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Clinical Applications of Pediatric Electromyography in Surgical and Neuromuscular Pathologies

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Abstract: Peripheral nerve and muscle disorders are important to evaluate with peripheral nerve and muscle tests, such as pediatric electromyography (EMG) and nerve conduction studies (NCS). The purpose of this study was to assess the clinical results of pediatric EMG, to determine whether there is a difference between surgical and neuromuscular disease, to identify independent electrophysiological predictors for surgery, and to evaluate the functional and electrophysiological outcome of treatment at 12 months. A cohort of 113 children with various diagnoses of childhood neuromuscular disorders was therefore analyzed and divided into a surgical group (62) comprising patients with obstetric brachial plexus palsy, traumatic nerve injuries, spinal dysraphism, and entrapment neuropathy, and a neuromuscular group (51) comprising patients with muscular dystrophies, spinal muscular atrophy, CIDP/GBS, CMT, and myasthenia. Multivariable logistic regression was used to determine predictors of surgical intervention, and 12-month follow-up data were used to analyze functional and electrophysiological improvements. There were large differences between the two groups at baseline: the surgical group was younger and had a shorter duration of symptoms. The surgical group had significantly lower motor and sensory nerve conduction velocity, lower amplitude of compound muscle action potential (CMAP), and higher percentages of fibrillation potentials and neurogenic patterns. The presence of fibrillation potentials, the age <3 Years and complete denervation were strong independent predictors of surgical intervention in multivariable regression. Patients at 12 months had significantly improved MRC muscle strength (+0.8), active ROM (+20.5%), and Functional Independence Score (+15.4%) with an 87.1% EMG-surgical concordance rate. Overall, pediatric EMG allows for the identification of unique electrophysiologic patterns useful for distinguishing surgical and neuromuscular disease. Certain EMG characteristics are good discriminators of the need for surgical treatment.

Keywords: Pediatric Electromyography, Neuromuscular Disorders, Surgical Neuropathy, and Functional Outcomes.

INTRODUCTION

Pediatric electromyography (EMG), which includes both nerve conduction studies (NCS) and needle EMG, is a fundamental diagnostic tool for assessing the integrity of the lower motor neuron, peripheral nerves, neuromuscular junction, and skeletal muscle in children [Fardeau, M., & Desguerre, I. 2013; Sabouraud, P. *et al*., 2009; Wang, C. H. *et al*., 2007].

The dynamic myelination and maturation of muscle fibers in early development necessitate the establishment of special technical adjustments in the examination of children and acknowledge the age-dependent normative physiological values. Because of the dynamic myelination and maturation of the muscle fibers during early development, special technical adjustments [Cuisset, J. M., & Estournet, B. 2012] are needed for children, and it is necessary to recognize the age-dependent normative physiological values. In addition, the technique and behavior need to be tailored to gain patient co-operation and minimize discomfort, reflecting the need for clinical awareness and precise technique. Thus, pediatric EMG is much more than an ancillary test, but one that is essential to the process of investigation and helps connect the clinical phenomenon to underlying pathophysiological mechanisms in the developing nervous system [Jani-Acsadi, A. *et al*., 2015; Mary, P. *et al*., 2018; Duboc, D. *et al*., 2007].

Pediatric EMG plays a crucial role in the diagnosis of neurogenic and myogenic processes in the context of neuromuscular disease and is critical to guide the genetic/molecular diagnosis and further management. Electrodiagnostic (EDG) studies play an important role in the phenotypic characterization of congenital and early-onset disorders such as SMA, congenital myopathies, and muscular dystrophies [Bushby, K. *et al*., 2010]. The widespread fibrillation potentials and positive sharp waves with motor unit recruitment decrease are very suggestive of anterior horn cell or axonal pathology [Bushby, K. *et al*., 2010]. Conversely, MUAPs, which are small in amplitude, short in duration, and are recruited early, are correlated with primary myopathic processes [Vialle, R. *et al*., 2013].

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Apart from the intrinsic neuromuscular disease, pediatric EMG can be extremely useful in the diagnosis and treatment of surgery [Morillon, S. *et al*., 2007]. Some of the most significant examples are obstetric brachial plexus injury (OBPI), for which serial EMG and NCS is important for prognosis and surgery [Hickey, B. A. *et al*., 2014], and traumatic injury that may involve a concussion, in which serial testing is important for prognosis [Cunin, V. 2015; McElroy, M. J. *et al*., 2011; Bai, S. *et al*., 2018]

Electrodiagnosis can be helpful in the early detection of denervation or the early detection of reinnervation, and thus ensure that nerve grafting or nerve transfer may be performed at the best time and prevent irreversible muscle fibrosis. Similarly, EMG can accurately localize lesions and quantify axonal damage in peripheral nerve trauma, compartment syndrome, and entrapment neuropathy [Cunin, V. 2015].

METHOD AND PATIENTS SELECTION

This cross-sectional study aimed to review the clinical uses of pediatric electromyography (EMG) for the diagnosis and treatment of surgical and neuromuscular disorders. A total of 113 pediatric patients (all <2 years old) were evaluated at a tertiary pediatric neurology and orthopedics center during five years of the study. Patients were divided into two main groups: a surgical group (n=62, which included obstetric brachial palsy, traumatic nerve injury, spinal dysraphism, and entrapment neuropathy), and a neuromuscular group (n=51, including Duchenne/Becker muscular dystrophy, spinal muscular atrophy, CIDP/GBS, Charcot-Marie-Tooth disease, and myasthenia.

Extensive clinical information was retrieved, including demographics, symptom duration, referral source, and family history. Affected limbs were tested with both the surface and concentric needle electrodes with standardized electrodiagnostic protocols. Motor and sensory NCV, amplitudes of compound muscle action potential (CMAP), sensory nerve action potential (SNAP), distal motor latency, and F-wave latency were obtained. Needle EMG was performed systematically to assess spontaneous (fibrillation potentials, positive sharp waves, fasciculations), recruitment patterns, and motor unit action potential (MUAP) morphology to distinguish a neurogenic from a myopathic pattern. In addition, adjunctive data, including serum creatine kinase (CK) levels, repetitive nerve stimulation (RNS) responses, and genetic confirmation, were recorded for the neuromuscular subgroups.

Blinded evaluators carefully evaluated clinical and functional outcomes at 12 months. Medical Research Council (MRC) muscle strength grading, active range of motion (ROM), Functional Independence Score (FIS), and pain visual analog scale (VAS) scores were used as primary outcome measures. In addition, EMG-surgical concordance was strictly defined as a direct agreement between the predicted and the pathological findings in the operating room.

Analysis of data was done using SPSS version 26.0. Continuous variables were presented as mean ± standard deviation (SD) or median with interquartile range [IQR] and evaluated with an independent t-test, Mann-Whitney U test, one-way-ANOVA, or Kruskal-Wallis test, depending on the type of the variables. A multivariable logistic regression model was developed to determine independent predictors of surgical intervention, and odds ratios (OR) with 95% confidence intervals (CI) were reported. The level of statistical significance was set at a two-tailed p-value < 0.05.

RESULTS

Table 1: Demographic characteristics of the 113 patients' selection.

VARIABLE	TOTAL (N=113)	SURGICAL GROUP (N=62)	NEUROMUSCULAR GROUP (N=51)	P-VALUE
Age (years), mean ± SD	6.8 ± 4.2	5.4 ± 3.8	8.5 ± 4.1	0.001
Age (years), median [IQR]	6.0 [3.2–10.1]	4.5 [2.1–8.0]	8.0 [5.5–11.8]	—
Male sex, n (%)	68 (60.2%)	39 (62.9%)	29 (56.9%)	0.512
Female sex, n (%)	45 (39.8%)	23 (37.1%)	22 (43.1%)	—
Weight (kg), mean ± SD	24.3 ± 14.6	20.1 ± 12.8	29.4 ± 15.3	0.001
BMI (kg/m²), mean ± SD	16.8 ± 3.4	16.2 ± 3.1	17.5 ± 3.6	0.042
Duration of symptoms	8.4 ± 6.7	4.2 ± 3.1	13.5 ± 6.8	<0.001

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(months), mean ± SD				
Duration of symptoms (months), median [IQR]	6.0 [3.0–12.0]	3.5 [2.0–6.0]	12.0 [8.0–18.0]	—
Referred from orthopedics, n (%)	48 (42.5%)	38 (61.3%)	10 (19.6%)	<0.001
Referred from neurology, n (%)	52 (46.0%)	18 (29.0%)	34 (66.7%)	<0.001
Referred from primary care, n (%)	13 (11.5%)	6 (9.7%)	7 (13.7%)	0.498
Family history of neuromuscular disease, n (%)	19 (16.8%)	3 (4.8%)	16 (31.4%)	<0.001
Previous surgical intervention, n (%)	14 (12.4%)	11 (17.7%)	3 (5.9%)	0.054

Table 2: Outline the electromyographic clinical outcomes.

PARAMETERS	TOTAL (N=113)	SURGICAL GROUP (N=62)	NEUROMUSCULAR GROUP (N=51)	P-VALUE
Motor NCV, upper limb (m/s), mean ± SD	48.2 ± 8.6	44.3 ± 9.2	52.9 ± 5.8	<0.001
Motor NCV, lower limb (m/s), mean ± SD	42.6 ± 9.4	39.1 ± 10.1	46.8 ± 7.2	<0.001
Sensory NCV (m/s), mean ± SD	44.8 ± 7.9	41.6 ± 8.4	48.7 ± 5.9	<0.001
CMAP amplitude (mV), mean ± SD	4.8 ± 2.9	3.4 ± 2.5	6.5 ± 2.6	<0.001*
CMAP amplitude (mV), median [IQR]	4.2 [2.6–6.8]	2.9 [1.5–4.8]	6.1 [4.5–8.2]	—
SNAP amplitude (μV), mean ± SD	12.4 ± 6.8	9.1 ± 5.9	16.4 ± 5.8	<0.001
Distal motor latency (ms), mean ± SD	4.1 ± 1.3	4.6 ± 1.4	3.5 ± 0.9	<0.001
F-wave latency (ms), mean ± SD	26.8 ± 5.4	28.9 ± 5.8	24.2 ± 3.9	<0.001
Fibrillation potentials present, n (%)	72 (63.7%)	51 (82.3%)	21 (41.2%)	<0.001
Positive sharp waves present, n (%)	65 (57.5%)	47 (75.8%)	18 (35.3%)	<0.001
Fasciculation potentials, n (%)	28 (24.8%)	8 (12.9%)	20 (39.2%)	0.001
Reduced recruitment pattern, n (%)	78 (69.0%)	49 (79.0%)	29 (56.9%)	0.011
Polyphasic MUAPs, n (%)	54 (47.8%)	22 (35.5%)	32 (62.7%)	0.004
Myopathic pattern, n (%)	24 (21.2%)	2 (3.2%)	22 (43.1%)	<0.001
Neurogenic pattern, n (%)	76 (67.3%)	55 (88.7%)	21 (41.2%)	<0.001

Table 3: Determining the surgical pathologies in the patients.

DIAGNOSIS	OBPP (N=24)	TRAUMATIC NERVE INJURY (N=18)	SPINAL DYSRAPHISM (N=12)	ENTRAPMENT NEUROPATHY (N=8)	P-VALUE
Age at EMG (years), mean ± SD	1.8 ± 1.2	8.4 ± 3.6	5.2 ± 2.9	11.3 ± 2.4	<0.001
Male sex, n (%)	14	13 (72.2%)	7 (58.3%)	5 (62.5%)	0.764

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	(58.3%)				
Time to EMG (months), mean ± SD	3.8 ± 1.4	2.9 ± 1.8	6.1 ± 3.2	5.4 ± 2.7	0.003
Motor NCV (m/s), mean ± SD	38.2 ± 8.4	42.6 ± 9.8	44.8 ± 7.6	46.2 ± 5.9	0.038
CMAP amplitude (mV), mean ± SD	2.1 ± 1.8	3.8 ± 2.4	4.2 ± 2.1	4.6 ± 1.9	0.004
Fibrillations present, n (%)	22 (91.7%)	15 (83.3%)	9 (75.0%)	5 (62.5%)	0.182
Complete denervation, n (%)	8 (33.3%)	4 (22.2%)	2 (16.7%)	0 (0%)	0.148
Partial denervation, n (%)	14 (58.3%)	11 (61.1%)	7 (58.3%)	5 (62.5%)	0.993
Surgical intervention performed, n (%)	18 (75.0%)	12 (66.7%)	8 (66.7%)	4 (50.0%)	0.581
Nerve grafting, n (%)	10 (41.7%)	6 (33.3%)	0 (0%)	0 (0%)	0.006
Neurolysis, n (%)	5 (20.8%)	4 (22.2%)	3 (25.0%)	4 (50.0%)	0.371
Tendon transfer, n (%)	3 (12.5%)	2 (11.1%)	5 (41.7%)	0 (0%)	0.039
EMG guided surgical decision, n (%)	20 (83.3%)	14 (77.8%)	9 (75.0%)	6 (75.0%)	0.897
Functional improvement at 12 mo, n (%)	16 (66.7%)	13 (72.2%)	7 (58.3%)	7 (87.5%)	0.457

Table 4: Identifying clinical outcomes of neuromuscular pathology into pediatric electromyography.

DIAGNOSIS	DMD/BMD (N=16)	SMA (N=12)	CIDP/GBS (N=11)	CMT (N=7)	MYASTHENIA (N=5)	P-VALUE
Age at EMG (years), mean ± SD	7.2 ± 2.8	4.1 ± 3.6	9.8 ± 3.4	11.4 ± 2.9	12.6 ± 3.1	<0.001
Male sex, n (%)	14 (87.5%)	7 (58.3%)	6 (54.5%)	4 (57.1%)	2 (40.0%)	0.186
CK level (U/L), median [IQR]	8420 [5200–14600]	142 [88–210]	98 [62–156]	124 [78–198]	86 [52–134]	<0.001
Motor NCV (m/s), mean ± SD	52.4 ± 4.8	48.6 ± 6.2	34.2 ± 8.6	28.4 ± 7.8	54.2 ± 3.6	<0.001
CMAP amplitude (mV), mean ± SD	5.8 ± 2.2	3.2 ± 2.4	4.6 ± 3.1	3.8 ± 2.6	6.4 ± 1.8	0.012
Myopathic pattern, n (%)	15 (93.8%)	1 (8.3%)	0 (0%)	0 (0%)	2 (40.0%)	<0.001
Neurogenic pattern, n (%)	0 (0%)	11 (91.7%)	8 (72.7%)	7 (100%)	0 (0%)	<0.001
Decremental response on RNS, n (%)	0 (0%)	0 (0%)	1 (9.1%)	0 (0%)	4 (80.0%)	<0.001
Fibrillations present, n (%)	8 (50.0%)	9 (75.0%)	3 (27.3%)	2 (28.6%)	0 (0%)	0.012
Fasciculations present, n (%)	0 (0%)	10 (83.3%)	2 (18.2%)	1 (14.3%)	0 (0%)	<0.001

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Conduction block present, n (%)	0 (0%)	0 (0%)	8 (72.7%)	1 (14.3%)	0 (0%)	<0.001
Temporal dispersion, n (%)	0 (0%)	0 (0%)	7 (63.6%)	3 (42.9%)	0 (0%)	<0.001
Genetic confirmation, n (%)	14 (87.5%)	11 (91.7%)	0 (0%)	5 (71.4%)	0 (0%)	<0.001
Ambulatory at last follow-up, n (%)	9 (56.3%)	5 (41.7%)	9 (81.8%)	6 (85.7%)	5 (100%)	0.038

Table 5: Treatment and functional outcomes for 12 months follow - up.

OUTCOME MEASURE	BASELINE	12-MONTH FOLLOW-UP	CHANGE (Δ)	P-VALUE
MRC muscle strength grade, mean ± SD	2.8 ± 1.1	3.6 ± 0.9	+0.8 ± 0.7	<0.001
Active ROM (% of normal), mean ± SD	48.2 ± 22.4	68.7 ± 19.8	+20.5 ± 14.2	<0.001
Functional Independence Score, mean ± SD	52.4 ± 18.6	67.8 ± 16.2	+15.4 ± 11.8	<0.001
CMAP amplitude (mV), mean ± SD	4.8 ± 2.9	6.2 ± 2.6	+1.4 ± 1.8	<0.001
Motor NCV (m/s), mean ± SD	48.2 ± 8.6	50.8 ± 7.4	+2.6 ± 4.2	0.001
Pain VAS score (0–10), median [IQR]	4.0 [2.0–6.0]	2.0 [0–3.0]	−2.0 [−4.0 to −1.0]	<0.001
Patients with functional improvement, n (%)	—	76 (67.3%)	—	—
Patients with stable function, n (%)	—	28 (24.8%)	—	—
Patients with functional decline, n (%)	—	9 (8.0%)	—	—
Return to age-appropriate activities, n (%)	—	64 (56.6%)	—	—
Required repeat EMG, n (%)	—	34 (30.1%)	—	—
Surgical complications, n (%)	—	7 (6.2%)	—	—
EMG-surgery concordance rate, n (%)	—	54/62 (87.1%)	—	—

Table 6: Multivariable logistic regression analysis of surgical intervention indicators.

PREDICTOR VARIABLE	ODDS RATIO	95% CI	P-VALUE
Age < 3 years	3.42	1.58–7.41	0.002
Fibrillation potentials present	4.18	1.92–9.12	<0.001
Complete denervation pattern	6.74	2.31–19.66	<0.001
CMAP amplitude < 2.0 mV	5.21	2.14–12.68	<0.001
Motor NCV < 40 m/s	2.86	1.28–6.39	0.010
Duration of symptoms > 6 months	0.48	0.21–1.09	0.078
Positive sharp waves present	2.14	0.94–4.87	0.069
Absent F-wave response	4.92	1.68–14.42	0.004
Reduced recruitment (>50% loss)	3.67	1.52–8.86	0.004
Upper limb involvement	2.93	1.34–6.41	0.007
Male sex	1.24	0.56–2.74	0.594
BMI > 18 kg/m²	0.72	0.31–1.67	0.442
Family history of NM disease	0.34	0.09–1.28	0.112
Referred from orthopedics	2.48	1.12–5.49	0.025*

DISCUSSION

This study illustrates the potential importance of PEMG in the differentiation of surgical from neuromuscular pathologies, as well as its diagnostic and prognostic significance. Our results are consistent with the previous literature in Canada [Cunin, V. 2015], which stressed the

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importance of early neurophysiological evaluation in a pediatric population. The marked difference in amplitude of motor nerve conduction velocity (NCV) and compound muscle action potential (CMAP) between the surgical and the neuromuscular group confirms that clear electrophysiological characterizations of focal axonal loss and primary muscle or diffuse nerve disease are present [McElroy, M. J. *et al*., 2011; Bai, S. *et al*., 2018; Bashivan, P. *et al*., 2015]

For surgical cases, especially obstetric brachial palsy (OBPP) and traumatic nerve injury, EMG was very predictive of the need for surgery. Complete denervation, the absence of F-waves, and a less than 2.0 mV CMAP were all strong predictors of surgical intervention in multivariable regression analysis. A few studies [Bouche, P. *et al*., 1999; Chan, H. P. *et al*., 2020; Craik, A. *et al*., 2019; de Jonge, S. *et al*., 2024] determined that early EMG results of fibrillation potentials and severe axonal loss were predictive of the need for nerve grafting or neurolysis in OBPP. With an EMG to surgery concordance rate of 87.1%, we are reinforcing the literature [Ghafoorian, M. *et al*., 2017], which has come to a consensus that preoperative EMG will correctly predict intraoperative anatomical realities, thus optimize surgical planning and reduce unnecessary surgery.

The distinctive myopathic features and very elevated creatine kinase in DMD/BMD, as compared with neurogenic and prominent fasciculations in SMA, is representative of the accepted diagnostic features. Additionally, the presence of conduction blocks and temporal dispersion in the CIDP/GBS cohort is exactly what has been reported in the electrodiagnostic literature [Guérit, J. M. *et al*., 2009] for acquired demyelinating polyneuropathies. Most importantly, the 12-month follow-up demonstrated that there were important functional improvements, with a mean increase of 0.8 on the Medical Research Council (MRC) muscle strength score and a 20.5% improvement in active range of motion [Habashi, A. G. *et al*., 2023].

While the results of the following were encouraging, the following problems were noted: Retrospective study design and limited numbers of subgroups (e.g., myasthenia, n=5). The present study, however, further substantiates the importance of Paediatric EMG as an indispensable tool which has a significant role in guiding therapeutic decisions and complements and adds to the existing organic neurophysiological models in paediatrics.

CONCLUSION

Pediatric EMGs can be useful in making clinical decisions and can be used to distinguish the surgical from the NM patient's symptoms. The data analysis reveals that these specific EMG parameters (full denervation, low CMAP amplitude, and absence of F-wave response) are promising as independent predictors for surgery. Furthermore, the moderate EMG surgical concordance level (87.1%) and the enhancement of muscle strength and functional independence, as well as pain relief after 12 months, emphasize the importance of EMG participation in the planning of treatment strategies of the paediatric population to achieve optimal long-term functional outcomes.

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