MATHEMATICAL MODELING OF ORAL HYGIENE IN CHILDREN WITH CEREBRAL PALSY DEPENDING ON THE DEGREE OF SEVERITY OF MOTOR IMPAIRMENT AND ELECTRONEUROMYOGRAPHY PARAMETERS

I.A.ZORII[1], Kh.V.PRYIMAK[2], N.V.BIDENKO[3], Y.G.KOLENKO[3], I.A. VOLOVYK[3]

[1]State Higher Education Institution of Ukraine, Bukovinian State Medical University, Chernivtsi, Ukraine
[2]City Children's Dental Clinic, Chernivtsi, Ukraine
[3]"Bogomolets" National Medical University, Kyiv, Ukraine
Corresponding author: Yulia G. Kolenko; e-mail: kolenko.julia@gmail.com

Abstract

Introduction. Examination of the dental status of children with cerebral palsy (CP) is indicative of a high occurrence and intensity of lesions of the hard dental and periodontal tissues. One of the leading etiopathogenic factors promoting the development of major dental diseases among these children is an unsatisfactory oral hygiene. **Objective:** to design a mathematical model to predict the state of oral hygiene in children suffering from CP with various degrees of severity of the underlying disease. **Materials and methods.** 122 children (average age 8.8±3.7 years) with spastic forms of CP were examined. The state of oral hygiene and intensity of dental caries were determined in all children. Electoneuromyography (ENMG) was conducted for all of them with CP, by means of stimulation methods. **Results and discussion**. Stomatological examination of children demonstrated a certain tendency of caries intensity increase and deterioration of oral hygiene with increasing the degree of motor function impairments. ENMG examination of patients with CP found neurophysiological signs of supra-segmental disorders, correlated with the degree of motor function impairments. The mathematical model was developed on the basis of the data obtained, enabling to prognosticate the degree of oral hygiene depending on ENMG parameters. **Conclusions.** The mathematical prognostic model developed enables to prognosticate oral hygiene state in every particular case, on the basis of ENMG examination carried out in the neurological department during general medical examination of children, thus laying the bases for differential indication of preventive measures and optimal direction of appropriate recommendations for both parents and children.

Keywords: *cerebral palsy, electroneuromyography, oral hygiene, mathematical modeling.*

1. INTRODUCTION

Cerebral palsy (CP) is the most common neurologic disease diagnosed among children of early age. This term includes a number of syndromes occurring due to organic brain lesion. CP results from brain injuries both during intrauterine development and birth or in the first weeks of life, being associated with motor, speech and psychic disorders [1,2]. The main clinical sign of CP is impairment of motor functions, associated with retarded development and malformation of statokinetic reflexes, pathological tonus, and paresis [3]. Occurrence of CP in the world has been constantly increasing - approximately 1.6-2.8 cases per 1,000 of neonates [3]. About 100,000 disabled children with pathology of the nervous system are registered in Ukraine, namely 2.56 per 1,000 of live neonates [4].

Examination of the dental status of children with CP is indicative of high occurrence and intensity of lesions of the hard dental and periodontal tissues [5-12]. A leading etiopathogenic factor promoting development of major dental diseases among these children is unsatisfactory oral hygiene. The causes of this condition are both imperfect manual skills and incomplete self-cleaning of the oral cavity with often underlying maxillofacial defects, functional disorders of the salivary glands, masticatory muscles, and speech [13,14]. All such considerations stipulate the necessity of a special attention paid to individual oral care in this group of children, from the part of both dentist and neurologist who control and treat the disease. Thus, the issue to predict the level of individual oral care considering general condition of a child and severity of motor disturbances appears to be rather urgent.

Mathematical methods are widely applied to predict the occurrence of diseases, the dental ones in particular [15,16]. To design a mathematical model requiring accurate parameters, the results of electroneuromyography (ENMG) are to be reasonably used. To a certain extent, ENMG parameters can reflect severity of motor disturbances in case of CP, so that this kind of investigation can be widely used in examination of children suffering from CP in the neurological department.

Objective: To design a mathematical model for predicting the state of oral hygiene in children suffering from CP of various degree of severity of the underlying disease.

2. MATERIALS AND METHODS

122 children (average age 8.8±3.7 years) with spastic forms of CP treated at the Regional Center of Medical-Social Rehabilitation of children with organic lesions of the nervous system (city of Chernivtsi) were examined. Children with CP were divided into 5 groups, according to the Gross Motor Function Classification System – Expanded & Revised (GMFCS - E&R) [17] (Table 1). The parents of all children involved were informed on the research and their written consent was obtained.

Table 1. Distribution of patients with CP according to the Gross Motor Function Classification System – Expanded & Revised (GMFCS - E&R)

Groups of patients with CP examined	Mean age, years	Number	
		n	%
1st group (children walk without limitations)	8.16±3.02	23	18.9
2nd group (children walk with limitations)	10.05±4.20	26	21.3
3rd group (children walk with supervision or assistance)	9.10±1.90	26	21.3
4th group (children with limited self-initiated movements)	8.2±2.7	25	20.5
5th group (a child is transported in a wheelchair)	7.41±3.91	22	18.0
Total	8.8±3.7	122	100

The state of oral hygiene and intensity of dental caries were determined in all children by means of Decayed-Missing-Filled (DMF) index for permanent teeth and dmf for deciduous teeth, respectively. The state of oral hygiene was determined with the Oral Hygiene Index – Simplified (OHI-S) (J.C.Green, J.R.Vermillon, 1964). To determine the state of oral hygiene in temporary occlusion the modified index introduced by N.A. Sedky (2018) for children under years [7] was used.

ENMG was conducted for all children with CP on the computer software complex M-TEST («DX-systems», Kharkiv, Ukraine). The two nerves (median and fibular) were examined by the stimulation method. The nerve conduction velocity (NCV) by motor fibers, the amplitude and form of the muscular motor response (M-response) were estimated according to the standard methods. To assess the supra-segmental (upper motor neuron) and segmental (α-motor neurons of the spinal cord and peripheral nerves) levels of lesion, the parameters of H-reflex and F-wave that characterizing the state of general conductivity along the nerve were analyzed [18].

The results of the studies conducted were considered for creating the mathematical model. Mathematical processing included the following stages: calculation of the initial statistical parameters; empiric distribution concerning conformity with the normal (Gaussian) distribution estimated for the quantitative parameters, differences between the groups by statistical indices were found; finding interrelations between the variables by means of parametric and nonparametric correlation analysis; application of the multivariable statistics method (discriminant) [19]. To create a regression model, the parameters were selected in the following way: 1) selection of variables on the basis of a specialist's opinion; 2) calculation of the significance of variables in the analysis indicated above; 3) exclusion of inconsiderable variables; 4) use of valuable variables (significance level) to design a prognostic model. The data obtained was statistically processed by means of the applied programs MS® Excel® 2007тм, Biostat®, Statistika® 6.0 using paired and unpaired Student t-criteria. The main part of statistical processing of data was performed by

the methods of free and open environment RStudio.

3. RESULTS

Stomatological examination of children with CP showed a caries occurrence of 100%. The average value of caries intensity in children with CP was 6.27±1.19. Stomatological examination demonstrated certain differences in both caries intensity and oral hygiene in different groups of children suffering from CP examined depending on the degree of motor function impairment (Table 2).

Table 2. Comparative characteristic of DMF (DMF+dmf, dmf) and oral hygiene index in children with CP from different groups according to the Gross Motor Function Classification

Parameters	Groups of children with CP according to the Gross Motor Function Classification System				
	1 group (n=23)	2 group (n=26)	3 group (n=26)	4 group (n=25)	5 group (n=22)
DMF, DMF+df, df	4.52±1.19	5.57±1.34	6.15±1.11	6.6±1.63	8.36±2.21
Oral hygiene index	1.68±0.16	1.86±0.34	2.05±0.26	2.16±0.25	2.27±0.22 p<0.05

Note: **p – difference reliability from the parameters of the 1st group.**

Analysis of the oral hygiene state in children with CP demonstrated a certain correlation of the hygienic index parameters with the level of motor impairment severity (Table 2). The average value of the hygienic index in children from the 5th group was 2.27±0.22, which was 1.4 times higher in comparison with the similar index in the 1st group (p=0.035).

ENMG of patients with CP found neurophysiological signs of supra-segmental disorders (Table 3).

Table 3. Electroneuromyography parameters in children with CP from different groups ccording to the Gross Motor Function Classification

Parameters		Groups of children with CP				
		1 group (n=23)	2 group (n=26)	3 group (n=26)	4 group (n=25)	5 group (n=22)
Amplitude of M-response (mR)	**n. medianus**	7,17 ±0,87	6,86 ±0,81	5,92 ±0,63	4,51 ±0,36 p<0,01 p_1<0,05	4.30 ±0.31 p<0.01 p_1<0.01 p_2<0.05
	n. peroneus	4.83 ±0.64	5.19 ±0.99	3.13 ±0.44 p<0.05	2.43 ±0.57 p<0.01 p_1<0.05	2.03 ±0.22 p<0.01 p_1<0.01 p_2<0.05
Rate of stimulus conduction, m/sec		45.12 ±2.03	44.74 ±1.82	46.12 ±2.31	43.87 ±2.36	44.65 ±1.92
Average amplitude of F-waves, mcV		766.14 ±44.52	909.82 ±76.58	1029.48 ±90.89	1281.30 ±140.91 p<0.01 p_1<0.05	1763.31 ±196.45 p<0.01 p_1<0.01 p_2<0.01
Amplitude of H-reflex (mV)		4.27 ±0.53	4.85 ±0.42	5.83 ±0.51 p<0.05	8.25 ±0.57 p<0.01 p_1<0.01 p_2<0.01	9.06 ±0.63 p<0.01 p_1<0.01 p_2<0.01

p – reliability of differences from the parameters of the 1st group;
p_1 - reliability of differences from the parameters of the 2nd group;
p_2 - reliability of differences from the parameters of the 3rd group.

Table 3 shows that children with significant motor impairments (4th and 5th groups) present a reliable decrease of motor response parameters while testing median and fibular nerves, compared to the patients from other groups, which is indicative of a considerable decrease of muscular contraction ability of the upper and lower limbs. A reliable increase of F-wave amplitude was found in children from the 4th (40.2%) and 5th (56.6%) groups, compared with the 1st one, indicating a considerable increase of a synchronous stimulation of α-motor neurons in the cervical and sacral-coccygeal segments of the spinal cord, and marked neurophysiological signs of conductive (pyramidal) insufficiency with lesions of the cortical-cervical and cortical-lumbar passages. A reliable increase of reflex excitability by the parameters of H-reflex was registered in the 4th and 5th groups, namely a 41.2% increase of H-response amplitude in children from the 4th group and a 52.8% increase, respectively, in the 5th group, which indicates a marked spastic degree in the patients of these groups.

Correlation analysis between ENMG parameters and values of oral hygiene index found close correlations with H-reflex parameters ($r=0.746$; $p<0.001$) and F-wave parameter ($r=0.783$; $p<0.001$), which confirms that oral hygiene in children with muscular-skeletal impairments due to CP could be associated with limitation of motor function, reduced dynamic possibilities related to the peculiarities of fine motor skills, and marked spastic syndrome in children suffering from CP.

Table 4 presents distribution of hygienic index and ENMG parameters.

Table 4. Distribution of hygienic index and electroneuromyographic parameters

Parameters	Hygienic index	ENMG parameter of F-wave amplitude	ENMG parameter of H-reflex amplitude	ENMG parameter of Hmax/Mmax ratio	ENMG parameter of M-response fibular nerve amplitude
Min:	0.600	116.9	3.400	28.00	260
1st Qu:	800	915.9	4.800	47.00	2.300
Median:	2.000	1040.5	5.500	65.00	3.300
Mean:	2.003	1085.7	5.480	63.54	3.551
3rd Qu:	2.300	1270.0	6.275	78.00	4.500
Max:	2.800	1998.0	7.200	109.00	6.760

On the basis of the data obtained, a model that enables to predict a degree of oral hygiene depending on intensity of neurological symptoms (Table 5 and formula 1) was developed. The model is adequate ($F=1,070$; $p<0.0001$), and it correlates with the terms of Gauss-Markov theorem (Fig. 1), which means that evaluation of the coefficients obtained is not shifted and effective.

Table 5. Values of the dependence of hygienic index parameters on predictors

Variable	Estimate	Std. Error	t-value	Pr(>|t|)
ENMG of H-reflex amplitude parameter	0.360125	0.006352	56.7	<2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 0.3908 on 121 degrees of freedom
Multiple R-squared: 0.9637, Adjusted R-squared: 0.9634
F-statistic: 3215 on 1 and 121 DF, p-value: < 2.2e-16

$$Y = 0,360125 \times H - reflex \quad (1),$$

where y – oral hygiene index.

The results of the study conducted showed that the H-reflex amplitude parameter that increases gradient by gradient in children with CP with growing intensity of the underlying disease (according to the Gross Motor Function Classification System – Expanded & Revised (GMFCS - E&R)) affects considerably oral hygiene (Table 5). Coefficient of determination for the pattern obtained is 96.4 %.

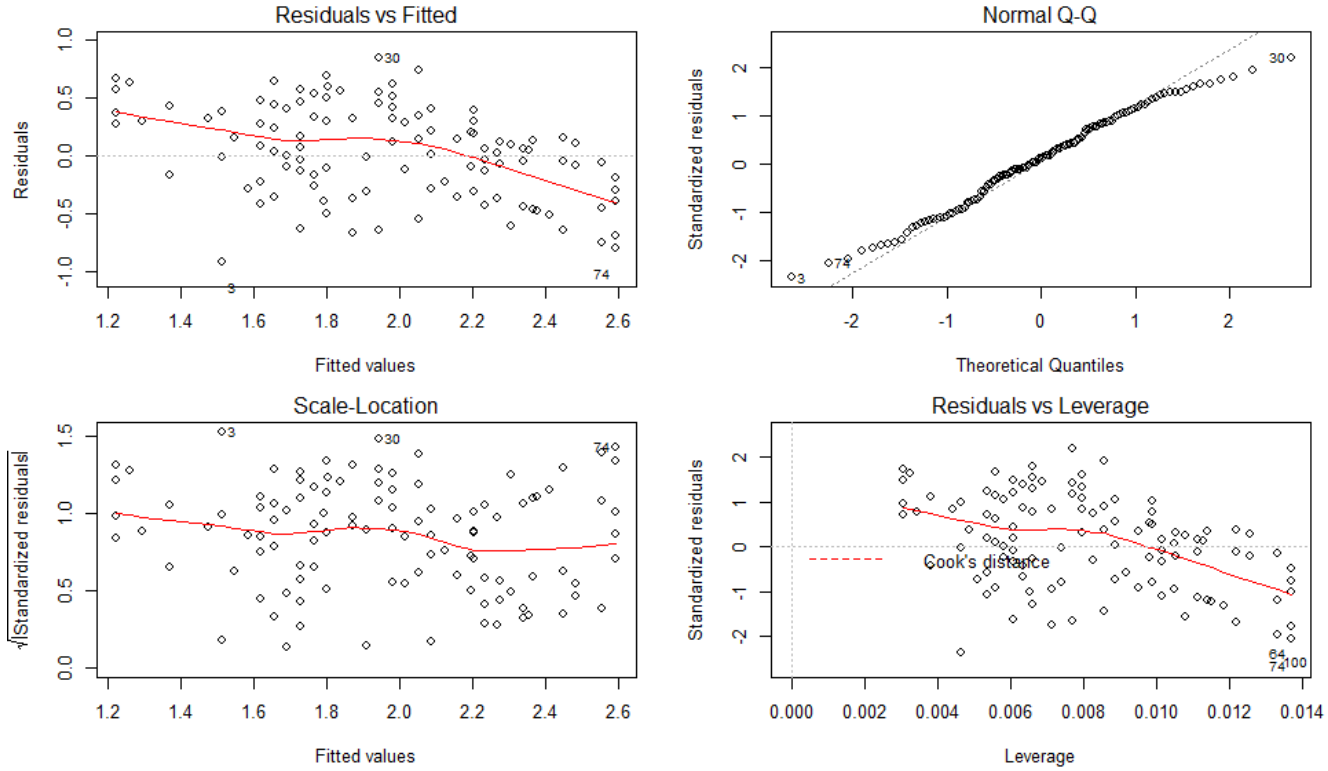

Fig. 1. Diagnostic diagrams for the pattern of oral hygiene index depending on electroneuromyographic parameters (H-reflex amplitude)

The significance of oral hygiene level depending on the functional group according to the Gross Motor Function Classification System – Expanded & Revised (GMFCS - E&R) is found (Table 6), which in its turn is indicative of the deterioration of oral hygiene due to marked motor functional impairments in children with CP.

Table 6. Significance of oral hygiene index depending on predictors

Variable	Estimate	Std. Error	t-value	Pr(>|t|)
Functional group	0.1821783	0.3669407	0.496	0.62050
Hygiene index	0.2178694	0.4728496	0.461	0.64584
ENMG parameter of F-wave amplitude	0.0024669	0.0007865	3.137	0.00217 **
ENMG parameter of H-reflex amplitude	-0.0919052	0.2395857	-0.384	0.70198
ENMG parameter of Hmax/ Mmax ratio	0.0410644	0.0161213	2.547	0.01218 *
ENMG parameter of M-response fibular nerve amplitude	0.2847074	0.1978121	1.439	0.15279

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.728 on 115 degrees of freedom; Multiple R-squared: 0.3999, Adjusted R-squared: 0.3686; F-statistic: 12.77 on 6 and 115 DF, p-value: 5.197e-11

The results of the study indicate that the significance of oral hygiene parameter does not depend on ENMG parameters, such as M-response fibular nerve amplitude and Hmax/Mmax ratio (Table 6).

The advantage of the model developed is possibility to predict oral hygiene in children with CP depending on the severity of the underlying disease, that is the intensity of motor impairments and spastic syndromes, and possibility of its practical use.

4. DISCUSSION

Impairments of gross motor functions in children with CP, correlated with changes of electroneuromyography parameters, stipulate considerable limitations in the self-care of such children, and in the individual care of oral cavity without assistance in particular, as well as certain difficulties in taking care of the oral hygiene by their parents. It could be a factor causing high dental caries occurrence and its marked intensity with growing intensity of the impairments of motor functions.

The importance of motor function impairments in children with CP and inadequate oral care associated with it is indicated by many researchers [5,9,20,21]. At the same time, examination of stomatological status and oral hygiene was not differentiated, depending on the degree of motor function impairments. High caries intensity and unsatisfactory oral hygiene in children with spastic diplegia, hemiplegia [20], spastic tetraparesis [22], mixed and athetoid forms of CP [23] is evidenced, which matches the results of our study. Since the state of oral hygiene considerably depends on child's skills of self-care, which is associated with severity of neurological disorders with CP, it is reasonable to evaluate the risk of development of dental diseases on the basis of parameters of neurological disorders [21,23,24]. Our study confirms the reasonability of such an approach, since it permits not only to speak about development of dental diseases, but also to predict the occurrence of dental problems dependent on the general condition. In its turn, it allows a differential approach to make up an individual program for preventing dental problems in children with various degrees of motor function impairments.

5. CONCLUSIONS

The mathematical prognostic model developed demonstrates that impairments of gross motor functions in children with CP, correlated with changes of electroneuromyography parameters and create considerable limitations of self-care of such children, individual oral hygiene in particular, as well as certain difficulties in taking care of oral hygiene by their parents, substantially determine objective parameters of oral hygiene. Therefore, the model enables to prognosticate oral hygiene state in every particular case on the basis of the ENMG examination carried out in the neurological department during general medical examination of children, thus creating the bases for differential indication of preventive measures and optimal direction of appropriate recommendations given to parents and their children.

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