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Determination of the Need and Assessment Algorithms of the Scope of Activity of Regional Centers for Diagnosis and Treatment of Bronchopulmonary Dysplasia

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Keywords: social medicine; bronchopulmonary dysplasia; incidence; regional center; models; algorithms; planning

Abstract.

Graphical and polynomial (quantitative) regional model of bronchopulmonary dysplasia (BPD) prevalence, depending on the number of premature children, was substantiated, composed and proposed for use for the first time. This provides an opportunity to perform generalized comparative (at the state level) analysis of BPD diagnosis. BPD incidence rates in groups of prematurely born children with different levels of BW deficiency (BW) were determined by calculating the ratio between the number of children with BPD and the total number of children in specific groups stratified according to the BW level.

Advanced (multi-criteria) algorithm of Centers for Diagnosis and Treatment scope of activity quantitation was substantiated and developed for the first time based on regional frequency of premature children and the degree of their body weight deficiency. Inverse verification of this algorithm was conducted and rather high accuracy for practical use by the health professionals was proved. Nomogram (graphical and tabular versions) for operating planning of the expected absolute number of patients with BPD depending on the number of regional premature children was newly developed and substantiated according to the results of the research.

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**Problem statement and analysis of the recent research**

Bronchopulmonary dysplasia (BPD) is an urgent problem of modern medicine, technologies of care for children's population, especially obstetric practice, pediatrics, family medicine. BPD is registered in 90-100% of children with body weight (BW) ≤ 750 gram, in 70% of children with 750-999 g of body weight and 30-60% of infants with BW <1500 gram in countries with high-technology health care organization [5, 7, 8]. In European countries, BPD is diagnosed in about 30% of premature infants who undergo artificial lung ventilation (ALV). Thus, it is diagnosed in 29.0% of children of a gestational age less than 32 weeks in Germany, in 27-33% premature infants with very low birth weight (VLBW) in Japan [9-11].

The high level of premature infants’ mortality constitutes 25.0% of children with BPD with BW ≤ 750 gram [55]. Mortality rate is 33-48% in case of comorbid pulmonary hypertension (PH) [2, 14]. During the first 12 months of life the mortality rate constitutes about 50% [8, 18]. BPD incidence varies between 2.3-26% in the former Soviet Union countries. This is determined by the level of specialized care standardization, different organizational models of its provision [10, 17, 19]. BPD incidence has not practically been investigated in Ukraine. Organizational models of care for these children are situational and determined by regional differences that certainly do not contribute to the prevention, prognosis, timely diagnosis, appropriate treatment [15-19].

Occasional reports about long-term BPD effects indicate the poor state of physical and mental development in older age, lower results of test on mental abilities [4-6, 11]. Patients with BPD often have immunodeficiency disorders and suffer from chronic non-communicable diseases [4-6], deficiency of auditory and visual functions. The risk of severe respiratory failure (RF) is 2.6 times higher in case of dysplastic dependent pathology (DDP) of bronchopulmonary system (BPS) [5, 11, 12, 14].

According to the findings of leading experts, diagnostic searches and approaches to BPD features defining and predicting the consequences agree on the need to develop modern organizational model of care, to provide information and communication support for medical and preventive institutions (MPI) of different levels, to provide specialized care, namely to create regional centers for BPD diagnosis and treatment [13, 17-19].

The objective of the research was to justify and develop quantitative models and algorithms of determining the need for and the scope of work of the regional centers for BPD diagnosis and treatment taking into account the frequency of premature infants and their distribution by level of BW deficiency.

**Materials and methods of the research**

Taking into account the lack of official reporting forms in Ukraine to obtain comprehensive information on BPD frequency/prevalence among infants, the frequency of its different clinical forms depending on infants’ sex and their interrelation with birth weight (as a general indicator of viability) was studied by means of expert assessments according to specially constituted "Card of Scientific Assessment of Hospital Neonatal Record" in which the data (years of 2007-2013) about the children in the neonatal unit were presented and advisory opinions of Regional Center for Diagnosis and Treatment of Bronchopulmonary Dysplasia in Children at Kharkiv Regional Children’s Hospital (there the child was treated until the age of three after the discharge from the neonatal in-patient department) were additionally included. Archival materials for 2007-2013 were studied using continuous method. It should be noted that the establishment of a modern network of neonatal in-patient departments in Ukraine and their technical equipment occurred along with the introduction of modern (European standard) technologies of medical care for children [1, 5, 11, 14, 18]. Classification approaches to BPD clinical forms and its possible consequences were unified as well [5, 16] allowing to distinguish between the classic (CF) and the new (NF) forms of BPD [5].

**Results of the research**

Analysis of trends in BPD prevalence to the introduction of new technologies (2007-2008) detected a relatively low level of BPD registration due to high mortality rates of premature infants and (due to the lack of technical equipment to verify the diagnosis) low level of the diagnosis pathogenetic substantiation in neonatal centers. Since the commencement of work of modern regional neonatal in-patient departments in Ukraine (2009) the specific gravity of premature infants with BPD has been stable within 12÷15.0%.

Figure 1 (bar chart) provides the dynamics of increase in BPD diagnosing rate (on the background of relatively stable annual registration of children with VLBW and ELBW) primarily indicating the improvement of the diagnostic process and technologies of prematurely infants management.

Certainly, the increase in BPD incidence was caused by the improved quality of neonatal care manifested in decrease in mortality rate of premature infants with very low (VL) and extremely low (EL) body weight (BW). Increase in BPD specific gravity in premature infants by 14.03±14.98% was registered in 2012 and to 14.87% in 2014 (Fig. 1).

The interrelation between the frequency of premature infants and the incidence of BPD in population was characterized by polynomial dependence (Fig. 1, published for the first time) making it possible to determine the expected (predicted) indices of BPD prevalence with high accuracy (R2>0.96, p<0.04) and, therefore, the need for specialized care (neonatal care, oxygen therapy, dynamic supervision until the age of three and at later stages of ontogenesis) in specific regions based on the number of premature infants.

![Graph showing specific gravity (%) and regional model of bronchopulmonary dysplasia (diagram and polynomial) in premature infants](image)

Fig.1. Specific gravity (%, bar chart) and regional model of bronchopulmonary dysplasia (diagram and polynomial) in premature infants

As an example (Example 1) we provided estimates of the expected load of specialized centers (offices) for oxygen therapy (as the main pathogenic agent for therapeutic effects). 500 premature infants were registered in one of the administrative regions of Ukraine in 2013. In order to determine
the specific gravity of infants who needed specialized care at the Center for BPD diagnosis and treatment the following formula was used: \( Y_1 = -0.40k^2 + 5.1k - 1.83 = -0.40x^2 + 5.1x - 1.83 = -19.6 + 35.7 - 1.83 = 14.27\% \). Thus, the absolute number of children in the need of specialized care in the Centers would be 500 \times Y_1 / 100 = 71 children (with BPD).

However, the heterogeneity of premature infants' body weight can greatly influence the BPD development and, thus, the need for the treatment at the Centers. Thus, BPD was diagnosed in almost all premature infants in case of extremely low body weight (BW \( \leq 750 \) g) (100% of infants according to our data and 95-100% of infants according to the data of foreign authors) [3, 5, 7]. In case of critically low body weight (BW = 750-999 g) BPD was detected in 96.6% of infants according to our data and in 70.0% of premature infants according to bibliosemantic analysis [5, 8]. According to the archival and published data [5, 10, 11] BPD development was diagnosed in 60% of premature infants weighing 1000-1249 g, corresponding to the upper limit of the disease incidence according to other researchers [7, 8].

However, resulting from terminology and classification differences and relatively recent determining of the BPD new form, the presented comparative data can be analyzed, including clinical variants and only from the perspective of further improvement of neonatal care technologies, taking into account comorbidities (such as cardiovascular diseases) and standardization of diseases accounting.

However, birth weight should be (and it is in the clinical practice) one of the major criteria for the need for specialized care in the Centers as BPD incidence is connected with it (BW). This means that both the frequency of premature infants (Fig. 1) and the structure of these children grouped by BW should be considered in the process of the quantitative determination of the need for the Centers work. As BPD incidence is known to possibly depend on birth weight, the author (for the first time!) processed analytical quantitative model of this dependence being presented graphically (Fig. 2) and by the relevant quantitative and analytical form (model) – polynomial of II degree. Based on the above mentioned information and adverting to Example 1, calculation of the need must be adjusted as the structure of premature infants by BW should be additionally taken into account This is possible if actual data in a particular region are available (differences in the influence of regional and environmental, medical and social and other factors are also considered including the quality and accessibility of this type of specialized care and other types of medical care).

We calculated the need for specific Center using the frequency of premature infants and their specific distribution by birth weight (Table 1). Advanced (multi-criteria) algorithm of scope of activity quantitation of the Center for diagnosis and treatment of bronchopulmonary dysplasia was based on the task to calculate the expected absolute number of newborns in the region (\( W_{\text{expected}} \)) taking into account the identified frequency patterns of infants with low birth weight (L1-4) and the frequency of BPD diagnosis depending on the level of BW deficiency (\( Z_{1-4} \)).

For this purpose, the frequency of BPD diagnosis in premature infants was studied depending on the level of BW deficiency. At the stages of forecasting retrospection (forecasting base) average index rate of infants with BPD and BW \( \leq 750 \) g ranged within 0.014±0.001 and with reliability \( R^2 = 0.99 \) this time pattern (2009-2013) could be represented as a polynomial function: \( L_1 = -0.0002k^3 + 0.0026k^2 - 0.0081k + 0.0213 \). Similarly, according to the results of our study polynomial functions (III-IV degrees) when modeling \( L_{2-4} \) criteria quantitation and corresponding average values of these indices were obtained. The logical value of these indices is that BPD with different frequency is diagnosed in premature infant with different BW. Consequently, the obtained quantitative dependence further reflected the level of diagnostic capabilities based on retrospective data (Table 1).

Determination of BPD incidence indices (Z1-4) in groups of infants with different levels of BW deficiency was the following stage of investigation.
Fig. 2. Interrelation of birth weight and general prevalence (different clinical forms: classic one and new one) of bronchopulmonary dysplasia in premature infants

It was performed by means of calculating the ratio between the number of children with BPD and the total number of children in specific groups stratified by the level of BW deficiency. The results of these calculations identified that the incidence rates of premature infants constituted the following: 1.0 in infants with BW ≤ 750 g; 0.956 in infants with BW within 751÷999 g; 0.704 in infants with BW within 1000÷1249 g; 0.597 in infants with BW within 1250÷1499 g.

Being a result of calculations the obtained above mentioned outcoming data made it possible to apply reasonably the formula for calculating the expected number of premature infants with BPD:

\[ W_{\text{expected}} = G \times (L_1 \times z_1 + L_2 \times z_2 + L_3 \times z_3 + L_4 \times z_4) \]

The results of this formula application, which included the indices and incidence rate proposed in this study (Table 1), were further verified using conversion (reversible) method. This allowed determining the accuracy of the algorithm.

The average levels of expected and actual number of premature infants with BPD were found not to be significantly different ((43.5±1.8) and (44.6±2.1) individuals respectively, \( p > 0.05 \)). Deviations of the estimated number of children from the actual one varied within (2.39±0.74) % at the maximum 4.0% (in absolute values it corresponds to one person). Considering the absence of any similar reasonable calculation algorithms during the study, the achieved accuracy should be considered high.

However, this algorithm is rather difficult for the operational planning of the scope of work of regional centers for BPD diagnosis and treatment. Therefore, we additionally developed a simplified version, namely nomogram of the number of patients with BPD (graphical and tabular versions) depending on the total regional number of premature infants. This assumes a high level of standardization of diagnostic procedures that can be achieved through the development and implementation of compared local protocols or standardized clinical protocol for management of such children. Nomogram is based on determined connection as a power function equation (Fig. 3) and involves the use of actual regional level of premature infants’ frequency which is known to vary from medical and
social, environmental, cultural and educational factors, the demographic situation in specific regions of Ukraine.

Advanced algorithm of scope of activity quantitation of Centers for Diagnosis and Treatment of Bronchopulmonary Dysplasia taking into account the regional frequency of premature infants and the degree of their body weight deficiency

Table 1

<table>
<thead>
<tr>
<th>Formula element</th>
<th>Quantitative connection (based on actual data for 5 years)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( L_1 )</td>
<td>( L_1=-0.0002k^2+0.0026k^2-0.0081k+0.0213; R^2=0.99 )</td>
<td>0.014 ±0.001</td>
</tr>
<tr>
<td>( L_2 )</td>
<td>( L_2=-0.0002k^2+0.0027k^2-0.0094k+0.0474; R^2=0.99 )</td>
<td>0.040 ±0.001</td>
</tr>
<tr>
<td>( L_3 )</td>
<td>( L_3=-0.0019k^3+0.0204k^2-0.0596k+0.091; R^2=1.00 )</td>
<td>0.050 ±0.005</td>
</tr>
<tr>
<td>( L_4 )</td>
<td>( L_4=-0.0037k^4+0.0439k^3-0.1782k^2+0.2854-0.088; R^2=1.00 )</td>
<td>0.063 ±0.004</td>
</tr>
<tr>
<td>( W_{\text{expected}} )</td>
<td>40.03</td>
<td>41.97</td>
</tr>
<tr>
<td>( W_{\text{actual}} )</td>
<td>40</td>
<td>43</td>
</tr>
<tr>
<td>( \Delta W, % )</td>
<td>+0.01</td>
<td>-2.4</td>
</tr>
</tbody>
</table>

Note. \( W_{\text{expected}} = G \times (L_1 \times z_1 + L_2 \times z_2 + L_3 \times z_3 + L_4 \times z_4). \) \( G \) – the expected number of premature infants in the region the next year; according to the previous period data: \( L_1 \) – specific gravity of premature infants with body weight \( \leq 750 \) g; \( L_2 \) – with body weight \( 751-999 \) g; \( L_3 \) – with body weight \( 1000-1249 \) g; \( L_4 \) – with body weight \( 1250-1499 \) g; \( z_1-z_4 \) – BPD incidence rates in the respective groups \( L_1-L_4; \) \( W_{\text{expected}} \) – the expected number of children with bronchopulmonary dysplasia the next year; \( W_{\text{actual}} \) – the number of newborns with developed bronchopulmonary dysplasia during the current year (all forms and clinical variants); \( \Delta W \) – permissible error; \( k \) – prospection period number.

The use of nomogram graphic form is simple and comprehensible and may be used in the practice of premature infants health care, for example when planning the opening or optimization of Centers for BPD diagnostics and treatment.

Example 2: statistics (absolute number of children) of premature infants during the current year (for example 275 individuals) is used to determine the annual absolute number of children who need diagnosis and treatment in the regional center. Then the corresponding value of the expected number of children with BPD is found on the graphic form of the nomogram (in this case – 40 individuals) providing the high accuracy of expectations \( (R^2=0.999) \).

The method of production function study should be used to justify the scope of certain activities (diagnostic, therapeutic and others) of the Center staff. The method is based on constituting and analyzing job profile diagrams (focused on the analysis of specific functions, their repetition and the number and quality of performance) and medical routes of children with BPD. In the process of further continuous work the multi-criteria algorithm of the scope of activity quantitation of the Center for BPD diagnosis and treatment may be used as both pathogenetic and clinically more adapted.

Conclusions

1. Graphical and polynomial (quantitative) regional model of bronchopulmonary dysplasia prevalence, depending on the number of premature children, was substantiated, composed and proposed for the use. It provides an opportunity to perform comparative (at the state level) analysis of BPD diagnosis. BPD incidence rates in groups of premature children with different levels of BW deficiency were determined by calculating the ratio between the number of children with BPD and the total number of children in specific groups stratified according to the WB level.

2. Advanced (multi-criteria) algorithm of Centers for Diagnosis and Treatment scope of activity quantitation was substantiated and developed for the first time based on regional frequency of premature children and the degree of their underweight body. Inverse verification of this algorithm was conducted and rather high accuracy for practical use by the health professionals was proved.

3. Nomogram (graphical and tabular versions) for operating planning of the expected absolute number of patients with BPD depending on the number of regional premature children was newly developed and substantiated according to the results of the research. It may be used in the planning of new and optimization of existing centers for diagnosis and treatment.
Prospects for further research on the problems of medical and organizational support of regional centers for BPD diagnosis and treatment involve the study and standardization of technologies of neonatal and postnatal medical and social monitoring of health and quality of life of children, the study of medical routes to assess the succession and interrelation in health care provision.

References


