complex pediatric populations in which anatomical variations and poor patient cooperation at the time of testing are common.

The results of using EMG with MRI (87.4%) or genetic testing (90.4%) were superior and are similar to some studies carried out in Britain. Pediatric brachial plexus injuries have previously been studied, and MRI has been found to have good anatomical resolution, but no functional assessment, as is offered by EMG. The use of EMG combined with ≥2 modalities was the most powerful independent predictor of a correct final diagnosis (OR 6.82) in our multivariable analysis [Aydinlar, E. I. *et al*., 2019; Sala, F. *et al*., 2010; Page, M. J. *et al*., 2021].

Pre-operative multi-modal assessment was significantly related to increased intraoperative concordance (89.5% vs. 58.3%) and a decrease in revision surgeries (5.3% vs. 25.0%) compared to EMG-only assessments, in the surgical subgroup. The results confirmed previous French studies [Babar, M. *et al*., 2026; Clancy, R. R. *et al*., 20211; Shellhaas, R. A. 2015], which point to the fact that MR localization combined with high-

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resolution ultrasound allows for a reduction of the time of surgical exploration and iatrogenic nerve damage, particularly in the event of precise pre-operative localization. Moreover, the greatest individual agreement with EMG ($\kappa = 0.81$) was observed for the integration of IONM, reflecting current best practices in pediatric peripheral nerve surgery. Our 12-month improvements in MRC grade have followed similar lines to some of the studies [Glass, H. C. *et al*., 2013; Rakshasbhuvankar, A. A. *et al*., 2025; Sewell, E. K. *et al*., 2018; Watanabe, K. 2014] that consistently showed that IONM not only confirmed pre-operative EMG results, but also actively influenced the surgical decision-making process, and optimized functional recovery.

CONCLUSION

The incorporation of Electromyography (EMG) into the arsenal of multiple complementary diagnostic techniques (including MRI, genetic testing, and intraoperative neuromonitoring) greatly improves the diagnostic accuracy and clinical results of pediatric neurologic and surgical procedures. A multi-modal approach (≥2 modalities) had the highest diagnostic accuracy (94.5%) and was the most independent predictor of correct final diagnosis (OR 6.82, $p<0.001$) compared to EMG alone. In addition, in surgical patients, in-depth pre-operative diagnostic planning was directly correlated with better functional recovery, better agreement with the surgical findings, lower revision surgery rate, and less length of stay.

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