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The effect of increased bilirubin level on the risk of cerebral palsy

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ABSTRACT: Increased bilirubin level in blood is mentioned among the potential factors with causal effect on cerebral palsy. The objective of the study was the analysis of its effect on the risk of cerebral palsy, considering all the significant risk factors as well as division into singleton, twin, term and preterm births. The research included a group of 278 children with cerebral palsy from selected educational-therapeutic institutions in Poland. The control group consisted of data from medical records of 435 neonates born in God's Mercy Hospital in Limanowa, Poland. The analysis considered socio-economic factors, factors associated with pregnancy and parturition as well as accompanying disturbances and diseases of the children. Constructed models of logistic regression were used in statistcal analysis. The results were presented as the odds ratio (OR) with 95% confidence interval (CI). Testing the effect of increased bilirubin level in blood showed that the increased level of bilirubin is a significant predictor of CP in the categories of all children (OR 2.52, 95% CI: 1.47–4.33), children from singleton births (OR 2.66, 95% CI: 1.55–4.57), term births (OR 2.18, 95% CI: 1.24–3.84), term singleton births (OR 2.35, 95% CI: 1.31–4.21), preterm births (4.87, 95% CI: 1.56–15.21) and preterm singleton births (OR 3.62, 95% CI: 1.24–10.58). Increased bilirubin level is an independent risk factor in the development of cerebral palsy.

KEY WORDS: cerebral palsy; bilirubin; type of birth

Introduction

Cerebral palsy (CP) includes various, non-progressive, but often changing disorders of movement and posture, co-occurring with other symptoms of permanent brain damage, such as: epilepsy, learning difficulties, behavioural problems and visual and hearing impairment. It's one of the most common motor disabilities in childhood. The prevalence of CP worldwide ranges from 1 to even 5 per live births (Kiely et al. 1981; Johnson and Catterson 1988; Kwolek et al. 2001; Zgorzalewicz et al. 2001; Platt and Pharoah 2004; Korzeniewski 2006; Öztürk et al. 2007; Wu et al. 2010; Milewska et al. 2011; Reid et al. 2011).

In Poland the prevalence is estimated as 2.0–2.5 per 1000 live born children; at the present birth rate it means that every day the group increases on average

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by 1200–2000 children. It is estimated that about 40–50 thousand children with motor impairment live in Poland, and half of them, i.e. 20–25 thousand, are patients with cerebral palsy (Jaskulski and Zgorzalewicz 1993; Nuthall et al. 2000; Zgorzalewicz et al. 2001; Rosenbaum 2003; Jacobsson et al. 2004; Koman et al. 2004; Thorngren-Jerneck and Herbst 2006; Robertson et al. 2007; Milewska et al. 2011).

Increased bilirubin level is mentioned among factors which damage the central nervous system through harmful effect on its development. There is still no agreement regarding the dependence between bilirubin concentration in the child's blood and the risk of damage to the central nervous system (Wasiluk et al. 2012). It is assumed however that in neonates with very low birth weight bilirubin is harmful even at the concentration of 10 mg%, leading to damage of the central nervous system and hearing. Bilirubin level above 20 mg% in prematurely born children with low birth weight constitutes a serious threat to life and requires transfusion blood exchange. Neonates who have survived without treatment suffer from considerable degree of neurological damage, deafness, and also show intellectual impairment (Śmiechura et al. 2010).

Sudies on neonates with high bilirubin levels persisting in the 1st to 3rd day of life indicate that hyperbilirubinemia may lead to "poisoning" of the central nervous system. This is associated with the fact that bilirubin not bound to albumins may cross the blood-brain barrier and damage nerve cells (Śmiechura et al. 2010; Wasiluk et al. 2012).

Bilirubin not bound to blood plasma proteins leads to damage to all cells, but it is especially neurons that suffer permanent damage through impairment of cell respiration, decrease in enzyme production, disturbance of energetic processes and inhibition of ATP production. Many factors may have an additional effect on penetration of bilirubin through cell membranes. Penetration of indirect bilirubin depends not only on its concentration in blood, but also on the albumin level, oxygenation, acid-base balance, as well as on the concentration of drugs binding to proteins. It should be emphasised that bilirubin penetration depends also on the degree of maturity of the nervous system. Bilirubin penetration into the brain in prematurely born infants is facilitated because bilirubin binding by blood plasma proteins in such children is weaker and the quantity of albumins is smaller (Śmiechura et al. 2010).

As the increased bilirubin level in blood is mentioned among the potential factors with a causal effect on cerebral palsy, the objective of the study was the analysis of its effect on the risk of cerebral palsy, considering all the significant risk factors as well as the division into singleton, twin, term and preterm births.

Material and Methods

Participants

The study included a group of 278 children with diagnosed cerebral palsy, born in 1976–2010, and frequenting education-therapeutic centres in Poland. The questionary was filled by the mothers of the children with cerebral palsy or, in the absence of such possibility, by the persons most involved in the care of the disabled child. The data were collected in 40 Polish institutions dealing with children with cerebral palsy.

The control group included data from the medical records of 435 neonates born without congenital defects, genetic syndroms, metabolic diseases, or other hereditary diseases, in 1990–2010 in God's Mercy Hospital in Limanowa, Poland. The data on the mothers and neonates were based on the available medical record (hospital information card, nursing care card, obstetric care card, neonate card – information on parents and neonate's condition).

Study group and control group were controlled according to socioeconomic status and paternal age. Socioeconomic status (SES) of the father was defined on the basis of survey questions: education (primary, vocational, secondary, tertiary), occupation, type of work (permanent, casual), additional questions (place of residence, the main source of income, family economic status stated as subjective assessment of the surveyed) and housing conditions. All these questions were used to determine one variable with 3 categories: manual work, lack of work, and intellectual work (used as a reference group in logistic regression models). In logistic regression models, the category "lack of work" determined low economic status (SES), "physical work" – medium SES, and intellectual work – high SES. The last category (intellectual work) in the regression models was used as the reference group against which the model estimated the risk (OR) of the cerebral palsy.

Data collection

This paper presents only a fragment of extensive studies aimed at identifying independent risk factors for cerebral palsy among demographic, antenatal, perinatal and neonatal factors (for more results from this study please see Sternal et a. 2020). For this purpose the questionary was divided in three parts. The first part included medical, family and obstetric record of the mother, it also included questions about childbirth, pregnancy, gynecological disturbances, as well as information on the child's father. The second part contained questions pertaining to medical and anthropological information, as well as to the occurrence of accompanying disturbances and child's diseases. The last part included environmental diagnose pertaining to the family stucture, address, education level and profession of the parents and the mother's material situation during pregnancy.

Cases of acquired cerebral palsy, congenital hydrocephalia, genetic syndromes (Arnold-Chiari malformation, Dandy-Walker syndrome) and congenital microcephalia were excluded from the analysis.

Study design

The etiology of cerebral palsy differs between preterm- and term-born neonates, and between neonates from singleton and twin pregnancies. Thus in order to obtain a reliable assessment of the risk of cerebral palsy the material was divided into categories according to singleton and twin, term (≥37 weeks) and preterm (<37 weeks) births (Table 1).

The main predictors of cerebral palsy are gestational age and singleton vs. twin pregnancy. Accordingly, all the research procedure was aimed at showing that the risk factors of cerebral palsy differed depending on the category of gestational age. Consequently, the proposed models estimating the risk should be different. The categories distinguished in the material, considering singleton, twin, term

Table 1. Numbers of children with cerebral palsy and in control group in the categories adopted in the analysis

Category	N
All children	713
Singleton pregnancies	669
Twin pregnancies	44
Term births	548
Term singleton births	527
Term twin births	21
Preterm births	165
Preterm singleton births	142
Preterm twin births	23

and preterm births, differ significantly in the etiopathogenesis of cerebral palsy.

Thus the initial assumption was an existence of variables which differentiate between the above-mentioned categories. The planned univariate analyses, using such variables as birth weight, birth length, gestational age, birth order and sex, were aimed at comparative characteristics of children from the cerebral palsy group and the control group within the categories, and at identifying the variables which, once included into logistic regression models, served as accompanying variables and controlled the correctness of statistical conclusions.

Statistical analyses

Several logistic regression models were proposed to assess the probability of occurrence of cerebral palsy depending on the category and co-occurring accompanying variables:

– simple model determining the probability ratio of cerebral palsy depending on the studied factors in each category,
– adjusted model considering the effect of accompanying variables determined in univariate analysis,
– complete model which, besides accompanying variables and significant risk factors, considered also the effect of bilirubin level.

In order to reduce the probability of occurrence of augmented matrix the studies considered also logistic regression models constructed with and without data aggregation. Furthermore, considering the possibility of skewness of accompanying variables, we also used a regression model with transformed variables.

For the ultimate assessment of independent factors of risk of cerebral palsy, we used logistic regression model considering all factors which were significant in multivariate analyses: demographic, antenatal, perinatal and neonatal, and also significant accompanying variables.

The statistical analysis included the Mann-Whitney test, Student- t test (for quantitative data) and Chi- square test (for qualitative date). A p-value of less than 0,05 was selected as statistically significant. The analysis was performed using STATISTICA 12.5 programme.

The variables which differentiated between the group with cerebral palsy and the control group, and in univariate analyses proved to be statistically significant, were included in the principal component analysis. This made it possible to identify non-correlated accompanying variables which were included in further multivariate analyses.

The odds ratio (OR) was calculated to ascertain the dependence between the studied variables and the prevalence of cerebral palsy. The OR values were given with 95% confidence interval (CI), the significance level being p for the Wald Chi square test. The fit of the model were expressed using Cox-Snell and Nagelkerke coefficients, and Hosmer-Lemeshow test.

Results

The univariate analysis showed that in the category of all children and in the category of singleton pregnancy children, the variables: birth weight, birth length, birth order and gestational age, significantly differentiated between the children with cerebral palsy and the control group. Within the group of children from twin pregnancies, sex, birth order and gestational age, were the significant differentiating variables between the cere-

Table 2. Comparative characteristics of all children from experimental and control groups and separately for singleton and twin pregnancies

All children			
Variable	Children with cerebral palsy N=278	Control group N=435	*p*
Sex m/f	152/126	219/216	NS
Birth weight (g)	440.0–5600.0 2554.9±997.2	1290.0–5170.0 3367.1±552.0	<0.001
Birth length (cm)	20–65 50.0±7.2	41–63 54.8±3.1	<0.001
Birth order	1–9 2.0±1.3	1–15 2.6±1.8	<0.001
Gestational age (weeks) <37 Gestational age (weeks) ≥37	126 151	39 396	<0.001
Singleton pregnancies			
Variable	Children with cerebral palsy N=250	Control group N=419	*p*
Sex m/f	136/114	217/202	NS
Birth weight (g)	440.0–5600.0 2615.2±1005.6	1430.0–5170.0 3403.87±514.07	<0.001
Birth length (cm)	20–65 50.3±7.12	45–63 54.9±2.9	<0.001
Birth order	1–9 2.0±1.3	1–15 2.6±1.8	<0.001
Gestational age (weeks) <37 Gestational age (weeks) ≥37	106 141	35 381	<0.001
Twin pregnancies			
Variable	Children with cerebral palsy N=28	Control group N=16	*p*
Sex m/f	16/12	2/14	<0.01
Birth weight (g)	830.0–3750.0 2025.7±745.4	1290.0–3230.0 2403.1±650.4	NS
Birth length (cm)	33–63 47.4±7.0	41–56 49.9±4.4	NS
Birth order	1–4 1.8±1.0	1–5 2.6±1.5	<0.05
Gestational age (weeks) <37 Gestational age (weeks) ≥37	20 8	4 12	<0.01

Data expressed as number in category, range or mean, standard deviation, *p* from Student *t*-test, Mann-Whitney *U*-test or Chi square test, NS – non-significant.

bral palsy children and the control group children (Table 2).

Within the category of children from term and singleton term births, the variables: birth weight, birth length and birth order, differed significantly between the children with cerebral palsy and the control group. Among the children from twin term births, the significantly differentiating factors were sex and birth order (Table 3).

In the category of children from preterm births and in the category of children from singleton preterm births, the variables birth weight and birth length significantly differentiated between the children with cerebral palsy and the control group. In the category of children from preterm twin births no variable was statistically significant (Table 4).

Following principal component analysis, birth weight and birth order were included in logistic regression models as accompanying variables (controlling statistical conclusions) in the category of all

Table 3. Comparative characteristics of children from term, singleton term and twin term births from experimental and control groups

Term births			
Variable	Children with cerebral palsy N=152	Control group N=396	p
Sex m/f	86/66	203/193	NS
Birth weight (g)	2180.0–5600.0 3307.4 ±540.3	1480.0–5170.0 3453.3±472.5	<0.01
Birth length (cm)	35–63 54.3±3.9	46–63 55.2±2.7	<0.05
Birth order	1–9 1.9±1.2	1–5 2.6±1.5	<0.001
Singleton term births			
Variable	Children with cerebral palsy N=143	Control group N=384	*p*
Sex m/f	80/63	201/183	NS
Birth weight (g)	2225.0–5600.0 3339.7±529.7	2050.0–5170.0 3479.3±446.3	<0.01
Birth length (cm)	35–63 54.4±3.9	46–63 55.3±2.6	<0.05
Birth order	1–9 1.9±1.2	1–15 2.6±1.8	<0.001
Twin term births			
Variable	Children with cerebral palsy N=9	Control group N=12	p
Sex m/f	6/3	2/10	<0.05
Birth weight (g)	2180.0–3750.0 2801.1±470.9	1480.0–3230.0 2620.8±548.9	NS
Birth length (cm)	49–63 52.9±4.9	47–56 51.8±2.8	NS
Birth order	1–4 1.8±0.9	1–5 3.2±1.4	<0.05

Data expressed as number in category, range or mean, standard deviation, p from Student t-test, Mann-Whitney U-test or Chi square test, NS – non-significant.

children, children from singleton, term and singleton term births. In the category of children from preterm and preterm singleton births, only birth weight was considered. In the categories of children from twin, twin term and twin preterm births no accompanying variables were identified since the categories were too small for the estimate with the maximum likelihood method for logistic regression models.

Of all the logistic regression models estimating the risk of cerebral palsy for neonatal factors the models adjusted to accompanying variables with data aggregation was selected for interpretation of the results. The model was characterised by a higher ratio of correctly classified cases to incorrectly classified cases. Besides, the correctness of the estimates with the simple model and the transformed model was smaller than for the adjusted model.

Testing the effect of increased bilirubin level in blood with adjusted model (among neonatal factors) showed that

Table 4. Comparative characteristics of children from preterm, preterm singleton and preterm twin births from experimental and control groups

Preterm births			
Variable	Children with cerebral palsy N=126	Control group N=39	*p*
Sex m/f	66/60	16/23	NS
Birth weight (g)	440.0-4600.0 1644.9±572.8	1290.0-3580.0 2491.3±499.4	<0.001
Birth length (cm)	20-65 44.5±6.6	41-57 50.2±3.6	<0.001
Birth order	1-9 2.1±1.4	1-7 2.2±1.3	NS
Singleton preterm births			
Variable	Children with cerebral palsy N=107	Control group N=35	*p*
Sex m/f	56/51	16/19	NS
Birth weight (g)	440.0-4600.0 1642.4±581.0	1430.0-3580.0 2576.0±485.7	<0.001
Birth length (cm)	20-65 44.5±6.7	45-57 50.8±3.1	<0.001
Birth order	1-9 2.2±1.5	1-7 2.3±1.3	NS
Twin preterm births			
Variable	Children with cerebral palsy N=19	Control group N=4	*p*
Sex m/f	10/9	0/4	NS
Birth weight (g)	830.0-2360.0 1658.4±540.2	1290.0-2300.0 1750.0±502.1	NS
Birth length (cm)	33-55 44.6±6.4	41-48 44.8±3.8	NS
Birth order	1-4 1.9±1.1	1 1 ± 0	NS

Data expressed as number in category, range or mean, standard deviation, p from Student t-test, Mann-Whitney U-test or Chi square test, NS – non-significant.

Table 5. Results of adjusted model estimations for risk of cerebral palsy considering increased bilirubin level in blood in particular categories

Category	OR (95% CI)	Wald test
All children	2.29 (1.40–3.73)	p=0.0009
Singleton pregnancies	2.15 (1.28–3.61)	p=0.004
Term births	2.01 (1.15–3.51)	p=0.01
Term singleton births	2.04 (1.15–3.63)	p=0.01
Preterm births	3.36 (1.18–9.57)	p=0.02
Preterm singleton births	3.08 (1.09–8.68)	p=0.03

Table 6. Results of logit model estimations for risk of cerebral palsy considering increased bilirubin level in blood in particular categories.

Category	OR (95% CI)	Wald test
All children	2.52 (1.47–4.33)	p=0.0008
Singleton pregnancies	2.66 (1.55–4.57)	p=0.0004
Term births	2.18 (1.24–3.84)	p=0.006
Term singleton births	2.35 (1.31–4.21)	p=0.004
Preterm births	4.87 (1.56–15.21)	p=0.006
Preterm singleton births	3.62 (1.24–10.58)	p=0.020

the increased bilirubin level is the risk factor in the categories of all children, children from singleton, term, term singleton, preterm births and preterm singleton births (OR 2.29, 95% CI: 1.40–3.73; OR 2.15, 95% CI: 1.28–3.61; OR 2.01, 95% CI: 1.15–3.51; OR 2.04, 95% CI: 1.15–3.63; OR 3.36, 95% CI: 1.18–9.57; OR 3.08, 95% CI: 1.09–8.68, respectively) (Table 5).

Using the constructed logit models we selected potential independent variables which had a significant effect on the risk of cerebral palsy. Based on the set of obtained significant variables (among demographic, antenatal, perinatal and neonatal factors) an estimation was done using the complete model (all significant factors adjusted to accompanying variables), to obtain a model which would predict the effect of increased bilirubin level as an independent risk factor of cerebral palsy in each category.

Including the increased bilirubin level in the ultimate model (combined analysis of significant demographic, antenatal, perinatal and neonatal factors) showed that it is a significant predictor of cerebral palsy. In the categories of all children (OR 2.52, 95% CI: 1.47–4.33), children from singleton births (OR 2.66, 95% CI: 1.55–4.57), term births (OR 2.18, 95% CI: 1.24–3.84), term singleton births (OR 2.35, 95% CI: 1.31–4.21), preterm births (4.87, 95% CI: 1.56–15.21), and peterm singleton births (OR 3.62, 95% CI: 1.24–10.58) increased bilirubin level is associated with increased risk of cerebral palsy (Table 6).

Discussion

Neonate jaundice, as an effect of increased bilirubin level occurs in most neonates. It is estimated that neonate jaundice occurs in about 60% of term-born neonates and in about 80% preterm-born children. Usually it has a mild course, but because of neurotoxicity of bilirubin an acute hyperbilirubinemia may develop, less often jaundice of subcortical nuclei (kernicterus) or bilirubin encephalopathy. Because jaundice is associated with such serious diseases as infections, hemolythic disease, metabolic or hormonal disorders, disorders of liver and gall ducts, it still remains a diagnostic-therapeutic problem (Śmiechura et al. 2010; Wasiluk et al. 2012). Neurological disturbances resulting from bilirubin neurotoxicity show a varied intensity, from a mild, temporary encephalopathy to permanent damage of subcortical nuclei of the brain. Bilirubin neurotoxicity

may manifest as permanent damage to the nervous system, among others deafness as a result of hypoxia of ciliated cells in the Corti organ, epilepsia, damage to oculomotor nerves, retardation of psychomotor development, vision disturbances, convulsions and cerebral palsy, especially choreoathetoid form (Polani 1958; Blair and Staley 2002; Koman et al. 2004; Öztürk et al. 2007; Śmiechura et al. 2010; Reid et al. 2011; Wasiluk et al. 2012; Okperi 2013; Soleimani et al. 2013). Also our own studies confirm the damaging effect of increased bilirubin level in blood on the risk of development of cerebral palsy. Among all the risk factors (demographic, antenatal, perinatal, neonatal) increased bilirubin level as the only factor remained significant in all the constructed models, even in the complete ones. However our study was subject to some limitations, that is way it should be replicated and the association further explored.

In our opinion increased bilirubin level should be regarded as a significant risk factor when considering the reasons for cerebral palsy in children. Since brain damage is a serious complication of hyperbilirubinemia, increasing the neonate mortality and the incidence of many diseases resulting from damage to the central nervous system, including cerebral palsy, it is necessary to consider increased bilirubin level in blood in epidemiological studies on cerebral palsy.

Moreover, as a limiting factor in this study, it should be also mentioned in the method used. The authors are aware of the limitations of the retrospective method and further studies, if possible, should be conducted by the prospective method as well. Additionally, the broad time range of this study could influence the obtained results. Socioeconomic changes, life quality and development of medicine changed over this time range. The authors are aware of this limitation, but he data were collected in as many as 14 voivodships, in 40 medical centers and the size of the research group was a condition of its representativeness. It should be emphasized that although people with cerebral palsy are a large group, it is scattered throughout the country. It is not possible to narrow down the group in terms of the time period, because the group would simply become unrepresentative. The statistical analyses showed furthermore that birth weight and birth order were significant accompanying variables, which significantly changed the values of estimated parameters; hence they should be used as controlling variables when attempting to assess risk factors of cerebral palsy. Besides, the multivariate analyses showed that, depending on the category (twin, singleton, term, preterm births), risk factors of cerebral palsy were different, and models estimating the probability ratio of cerbral palsy should take this into account. Further studies are necessary, considering twin pregnancies, twin term and twin preterm births, in order to identify all independent risk factors of cerebral palsy.

Authors' contribution

MS conceived the paper, collected the data, performed statistical computations and drafted the manuscript. BK was project supervisor, co-edited the final version of the manuscript. KB performed statistical computations and co-edited the final version of the manuscript. AT performed statistical computations, drafted the manuscript, co-edited the final version of the manuscript

Conflict of interest

The authors declare that there is no conflict of interest.

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